PROCEEDINGS

40TH ANNUAL BROADCAST ENGINEERING CONFERENCE

NATIONAL ASSOCIATION OF BROADCASTERS
DALLAS, TEXAS
1986

Ballard

PROCEEDINGS

40TH ANNUAL BROADCAST ENGINEERING CONFERENCE

NATIONAL ASSOCIATION OF BROADCASTERS
DALLAS, TEXAS
1986

These proceedings contain technical papers presented at the NAB Engineering Conference April 12-16, 1986, in Dallas, Texas.

Published by the NAB Office of Science and Technology

ISBN 0-89324-011-7

Additional copies of the 1986 *Proceedings* are available through NAB Services, 1771 N Street, N.W., Washington, D.C. 20036. For price information, please write or call (800) 368-5644.

1771 N Street, N.W.
Washington, D.C. 20036

National Association of Broadcasters

Thomas B. Keller
Senior Vice President
Science and Technology
(202) 429-5337

March 14, 1986

Dear Reader:

These Proceedings contain many of the technical papers presented during the 40th Annual Broadcast Engineering Conference held in conjunction with the NAB Convention in Dallas, Texas, April 12-16, 1986.

The Proceedings contain papers of interest to engineers and technicians in all areas of broadcast radio and television. Subjects covered include AM improvement, AM-FM-TV engineering, maintenance, new technology, stereo sound for AM-FM-TV, broadcast auxiliary, non-ionizing radiation, television satellite news gathering and advanced television systems.

Take the time to read and learn from the papers within this volume; papers which have been prepared with great care by their authors. To a large extent the technical development of the future of our industry relies on your interest and ability to understand and utilize the technological concepts and applications described here. In many respects they are blueprints of our future; a valuable reference source to complement the Proceedings of past engineering conferences and the NAB Engineering Handbook. Further, in the increasingly diverse and competitive broadcast marketplace, engineering becomes even more important to the maintenance of high quality signal transmission and the ability of a station to compete effectively.

Note that we have reduced the size of the Proceedings to one of manageable proportions by using smaller type and arranging the text into two columns. By doing so we avoided reducing the total number of papers without sacrificing readability.

We at the NAB are proud to publish these Proceedings. Your comments on any of the papers or on any aspect of the 1986 Engineering Conference are always welcome.

Best personal regards,

Thomas B. Keller

Thomas B. Keller

TABLE OF CONTENTS

RADIO NEW TECHNOLOGY

RADIO PRODUCTION

AM STEREO

TELEVISION RECORDING AND TAPE TECHNOLOGY

TELEVISION MULTICHANNEL SOUND

TELEVISION GRAPHICS

TELEVISION SYSTEM MAINTENANCE

TELEVISION ENGINEERING AND NEW TECHNOLOGY

ADVANCED TELEVISION SYSTEMS

TELEVISION SATELLITE SYSTEMS

UHF TELEVISION SYSTEMS

BROADCAST AUXILIARY

NON-IONIZATION RADIATION

THE NAB AM IMPROVEMENT PROJECT

Charles T. Morgan, Vice President/Engineering
Susquehanna Radio Corporation
York, Pennsylvania

Michael C. Rau, Staff Engineer
National Association of Broadcasters
Washington, District of Columbia

It was two years ago that the AM Improvement Subcommittee gave its first report to this convention. That first report outlined the Committee's progress in its attempt to identify the technical problems that face AM broadcasting. Later that year, the Committee issued its completed report and began the task of implementing procedures designed to resolve these problems.

Of the eight areas originally identified, all have been addressed. In some areas, our task has been completed; in other areas, our work is well underway; while in others, there is a great deal of work ahead of us.

Through this Committee's work, the NAB has in operation an "AM Improvement Technical Reference Center." A bibliography has been sent to all NAB radio stations listing more than 250 articles that are available to help the station engineer understand and maintain the radiation portion of his transmission system. These articles deal only with the signal after it leaves the transmitter, and covers Transmission Lines, Phasors, Directional Antennas, Broadbanding, and all facets of the radiated signal. These are the least understood areas of your technical facilities, and they are categorized by both subject matter and complexity. Most subject matter is covered with both the theoretical and practical approach, and you can obtain articles written at a level to meet your particular need. This is a valuable resource for any engineer that deals with AM Radio. It is in place at the NAB and ready for your use.

One of the main concerns of this committee is electrical interference to AM reception caused by electrical devices, particularly the newly developed R F Lighting devices. These "new generation" light bulbs are targeted to replace the present incandescent light bulbs. They are very energy efficient, and in an energy conscious future they could find widespread use in the home and industry. The problem . . . they use R F energy to provide light. This R F energy is particularly harmful to AM reception.

In August of 1985, the Commission issued a Report and Order concerning R F Lighting devices that set limits on interference conducted through the AC Power Line, but it did not include limits placed on radiated interference on AM broadcast frequencies.

This Subcommittee conducted a study of these R F Lighting devices, as well as other sources of interference, and the report of these findings was submitted to the Commission in support of the NAB's Petition for Reconsideration of this decision. In its request, the NAB asked the Commission to adopt interim technical standards to prevent electrical interference to AM reception from these devices. This request is presently being considered by the Commission.

Electrical interference from R F light bulbs, as well as other interference sources, is an area where AM Broadcasters must be constantly vigilant. By its very nature, AM is most susceptible to such interference, and if we are not constantly on guard we may lose out to the "hash" of an electric and electronic environment.

AM can sound good. AM radio can be a quality medium. This is a fact, but it is a fact that is not universally accepted or understood. Yes, AM has its problems. Its susceptibility to noise and interference, as well as other factors, has caused receiver manufacturers to build narrow band and poorer quality receivers. If the introduction of AM Stereo does nothing else, it has shown us that receiver manufacturers can make better quality receivers. Most of the new generation of AM Stereo Receivers sound great--not because they are stereo, but because they are "wide-band." This quality improvement holds true for stations broadcasting in mono, as well as stereo. The NAB has launched a nationwide campaign promoting "quality stereo receivers."

The AM Improvement Subcommittee is sponsoring a series of demonstrations of "Wide-Band AM Stereo Receivers." This is not a promotion of stereo, but of quality AM, and it is presented in "Mono." Those who hear it, like it, and many are astounded at just how good AM can sound. This Subcommittee is committed to continued promotion of high quality AM Receivers.

One of the most exciting and particularly rewarding areas of AM Improvement is the development of new antenna designs. It would appear that there has been no serious research or development in the basic design of AM antennas since the 1930s. Yes, we have developed more complex directional antenna systems in order to maximize the number of stations that we can squeeze into our broadcast band, but no one has taken a serious look at how the signal is radiated from the antenna.

Two engineers working independently, Richard Biby and Ogden Prestholdt, have developed preliminary designs which they believe can increase groundwave signals, while reducing skywave radiation. These computer generated designs exist only on paper, and until working prototypes are built, there is no guarantee that either of them will work. As a direct result of this committee's involvement with these two engineers, the NAB will fund the construction of "full scale" prototypes for both of these designs.

The benefits of these designs are enormous. Possibly new stations may become available, but the major benefit is to existing stations. Daytime stations may be able to operate at night, and nighttime directional stations may be able to operate non-directional, or increase power. You may be able to "fill the nulls" that now hamper your nighttime operation.

This may be the technical breakthrough that AM so desperately needs in order to remain a competitive media at night. Both Mr. Biby and Mr. Prestholdt are with us this morning and will discuss their respective designs.

It was through the efforts of this committee that the National Radio Systems Committee was re-activated in June of 1985. In our initial meeting our goal was to determine if there was any common ground on which receiver manufacturers and broadcasters could agree, in order to jointly work towards developing a wider-band AM broadcast system. At the meeting, it was acknowledged that we have a system problem which involves the broadcaster, the receiver manufacturer, and the medium itself, and the quality of AM broadcasting can only be improved by both sides working together.

In this and subsequent meetings, we found that not only the engineers but the marketing representatives of these receiver manufacturers are interested in wide-band receivers. We all know receiver manufacturing is a market-driven industry, and they now see a market for wide-band receivers.

Active members of the NRSC include representatives of most U.S. and off-shore manufacturers, the members of the AM Improvement Committee, as well as other broadcasters and interested parties. A performance evaluation sub-group, under the chairmanship of John Marino of Katz Broadcasting, and Bill Gilbert of Delco, has been meeting monthly in an effort to develop a practical pre-emphasis/de-emphasis curve as a suggested voluntary standard. This morning they will provide you with a complete up to date report of NRSC activity.

The need for AM technical improvements is obvious. Our committee has received a great deal of interest and support from the entire industry.

Through the NRSC, we have the receiver manufacturers working toward the same goals. James McKinney, Chief of the FCC Mass Media Bureau, in a speech to the IEEE in September, 1985, recognized the need for a complete look at the problems of AM. His office is in the process of developing a report for the Commission which will not only identify the problems, but suggest options for possible rulemaking proceedings, where applicable, to overcome these problems. The Advisory Committee on Radio Broadcasting, a group composed of both Government and Industry representatives, has also taken an active role in trying to bring about improvements in AM broadcasting. There is a great concern and a massive effort on all fronts to do everything possible to bring about technical improvements to our system of AM broadcasting. You can be assured that the NAB and this Subcommittee will continue its efforts in this respect.

HOW THE NRSC IS HELPING TO IMPROVE AM RADIO

John Marino
Katz Broadcasting Company
Bridgeport, Connecticut

INTRODUCTION

As many of you know, the National Radio Systems Committee has recently been re-activated for the purpose of studying and recommending ways to improve the AM radio service. The Committee is composed of representatives from the broadcast industry and the receiver industry. Indeed, this is not the first time these two industries have met to discuss common problems but, it may very well be historic in that realizable solutions seem to be within reach.

HISTORY

If you plot a curve showing AM radio listeners vs. time, you would probably find that the peak listenership to the standard broadcast band occurred during the 1930's. With the exception of a few minor peaks and valleys, AM listenership steadily declined and began to literally plummet through the 1970's and 1980's.

Several interesting things happened during the 1960's which had an impact on AM broadcasting. From a programming standpoint, this was the era of the consultant. "Top 40" radio was in full bloom and broadcasters were attempting to establish a signature for their stations through the use of various audio processing techniques such as, compression, equalization, and reverb.

Those stations that were successful became legends in the industry inviting a lot of competition. In their attempts to copy these "giants" of the industry, many broadcasters stressed their transmitting plants to the limits, trying to "supermodulate" with transmitters basically designed for 30% to 40% average modulation. The results were catastrophic in many cases, with engineers faced with numerous transmitter failures.

The AM band became crowded with "splatter" of various degrees because those transmitters which were modified to handle this highly processed audio were trying to push it into antenna systems not designed for this type of service. So, we wound up essentially with a band loaded with "garbage". Receiver manufacturers, who were moving from vacuum tube to solid state design had their own problems with filter design and overload protection. But, with all the "grunge" on the AM dial, they felt that it may be less objectionable, to the listener, to narrow the bandwidth of the radio in an attempt to eliminate some of the artifacts being transmitted by broadcasters.

The battle began with receiver manufacturers blaming broadcasters and broadcasters blaming receiver manufacturers. The "sweet six" six transistor superhet portable radio was born, with its hi Q ferrite rod antenna and lo-fi audio. Every kid had to have one. It was the age of the personal radio.

During the 60's, broadcasters discovered FM and promoted its growth. It became the medium for music and experimental program formats. As FM continued to grow, many of the best programming people in the industry moved to the new medium or left the business. In general, AM was becoming the stepchild of FM which just a few years earlier, was mainly used for background music. Receiver people were working on high quality FM receivers now and not putting a lot of effort into new AM designs. AM was all but forgotten. The backbone of an industry was broken and laid in a sad state of disrepair. This continues to be the state of AM radio today.

THE PROBLEMS

Any significant progress toward improvement of the AM system must start with a definition of the problems. Since broadcasters and receiver manufacturers have seldom been able to cooperate at past meetings, considerable time has been spent by the NRSC identifying our common problems.

First of all, there are in excess of 4000 AM radio stations on the air at the present time. Interference is the primary concern of receiver manufacturers. The average person can only tolerate so much of it before tuning out, or over to another audio source. Some may say that we could alleviate the interference problem by eliminating 50% of the stations. It's not going to happen so, we must look toward a more practical approach.

Interference has plagued AM broadcasting since its beginnings. We have learned to live with natural electrical disturbances, such as, lightning. But, with the steady growth of technology, man-made interference to the AM service has been greatly increasing. The NAB recently petetioned the FCC to take another look at setting standards for radiated and power line coupled interference from industrial, scientific and medical electronic equipment. Included here are the new RF lighting devices, computing devices, and PBX telephone equipment. Our automobiles have become very harsh environments for AM radio, with the proliferation of microprocessor control and ignition systems. Auto receiver manufacturers have taken considerable pains to make their radios immune to this interference, in some cases, even to the point of having the AM section of the typical car radio more complex than the FM section.

We cannot stress enough the importance, to the future of AM broadcasting, of the FCC taking a hard stand on RF pollution of our broadcast spectrum.

Another major problem with our AM system has to do with overmodulation. We all know what it is but, we must now take steps to eliminate the interference caused by overmodulation if our revamping of the AM system is to be successful. Through the NRSC, a tutorial is being published which will address this problem in detail and suggest ways for broadcasters to monitor overmodulation products which do not show up on conventional equipment. There are many antenna systems in use by broadcasters that will not handle highly processed audio without proper precautions and adjustments. Maybe you won't need to spend a fortune rebuilding your antenna system. Perhaps your audio can be carefully processed to complement the filtering effect of the antenna without creating undesirable artifacts. Let's exercise a little creative engineering. Everyone knows what a "dirty" signal sounds like; now is the time to clean it up and protect your neighbors on the AM band.

THE PRE-EMPHASIS/DE-EMPHASIS ISSUE A POSSIBLE SOLUTION

AM pre-emphasis and de-emphasis has been discussed for many years. There is no technical advantage for pre-emphasis on the AM band, except for the fact that we have radios with poor high frequency response. Consequently, we have no standard and the pre-emphasis curves used by broadcasters vary with the subjective judgement of broadcast station management (conversely, we have the subjective judgement of receiver manufacturers defining the de-emphasis of their products). It is a futile attempt to make these "bad" radios sound good that is causing a lot of problems with the AM system. Several radios in production today have such sharp filters that there is no way the audio coming out of them could be improved by pre-emphasis. As we mentioned earlier, this cycle of broadcasters boosting high frequencies and receiver manufacturers narrowing bandwidths must come to an early end. Audio processor manufacturers have given broadcasters a very wide range of high frequency audio control but, we must know how the system will react when we boost these upper frequencies.

An NRSC subgroup is now working on a voluntary standard for pre-emphasis and de-emphasis for AM broadcasting. We feel that a standard is necessary to serve as a starting point for a compatible transmitter/receiver system. This does not mean that we are proposing to take away broadcaster's artistic license in tailoring the sound of their station. Simply put, we are looking for some sort of benchmark from which audio processor manufacturers, transmitter manufacturers, broadcasters and receiver people can start their design work based upon higher quality, consistant AM technology.

Future trends in receiver design show most design effort going into the Electronically Tuned Radio (ETR). IF strip tuning adjustments are being eliminated and more sophisticated filter designs are being incorporated into the new generation receivers. Many of these filters are not tolerant of excessive pre-emphasis and much distortion and ringing results when they are excited by the "stuff" some of us are transmitting. It is also intresting to note that with many of the varactor tuned ceramic filter receivers on the market today, there are frequency response errors from one end of the broadcast band to the other. Designers are working on ways to solve this problem. Perhaps they must go to the sources of their components and demand tighter tolerances. At least we have defined the problem.

To gain a better understanding of the pre-emphasis/de-emphasis issue, we must first take a look at AM allocations. The present FCC rules state that the 0.5 mv/m coverage contours of first adjacent stations must not overlap. Also, for second adjacent stations, the 2 mv/m and the 25 mv/m coverage contours must not overlap.

If a station is broadcasting with sideband energy above 5 kHz, it will overlap the first adjacent station's sidebands. With sideband energy above 10 kHz, the station will also overlap into the second adjacent station's sidebands. This process continues as the frequency increases and is a very important consideration in the design of wideband receivers.

In order to determine the shape of a pre-emphasis/de-emphasis curve we must decide how much adjacent channel interference we can tolerate. There appears to be a direct dB for dB tradeoff between adjacent channel protection ratio and the amount of high frequency energy transmitted. A typical, present day, auto radio approaches full quieting with signal strengths as low as 0.5 mv/m. A study has been commissioned to tell us at what signal levels AM listeners "tune out" and listen to something else. This will give us a clue as to weighing a pre-emphasis curve against a given adjacent channel protection ratio.

The NRSC is researching second adjacent overlaps as they occur here in the United States. We can then pinpoint problem areas and use this information to aid in the decision making process. The goal being the widest bandwidth receiver and the least possible pre-emphasis.

Studies have shown that with most typical AM radios, we must use some sort of pre-emphasis. With flat audio, many of these radios are barely intelligible at the voice frequencies. Indeed, some are worse than the standard voice grade telephone circuit. The NRSC feels that as more and more new generation radios are sold, most of these inferior receivers will be phased out of the marketplace. This means that our pre-emphasis/de-emphasis standard should be evolutionary, changing with the propagation of wideband receivers.

Of course, an accurate evaluation of anything as subjective as audio frequency response must entail actual, real world listening tests, not only by trained professionals but also, by a cross-section of the general public. The average person who buys a new radio must hear an improvement or else all efforts will have been in vain. Our work is progressing now in this direction.

Considerable amounts of time and money are being spent by dedicated broadcasters, audio processor and receiver manufacturers to improve the AM service and make it, once again, profitable to our intertwined industries. The NRSC must have the support of all of us to be successful.

SUMMARY

The National Radio Systems Committee, a joint committee composed of broadcast industry and receiver industry representatives has set the following goals:

1. To educate broadcasters as to the effects of overmodulation. A tutorial will be published to help the industry deal with this interference causing problem. Any equipment manufacturer who desires to study this problem in greater detail and design a device which will measure instantaneous adjacent channel "splatter" is encouraged to do so.

2. To establish a voluntary standard pre-emphasis curve to be used by broadcasters and a complementary standard de-emphasis curve for use by receiver

manufacturers. This standard will be evolutionary and will change as new "wideband" receivers proliferate and older receivers are phased out. Toward this goal, two studies have been started. One, will show areas of the US affected by second adjacent channel overlap. The other will attempt to correlate AM listening habits with signal strength.

These goals are ambitious and somewhat controversial but, we feel, absolutely necessary for the survival of the AM broadcast service. The time is right for change. Many broadcasters have taken it upon themselves to clean up their systems and are broadcasting quality signals along with quality programming. But, these efforts must be echoed by the entire industry if they are going to be of any value toward AM's salvation. We, as broadcasters, have the attention of the receiver industry, the audio processor manufacturers, and the FCC. Never has there been a better time to take a fresh look at an old system and bring it back to life.

ASWA—THE ANTISKYWAVE ANTENNA

Richard L. Biby, P.E.
Communications Engineering Services, P.C.
Arlington, Virginia

Medium Frequency AM Broadcast stations depend upon the propagation of a ground wave, which travels along (or near) the surface of the earth. Of the energy radiated from a typical AM broadcast antenna, about 85% travels outward and upward (the "skywave"), and only about 15% goes into the groundwave. During the nighttime period, the skywave reflects off the ionosphere and can create extensive interference hundreds or even thousands of miles from the source. A new antenna design concept, presented here, may roughly reverse the percentage of energy flowing into the two waves. If so, the strength of groundwave signals would be enhanced, and nighttime interference diminished. Total performance gain (increase in signal strength in the service area, and the reduction of interference) could be on the order of twenty (20) decibels.

Present Practice

Most, if not all, U.S. standard broadcast stations use vertical radiators, generally about one-quarter wavelength high, operated over a ground system which typically consists of 120 copper wires, one quarter wavelength long. The physical radiator, along with its image (which is least partially in the highly conductive copper ground screen), forms a center-fed dipole. (See Figure 1.)

The Theoretical Foundation

The problem of radiation from a vertical current element above an imperfectly conductive earth was first solved by Sommerfeld[1] in 1909. Unfortuately, in at least one version of his papers on the subject, Sommerfeld inverted the sign of an important coefficient. That error resulted in some very unattractive behavior, such as oscillations in the magnitude of the ground wave field strength as a function of distance. Also, Sommerfeld's equations were left in forms which were inconvenient for engineering use.

Kenneth A. Norton, while a member of the Federal Communications Commission Staff, published a classic series of articles[2] which present formulas for the fields generated by various sources over an imperfectly conductive earth (without the sign problem).

In his original work, Sommerfeld stated that the waves so generated could be divided into a space wave and a surface wave. Norton's formulas for the fields generated by a vertical electric dipole,

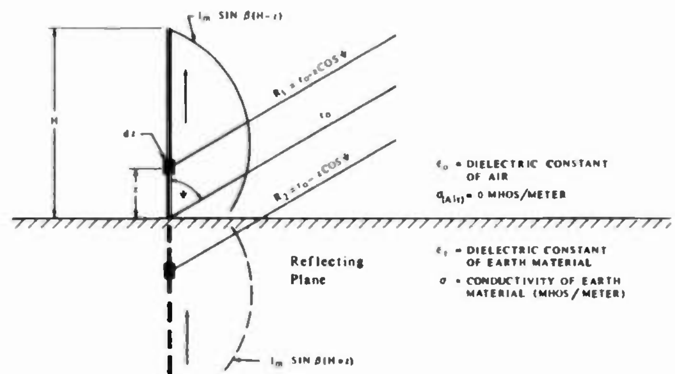


Figure 1

evaluated at distances large enough that terms containing orders higher than 1/R1 and 1/R2 can be neglected, become:

EQUATION 1)

$$E_{Space} = j30\beta l\, dz \cos\Psi\left(\frac{e^{-j\beta R_1}}{R_1} + R_v \frac{e^{-j\beta R_2}}{R_2}\right)$$

EQUATION 2)

$$E_{Surface} = j30\beta l\, dz(1-R_v)F\frac{e^{-j\beta R_2}}{R_2}$$

$$\sqrt{1-2u^2+(\cos^2\Psi)u^2\left(1+\sin^2\frac{\Psi}{2}\right)}$$

With the geometry as shown in Figure 1 and where:

EQUATION 3)

$$u^2 = \frac{1}{\epsilon_r - jx}$$

ϵ_r = RELATIVE DIELECTRIC CONSTANT OF EARTH MATERIAL

EQUATION 4)

$$x = \frac{1.8 \times 10^4 \sigma}{f}$$

σ = CONDUCTIVITY OF EARTH MATERIAL (MHOS/METER)

EQUATION 5)

$$\beta = \frac{2\pi}{\lambda}$$

f = FREQUENCY (MHz)

EQUATION 6)

$$F = \left[1 + j\sqrt{\pi\omega}\, e^{-\omega}\, \mathrm{erfc}(-j\sqrt{\omega})\right]$$

EQUATION 7)

$$\omega = \frac{j\beta R u^2 (1 - u^2 \cos^2 \Psi)}{2} \left[1 + \frac{\sin \Psi}{u\sqrt{1 - u^2 \cos^2 \Psi}} \right]$$

EQUATION 8)

$$\operatorname{erfc}(-j\sqrt{\omega}) = \frac{2}{\sqrt{\pi}} \int_{-j\sqrt{\omega}}^{\infty} e^{-v^2}\, dv$$

EQUATION 9)

$$R_v = \frac{(\epsilon_r - jx)\sin\Psi - \sqrt{(\epsilon_r - jx) - \cos^2\Psi}}{(\epsilon_r - jx)\sin\Psi + \sqrt{(\epsilon_r - jx) - \cos^2\Psi}}$$

For an imperfect dielectric (that is, one with finite conductivity), the skyward field has a relative magnitude as a function of the vertical angle (Ψ) similar to that shown in Figure 2.

The magnitude of this field is zero at both the zenith (Ψ=90 Deg.) and at the horizontal plane (Ψ=0 Deg.). The zero (null) at the zenith follows from the direction of current flow in the conductor; the null at the horizontal plane is due to the fact that the two terms in Equation 1), which describe the contributions from the source (R_1) and from its image (R_2) are equal in magnitude. However, the vertical coefficient of reflection, R_v, has a unique value of -1.0 at the horizontal plane. Thus, complete cancellation of these two terms occurs at Ψ=0.

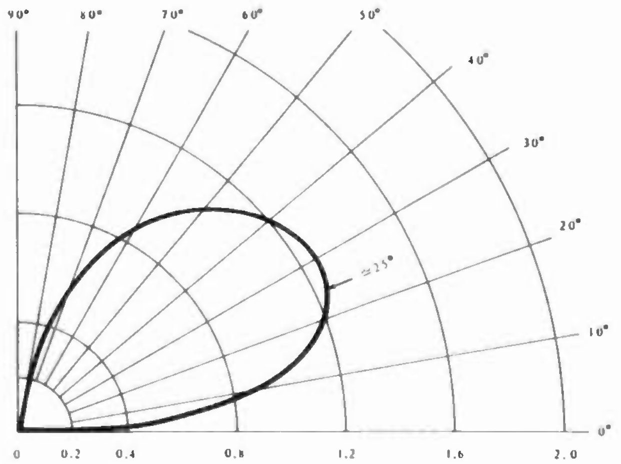


Figure 2

The vertical coefficient of reflection varies rapidly, in both magnitude and phase, as a function of Ψ. Rough graphs of magnitude and phase of R_v vs. Ψ for a typical earth material are shown in Figures 3-A and 3-B, respectively.

The maximum magnitude in the skyward field pattern of a short vertical radiator in the U.S. AM broadcast band typically occurs about 25 to 30 degrees above the horizontal.

This skyward energy is, of course, that which travels outward and upward and, upon reflection from the ionosphere, returns to earth to possibly create interference.

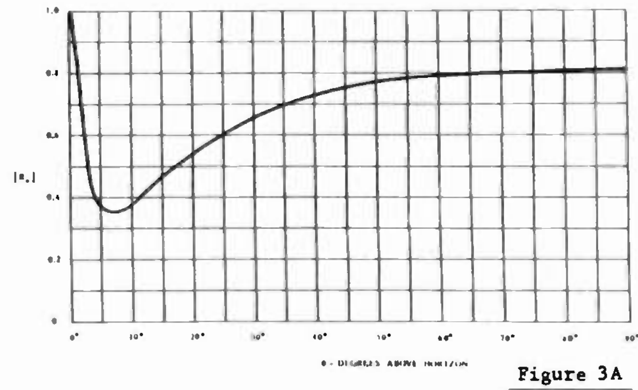


Figure 3A

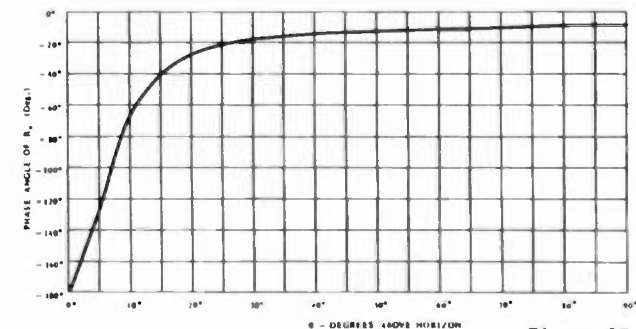


Figure 3B

The surface wave, on the other hand, appears to result only from the image, not from the source itself. There is no term dependent upon R_1 in the surface wave equation - EQUATION 2).

The term $(1-R_v)$ equals 2.0 at the horizontal plane, because (as discussed above) the vertical coefficient of reflection (for all finite conductivities) is equal to -1.0 at the angle Ψ=0. Because of the manner in which R_v varies with Ψ and the behavior of the surface wave attenuation term, F, the surface wave field decreases rapidly with height above the surface, and in no practical case is it a source of (broadcast band) ionosphere-reflected interfering signals.

The surface wave (for a short radiator) has a vertical plane pattern generally similar to that shown in in Figure 4. The exact vertical plane pattern naturally depends upon radiator height (length), current distribution, earth constants, etc.

The surface wave has the rather interesting characteristic of traveling outward and downward from the source. In addition to the vertical electric field component (which is to be expected, since the current flows in the vertical direction in the radiator), there is a horizontal component of electric field, parallel to the surface of the earth. Since the earth has a finite conductivity, there is a flow of energy downward into the earth, which accounts for the greatly increased attenuation of the surface wave as compared with the skyward wave.

Conventional engineering practice is to assume that the conductivity of the earth is infinite. In that case, x becomes infinite, and the reflection factor for vertical polarization is 1.0 (at a phase angle of zero) for all angles of incidence greater than zero.

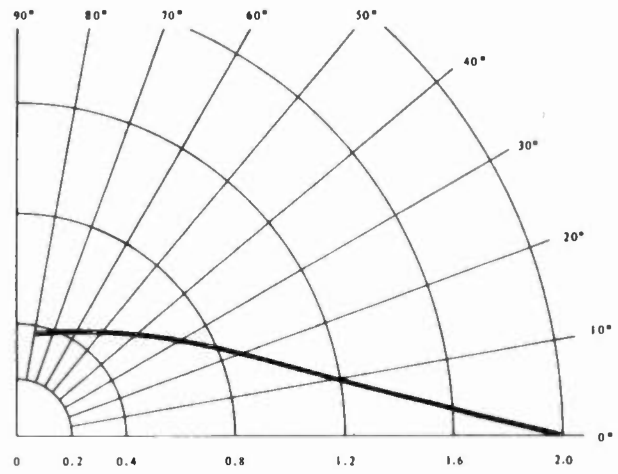


Figure 4

Computer Model

Norton's equations have been used as the basis of a computer model of broadcast antenna systems. The model permits the specification of the dimensions of the radial ground system, discussed earlier, and of the effective conductivity and dielectric constant of the surrounding earth material. The electrical characteristics of the ground system are also permitted to vary, so that the behavior of a vertical radiator over perfectly conductive earth can be studied. Sinusoidal current distribution is assumed on the central radiator, whose height can also be specified.

Figure 5A presents the vertical plane pattern ("slice") for a 90 degree (electrical height) radiator, operated over a perfectly conductive earth. As all well behaved computer models should, this one agrees closely with other theory, and predicts a field of 313.5 mV/m @ 1 km (194.8 mV/m @ 1 mile) for a radiated power of 1 kW.

Also shown on Figure 5A, and those to follow, is the predicted nighttime interference contribution of the antenna system, assuming a radiated power of 1 kW. The interference prediction is based on graphs shown in the FCC's Rules for Class I and II stations (Figures 1a and 6 from Section 73.190 of the Rules.) It has been used here to give some sense of the performance possibilities of different antenna systems.

Figure 5B shows what happens when the 90 degree radiator is operated over a quarter-wave ground system, where the surrounding earth material has a dielectric constant of 15 and a conductivity of 4.0 millimhos/meter. A null appears in the skywave pattern at the horizontal, and a surface wave appears. Interestingly enough, nothing very dramatic happens to the skywave interference. Though not shown on Figure 5B, the drive point (base) resistance drops from 36.7 ohms to 28.5 ohms and the horizontal plane field strength at one km increases from 313.5 mV/m to 354.6 mV/m (220.4 mV/m @1 mile).

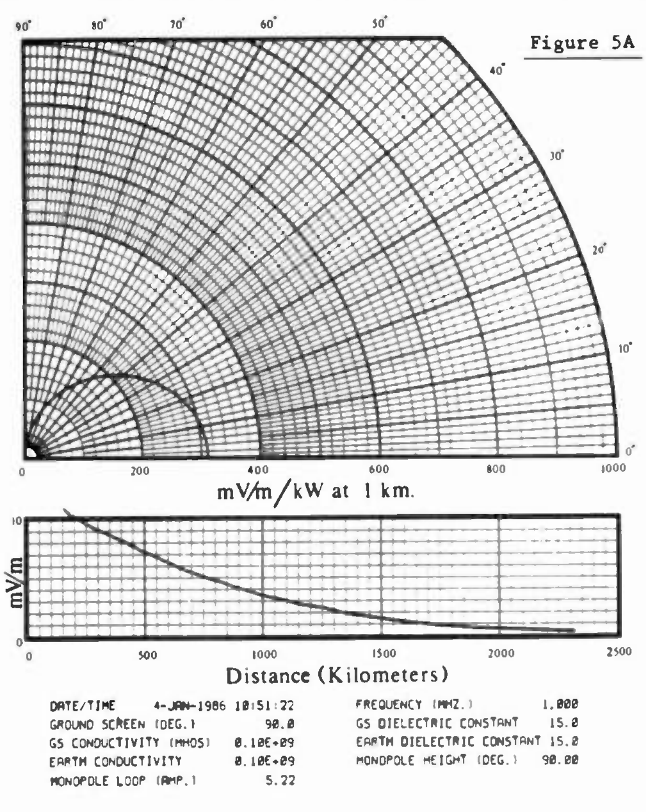


Figure 5A

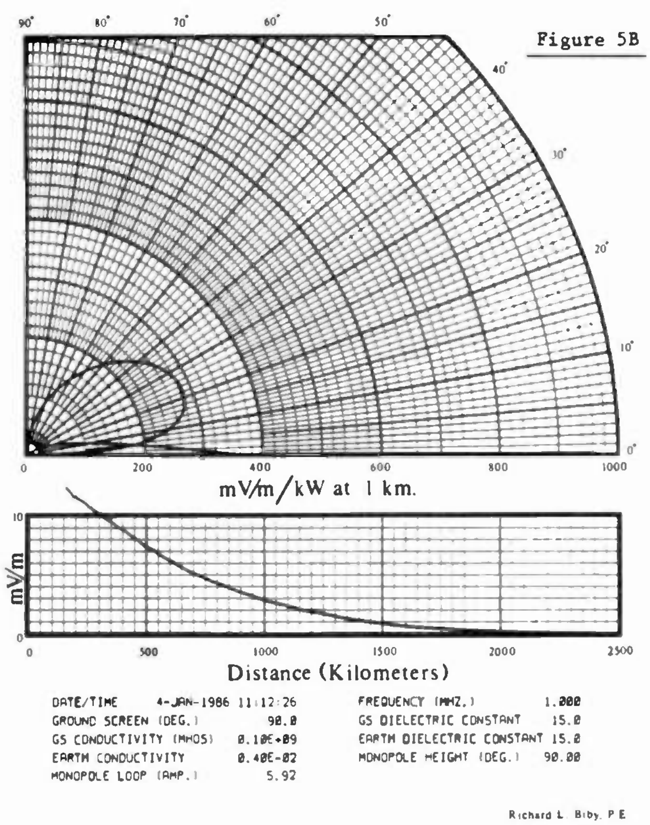


Figure 5B

Desirable Characteristics Of Broadcast Radiators

Conventional broadcast AM radiators actually have some very desirable characteristics. They are relatively inexpensive to construct, as compared (for example) with the earlier "T" radiators, which required two supporting structures. In fact, they neatly combine the support structure and the radiator. They also make excellent building blocks for directive antenna systems, inasmuch as they show no variation in the phase or amplitude of the radiated fields as a function of azimuth.

To be generally useful, a broadcast antenna system should not unnecessarily discriminate against coverage in any direction, and it should have reasonable impedance and bandwidth characteristics.

An antenna system with improved groundwave vs. skywave characteristics should have these attributes. If at all possible, the improved antenna should be so conceived as to permit the conversion of existing antenna systems at a minimum cost.

In order to be really economically viable, then, an "antiskywave" antenna design concept must be able to take the typical, 90 degree vertical (tower) radiator, with a conventional buried copper wire ground system, make minimal changes thereto, and end up with decreased nighttime interference and improved groundwave signal strength. All the while, the system should remain non-directive, but still offer the possibility of being made directive in the horizontal plane if such were needed.

It is believed that the ASWA antenna, as described here, will meet all of those design goals.

Earlier Antiskywave Antennas

Efforts to design medium frequency broadcast antennas with significant reduction of the skywave fields must depend upon achieving some specific distribution of current and phase so as to shape the radiation pattern in the vertical plane. (That is, to "squeeze" the radiated signal pattern down as close as possible to the horizontal plane.)

Such attempts have met with varying degrees of success. In general, it appears that attempts to drastically improve the vertical plane radiation characteristics of short (e.g., one half wavelength or less) radiators have not been particularly successful. Some improvement in the groundwave/skywave characteristics have been obtained, but the magnitude of such improvements has not been great enough to cause wide adoption of these techniques.

Examples include the patents of Raymond Wilmotte[3], who sought to modify the current distribution of short antennas so as to place the current loop well above ground; and the work by W.W. Hansen (and others)[4] with arrays of short elements arranged in circles about a common axis. The latter class of radiators achieves considerable gain in the horizontal plane, and corresponding decreases in radiation above the horizontal, by providing a large aperture (on the order of a wavelength squared or over 50 acres in the middle of the AM band) in the horizontal plane... a very interesting and very sound idea which becomes impractical in view of today's real estate prices.

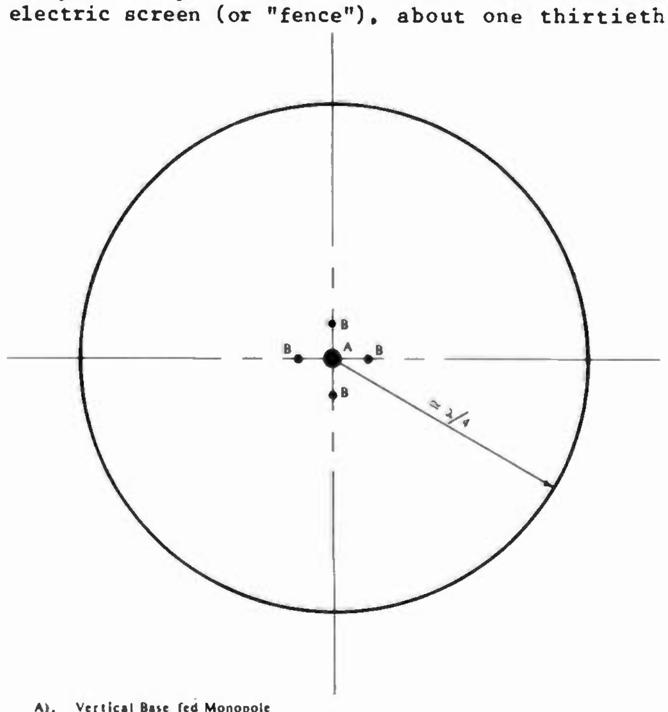
Some larger radiating structures do give good performance and are capable of generating strong ground waves while providing considerable suppresion of skyward radiation over at least a range of vertical angles. The Franklin Antenna, which is a good example of such large systems, amounts to a half-wave dipole, standing on end. Since it is on the order of a full wavelength in height, midband Franklins are about 1000 Ft. high.

Such designs, however, do not provide as much suppression of skyward radiation as is desirable over as wide a range of vertical angles as is needed. Further, these structures are generally quite expensive to build and maintain.

Description Of The Antiskywave Antenna (ASWA)

The following paragraphs describe the theory behind an antenna structure intended to be capable of generating strong ground waves while radiating only limited amounts of energy skyward.

Figures 6-A and 6-B are sketches of the proposed antenna design. A monopole (a quarter wavelength or so in height), operating over a conventional ground system consisting of perhaps 120 buried copper radial ground wires about one quarter wave in length, forms one important element of the system. Arrayed around the base of the monopole are several short (one-thirtieth of a wavelength or so) base-fed radiating elements. Around the entire array of monopole and short radiators is a circular electric screen (or "fence"), about one thirtieth



A). Vertical Base fed Monopole
Height $\simeq \lambda/4 - \lambda/2$

B). Collection of Short Base fed Vertical Conductors
About 10° in Height

C). Electric Screen – About 10° in Height

Figure 6A

of a wavelength high and at a distance of about one quarter wave from the monopole.

As viewed from a distant observation point on the earth's surface, the electric screen acts to impede the illumination of the surface of the earth by the collection of short radiators. Thus, the screen, in concert with other design factors, decreases the ability of the short radiators to generate a strong surface wave. At appreciable angles above the horizon, however, the geometry of the structure permits more and more of the current carrying length of the short radiators to become effective in radiating a skyward field.

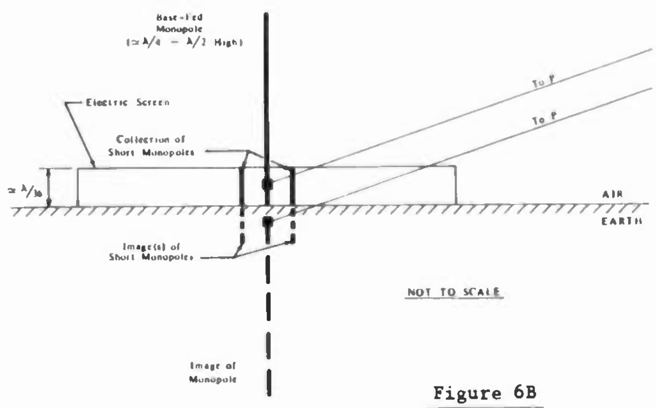


Figure 6B

The number and placement of the short radiators, together with their height and the height of the circular electric screen ("fence") can be so designed as to provide a close match in both amplitude and phase to the skyward radiation from the taller monopole. By appropriate adjustment of the phase and magnitude of the currents flowing in the short radiators, this skyward radiation can be made to very nearly cancel the skyward radiation of the taller monopole over wide ranges of vertical angles. Since the screen, acting with the ground system, has a drastic effect upon the ability of the short radiators to generate a surface wave, while only modestly affecting the surface wave characteristics of the taller monopole, a strong ground wave results, even though the skyward radiation is severely curtailed.

More than one short radiator is used to aid in obtaining the desired radiation pattern (both in amplitude and in phase) from the short sources, and to achieve a gain in efficiency through mutual impedance effects. For the same reasons, the effective length of the short radiators should be increased by top-loading or other appropriate techniques.

This antenna design should result in greatly increased ground wave signal strengths (per unit of input power) as compared with that obtained with conventional antenna systems. The fields so generated are on the order of twice those usually obtained in practice, but exact values are greatly influenced by frequency, antenna system design, and the electrical characteristics of the earth.

Computed Performance of ASWA

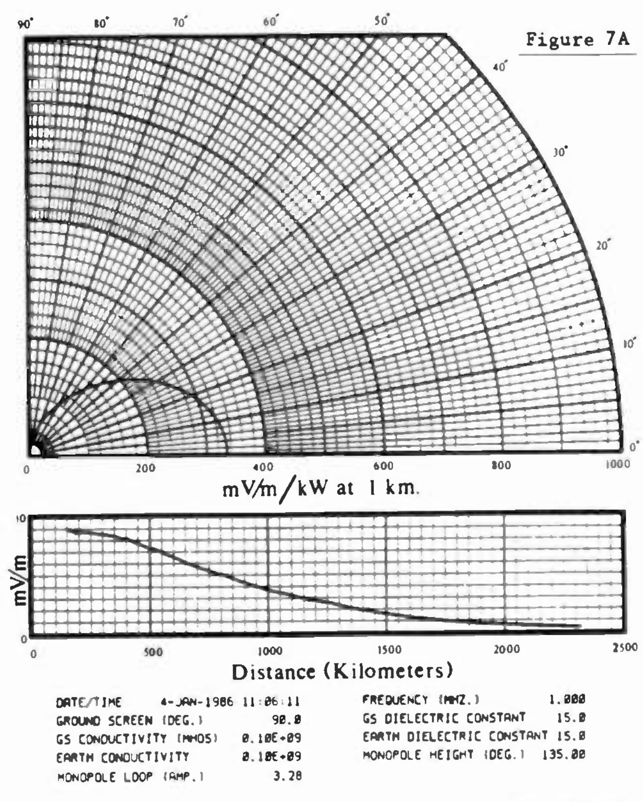
The computer model, mentioned briefly earlier, includes all the more important features of the ASWA antenna, such as height of center (tall) monopole, the height and number of short radiators, their distance from the axial center of the system, the conductivity and dielectric constant of the material forming the ground system and the surrounding earth material (soil), the radius and height of the ground system and the "fence", and so on.

As an example, the theoretical performance of an ASWA antenna system built around a conventional base-fed (tower) radiator, 135 electrical degrees in height, is shown in Figures 7A through 7D. Figure 7A shows a vertical plane pattern for the basic radiator, assuming a perfectly conductive earth. It's calculated field of 335.7 mV/m @1 km (208.6 mV/m @1 mile) per kilowatt radiated is in good agreement with the value calculated using other, more conventional techniques. The loop resistance is about 93.0 Ohms.

Figure 7B shows what happens when the same 135 degree radiator is operated over a conventional (quarter-wave radius) copper ground system, where the surrounding earth material has a dielectric constant of 15 and a conductivity of 4 mmhos/m. The (unattenuated) groundwave field strength is now 401.0 mV/m @1 km (249.2 mV/m @1 mile) and the loop resistance has become 65.0 Ohms.

Norton's series of articles discusses the fact that the (unattenuated) groundwave field strengths can exceed the corresponding values calculated on the basis of perfectly conductive earth. The results

Figure 7A



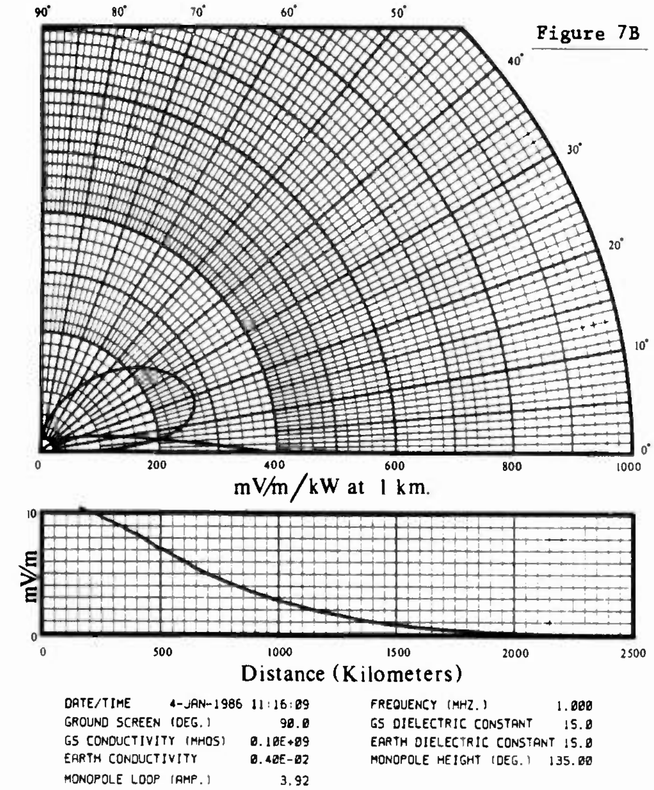


Figure 7B

shown by the model are therefore, only independent verification of an expected result.

Figure 7C shows the effects of a set of eight short (10 deg. high) radiators, arranged in a circle of radius 5 degrees, and the inclusion of a "fence" (also 10 degrees high) located at the edge of the quarter-wave ground system. The unattenuated ground wave field strength is now 827 mV/m @1 km (514 mV/m @1 mile), and the loop resistance has dropped to 13.2 Ohms. The current flowing in each of the short radiators is 7.32 amperes.

One characteristic of the ASWA design is that a null can be placed in the skyward radiation pattern at angles of about 15 or more degrees above the horizontal. A suppression angle of 25 degrees corresponds to a distance of about 450 km (280 miles) and 15 degrees to about 750 km (470 miles).

Considering the example at hand, for which the null angle has been set to 25 degrees above the horizontal, and discounting the extreme skywave suppression performance at that particular angle, it appears that the proposed antenna design can provide average suppressions on the order of 6 to 20 dB at the range of angles which corresponds to interference distances of 600 to 1200 km (370 to 750 miles). The increase in groundwave signal stength is on the order of 6 dB.

An interesting, and pertinent question, is: Just how important is the "fence" around the whole system. Figure 7D shows what happens when the height of the fence is set to zero. The (unattenuated) groundwave has dropped to 313.5 mv/m @1 km (194.8 mV/m @1 mile) and the maximum value of "groundwave" field strength is no longer on the

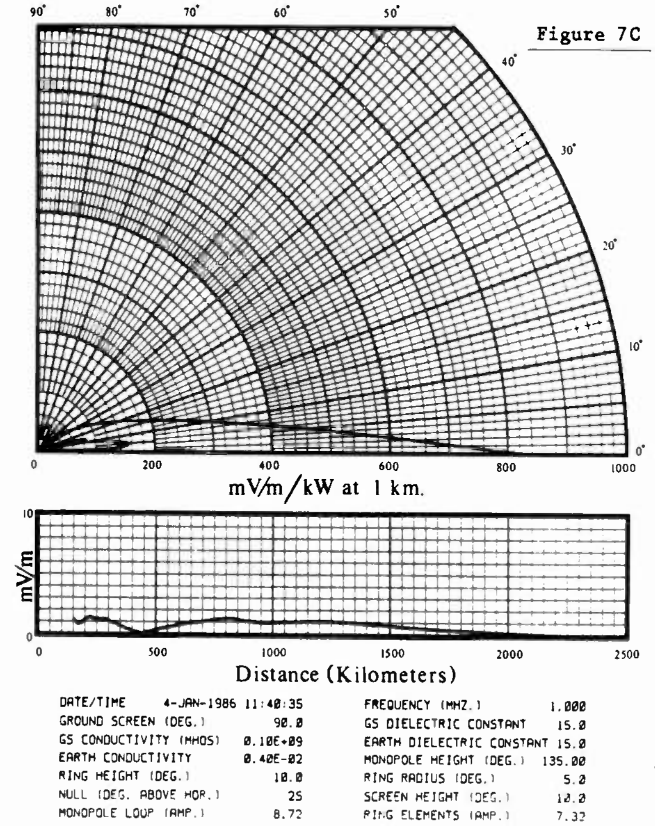


Figure 7C

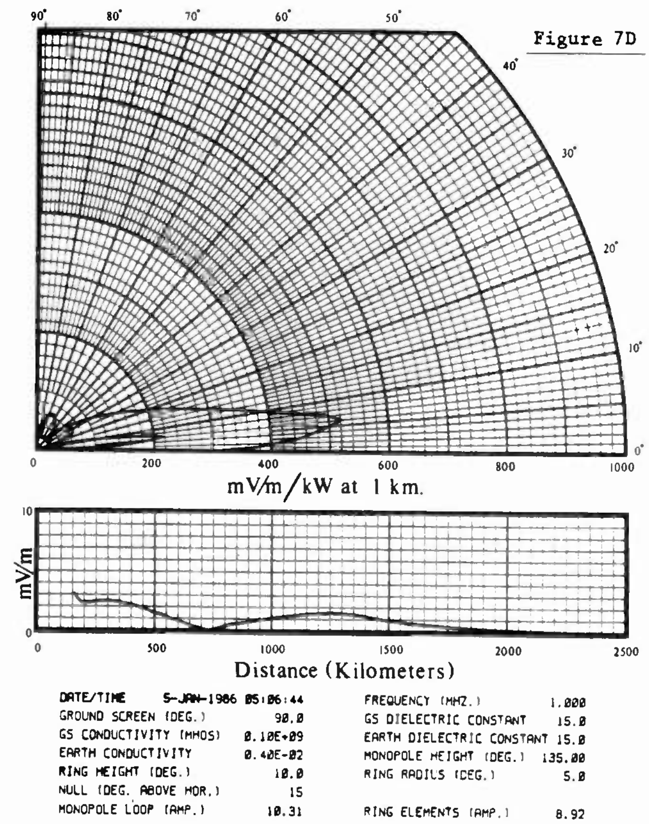


Figure 7D

surface!

Rather surprising, all in all. But then, perhaps not so surprising, really. The short radiators don't illuminate as much of the earth's surface as their taller companion. The taller radiator, then, can be expected to be a better generator of surface waves than would be the case for the shorter ones. The relative suppression of the groundwave at the horizontal plane is to be expected. Also, as would be expected, the element currents increase.

What would be the attenuation Vs. Distance characteristics of the peculiar "groundwave"? Would it have a more attractive attenuation characteristic then is characteristic of ordinary radiators? Realizing that the very great attenuation of AM groundwave signals arises from the horizontal electric field component causing power flow into the earth, then might not the wave which has most of its energy above the surface have less attenuation? Unfortunately, even after the enormous simplifications provided by Norton, the formulas which describe the groundwave attenuation factors are difficult to evaluate. (Truculent is probably a more apt description.)

The "fence" is an important design factor, but the requirements placed upon it depend upon the circumstances at hand.

Teachings Of The Computer Model

Evaluation of the computational results provided by the computer model has made several points abundantly clear:

1) As would be expected from the fact that a proper ASWA design would compress the radiated energy into the surface wave (with the net result that field strengths on the surface would be considerably increased), the total current moment in the radiating system (i.e., the product of amperes of current flowing in meters of conductor) must correspondingly increase. However, it is one of the basic design principles of the ASWA system that existing antenna systems should be (generally) usable as the basic building block. Therefore, either a way must be found to provide more length of current carrying conductor without extending the height of the existing tower radiator, or the drive point impedances of the system are going to suffer.

Areas which are to be explored regarding this aspect of ASWA system design include the use of top-loading (as by connecting the top segment of a guy strand to the top of the radiator) and multiple tuning. The latter idea would involve, say, two outriggers, connected to the ground system at the bottom (perhaps through an electrical network) and (each) to one of the two remaining guy strands at the top. This, of course, is just a variation of techniques used many years ago to improve the radiation efficieny of low-frequency antenna systems.

The short radiators can be effectively top-loaded by connecting a horizontal wire, one quarter-wavelength long, to the top of each of the short radiators. The open-ended transmission lines so formed have zero ohms impedance as viewed from the top of the short radiator. Again, this is old art.

The model has been insistent about one point: the current loop of the (tall) center radiator should be above the surface. Somewhere around 45 degrees above the surface, in fact, seems to be about optimum.

As would be expected, the dimensions (in terms of wavelength) of an optimized system, and the groundwave fields achievable, are significantly influenced by the frequency and by the electrical characteristics of the surrounding earth material.

Conclusions

The proposed ASWA antenna concept offers reasonable hope of significant improvement in the groundwave efficiency of standard broadcast antenna systems, with corresponding decreases in nighttime skywave interference. Significant, but not insurmountable, design problems do exist with the concept.

Bibliography

[1] A. Sommerfeld The Propagation Of Waves In Wireless Telegraphy, Ann. Physik, Vol. 28, p. 665, March, 1909.

[2] K.A. Norton, The Physical Reality Of Space And Surface Waves In The Radiation Fields Of Radio Antennas, Proc. I.R.E., Vol. 25, p. 1192, September, 1937.

The Propagation Of Radio Waves Over The Surface Of The Earth And In The Upper Atmosphere (Part I), Proc. I.R.E., Vol. 24, 1367, October 1936. (Part II) Proc. I.R.E., Vol. 25, p. 1203, September, 1937.

[3] R.M. Wilmotte, U.S. Patent Nos. 2,233,618 (May 19, 1942), 2,283,617 (May 19, 1942), and 2,609,504 (September 2, 1952)

[4] F.E. Terman, Radio Engineers Handbook, McGraw Hill Book Company, Inc., 1940, p. 817.

[5] E.C. Jordan, Electromagnetic Waves And Radiating Systems, Prentice-Hall Electrical Engineering Series, 1950, Chapt. 16 ("Ground Wave Propagation")

NEW DIMENSIONS FOR THE DESIGN OF MEDIUM WAVE ANTENNAS

Ogden L. Prestholdt
A.D. Ring & Associates, P.C.
Washington, District of Columbia

ABSTRACT

A new concept for the design of medium wave directional antennas is proposed. Significant separate control of ground wave and sky wave radiation is provided. The antenna system utilizes separately excited vertical and horizontal and/or diagonal elements. The introduction of non-vertical element provides greater flexibility in antenna design and permits optimizing coverage while maintaining protection to other stations.

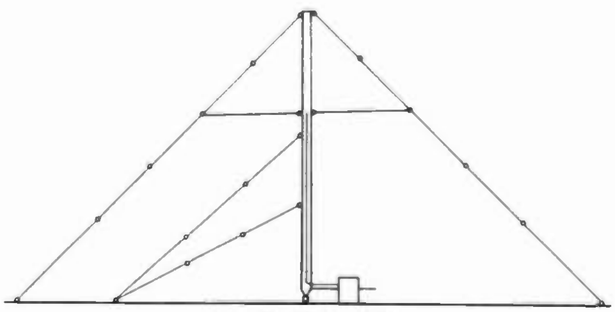
I INTRODUCTION

In the medium wave (AM radio) band there are two basic modes of propagation. During both the daytime and nighttime a ground wave signal is propagated. Further, during the nighttime a signal is reflected from the ionosphere and returns to the earth at greater distances with significantly less attenuation than that suffered by the ground wave.

For more than 50 years we have used combinations of vertical radiators to make directional antennas. These directional antennas have been used to minimize co and adjacent channel interference to other stations both day and night and to provide coverage to the desired areas. These conventional directional antennas suppress both the ground wave and the sky wave and consequently have limited ability to optimize coverage while minimizing sky wave interference to other stations.

A horizontal antenna will radiate both horizontally and vertically polarized waves at certain azimuths and angles of elevation. Here it is proposed to use a combination of vertical, horizontal and/or diagonal antenna segments to obtain significant separate control over ground wave and sky wave radiation. These various antenna segments will have to be excited with carefully chosen current amplitudes and phases in order to obtain this control. It has been found that the currents and phases associated with "Tee" or "L" antennas as used in the past have not provided this choice of amplitude and phase.

In order to illustrate this concept a model consisting of a vertical antenna with a center fed horizontal antenna supported from the vertical antenna will be described.



VH ANTENNA MODEL

FIGURE 1

II MODEL ANTENNA

Figure 1 shows the principle features of the model. A typical base fed vertical antenna tower and support guy cables is shown. At a suitable height, a center fed horizontal antenna is shown. It is oriented parallel to the Y axis. Its ends are supported by insulators and an auxiliary set of transparent guy cables. The horizontal element would be fed from a balanced feed network supported in the tower. This network would be fed by a coaxial transmission line supported inside the tower and insulated from the tower as we do for FM antennas. A matching and phase control network would feed the transmission line for the horizontal antenna. A conventional matching network would be provided for the vertical antenna. A typical combining network would be used to combine the antennas for a common feed line.

III CALCULATION OF RADIATION

The radiation from this antenna system can be analyzed by developing separate equations for the total radiation from each element. Sinusoidal current distribution is assumed. The far field was calculated by the integration of the antenna current elements and their images for each antenna segment.

Figure 2 is a set of cartesian and spherical coordinates chosen to describe the model and its radiation characteristics. The ground plane is the X-Y plane and the positive Z direction is toward the zenith. The positive R direction is out from the origin, positive Theta is away from the zenith (Z axis), and positive Psi is counter clockwise from the X axis.

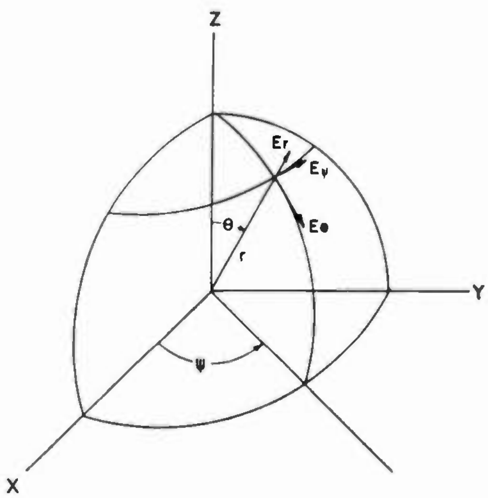


FIGURE 2

Instead of discussing vertical and horizontal polarization or field components it is desirable to use the Theta and Psi components.

For a vertical antenna, there is only a Theta component of the electric field, it is given by the following equation:

$$E\theta = j\,\frac{60 I_v}{R_o}\left[\frac{\cos(\beta h \cos\theta) - \cos\beta h}{\sin\theta}\right] \text{ V/M} \quad (1)$$

Where I_v = vertical antenna loop current in amperes (its phase is assumed to be zero)

R_o = distance to observation point in meters

βh = electrical height of the vertical antenna

θ = the angle Theta

Using the same procedure the Theta and Psi fields (there is no radial component) from the horizontal wire are given by the following equations:

$$E\theta = -\frac{120 I_h}{R_o}\left[\frac{(F1)(M1)(M2)(M3)}{1-\sin^2\theta\,\sin^2\psi}\right] \text{ V/M} \quad (2)$$

$$E\psi = -\frac{120 I_h}{R_o}\left[\frac{(F1)(M1)(M4)(M3)}{1-\sin^2\theta\,\sin^2\psi}\right] \text{ V/M} \quad (3)$$

Where I_h = the magnitude of the loop current in the horizontal wire

ϕ = the phase of the loop current

$F1 = \cos\phi + j\sin\phi$

$M1 = \sin(\beta a \cos\theta)$

$M2 = \cos\theta\ \sin\psi$

$M3 = \cos(\beta l \sin\theta \sin\psi) - \cos\beta l$

$M4 = \cos\psi$

βa = the electrical height of the horizontal wire

βl = the electrical half length of the horizontal wire

Note that the $E\theta$ components in equations 1 and 2 are in time quadrature, this may be the reason that the concept was not previously discovered!

IV CALCULATION OF CONIC SECTIONS

The radiation from the model antenna is best described with the use of a series of conic sections. A computer program was written to perform the necessary calculations. By means of a hemispherical integration the total power flow for both the Theta and Psi components of field were summed up and a multiplication factor established to correct the assumed currents so that the radiated fields would be in mV/m at one kilometer for one watt.

In the model it is assumed that the vertical antenna has a loop current of 1.00 at a phase of 0 degrees. The horizontal antenna has a loop current of 5.00 at a phase of 90 degrees. In this example the calibration factor was found to be 0.06875. Thus the actual currents would be 0.06875 amperes for the vertical antenna and 0.3438 amperes for the horizontal antenna.

Pertinent conic sections were then drawn by the computer for the model antenna. In the following conic section graphs it is assumed that each antenna is operating with the current that is necessary for the combined system to radiate one watt.

Figure 3 shows the conic sections for the E(Theta) component from the vertical antenna alone, as expected they all show an omnidirectional pattern. Note that Theta = 90 degrees corresponds to an angle of elevation of zero.

Eθ COMPONENT OF RADIATION
VERTICAL RADIATOR

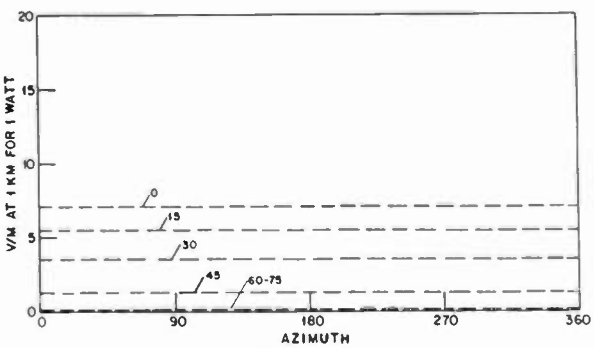


FIGURE 3

Figure 4 shows the conic sections for the E(Theta) component from the horizontal antenna only. At an azimuth or Psi angle of 0 and 180 degrees there is no E(Theta) component because that direction is at right angles to the horizontal wire. Also at an azimuth of 90 and 270 degrees (the direction of the horizontal wire) the Theta radiation is zero on the ground (Theta=90) and goes through a maximum at Theta approximately 30 degrees.

Eθ COMPONENT OF RADIATION
HORIZONTAL RADIATOR

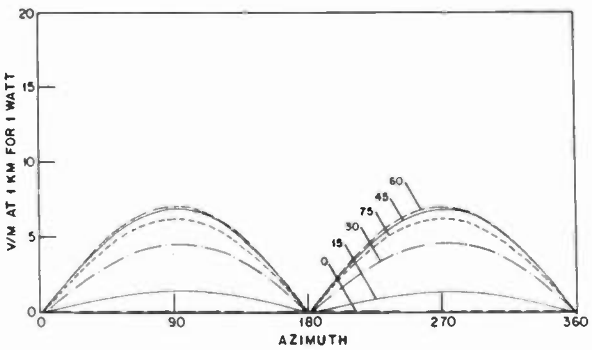


FIGURE 4

Figure 5 shows the conic sections for the E(Psi) component from the model antenna. Note that this is the only E(Psi) component so it is also the total E(Psi) component from the model antenna.

Eψ COMPONENT OF RADIATION
HORIZONTAL ELEMENT ONLY

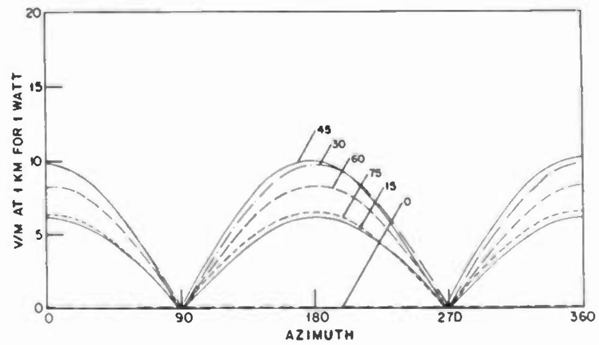


FIGURE 5

Figure 6 shows the conic sections for the total E(Theta) field. For Theta = 90 degrees (on the ground) the field is omnidirectional. As the angle of elevation increases (Theta decreases) the E(Theta) component first decreases, goes through zero and then increases.

Eθ COMPONENT OF RADIATION
VH ANTENNA SYSTEM

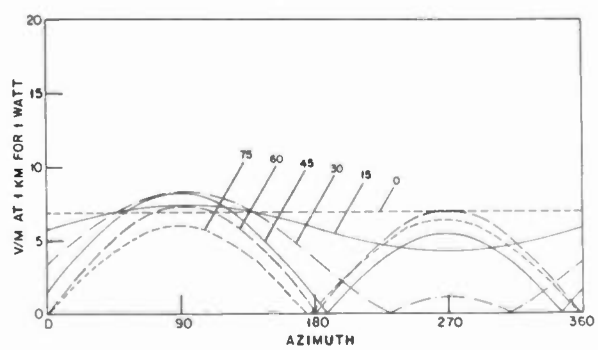


FIGURE 6

V ALLOCATIONS IMPACT

Figure 7 illustrates the service areas for two AM stations under several different operating conditions. They operate with a power of 1 kW utilizing 190 degree vertical antennas on 1000 kHz. They are separated by 260 miles in a area where the conductivity is 10 mmhos per meter and the dielectric constant is 15. The illustration shows to approximate scale the daytime ground wave service, the nighttime service as it would be limited by sky wave interference with the vertical antenna only and the improved night time service that would result from the use by both stations of the model antenna with the horizontal element.

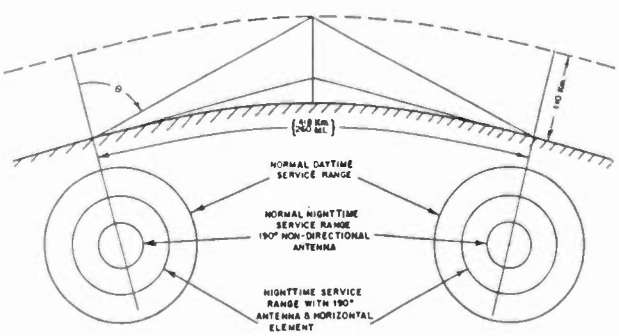


FIGURE 7

Figure 8 shows the ground wave field strength versus distance from both the vertical antenna alone and with the addition of the horizontal antenna and the interference producing sky wave signal of the other station.

The station is protected during the daytime to its 0.43 mV/m ground wave contour. Its 0.5 mV/m contour occurs at 60.5 miles. At night with the same power and antennas the interference limit is to the approximate 6.8 mV/m contour which occurs at 17 miles.

Now with the model antenna which has a horizontal antenna added with the appropriate current amplitude and phase the nighttime limit is reduced to the approximate 1.0 mV/m contour which now occurs at 33 miles. To obtain this change in vertical pattern from the model a ratio of horizontal loop current to vertical antenna current of 5/1 is required. A phase of -90 degrees was required assuming that the horizontal

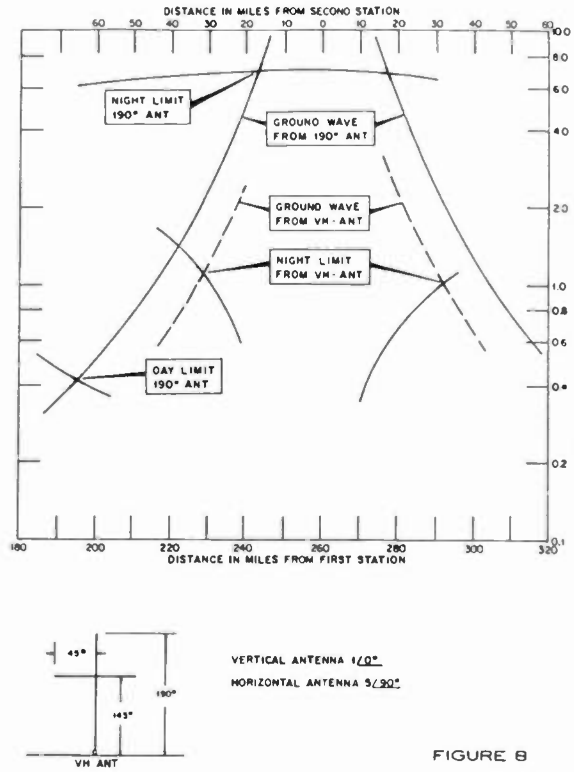


FIGURE 8

wire was parallel to the line joining the stations and that the reference of zero degrees corresponds to current flow toward the other station.

For the same input power to the combined antenna system this addition of the horizontal antenna reduced the RMS of the ground wave to 65 percent of its former value. In spite of this reduction in ground wave efficiency the service radius is nearly doubled.

VI CONCLUSIONS

An antenna system consisting of both vertical and horizontal radiating elements has been described. It truly adds another dimension or perhaps several dimensions to the design of medium wave antennas. It is not yet known how versatile the system will eventually be but it is anticipated that it will permit new stations to be added to the spectrum, for existing stations to improve their local service and to result in reduced interference to many stations.

IMPROVING AM BROADCAST SERVICE BY MEANS OF SYNCHRONOUS TRANSMITTERS

Oscar Reed, Jr., Ross H. Beville
and Granville Klink, Jr.
Oscar Reed, Jr. & Associates
Silver Spring, Maryland

ABSTRACT

James McKinney, Chief, Mass Media Bureau of the FCC in his luncheon address to the IEEE Professional Group on Broadcast Transmission Systems on September 20, 1985, indicated that the Commission was giving considerable thought to improving AM Standard Broadcast services to the U.S. Among the techniques being given study was that of synchronous operation of broadcast transmitters. In Washington, D.C., during the 1947-49 period, engineers of Jansky & Bailey demonstrated the feasibility of an improved technique linking 3 transmitters for WINX on 1340 kilohertz, located in Arlington, Virginia, downtown Washington, D.C., and nearby Bethesda, Maryland. With carriers locked in to precisely identical frequencies, and phase stabilization achieved via 936 megahertz links, the practicality of improving service to a large metropolitan area utilizing Class IV local channel facilities was demonstrated. It would be feasible today to build multiple AM transmitters (along a narrow corridor from Washington, D.C. to the North Carolina border) and provide the daytime travelling public with continues news, entertainment, and travelers information.

INTRODUCTION

"The congestion in the broadcasting frequency range is so great that consideration has naturally been given by various engineers to the possibilities of different stations using the same frequency for broadcasting. It is hoped that the following statements may be of some interest in the consideration of this question." Doesn't that sound like a statement applicable to the recent past as we have grown past the presence of well over 4000 licensed AM stations? Well, it certainly is applicable today, but the quoted statement was the opening paragraph from the 1927 paper presented before the I.R.E. National Convention in New York, N.Y. on January 11.[1] Martin, Gillett, and Bemis the authors were in the Department of Development and Research of the American Telephone and Telegraph Company. (Before the Bell Telephone Laboratories).

Glenn D. Gillett, later a part of the Washington Radio Consultants fraternity, was developing his early experience in broadcasting. Interference Between Stations, Frequency Control, and Experimental Data were the three major topic headings of the technical paper containing four Figures and diagrams. References to this paper were earlier treatments of allied topics by Bown and Gillett in 1924; A.N. Goldsmith in 1926; and L. Espenschied in 1927. The first two were I.R.E. Proceedings papers, and the latter in A.I.E.E. presentation published in January issue.

In the March, 1930 I.R.E. Proceedings, appeared a 3-page paper by F. Gerth entitled, "A German Common Frequency Broadcast System."[2] Reference was to doing away with "wave congestion" by the use of transmitters "operating on perfectly equal waves."

In 1931 P.P. Eckersley, of the High Frequency Engineering Co. Ltd., North Acton, W, 3, England reported in the I.R.E. publication "On The Simultaneous Operation of Different Broadcast Stations on the Same Channel."[3] In the same year G.D. Gillett, now of the Bell Telephone Laboratories, New York City was reporting on "Some Developments in Common Frequency Broadcasting."[4] Glenn himself is pictured in Figure 5 in a corner of the operating room at station WOC, Davenport, Iowa. The fascinating thing about some of these early I.R.E. proceedings is the portrayal of some of the later-renowned engineering personages in their earlier years. Even then one could see that Glenn was on his way to assuming a size suitable for a Chicago Bears plunging half back like "Refrigerator" Perry. I can remember him over-filling his chair in the ninth floor National Press Building offices, right next to those of Jansky & Bailey in 1940. Come to think of it even then C.M. Jansky was beginning to assume pro full-back like proportions. It probably went with the successful practice of radio consulting engineering and good client entertaining.

WOC was required in those days to share operating hours equally with WHO in Des Moines on 1000 kilohertz. The stations were 153 miles apart. Ergo, why not operate them simultaneously by maintaining the carriers of these two stations within the limits of "isochronism"? Bell telephone Laboratories, therefore, undertook the necessary development work. Newly developed crystal controlled oscillators came into their own. Remember? Figure 3 shows a six-foot rack full of the crystal-controlled oscillator amplifier unit. Remote controlled monitoring point receivers checked frequency every ten minutes and maintained the carriers within an average of two cycles per minute of absolute "isochronism". Numerous "Ratio of distortion products to the fundamental," curves were included for various field strength ratios.

It remained for Charles B. Aiken, of the same laboratories, in the September 1933 Proceedings of the I.R.E. in "A Study of Reception from Syncronized Broadcast Stations,"[5] to treat mathematically the effects of differences in path lengths from the two transmitters to a receiving point. It was shown that these differences, the effects of time delay in the program distribution circuits, and differences in circuit elements in the two transmitters may all be expressed in terms of two fundamental angles γ and β . γ is the phase angle between the two carriers at the receiving point, and β is an angle determing the relation between the side frequencies received from the two stations He states as follows - "At any given point there will be a different value of β for each modulation frequency. Analyses in these terms yield quantitative descriptions of the distortions present in the rectified wave. From these results it is possible to determine how the distortions vary from point to point in space and upon what significant quantities they are dependent."

James L. Hollis in the Proceedings of 1944 described "A Remote-Controlled Radio-Frequency Booster for a Broadcast Station."[6] In this paper the conditions prescribed by Charles B. Aiken were met by using a "Booster Transmitter" fed via a shielded loop pickup system. This fed a straight-radio frequency amplifier without detection to feed the booster. In this case the system was used to boost the signal in the downtown business district of Cincinnati. WSAI on 1360 kilocycles, in order to meet the requirements for protecting several other stations on the channel, had to be located 10 miles from the heart of the city in order to find sufficient acreage for the multi-tower directional antenna. This has been a particular problem for higher frequency regional stations in the broadcast band, where the 5 kilowatt power limit and higher signal attenuation over large built up city areas, rendered the provision of an adequate 25 millivolt per meter signal for the city business district almost impossible to achieve.

- - - -

Ross H. Beville, a co-author of this paper, was associated with WWDC, a 250 watt Class IV operation in Washington, D.C., when he had published in Electronics in July 1945 an article entitled, "Broadcast Band Satellite Transmitters."[7] He was concerned with extending the coverage of such stations, which today are still limited by nature of their FCC classification to 1000 watts power, to adequately cover large metropolitan urban areas having high man-made ambient noise levels and signal absorption by man made structures. He pointed out that a low power station with several strategically located boosters can provide coverage comparable to that of a much higher-power station.

The article discussed the two different techniques employed at that time by WWDC and WINX to extend their coverage from central Washington, D.C., where each was located to reach different important suburban areas beyond the range of the centrally located stations. Such suburban areas, were even at that time, growing to such an extent that lower signal values suitable for service to rural areas, were increasingly inadequate to provide noise-free broadcast service. The WWDC booster, located near Chevy Chase and Silver Spring, Maryland was fed using r-f lines, and the WINX system located at American University in North-West Washington was fed via space radiation as in the WSAI case. Both systems utilized ordinary telephone pairs for remote control purposes.

In the WWDC case, Western Union open wire line, consisting of 8.75 miles of No. 9 copper wire, spaced 10.25 inches apart, was used for the longest run. This presented a space impedance of approximately 700 ohms. It followed the route of the B and O railroad to Silver Spring and then along East-West Highway on telephone line poles. About 7762 feet of a No. 19 gage pair, in a 26 pair lead cable was used, to reach from the transmitter to the railroad yards. The twisted pair in the lead cable measured 170 ohms at the 1450 kilohertz frequency. The entire line loss, over 10 miles was 97 dB. Approximately 29 watts was fed into the line from the final stage of the main transmitter, with about 2 millivolts being received at the booster end.

A MORE MODERN OPERATION

Jansky & Bailey, commencing in the spring of 1947, had an opportunity through the interest of the Washington Post to refine the Satellite booster technology then in use. The newspaper publisher had purchased the experimental FM station, W3XO, from the consulting partnership. Wayne Coy, newly from the White House Staff function, was brought into the Post Organization to develop WINX which had also been purchased. The way was opened to think of adding satellite transmitters in both Maryland and Virginia suburbs of Washington, D.C. using very high frequency radio links for interconnection of the three facilities. Work over the two-to-three year period was filed with the Federal Communications Commission. The efforts and accomplishments were detailed in documentation referred to in References 8 through 15.

The initial report in the series starts out by referring to the earlier work of Beville. Originally the booster had been operated by picking up a received signal at a point 1000 feet from the booster transmitter and feeding it through linear amplifiers directly to the booster. Tuned loops were used to pick up the received signal from the main transmitters.

Work on this program was carried out by Delmer C. Ports, chief engineer of Jansky & Bailey, with associated staff, under the direction of Stuart L. Bailey. The following section on Basic Principles is quoted from Reference No. 8

"BASIC PRINCIPLES

"The method of synchronization utilizing a very high frequency link was chosen after a careful consideration of many possible methods. It was determined that to be successful this type of operation is subject to rather rigid requirements if the booster is to provide good service to a reasonably large area and at the same time keep the areas of degraded service to a satisfactory minimum. The first and obvious requirement to be fulfilled is the phase stability of the booster carrier in relation to the main transmitter carrier.

"In the area between the two transmitters where the two signals are approximately equal, the resultant signal will be alternately increased and decreased in accordance with the relative distance from the two transmitters and, at times, will go almost to zero at the points of cancellation. These local areas will receive inferior service due to lower signal strength and possibly some distortion. If the relative time phase of the booster is not maintained absolutely fixed with respect to the main transmitter, these local areas will wander aimlessly back and forth, thus interfering at times with the quality of reception throughout a relatively large area. It is preferable to maintain these points at fixed locations, thus preserving the good service where it is available and accepting the poor service at fixed points where it will exist. This requirement automatically eliminates any type of operation that does not absolutely control the booster carrier from the main transmitter carrier. Thus it eliminates any type of carrier control over ordinary phone lines.

"It has been determined that if complete carrier phase stability can be achieved, it is also necessary to maintain identical modulation characteristics of the two carriers. This includes the relative time phase of the modulating. envelope.(1)

"If the carrier from the main transmitter is taken as the reference, it may be presented by

$$E\ (1 + M \cos Pt) \cos \omega t$$

where P is 2π times the modulating frequency and ω is 2π times the carrier frequency. The corresponding expression for the booster carrier at the same point may be given by

$$e\ (1 + m \cos (Pt + \beta)) \cos (\omega t + \psi)$$

where β is the relative phase shift of the modulating frequency and ψ is the relative phase shift of the carrier. The resulting signal is the instaneous sum of these two quantities.

"The value of ψ will, of course, change rapidly as the position is changed along a line between the two transmitters and will assume values from zero to π as the point is moved one-quarter wavelength in space. The value of β is subject to any delay in the audio signal at the booster if modulated separately or to differences in modulating characteristics. It is also a function of distance if the modulated carrier of the main transmitter is conducted over an electrically long path to the booster because of the slightly different frequencies of the side bands in relation to the carrier. It has been shown that if the value of β is not zero or sufficiently small, distortion will result in the area where the signals are approximately equal and are not directly in phase. However, if it is maintained at a satisfactory minimum value, distortion will not be objectionable except at the points where the two carriers almost completely cancel.

"This would completely rule out open wire lines as a means of conducting the modulated carrier to the synchronized booster if it were not already eliminated by previous considerations. It might possibly eliminate coaxial lines if they were available.

"Theoretically, it would be possible to achieve the desired result by conducting the desired audio over a line to the booster and inserting equivalent time delay at the transmitter end. Then with the identical modulators, the appropriate signals could be broadcast. This would also require a separate means of carrier control for proper synchronization. The degree of refinement required of equipment necessary to perform satisfactorily with this system is not available from a practical standpoint.

"This leaves as the only feasible method available, a very high frequency link with the modulated carrier of the main transmitter conveyed directly on the high frequency carrier. Two alternative methods are available with which to accomplish this. The first, if the bandwidth of the high frequency link will permit it, is to modulate the link carrier directly with the output of the main transmitter. The exact counterpart of the transmitter output is then recovered at the detector of the high frequency receiver. The second method, if the bandwith is restricted, is to heterodyne the modulated carrier down to a lower frequency then convey this and the control frequency used in heterodyning on the high frequency carrier to the receiving point. The recovered modulation is then restored to the original counterpart by the reverse process.

"In order to avoid undue complications and since the available bandwidth at 189 megacycles is sufficient to accomplish the desired purpose, the first method using the direct modulation of the full carrier was chosen for this installation.

"The difference in distance from the two transmitters to the area of equal signal is not so great in this case that relative change in phase between each carrier and its side bands will be objectionable as the modulated wave passes along the path of propagation."
(Ports uses ψ rather than γ)

(1) Charles B. Aiken, 'Study Of Reception From Synchronized Broadcast Stations,' Proc. I.R.E., vol. 21, pp 1265-1301, September (1933)

IMPLEMENTING A SYNCHRONIZED SATELLITE SYSTEM

The following 12 illustrations from the Jansky & Bailey 1947 through 1949 engineering reports to the Federal Communications Commission constitute a synopsis of planning elements and implementation phases for a satellite system to improve AM broadcast coverage on a Class IV local facility channel. In the late 1940's, and for 30 years thereafter, the maximum individual transmitter power was 250 watts. We thought of an aggregate power for a 3 transmitter system of 750 watts. Today, we can think in terms of a power up to 3 kilowatts. This is quite a substantial difference. We thought of serving a major metropolitan area with population in those days of about 1,500,000 persons.

1. Transmitting Tower Considerations

WINX, in 1947, had an FM station in Arlington, Virginia. From its 350 foot height it was possible to overlook Washington, D.C. and the Maryland suburb near Chevy Chase. Therefore it was made the main transmitting location and the other two locations the satellites. A ground system for 1340 kilohertz was added at the Garden City, Virginia as shown on Figure 1. As I recall the tower was shunt fed. Today, we would probably use the superior Mullaney Matching Unipole System.

2. Satellites Interconnection Equipment

Figures 2A and 2B show the auxiliary transmitter and receiver terminal equipment which provide for meeting the "Basic Principles" requirements. Initially 189 megahertz was used for the VHF carrier to Chevy Chase from Washington, D.C. Eighth and I Street Location of WINX. Finally, with the 3 transmitter system 936 MHZ was used. TV channel 9 had come in to operation in Washington!

3. Diagramatic Layout of System

As the diagram shows the "booster" near Chevy Chase used the tower formerly used by WWDC in the pioneering experiments covered by Ross Beville in the 1945 Electronics magazine article. A telephone line was used to interconnect the station studios, which remained at Eighth and I Streets, N.W. in Washington, to the relocated Main AM Transmitter at the Arlington FM site.

4. Interference Avoidance

Figure 4 illustrates the protection consideration to WEPM in Martinsburg, West Virginia at that time. As Class IV power increases have been authorized in more recent times across the board, a philosophy of increasing signals to urban areas and relying upon maintaining the equivalency of signal ratios between stations in rural areas has become the norm.

5. Definition of Existing Service

Figures 5 and 6 illustrate that in the case of planning for WINX improvement, measurements were used to define initial coverage conditions as an aid to planning for expansion. This process also gives a sound clue as to desirable areas for signal reinforcement. Figure 5 shows daytime reference contours and Figure 6 an approximation of the nighttime coverage case.

6. Step-at-a-Time - The Experiment Stage If Desired

In the WINX case the Chevy Chase "Booster" was explored and measured before the second Satellite was added. The 189 megahertz frequency relay system was the initial one applied.

7. Develop Proposed Contours for FCC Application

Predict 25, night limit, 5, 2, and 0.5 millivolt per meter contours. Figures 8 and 9 show these predictions for the Washington, D.C. area. Will the costs for "3 stations" and a synchronizing methodology yield sufficient audience and revenue potential increase to justify the program? What is the dimension of immediate population coverage gain? Demographic estimates for future years should also be made.

8. Your New 2 to 3 Kilowatt System

Figures 10 and 11 show the measured "proof of the pudding." In areas between transmitters, where the signals from the respective units are nearly equal, are the momentary cancellation bounds sharply defined and only momentarily noticeable? Do these zones stay in place and are they in lightly populated areas compared to the major portions of the service areas? Again the daytime and nighttime appropriate reference contours should be measured and defined on appropriate coverage maps.

9. Coverage Improvement Between Transmitters

Figure 12 contains recordings over the daylight hours at the Jansky & Bailey Laboratories at 1339 Wisconsin Avenue in a region between the Eighth and I Street plant and the Arlington, VA. plant. The left half of the upper recording is for Eighth and I only, and the right hand shows the deflection for the Arlington signal alone. The middle recording was taken with both units on the air simultaneously and the general increase in signal magnitude with both signals present can be noted. Reception was uniformly excellent and fully coherent in this region where the signals were of approximately equal amplitude from the two transmitters. There were some cancellation zones over about a one-mile area as discussed in the Conclusions section herein.

CONCLUSIONS

In the Jansky & Bailey report of April 22, 1949 (Reference No. 11) the following appears:

"RELATIVE PHASE STABILITY

"Continuing studies have been made for the past several months of the phase stability of this type of operation. Some continuous recordings have been made, (Note Figure 12 herein), and it is anticipated that additional recordings will be made when operation is resumed. It is planned to submit these to the Commission as soon as they can be prepared in exhibit form. In addition to this, observations at almost nightly intervals during the equipment test period of several nulls where the signals from Arlington and Eighth and I Streets have been nearly equal have been made. One in particular at the corner of Dumbarton Avenue and Wisconsin Avenue has been used as a reference. Through a wide variety of circumstances this null appears to be within ten feet of the original spot. Even when intentional alterations were made in adjustments or components known to have an effect on the relative phase relationship, it appears to have moved only about 25 feet.

"It is planned to submit further data including recordings to evaluate completely the phase stability of this type of system. This can only be done adequately by observing the system under actual operation, and best results will be obtained with the synchronous operation of only two transmitters first, then three after a reasonable interval of time."

These tests were completely successful and yielded substantial coverage improvements.

The 1947 census estimates indicated 1,205,220 persons in the metropolitan area. This represented a considerable growth over the 1940 figure of 907,816. The daytime coverage improvement as between the present and proposed population values would be substantially more favorable today as population in the nearby suburbs has burgeoned.

1947 Estimates

	Present	Proposed
District of Columbia	638,424	676,095
Montgomery County	62,729	90,574
Prince Georges County	81,028	95,497
Arlington County	64,305	72,343

The nighttime coverage improvements were even more substantial. A nominal 6.6 millivolt per meter contour was used as a reference.

	Present	Proposed
District of Columbia	593,902	639,412
Montgomery County	3,379	36,786
Prince Georges County	1,585	6,156
Arlington County	8,038	56,267

Further listening tests along the path between Arlington and Eighth and I Streets in Georgetown where the signals were very nearly equal showed that the position of the nulls was very stable. As Aiken had pointed out where one signal began to exceed the other by a value of approximately 2 to 1 the cancellation effect disappeared. Quoting from the concluding pages 10 and 11 of reference No. 12:

"They (the nulls) appear to occur with a sufficient degree of cancellation to cause distortion for a distance of approximately one mile. Within this distance, distortion can be observed in approximately two-thirds of the nulls. The extent of the distortion and width of the nulls is dependent upon the varying signal from both transmitters and appears to vary in width from practically zero up to 60 or 70 feet. They occur every 350 feet along the line between the transmitters.

"If further observations substantiate these preliminary findings, there will be a degraded service area approximately one mile in width. Within this zone, the distortion will be apparent in approximately ten percent of this area. These distortion areas will remain fixed in position and are similar in nature, so far as listening is concerned, to the selective fading characteristic of skywave signals or the distortion sometimes observed from a single transmitter in the vicinity of street car lines or overhead power lines.

"The increase in the area of a contour, such as the 6.6 millivolt per meter contour, for this type of operation is from 40 square miles for a single transmitter to 126 square miles for the three synchronized transmitters."

Transmitter performance measurements were made for the operation and all parameters including the measured noise level met or exceeded FCC requirements. These are reported in Reference No. 15 of June 6, 1949. The experimental operation was judged to be a complete success. Very substantial coverage improvement was achieved in the Washington metropolitan area.

The last 3 paragraphs of Charles B. Aiken's September, 1933 Summary proved to be remarkably accurate as judged by the Washington, D.C. tests so far improving service to urban areas is concerned. There seems little doubt, that his hypothesis regarding stations within 25 miles of one another for creation of an "extended linear" type of coverage with identical programming, would be any less accurate.

"On the other hand it is shown that if the two broadcast stations with synchronized carriers are fairly close together, that is,within about twenty-five miles of each other, there is no distortion in the middle zone between them if the modulated waves radiated from the two stations are identical. There may, however, be variations in resultant field strength. The effect of such variations may usually be eliminated by the use of automatic volume control in the receiving set. An exception must be noted at points where the resultant field strength falls below the noise level. At such points the use of a receiving antenna having slightly directive properties will eliminate this difficulty.

"The results of the analysis suggest an interesting possibility for supplying service to urban areas. Instead of employing one high power transmitter at a distance from the region to be covered, it may be possible to distribute a number of low power transmitters throughout this area and to supply each of them with identically the same modulated wave from a central point by means of appropriate transmission circuits. The total rediated power required for adequate coverage should be far less than that required when a single high power transmitter is used. On this account there would be a great reduction in the total sky wave and consequently a great reduction of interference at distant points. For this reason several station groups of this kind could be operated on one channel with the same geographical separations that would be required by several individual low power stations.

"If, within station groups, the program were to be distributed to the various transmitters at audio frequencies, the requirements on transmission time, frequency-transmission characteristic, and modulation characteristic would have to be very severe in order to meet the necessity of identical radiated waves from all stations in the group. This technical difficulty would be avoided if the modulation of a carrier were effected at a central point and the resulting modulated wave distributed to the several transmitters over high-frequency transmission lines of equal lengths, <u>or distributed directly by radiation through the ether</u>." (underscoring supplied)

In final conclusion, I wish to admonish all of you good radio engineers who may follow this trail to follow the precepts of Figure 12, "<u>Keep checking your tuning and calibration</u>." Finis.

REFERENCES

1. De Loss K. Martin, Glenn D. Gillett, Isabel S. Bemis, Proceedings of the I.R.E., Vol. 15, No. 3, March 1927, pp. 213-223.

2. F. Gerth, Proceedings of the Institute of Radio Engineers, Volume 18, Number 3, March, 1930, pp. 510-513.

3. P.P. Eckersley, Proceedings of the Institute of Radio Engineers, Volume 19, Number 2, February, 1931, pp. 175-195.

4. G.D. Gillett, Proceedings of the Institute of Radio Engineers, Volume 19, Number 8, August, 1931, pp. 1347-1369.

5. Charles B. Aiken, Proceedings of the Institute of Radio Engineers, Volume 21, Number 9, September, 1933, pp. 1265-1301.

6. J.L. Hollis, Associate, I.R.E., A. Remote-Controlled Radio-Frequency Booster for a Broadcast Station. Proceedings of the Institute of Radio Engineers, 1944,

7. Ross H. Beville, Electronics Magazine, July, 1945.

The following reports all signed and sworn by Delmer C. Ports were supervised by Stuart L. Bailey:

8. Description of 189 Megacycle VHF Link Used for the WINX Synchronized Booster Operation, April, 1947.

9. Field Intensity Survey of WINX Booster Transmitter on 1340 Kilocycles With 50 Watts Power, April, 1947.

10. Engineering Report in Support of Application for Construction Permit for Standard Broadcast Station, WINX Broadcasting Company, Washington, D.C., July, 1947.

11. Supplemental Report to Transmitter Performance Measurements on the Synchronized Operation of Station WINX, Washington, D.C., April 22, 1949.

12. Preliminary Report on the Technical Phases and Continuing Studies of the Performance of the Synchronized Operation of Station WINX, Washington, D.C., April 28, 1949.

13. Operation of Synchronous Transmitters of Radio Station WINX, Washington, D.C. During Twenty-Day Test Period, May 24, 1949.

14. Transmitter Performance Measurements on the Synchronous Transmitter at Rock Creek Park for the Synchronized Operation of Radio Station WINX, Washington, D.C., May 25, 1949.

15. Supplemental Report on Transmitter Performance of the Synchronized Transmitter at Rock Creek Park for the Synchronized Operation of Radio Station WINX, Washington, D.C., June 6, 1949.

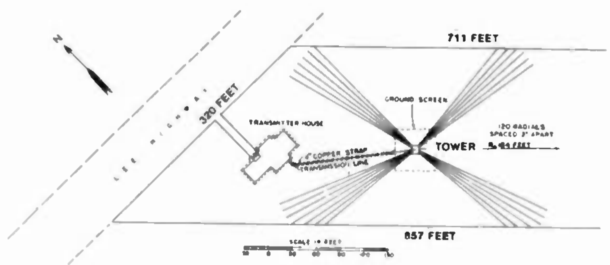


FIG. 1
GROUND PLAN
OF ARLINGTON SITE
WINX BROADCASTING COMPANY WASHINGTON, D.C.
JANSKY & BAILEY WASHINGTON, D.C.
JULY 1947

JANSKY & BAILEY WASHINGTON, D.C.

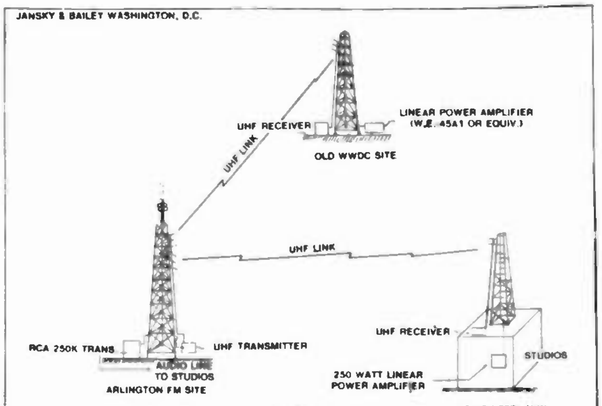


FIG. 3
DIAGRAM ILLUSTRATING
PROPOSED OPERATION OF WINX
WITH SYNCHRONIZED TRANSMITTERS
AT ROCK CREEK PARK AND ARLINGTON
APRIL 1947

FIG. 2A
TENTATIVE HETERODYNING EQUIPMENT FOR
WINX BOOSTER LINK OPERATION

JANSKY & BAILEY WASHINGTON, D.C.
JULY 1947

TRANSMITTER TERMINAL EQUIPMENT

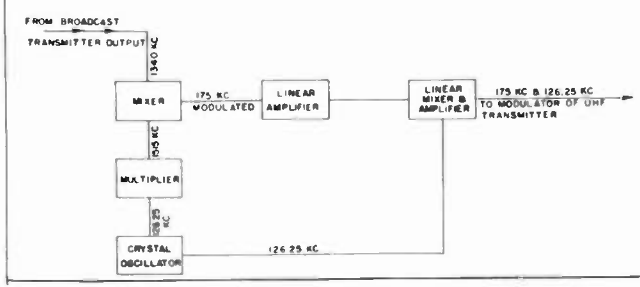
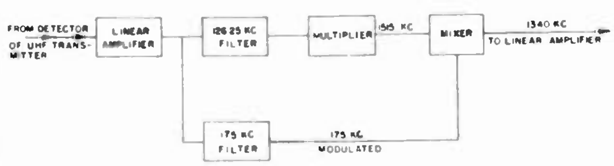


FIG. 2B

RECEIVER TERMINAL EQUIPMENT



JANSKY & BAILEY
WASHINGTON, D.C.
JULY 1947

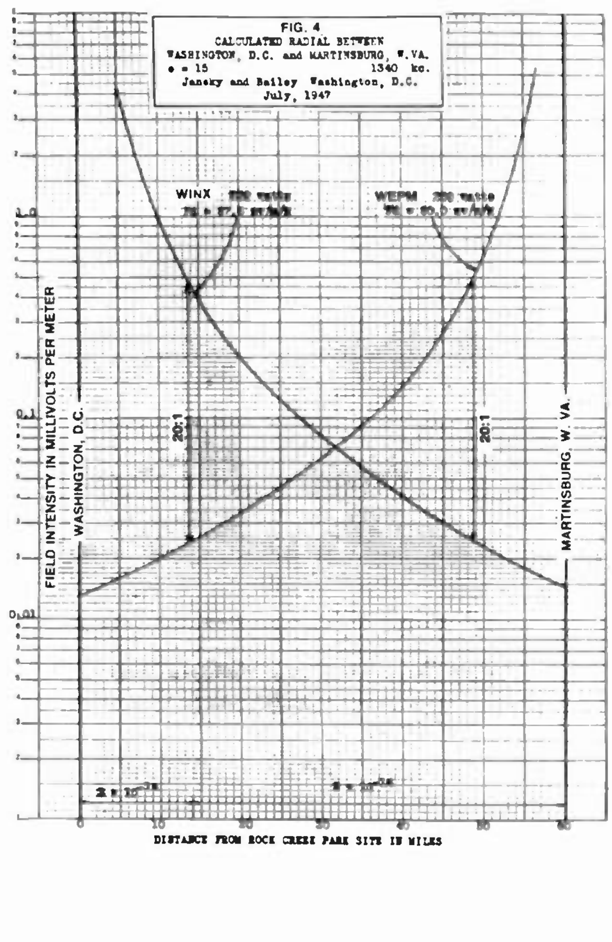


FIG. 4
CALCULATED RADIAL BETWEEN
WASHINGTON, D.C. and MARTINSBURG, W.VA.
σ = 15 1340 kc.
Jansky and Bailey Washington, D.C.
July, 1947

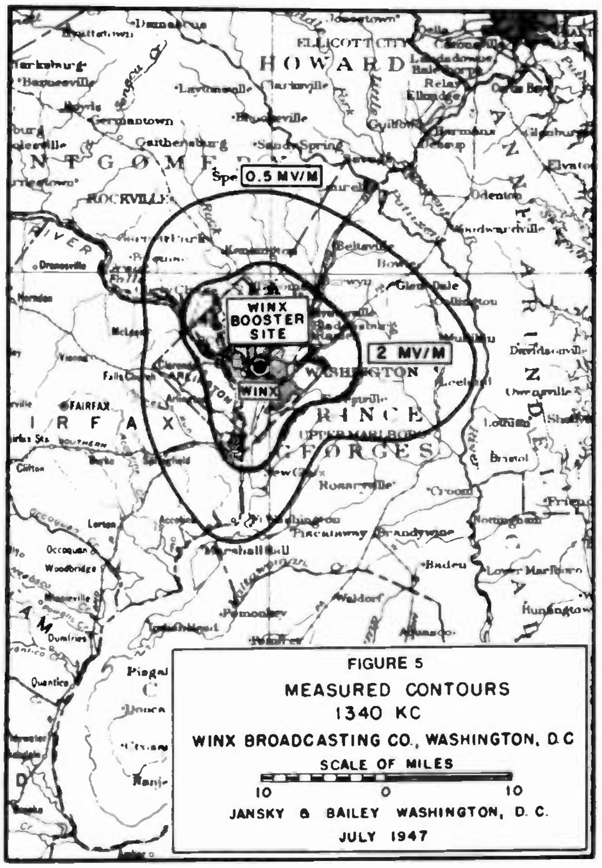


FIGURE 5
MEASURED CONTOURS
1340 KC
WINX BROADCASTING CO., WASHINGTON, D.C
SCALE OF MILES
10 0 10
JANSKY & BAILEY WASHINGTON, D. C.
JULY 1947

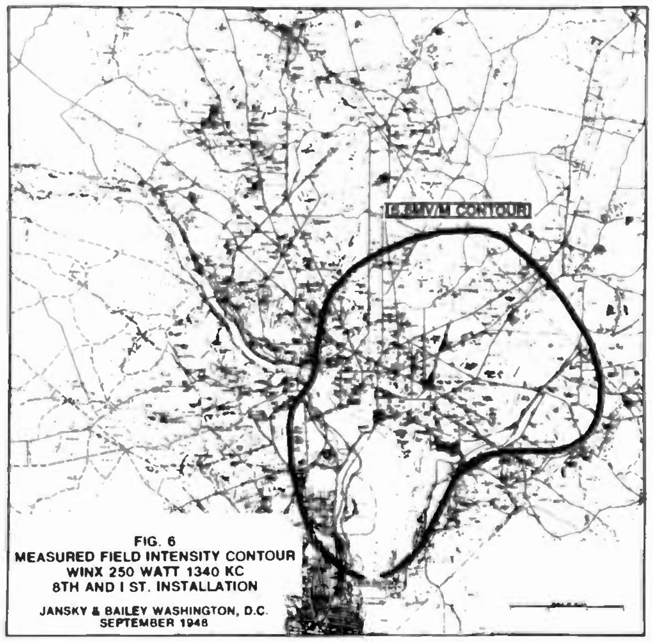


FIG. 6
MEASURED FIELD INTENSITY CONTOUR
WINX 250 WATT 1340 KC
8TH AND I ST. INSTALLATION
JANSKY & BAILEY WASHINGTON, D.C.
SEPTEMBER 1948

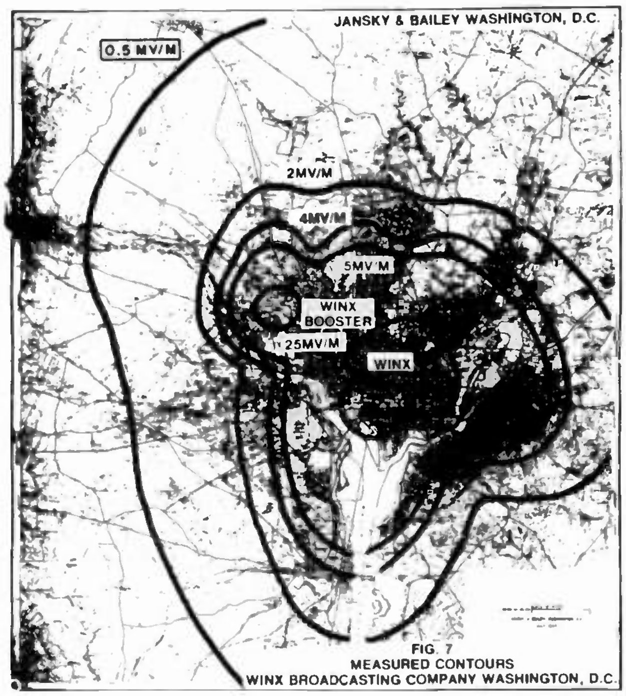


FIG. 7
MEASURED CONTOURS
WINX BROADCASTING COMPANY WASHINGTON, D.C.

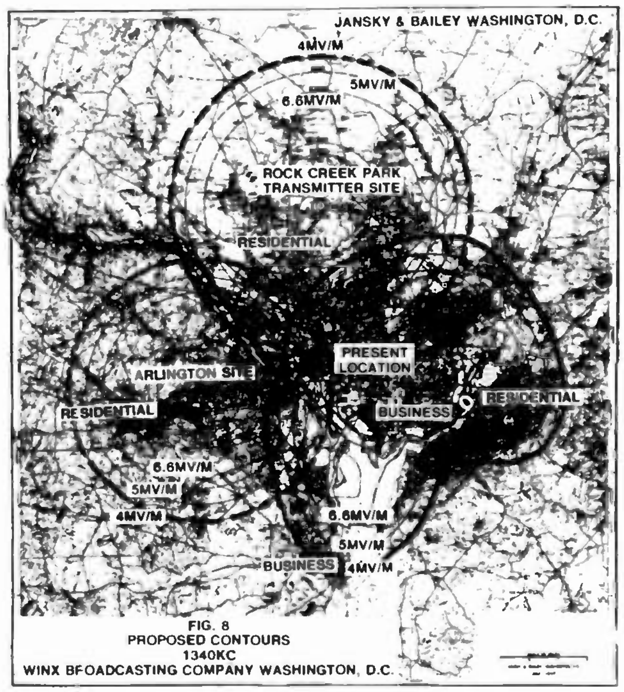


FIG. 8
PROPOSED CONTOURS
1340KC
WINX BFOADCASTING COMPANY WASHINGTON, D.C.

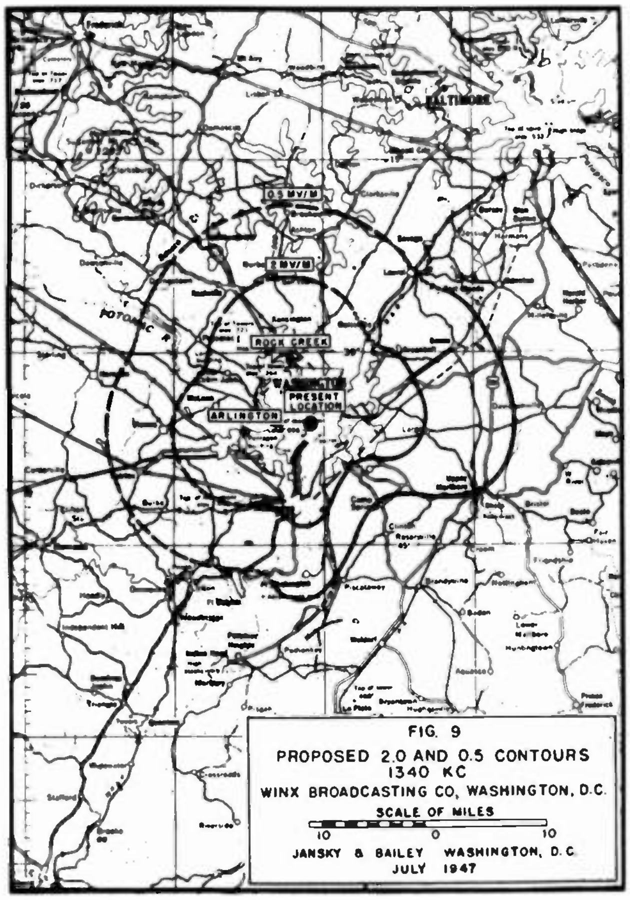


FIG. 9
PROPOSED 2.0 AND 0.5 CONTOURS
1340 KC
WINX BROADCASTING CO, WASHINGTON, D.C.
SCALE OF MILES
10 0 10
JANSKY & BAILEY WASHINGTON, D.C.
JULY 1947

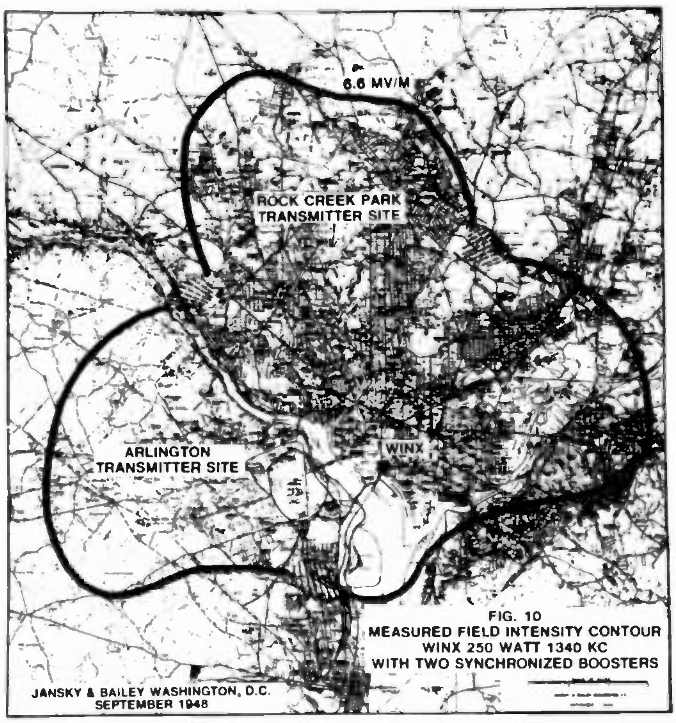


FIG. 10
MEASURED FIELD INTENSITY CONTOUR
WINX 250 WATT 1340 KC
WITH TWO SYNCHRONIZED BOOSTERS

JANSKY & BAILEY WASHINGTON, D.C.
SEPTEMBER 1948

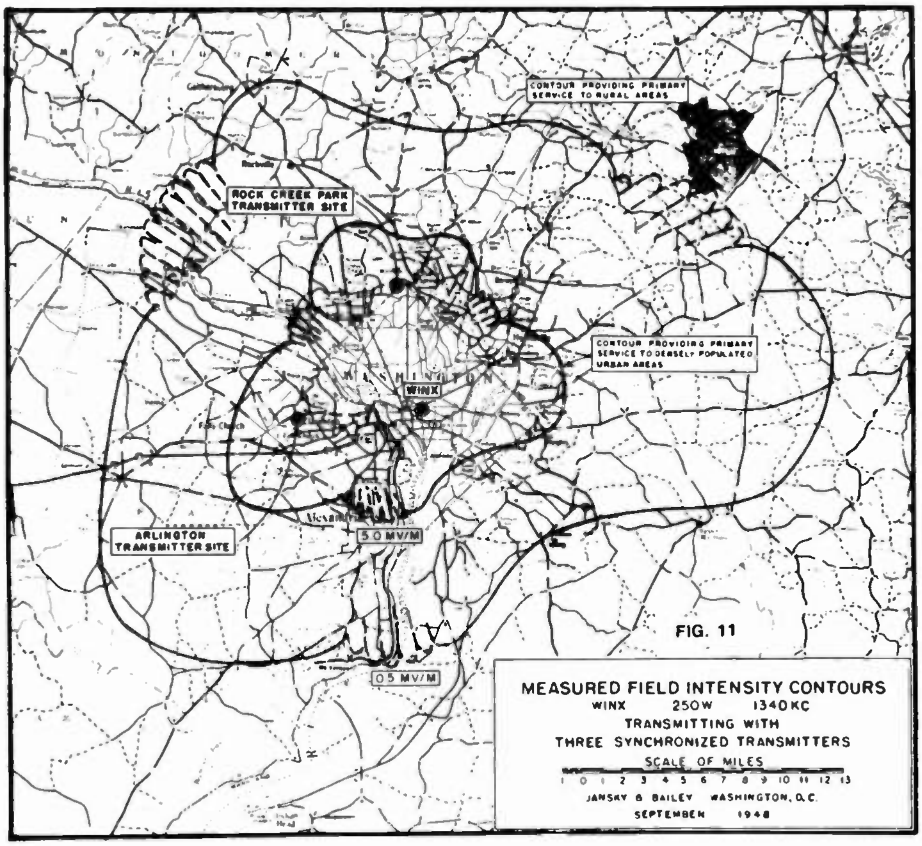


FIG. 11

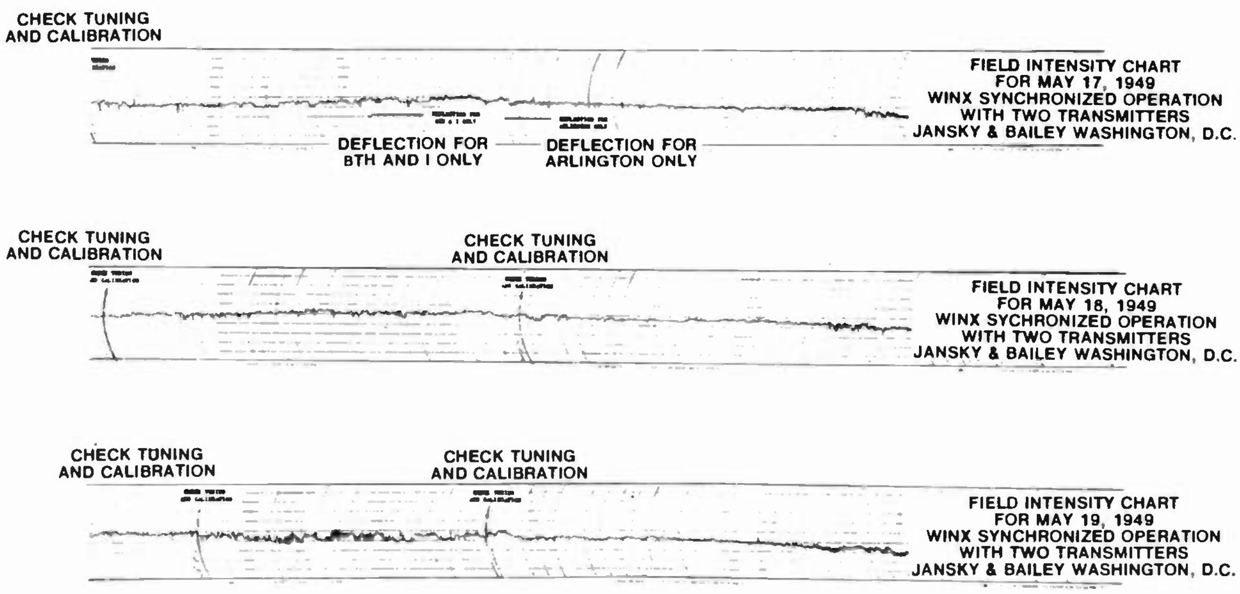


FIG. 12
FIELD INTENSITY RECORDINGS
IN GEORGETOWN D.C. FOR WINX
WITH SYNCHRONIZED OPERATION
JANSKY & BAILEY WASHINGTON, D.C.
MAY 1948

ANALYTIC TOOLS FOR BROADBANDING AM ANTENNAS FOR HIGH FIDELITY SOUND

William G. Ball
Carl T. Jones Corporation
Springfield, Virginia

ABSTRACT

The use of the general circuit parameters is introduced as a easy means of analyzing AM coupling and phasing circuits to improve the station's fidelity. The conversion from the general circuit parameters to impedance matrixes is shown as a method to allow ease of analysis of complicated circuits associated with phasing and coupling equipment and as a tool in calculating the total system design parameters.

INTRODUCTION

There have been many papers in the past dealing with the problems of broadbanding AM antenna systems. There is little if no dispute that a flat load at the transmitter, lowers distortion, and permits a higher fidelity sound to be transmitted at higher levels of average modulation. If we keep in mind that the purpose of this paper is to aid the engineer in the design of wideband circuits, then a higher fidelity sound will result. To this end, this paper presents a few applied analytical tools, to permit anyone with a rudimentary knowledge of algebra and especially matrix algebra, to be able to design and analyze networks used to couple transmitters to transmission line and couple the transmission lines to the Antenna(s). The author came upon the use of matrix algebra for this purpose while learning how to use hand calculator programs, purchased for use with a card programmable hand calculator. The hand calculator program has been expanded to include transmission lines and a complete analysis can be made with a hand calculator. In order to make the task easier however, this method has been programmed in high level computer languages of BASIC, FORTRAN, and PASCAL. A long discussion of the programs will not be made, however the background for them will be presented. Where one goes from this point, is only determined by the creativeness of the design engineer.

"T" NETWORK DESIGN

In designing and having to adjust many single tower coupling networks, many of which were not my design or that of my firm, I came to the conclusion that in order to achieve a good broadband match, one had to consider the total phase rotation of the system, modify it where possible and minimize as many undesirable effects as possible. In the early days of radio, many Antenna Tuning Units (ATU) were designed simply using the formula of $X_{arm} = \sqrt{R_{ant} * Zo}$.

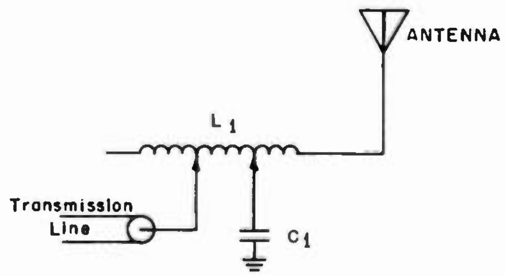


FIGURE 1

MATCH ALL NETWORK

The simple "Match All" network (Fig.1) used by many stations for many years consisted of a fixed capacitor and a single long coil. A match between the source and the load could be obtained, however no thought was given to the system bandwidth.

Experience has shown that in the initial design stages of a ATU, the design engineer desires. 1.) The input resistance of the ATU at the sideband frequencies should be equal and as close as possible to the input resistance at carrier. Furthermore, one would also like to find the condition where the input reactance at the lower sideband frequency is more positive than at the higher sideband frequency. An example is given in Table 1

TABLE 1

Frequency kHz	Resistance Ohms	Reactance Ohms
670	47	+j 8
680	50.0	0.0
690	47	-j 7.9

The standing wave ratio referred to 50 ohms is 1.192:1, 1.000:1, 1.190:1 for 670,680, and 690 kHz respectively. These standing wave ratios can be further improved by the addition of a series L-C network. This series network can be calculated as follows. The total reactance of the network is given by the formula $X_t = X_L - X_C$. From elementary circuit analysis we know that X_L=2*Pi*F*H, and X_C=1/(2*Pi*F*C). Writing the equations for 670 and 690 khz we obtain:

Eq. 1 X_{t670}= 2*Pi*670,000*H -1 /(2*Pi*670,000*C)

and

Eq. 2 X_t690= 2*Pi*690,000*H -1 /(2*Pi*690,000*C)

From Table 1 the desired X_t at 670 kHz is -8 ohms and +7.9 ohms at 690 kHz (to cancel the reactance at the sideband frequencies). Solving the equations simultaneously, one obtains the values of 63.2582 uH for H and 866.0021 pF for C. Putting these network in series with the input to the T network, the following input impedances are obtained.

TABLE 2

Frequency kHz	Resistance Ohms	Reactance Ohms
670	47	+j 0.0000
680	50.0	0.0083
690	47	-j 0.0000

The standing wave ratio referred to 50 ohms is now 1.064:1, 1.000:1, 1.064:1 for 670,680, and 690 kHz respectively.

The question naturally arises how does one find the phase shift where these conditions are fulfilled. Using a simple computer program TNET, a series of networks with various phase shifts can be computed. A sample output from the program is shown below (NTET Computer runs 1 & 2). The program TNET calculates "T" Networks at the carrier frequency while stepping through a series of phase shifts. The network calculated uses only a single component for each leg, i.e. if the reactance is negative, the computer assumes that there exists a capacitor, which gives the required reactance. This is achievable in the real world using a vacuum variable capacitor. After evaluating the printout, the design engineer choses a phase shift and designs and evaluates a network using the method of general circuit parameters.

It remains to be mentioned that most AM installations have a coaxial cable connecting the transmitter to the ATU. The program TNET has a provision to include the effects of the transmission line in its calculations. This gives a different result as TNET Computer Run #2 shows. The choice of the phase shift at the ATU may be different when the effects of the transmission line are considered.

Having an understanding of this procedure, let us now calculate a practical example. We have measured (bridged) a tower and have obtained the following data, corrected for frequency.

TABLE 3

Frequency kHz	Resistance Ohms	Reactance Ohms
670	44.5	+j 53.6
680	47.0	+j 64.2
690	49.5	+j 75.0

Next TNET is run to find the optimum network meeting the design criteria.

TNET COMPUTER RUN #1

PHASE	FREQ	R	X	SWR
-10.0	670	43.80	-10.12	1.2878:1
	680	50.00	0.00	1.0000:1
	690	57.26	+10.86	1.2758:1
-30.0	670	39.71	-4.16	1.2819:1
	680	50.00	-0.00	1.0000:1
	690	63.28	+2.51	1.2708:1
-50.0	670	39.55	+2.63	1.2735:1
	680	50.00	-0.00	1.0000:1
	690	60.42	-7.60	1.2638:1
-70.0	670	43.31	+8.69	1.2650:1
	680	50.00	-0.00	1.0000:1
	690	51.66	-11.61	1.2589:1

TNET COMPUTER RUN #1 (continuted)

PHASE	FREQ	R	X	SWR
-75.0	670	44.88	+9.86	1.2637:1
	680	50.00	-0.00	1.0000:1
	690	49.41	-11.45	1.2588:1
-80.0	670	46.69	+10.81	1.2629:1
	680	50.00	-0.00	1.0000:1
	690	47.30	-10.91	1.2595:1
-85.0	670	48.72	+11.47	1.2628:1
	680	50.00	-0.00	1.0000:1
	690	45.37	-10.06	1.2610:1
-90.0	670	50.96	+11.80	1.2636:1
	680	50.00	-0.00	1.0000:1
	690	43.66	-8.93	1.2635:1
-110.0	670	60.62	+8.68	1.2820:1
	680	50.00	-0.00	1.0000:1
	690	39.07	-2.69	1.2893:1
-130.0	670	67.31	-1.87	1.3486:1
	680	50.00	-0.00	1.0000:1
	690	37.56	+5.17	1.3628:1
-150.0	670	65.67	-17.43	1.5012:1
	680	50.00	-0.00	1.0000:1
	690	39.19	+15.26	1.5209:1
-170.0	670	57.75	-46.44	2.3402:1
	680	50.00	-0.00	1.0000:1
	690	43.73	+41.01	2.3639:1

LINE LENGTH = 0 DEGREES

The above printout has been edited, however it is believed that the trend of the computations is clearly shown. The area of interest has been highlighted.

A second run of the program, taking into account the 88.5 electrical degrees of phase shift introduced by the transmission line, yields the following print out. Again the printout has been edited for brevity.

TNET COMPUTER RUN #2

PHASE	FREQ	R	X	SWR
-10.0	670	52.86	+12.72	1.2877:1
	680	50.00	-0.00	1.0000:1
	690	42.19	-8.05	1.2780:1
-30.0	670	61.41	+7.76	1.2819:1
	680	50.00	-0.00	1.0000:1
	690	39.46	-1.63	1.2708:1
-50.0	670	63.36	-2.75	1.2735:1
	680	50.00	-0.00	1.0000:1
	690	40.71	+5.07	1.2638:1
-70.0	670	56.68	-10.61	1.2650:1
	680	50.00	-0.00	1.0000:1
	690	46.00	+10.32	1.2589:1
-75.0	670	54.36	-11.42	1.2637:1
	680	50.00	-0.00	1.0000:1
	690	47.94	+11.11	1.2588:1
-80.0	670	52.01	-11.76	1.2629:1
	680	50.00	-0.00	1.0000:1
	690	50.11	+11.57	1.2595:1
-85.0	670	49.73	-11.66	1.2628:1
	680	50.00	-0.00	1.0000:1
	690	52.44	+11.65	1.2610:1

TNET COMPUTER RUN #2 (continued)

PHASE	FREQ	R	X	SWR
-90.0	670	47.57	-11.18	1.2636:1
	680	50.00	-0.00	1.0000:1
	690	54.88	+11.27	1.2635:1
-110.0	670	40.91	-6.65	1.2820:1
	680	50.00	+0.00	1.0000:1
	690	63.65	+4.50	1.2893:1
-130.0	670	37.08	-0.07	1.3486:1
	680	50.00	+0.00	1.0000:1
	690	65.40	-8.87	1.3628:1
-150.0	670	34.96	+8.13	1.5012:1
	680	50.00	+0.00	1.0000:1
	690	55.56	-21.56	1.5209:1
-170.0	670	25.28	+18.95	2.3404:1
	680	50.00	+0.00	1.0000:1
	690	30.54	-28.69	2.3639:1

LINE LENGTH = 88.5 DEGREES

As is apparent when one examines the second computer run of TNET, the reactances at the transmitter end of the transmission line have the wrong slope in the vicinity of the equal sideband resistance, i.e. at approximately 82° of phase shift. In this instance, a series L-C network could be added to the T network between the "T" and the transmission line. The addition of this network introduces another complication in the evaluation of the network. Fortunately there is a relatively easy way to calculate the characteristics of the total network including transmission line.

Having finally chosen the desired phase shift, a network is calculated using standard T-Network design formulas. In designing a network, remember that the output arm, i.e. the arm towards the tower must compensate for the tower reactance.

The next step is to design a "T" network to match the antenna given in Table 3 to a 50 ohm source. The computer printout for the design of the network is given below.

NETWORK ANTENNA NO. ATU Table 3

INPUT RESISTANCE = 50
OUTPUT RESISTANCE = 47
PHASE DELAY = 82.5 0
POWER IN NETWORK = 5000 WATTS
Input arm = +j 42.31248 Ohms
Shunt arm = -J 48.8951 Ohms
Output arm = +J 42.70743 Ohms
[uncorrected for load reactance.]
Output Arm = -j 21.49257 Ohms
[corrected for load reactance.]
INPUT CURRENT = 10 AMPS
VOLTAGE ACROSS INPUT REACTANCE = 423.1248 VOLTS
SHUNT ARM CURRENT = 13.39618 AMPS
VOLTAGE ACROSS SHUNT REACTANCE = 655.0073 VOLTS
OUTPUT CURRENT = 10.31421 AMPS

COMPONENT SELECTION

The input arm (see figures 2 and 3) will be composed of a single coil L1 with a value of 9.90329 uH. The shunt arm could be a single capacitor with a value of 4786.81 pF (C103, Fig.2). Unfortunately, this value is not a stock item (if available at all). Therefore either a vacuum variable capacitor or a fixed capacitor and coil combination must be used (L103, C103, Fig.3).

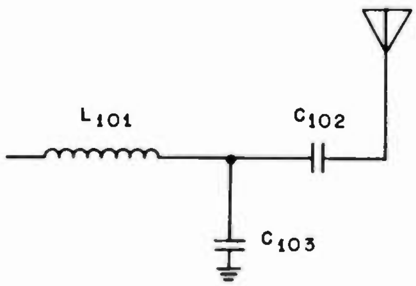


FIGURE 2

"T" NETWORK WITH IDEALIZED COMPONENTS

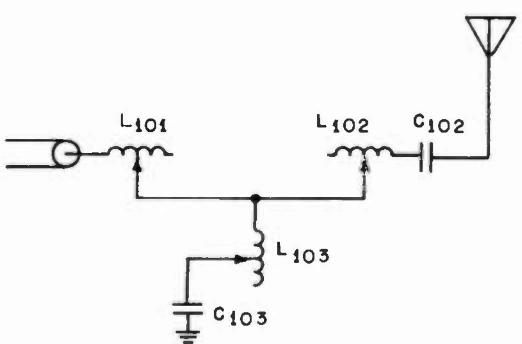


FIGURE 3

GENERAL "T" NETWORK

Table 4 lists combinations of inductance and capacitance which will produce the desired reactance at the carrier frequency.

TABLE 4

L3	C3	$X_L - X_C$
0.00000uH	4786.8066pf	-48.8951
2.25105uH	4000.0000pf	-48.8951
6.81605uH	3000.0000pf	-48.8951
15.94606uH	2000.0000pf	-48.8951
43.33609uH	1000.0000pf	-48.8951

For the output arm, the arm connected to the tower, a capacitive reactance is required to cancel the inductive reactance of the tower. The required reactance is 10,889.87 pf. This is not a common value. A table of values which produce the desired reactance is given below:

TABLE 5

L2	C2	$X_L - X_C$
0.00000uH	10,889.87pf	-21.4926
1.05631uH	9,000.00pf	-21.4926
1.81714uH	8,000.00pf	-21.4926
4.09964uH	6,000.00pf	-21.4926
5.92564uH	5,000.00pf	-21.4926

GENERAL CIRCUIT PARAMETERS

Having these combinations which produce the necessary overall reactance for both the output and shunt arms of the T network, one can easily evaluate their effect on the circuit. A matrix method exists for calculating networks. This method uses the general circuit parameters. These parameters are also known as the ABCD parameters. There are various references to these parameters in the literature.[1] A two terminal network is shown in figure 4.

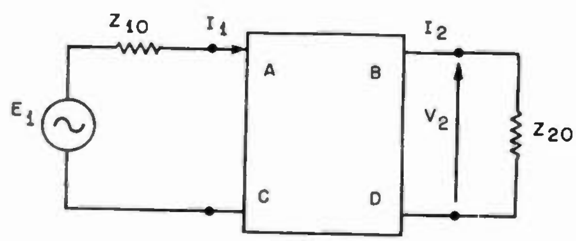


FIGURE 4

LINEAR PASSIVE FOUR TERMINAL NETWORK

The equations for the network may be written:

Eq.3 $V_1 = AV_2 + BI_2$

Eq.4 $I_1 = CV_2 + DI_2$

In Matrix form these equations can be written:

Eq.5 $$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \times \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

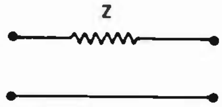
If more than one two terminal network exists and they are cascaded together, the matrix equations may be written as:

Eq.6 $$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \times \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \times \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

This process may be repeated as often as necessary to include all the components in the coupling system. It has been incorporated in a computer program called ABCD. Program ABCD requests as input the carrier frequency, the load impedances in rectangular form at the lower 10 kHz sideband, at carrier and at the upper 10 kHz sideband. The remaining input give details of the components in the system, starting at the load and working back toward the source (transmitter). The options are:

1 Series resistor
2 Shunt resistor
3 Series Inductor
4 Shunt inductor
5 Series Capacitor
6 Shunt Capacitor
7 Series Tank
8 Shunt LC (in series with each other)
9 Transmission Line
10 Pass reject trap
11 Ideal Transformer

The Matrixes for Numbers 1,3, and 5, i.e the series elements are shown in figure 5.

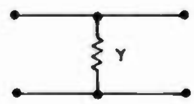


$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

FIGURE 5

SERIES IMPEDANCE

The shunt elements, Numbers 2,4, and 6 are shown in figure 6. The other elements can be derived from these or be found in the literature.



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

FIGURE 6

SHUNT ADMITTANCE

Given an ABCD Matrix and a load impedance, the input impedance to the whole network is given by:

Eq.7 $Z_{in} = (A*Z_l - B)/(C*Z_l - D)$

This is a very helpful relationship which forms the basis of the power of the General Network Parameter approach to network analysis.

The following printout is for the program ABCD, run with idealized components, the antenna resistance and reactance given in table 3, and for the network designed for the ATU with 82.5° of phase lag.

<u>ABCD Parameters Computer Run #1</u>

SERIES CAP. C= 10889.87 PF
SHUNT CAP. C= 4786.807 PF
SERIES COIL L= 9.90329 UH

FREQ	R	X	SWR(50)
670	47.67859	11.17775	1.262745
680	50.00001	-0.00000	1.000000
690	46.30827	-10.52104	1.260114

The calculations compare well with the interpoled values for 82.5° calculated by TNET RUN #1. In both cases, the SWR is on the order of 1:1.26. In order to achieve the absolute possible match, TNET could have been run at a much closer interval, however we are examining a method of evaluating a network, so the procedure is of essence. Changing the series input capacitor from 10,889.87 pf to 9000 pF and inserting a series coil in the output arm of 1.05631 uH (values taken from Table 5) produces the following computed results:

ABCD Parameters Computer Run #2

SERIES CAP. C= 9000 PF
SERIES COIL L= 1.05631 UH
SHUNT CAP. C= 4786.807 PF
SERIES COIL L= 9.90329 UH

FREQ	R	X	SWR (50)
670	47.57948	11.28097	1.266179
680	50.00001	-0.00000	1.000001
690	46.28026	-10.64107	1.263394

If a combination of 5,000 pF and a coil of 5.92564 uH as shown in Table 5 are chosen, the results are:

ABCD Parameters Computer Run #3

SERIES COIL L= 5.92564 UH
SERIES CAP. C= 5000 PF
SHUNT CAP. C= 4786.807 PF
SERIES COIL L= 9.90329 UH

FREQ	R	X	SWR (50)
670	47.11837	11.74754	1.282182
680	50.00001	0.00000	1.000001
690	46.1433	-11.19136	1.278671

By using a 5000pF capacitor (a common value) and a series coil in the output leg of the T network, no significant degradation of the SWR occurs . Next the design engineer has to investigate the effects of changing the L-C ratio in the shunt leg of the network. Table 4 gives the values of inductance and capacitance which produce the required reactance. Starting with a 2.25105 uh coil and a fixed 4000 pf capacitor, Program ABCD calculated the following:

ABCD Parameters Computer Run #4

SERIES COIL L= 5.92564 UH
SERIES CAP. C= 5000 PF
SHUNT L-C L= 2.25105 UH
C= 4000 PF
SERIES COIL L= 9.90329 UH

ABCD Parameters Computer Run #4
(continued)

FREQ	R	X	SWR (50)
670	47.44332	11.90212	1.283128
680	50.00000	0.00000	1.000001
690	45.54013	-11.09125	1.283859

Notice that the upper side band input resistance dropped. This trend continues even further as shown in the following two examples, where C is decreased in value (increased in reactance) and L is increased in value (also resulting in an increase in reactance).

ABCD Parameters Computer Run #5

SERIES COIL L= 5.92564 UH
SERIES CAP. C= 5000 PF
SHUNT L-C L= 6.81605 UH
C= 3000 PF
SERIES COIL L= 9.90329 UH

FREQ	R	X	SWR (50)
670	48.09254	12.22413	1.286128
680	50.00004	0.00000	1.000001
690	44.32348	-10.86819	1.296575

and

ABCD Parameters Computer Run #6

SERIES COIL L= 5.92564 UH
SERIES CAP. C= 5000 PF
SHUNT L-C L= 15.94606 UH
C= 2000 PF
SERIES COIL L= 9.90329 UH

FREQ	R	X	SWR (50)
670	49.35099	12.90022	1.296018
680	50.00007	0.00000	1.000001
690	41.91882	-10.34291	1.330731

There has been a steady worsening of the SWR at the upper side band. This is not a desirable condition. In such cases, a vacuum variable may be justified. The next best solution would be to use the 4000pF capacitor and the 2.25105 uH of inductance. Assuming that we choose the variable capacitor, the network still can be further improved. If a series L-C network is calculated by simultaneously solving equations 1 and 2 where $X_{t670} = -12.90022$ ohms and $X_{t690} = 10.34291$ ohms, an improvement can be obtained. This is shown in ABCD Run #7:

ABCD Parameters Computer Run #7

SERIES CAP. C= 5000 PF
SERIES COIL L= 5.92564 UH
SHUNT CAP. C= 4786.807 PF
SERIES COIL L= 9.90329 UH
SERIES CAP. C= 600.1072 PF
SERIES COIL L= 91.23841 UH

FREQ	R	X	SWR (50)
670	47.11841	-0.00029	1.061157
680	49.99994	-0.19399	1.003887
690	46.14326	-0.00025	1.083582

A more practical arrangement of components would be to simply use a 600 pf capacitor and to combine the two series coils in the input arm into one coil. Do this and running ABCD again, we obtain the final configuration of the network.

ABCD Parameters Computer Run #8

SERIES CAP. C= 5000 PF
SERIES COIL L= 5.92564 UH
SHUNT CAP. C= 4786.807 PF
SERIES COIL L= 101.1417 UH
SERIES CAP. C= 600 PF

FREQ	R	X	SWR (50)
670	47.11841	-0.070825	1.061175
680	49.99996	-0.263536	1.005285
690	46.14331	-0.068799	1.083595

The standing wave ratio has been reduced below 1.1:1 across the band of interest. To practically build and implement this network on high power stations, it may be necessary to break up the coil and capacitor combination into smaller coils and larger capacitors in series to obtain the net overall L and C. This helps prevent corona due to high voltages caused by high currents time large values of reactance (V =I*X). By using multiple coils and capacitors, the voltage gradient is lowered and the risk of corona reduced. This is diagramed in Figure 7.

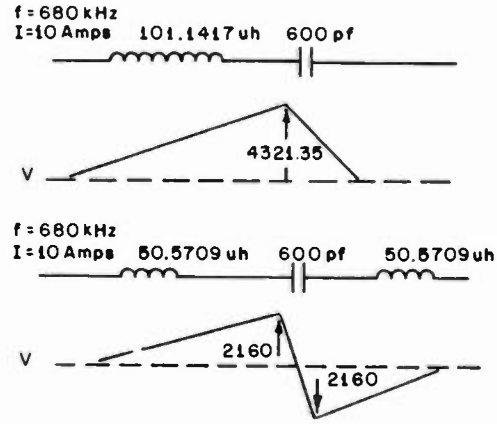


FIGURE 7
METHOD OF LOWERING VOLTAGE GRADIENT

In most cases (5 kW or less), this will not be a problem. Also use of the large inductance results in slightly higher circuit losses due to the resistance of the larger coil. For a non-directional station, where the antenna input power is measured at the antenna feed point, no problem should be experienced, since modern day transmitters have plenty of extra power reserve.

It has been shown , that introducing the transmission line, (TNET Run #2) would cause the overall phase shift to be such that, no corrections could be easily under taken at the input to the transmission line due to the impedance slope. The actual transmission line effects can be evaluated by ABCD. For the present case of the antenna given in Table 3, considering the 88.5 degree transmission line, the results shown in ABCD Run 9 were obtained.

ABCD Parameters Computer Run #9

SERIES CAP. C= 5000 PF
SERIES COIL L= 5.92564 UH
SHUNT CAP. C= 4786.807 PF
SERIES COIL L= 101.1417 UH
SERIES CAP. C= 600 PF
TRANSMISSION LINE Z0= 50 OHMS
88.5 DEGREES

FREQ	R	X	SWR (50)
670	53.0395	0.337774	1.061175
680	49.98906	0.263278	1.005285
690	54.17953	0.040569	1.083595

PARAMETER TRANSFORMATIONS

By this procedure one can calculate an entire feed system or branch of a phasing system using the general circuit parameters. The entire system can then be represented by an equivalent "T" network. Given the ABCD parameters for a system (or subsystem) the equivalent "T" network arms (as shown in figure 8) are given by:

Eq.7 $Z_{11} = A/C$
Eq.8 $Z22 = D/C$
Eq.9 $Z12 = 1/C$

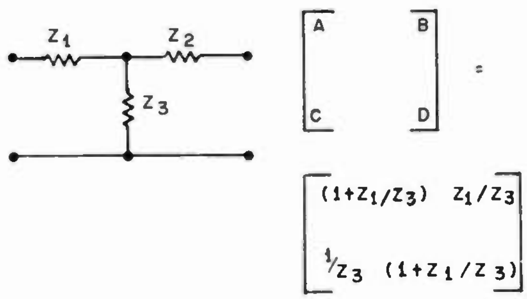


FIGURE 8

EQUIVALENT "T" NETWORK

If one were to attempt to analyze the circuit in figure 9 using loop currents, one faces a long job, possibly fraught with error.

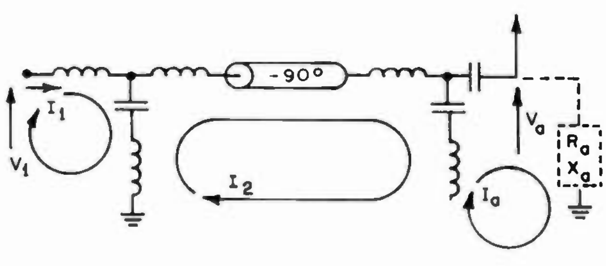


FIGURE 9

MULTIPLE LOOP

If the components are first "lumped" together using ABCD, the problem simplified to that shown in figure 10.

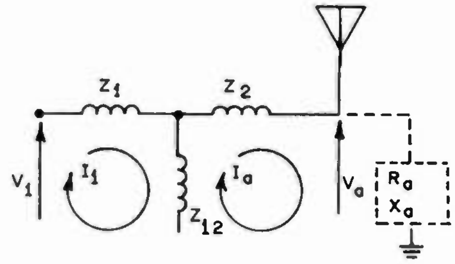


FIGURE 10

TWO LOOP EQUIVALENT

It can also be shown that the ABCD parameters are related to the the admittance parameters. The equations defining the admittance parameters are:

Eq.10 $I_1 = Y_{11}*E_1 + Y_{12}*E_2$

Eq.11 $I2 = Y_{21}*E_1 + Y_{22}*E_2$

The conversion formulae from ABCD parameters to Y parameters are:

Eq.12 $Y_{11} = D/B$
Eq.13 $Y_{12} = -1/B$
Eq.14 $Y_{21} = 1/B$
Eq.15 $Y_{22} = -A/B$

Knowing these relationships is an aid in analyzing circuits, since parallel admittances can be directly added together. For example in a two tower phasing system, the ABCD parameters for each feed of the system can be computed, the admittance matrixes added together, reconverted to ABCD parameters and then multiplied by the common point components to obtain the phasor input impedance.

APPLICATION OF THE GENERAL CIRCUIT PARAMETERS TO A TYPICAL PHASING SYSTEM.

The general circuit parameter method of analysis can be applied in yet another way to the analysis of directional antenna phasing and coupling equipment. A two tower station has the following parameters.

Twr	Field	Phase	Space	Bear.	Height
1	1.00	0.00	138.0	83.5	165.0°
2	0.87	45.00	0.0	0.0	165.0°

The station operates with a directional antenna nighttime and non-directionally daytime. The self and mutual impedances of the directional system were measured using a General Radio

Bridge driven by an Potomac Instruments SD-31 Synthesizer/Detector. In addition, the driving point impedances were measured with the old phasing and coupling equipment under load, by varying the transmitter frequency (again using the SD-31 generator to replace the transmitter crystal) and a Delta Electronics Operating Impedance Bridge. For the measurement of the self and mutual impedances, the towers were isolated using sample line isolation coils to the condition, in which they would be operated with the new phasing and coupling system. The data in Table 5 is based on actual measured data for the above directional antenna system.

The calculated antenna drive point impedances at carrier and at the 10 khz sideband frequencies for parameters which produced essentially the same null file and location at the sidebands as at carrier are:

TABLE 5

Tower	Carrier
1	276.7-j306.0
2	396.9-j476.2

Tower	+10 kHz	-10kHz
1	290.5-j324.5	268.5-j288.0
2	455.0-j480.0	350.0-j473.0

A simplified schematic for the night phasor is shown in figure 11.

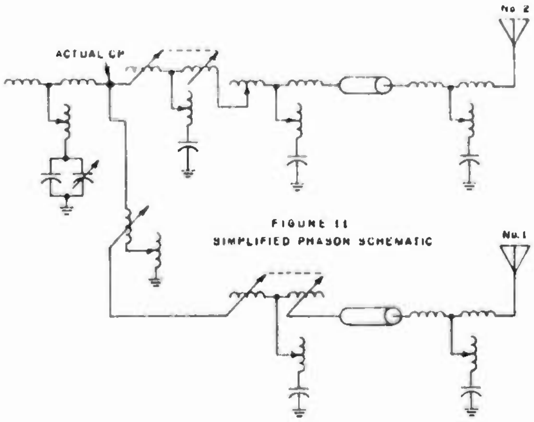


FIGURE 11
SIMPLIFIED PHASOR SCHEMATIC

The values of the components are not given here in the interest of conserving space, however the computer printouts were done with the components which were chosen to produce the pattern. Calculating the resistance and reactance of the number 1 tower phasing system i.e. that part of the networks up to the actual common point, one obtains:

FREQ	R	X	SWR (50)
1260	46.63328	5.775081	1.148352
1270	50.00016	0.000335	1.000007
1280	51.17989	-8.062038	1.174562

and for line # 2:

FREQ	R	X	SWR (50)
1260	48.66667	-13.13671	1.30589
1270	50.0012	-0.00179	1.000043
1280	53.68119	14.03995	1.322141

Next the actual common point impedance was calculated by paralleling the resistance and reactance of the two feed systems. This results in the actual common point impedance given below:

FREQ(KHZ)	R	X
1260	24.78	-j1.568
1270	25.00	0.000
1280	27.37	1.166

These impedances may now be used for the input impedances in ABCD, the common point network modeled and the following data obtained regarding the actual common point.

FREQ(KHZ)	R	X
1260	48.31	+j3.52
1270	50.00	0.00
1280	47.39	-j5.57

This common point impedance could be improved even further by the addition of a series L-C network to cancel the sideband reactances.

CONCLUSION

There are many approaches taken in designing optimum phasing and coupling networks for higher fidelity sound. Several techniques have been discussed with examples, and a method of evaluating the design given. Because of the flexibility of the ABCD parameters to be transformed into other parameters such as the Z or Y or Hybrid parameters, or to be used alone, they offer a useful tool to the design engineer in circuit design.

ACKNOWLEDGMENTS:

I wish to thank Herman Hurst and Tom Jones of Carl T. Jones Corporation for their support in this project and Lana Randall for typing and formatting of the manuscript. Special thanks goes to my friend and business associate, Ambrose J. Cavegn, Sr. for his preparation of the drawings and his encouragement.

---

[1] International Telephone and Telegraph Corporation, Reference Data for Radio Engineers, fourth edition, pages 143-145, New York, 1959 (later editions 6 and 7 do not mention these parameters- author)

FM ANTENNAS WITH MODIFIED INTERBAY SPACINGS SOLVE DOWNWARD RADIATION AND OTHER PROBLEMS

Joseph T. Semak
Engineering Manager, KWLT(FM)
San Diego, California

INTRODUCTION

Recently, the advantages of certain new FM antenna designs have become recognized. As a result, there has been substantial interest in the use of special antenna designs. The principle catalyst for these efforts stems from new Federal regulations limiting the permissible levels of human exposure to non-ionizing RF radiation in areas near broadcast towers, a problem that can usually be solved by application of the correct antenna. Unfortunately, it is generally unknown to broadcasters that many other problems occurring at the transmitter site such as RFI/EMI, antenna coupling, and pattern distortion can be controlled, reduced, or eliminated through the appropriate use of a specially designed antenna.

This report will familiarize the FM broadcaster with the various operational concepts, design, and construction applicable to all FM broadcast antennas; this is necessary to fully understand the specialty antenna. The application techniques and performance characteristics of the specialty antenna are thoroughly covered, with emphasis on pratical situations.

ANTENNA DESIGN OVERVIEW

For many years now, the FM transmitting antenna has seen relatively few changes in its design although many different styles of antenna bays (radiating elements) have appeared, they are almost always integrated into an array using a standard vertical separation of one wavelength (one lambda). This applies to both the side mounted ring type antennas as well as (reflector) panel types.

All FM antenna systems (except single bays) utilize the broadside array principles to develop gain over a single bay of the same type. This is true regardless of the type of bay used: side mounted rings, directionalized rings, or panels. A standard broadside array for broadcast applications consits of a number of identical bays stacked vertically along the same axis at some fixed separation, all of the bays being supplied the same amount of RF power at an identical phase angle. (In the cases of null fill or beam tilt, there are small variations of the amplitude and phase, respectively, in the RF currents fed to the different bays.) This arrangement will produce a certain amount of gain over a single bay due to the concentration of power in the plane normal to the axis of the antenna array (coverage area). This concentration of power is called the main beam (beam maximum). As the overall length of the antenna is increased, the width of the main beam narrows proportionately, thus increasing the concentration of power and producing more gain. See Fig. 1 below.

Antenna gain

Definition.--Antenna gain is simply described as the amount of power concentrated in the main beam of an antenna as compared to the amount of power concentrated in the main beam of the reference antenna, assumming that both have equal input power. For FM broadcast, the FCC has adopted the reference constant as a one-half wavelength linear dipole with a one kilowatt input power. For convenience, gain can be computed given the equivalent E field (field strength) values at a fixed reference distance, such as one mile.

Controlling parameters.--It is important to understand that the gain of a broadside array is not in direct proportion to the number of bays (on the antenna) as is commonly believed. Gain is primarily a function of the effective length or aperture of the antenna in wavelengths as measured from the centers of the two outermost bays; assuming that the bays are spaced at least every 1.5 wavelengths along this length. The number of bays contained within any given antenna aperture will vary with different interbay spacings; however, the resulting changes in beamwidth and gain will be rather small as long as the antenna's effective length (aperture) remains unchanged.

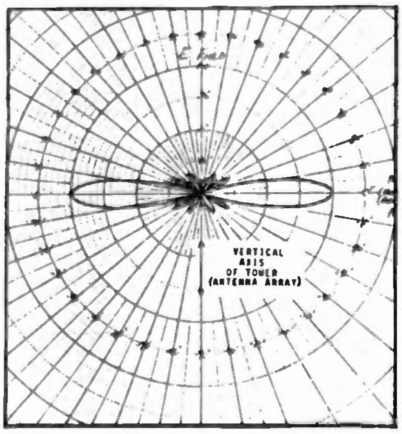


Fig. 1.--Polar plot of array pattern. Note main beam and minor lobes. (6 bays @ 0.5λ)

It is interesting to note that the maximum amount of gain for a given length of antenna aperature generally occurs when the bays are separated by five-eighths to three-fourths of one wavelength; however, other considerations overshadow this slight advantage, dictating bay separations based on the economy of one wavelength spacing, or the necessecity of radiation supression; calling for one-half wavelength bay spacing.

The directivity possessed by each of the bays in the antenna array is the final contributing factor to the gain of the array. The influence that the individual bay has on the overall system, and the relationships involved are discussed in detail later in the text.

Determination of gain.--The broadcast industry is used to describing (incorrectly) the gain of an antenna simply by the number of bays that is has. Presumably, this is because it is convenient with antenna systems using one wavelength interbay spacings. However, this will undoubtably result in considerable confusion with the introduction of specially modified antennas.

It is suggested that it is appropriate to characterize an antenna by the effective length of the array--the first bay through the last bay--in wavelengths. This is not difficult, and by doing so a person can estimate an antenna's gain regardless of the number of bays or the separation used. For example: a three wavelength (effective length) antenna that is omni-directional and circularly polarized will have a power gain of approximately two regardless of its bay separation. Refer to Eq. (1). Note that in this equation, the antenna's effective length is essentially divided by two; this takes into account the power division that takes place in a circularly polarized antenna.

$$G \cong \frac{\text{length in wavelengths + one}}{2} \qquad (1)$$

$G \cong$ antenna power gain for the case of omni-directional, circularly polarized broadside arrays.

Exact antenna gain can be determined through various mathematical and graphic procedures that are available in the antenna design textbooks. One method, known as the Poynting vector method, models the antenna array in the center of a large, imaginary sphere; thus allowing the power flowing out of the sphere to be determined in terms of density per unit of area. From this, the total power equivalent density and peak (main beam) power density can be determined. Relating the two power density figures will yield the concentration of power in the main beam relative to the total input power, and therefore, the gain of the antenna over an isotropic radiatior. This figure has to be corrected if a different gain reference is desired. When referencing to a half-wave dipole, the gain of the dipole--2.15 dB--has to be subtracted from any gain figure that has been referenced to an isotropic source.

Another method, algebraically derived, projects gain based on the knowledge of the RF currents flowing in the array. When using this method, the mutual impedances of every bay into every other bay must be known in order to establish the radiation resitances within the array. This is not practical though, as it is very difficult to accurately determine the mutual impedances through any type of analysis.

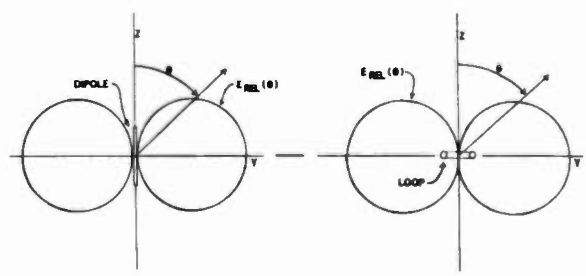
Unfortunately, no simple formula for gain for gain exists that will give exact results.

Measurement of gain.--Gain can be determined through controlled measurements of an actual antenna. If performed with care, measuring the elevation pattern (and azimuth pattern, if necessary) of an assembled antenna on a good antenna test range is considered an acceptable method of determining gain, and is often done on television antennas. As an off-shoot method, one could measure the elevation pattern of a single bay (of the type to used on the antenna) and multiple the results by a calculated array pattern. This will yield an accurate gain figure if properly done, and can be acommodated on the smaller test range.

Radiating elements

Most common FM antenna bays (radiating elements) are based on the use of one or more half-wave dipoles configured in such a way as to produce the desired polarization, power handling, and bandwidth characteristics. Recently, quite a bit of attention has been centered around the design of the bay, (radiating element) and if it's a panel antenna, the reflector as well. Different types of bays can produce substantially different radiation patterns; thus, the selection of a bay design is critical and plays a key role in the way the overall antenna will perform in virtually all aspects.

Radiation characteristics.--Ideally, an antenna bay for all side mounted ring type arrays and most panel types should posses the same relative field distribution for the elevation pattern as a perfect half-wave linear dipole and/or short horizontal loop located in free space. The radiator used as the reference depends upon the polarization(s) used. If the mode is vertical polarization, a vertically oriented linear dipole is the reference; for horizontal polarization the comparison is made against a horizontal loop. A perfect



(a) (b)

Fig. 2.--E field patterns for reference radiators.

linear half-wave dipole radiates an electric field that is proportional to the cosine of the angle of radiation as compared to any point normal to the axis of the dipole. See Fig. 2a. The short horizontal (end-loaded) loop illustrated in Fig. 2b has a donut-shaped field pattern (distribution) that is substantially the same as a linear dipole's, but it is horizontally polarized. The horizontal loop is formed from a linear dipole to effectively provide the omni-directional, horizontally polarized coverage that cannot be obtained from a linear dipole located with its axis parallel to the earth's surface.

Operating impedance.--Antenna bays must be designed to present correct and equal impedances within any array. This is generally accomplished through gamma matching and/or transmission line type matching principles applied on or inside the bay's feed stem, respectively. This adjusts the dipole's characteristic (low) impedance up to the proper level for correct RF distribution. Additionally, any reactance (undesirable) must be removed from the antenna in order to provide a purely resistive load at the operating frequency. This is done in several ways, the most common method is trimming the element length for proper resonance during manufacture. The bays used in modified antenna designs are usually identical to those used in the standard model antennas; however, there are sometimes differences in the way the operating impedance is determined and adjusted.

Mutual impedance.--The mutual impedances that result from the coupling of antenna bays is an area of particular concern when special antenna designs are approached. This is because the bays in most modified antennas are separated by less than a full wavelength. At large (one wavelength or greater) bay separations there is an insignificant amount of coupling among the elements; however, this situation rapidly changes as the bay separation is reduced to one-half wavelength. At this point, significant amounts of coupling will occur causing changes in the bays' radiation resistances that are related to both the magnitude and phase of the coupled energy. Changes in a bay's radiation resistance will produce similar changes in its input impedance. This will, in turn, affect the amount of power the various bays will radiate.

Because mutual impedances result from the close physical presence of other bays, it is a nonuniform effect over the length of the antenna. The bays assigned to the center of the array will be affected to a greater extent than those at the ends of the array. Obtaining even power distribution throughout the entire array is the primary obstacle to overcome when large amounts of mutual impedance are present. To this end, the manufacturer must determine to what extent an array is (or will be) impacted by mutual impedances and correct the power distribution by setting the individual bays' input impedances so that each bay assumes the correct level when operating in the array. For one-half wavelength bay separations, the center bays will tend to have a lower radiation resistnace than the outer bays; therefore, the center bays will receive more power. Power distribution within a specialy modified antenna must be carefully controlled, otherwise the desired effect can be ruined.

Feed systems

Standard applications.--When employing a one wavelength antenna configuration the manufacturer simply taps the main feed line at each bay location, resulting in an array with all of the elements fed in phase. This allows antennas to be produced rather simply and economically. The amplitude of the RF input to each of the bays shunted across the main feedline is dependent upon the impedance that each bay presents to the feedline. The bays are typically the same impedance in any one array, and thus the power for an eight bay antenna will divide across the bays in the same way it would across eight resistors, of equal value, connected in parallel.

Special applications.--There are unique variations to the feed systems of antennas that bay separations other than one wavelength. Uniform, in phase operation (RF excitation, not spacing) of the antenna's bays is requisite in any broadside array. In order to achieve this, several variations upon the standard feed schemes can be used. In the case of one-half wavelength separations, a sub-feeder system can be used as shown in Fig. 3, or the elements can be shunted directly across the main feedline at half-wavelength intervals by inverting every other bay. The latter method corrects the phase inversion inherent at every other feedline tap point by reversing the side of the dipole receiving the RF excitation; effectively restoring the bay to in-phase operation.

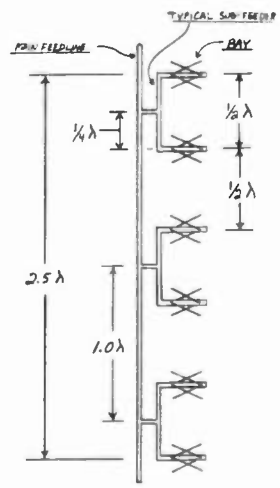


Fig. 3.-- Illustration of antenna with one-half wavelength bay spacing.

It is recommended that the sub-feeder type of system be used to avoid compromise in antenna performance due to the assymetry present in most bay designs. For the cases of bay separation greater than one-half wavelength, the common branch feed system is recommended as the most practical means of achieving the proper RF distribution.

Branch feeds.--When it is inconvenient to shunt bays or sub-feeders directly across the main feedline, as is the case with most panel antennas and certain modified antennas, a branch feed is used. A branch feed consists of a power divider at the input to the antenna from which individual feedlines--branches--run to their respective bays. This allows the proper phasing to be maintained simply by keeping the lengths of the branches a multiple of one wavelength.

Impedance matching.--There are different philosophies among the various manufacturers as to what the optimum impedance distribution within an antenna's feed system should be. Questions arise as to where the transformations should take place in the antenna in order to achieve proper impedance matching and power distribution, while obtaining a standard 50 ohm input. Several different systems have been used to meet these requirements in the many different available antennas, and although each has its advantages, they will not be reviewed here since the subject is well covered in other publications addressing broadcast antennas. It is mentioned so that the reader is reminded of these differences, and the ways they may impact the methods described in this text.

Basis for alternative antenna designs

In practice, even the best antennas never quite perform the way they theoretically should--the way they really need to. This is best illustated by recalling the discussion of the ideal antenna bay and the dough-nut shaped field pattern that it should have. (Previously shown in Fig. 2.) Now imagine that the nulls in the fields above and below the antenna are not very deep. Lets say there is about 10 dB less radiation (approximately 0.3 relative E field) in the general directions of 0° and 180° (the zenith and nadir of the elevation pattern, respectively) as compared to the beam maximums at 90° and 270°. The resulting pattern would tend to resemble that in Fig. 4.

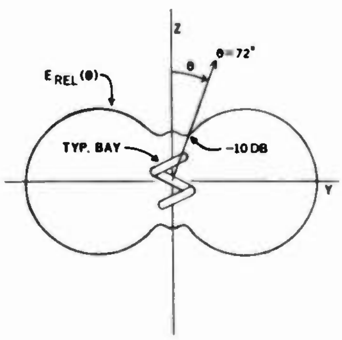


Fig. 4.--Typical E field pattern from a practical transmitting antenna bay.

Unfortuntely, this depicts what the author has typically field measured from the "good" antenna bays. This is the primary source of the excessive radiation that is present below many FM broadcast antennas.

At this point, it should be apparent that if practical antenna bays could radiate power as hypothetically they do in their ideal equivalent form, there would be no downward radiation. There would be no need for many unusual bay separation; one wavelength bay spacing would work fine. This is because the overall field distribution characteristics, i.e., the azimuth and elevation patterns, from a broadside array are the product of the same patterns for both the individual radiators and the array.

Interbay spacing is an important parameter of the broadside array, and as a variable, is incorporated into all of the modified antenna designs considered in this report. In theory, interbay separation can (and may) be any value from infinitly close to over a wavelength apart; all values included will allow gain from the array. Changing the number of bays within a fixed aperture will change the array pattern. The array pattern is defined as the full elevation pattern of a broadside array that substitutes (imaginary) isotropic radiators (equal radiation in all directions) in place of the bays actually used. The array pattern is calculated. Fig. 5 shows a bay pattern (a), an array pattern (b), and the resulting product of the previous two (c). It is the array pattern that generally determines what useful applications a modified antenna will have. This will be considered in further detail elsewhere in the text.

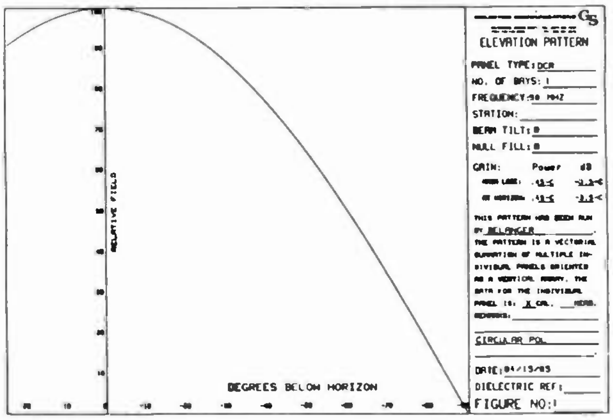


Fig. 5a.--Elevation pattern of a single bay.

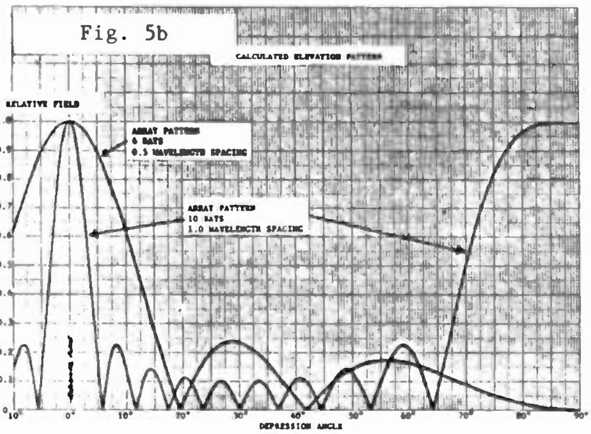


Fig. 5b.--Array patterns for indicated antennas. (6 bay is rectangular form of case in Fig. 1.)

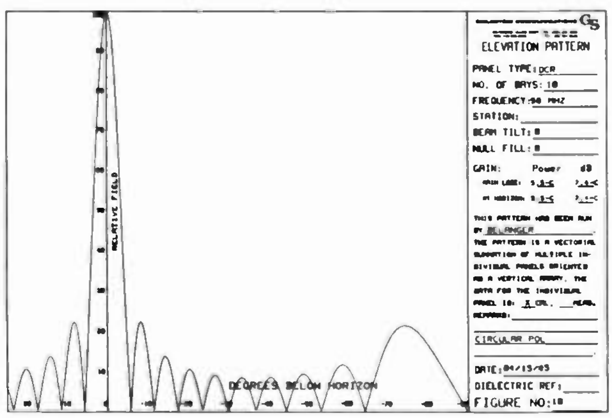


Fig. 5c.--Total elevation pattern as a product of (a) and (b) above for the case of 10 bays in a conventional antenna configuration.

THE MODIFIED ANTENNA AND ITS APPLICATION

Modified antennas fall into two general categories: The first group consists of those antennas designed to reduce the extraneous RF fields, which represents the majority of current applications. Group two is made up of antennas designed for a specific application requiring other than RF radiation. There are significant differences among these groups in both construction and end result.

Antennas for RF radiation suppression

The requirement for antennas falling into this group is primarily the reduction or elimination of undesired downward RF radiation from the antenna. Referring back to the discussion on antenna bays, the principle cause of radiation along the axis of an antenna is due to the imperfect characteristics of a practical transmitting antenna bay. In an antenna with bays spaced at one wavelength the array pattern is such that the radiation from all bays will add in phase along the axis of the array, forming an end-fire effect. Consequently, this augments the undesirable aspects of each bay. This is shown in Fig. 6. Since it is unlikely that anyone is

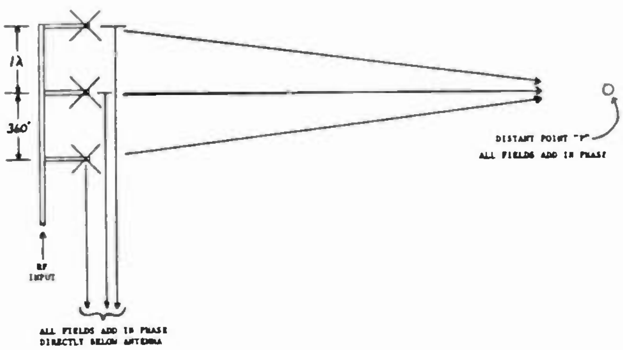


Fig. 6.--Illustration showing broadside and end-fire as predominant modes of a conventional antenna.

going to devise and implement the perfect radiator, any approach taken to control unwanted downward radiation must take into account and compensate for the shortcomings of the individual bays.

Technique.--A suitable approach to the elimination of excess downward radiation involves modifying the spacing of the bays along the length of the array in such a manner that the location of the radiators causes a phase cancellation of signals above and below the array. This method can be referred to as space-phasing (of the bays) and does nothing more than achieve the desired array pattern. Locating bays every one-half wavelength along the length of the antenna will satisfy the above requirment provided the antenn's total number of bays is an even number. (Assumes correct phasing of input.) Referring to Fig. 7, an antenna with one-half wavelength separations, it can be seen that waves traveling from the antenna and normal to its axis add in-phase as in any other broadside array; however, at the waves from a bay radiate along the axis (vertically) of the antenna they traverse the adjacent bays where a virtually complete cancellation takes place as a result of the 180° electrical

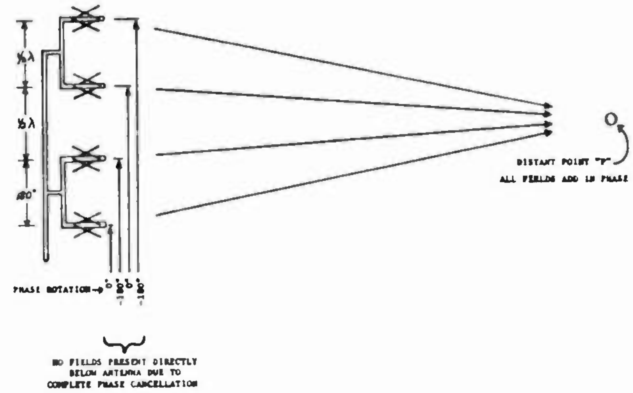


Fig. 7.--Illustration of one-half wavelength antenna showing space-phasing cancellation on axis.

distance between the bays.

Other space-phasing schemes are possible, and depending upon your requirements, may be worthy of investigation. These alternatives can offer similar characteristics to the one-half wavelength system at reduced cost. For example, three-fourths wavelength bay separation could be utilized on antennas with four, or multiples of four bays. This type of antenna will have similar RF suppression as the one-half wavelength case, although not to the same degree. Expect the downward RF supression of a three-fourths wavelength antenna to be at least 3 dB less than that of a one-half wavelength type of equal gain. Cancellation within an array using three-fourths wavelenth separations takes place across every other bay. In a similar fashion, other antenna system designs are possible if they too are configured to have every bay on the array out of phase with another bay along the array. An example of this would be the use of ten bays in conjunction with 0.9 wavelength interbay spacings.

The primary reason for considering a special antenna system with other than one-half wavelength bay separations would be either lower required performance and/or lower cost. (Applies to group one antennas only.) A half-wavelength type configuration will typically use about twice as many bays for the same amount of gain as a standard model antenna, and the feed system is complex; making this antenna expensive. It is, however, the best choice for a difficult transmitter site situation.

When contemplating specially designed antenna systems other than the one-half wavelength style, careful planning is necessary because of the extensive feed systems, particularly on the larger antennas. A branch feed is probably the only practical method of feeding these antennas, and with a large branch feed installation, special attention must be directed towards integrating the feed system onto the tower. This could partially offset any cost savings provided by these latter antenna systems. Don't forget to take tower windloading into consideration anytime an antenna with increased windload is contemplated.

Application.--An antenna used for RF radiation reduction must be properly applied to yield the best results. The gain of the array as well as the arrays location on the tower are important considerations that must be chosen to provide the desired cone of silence. The cone of silence as defined by this author, encompasses the area below (and above) the antenna that has RF radiation supressed by at least 20 dB relative to the main beam, measured at an equal distant point. The depression angle that defines the cone of silence can be found by referring to the proper elevation pattern for the antenna in question, and locating on it the point for which the relative field falls below 0.1 (-20 dB) and remains below this level through -90°; the nadir of the elevation pattern. (This applies to the complementary side of the pattern, the zenith, as well.) See Fig. 8. ("Cone" appears in inset.)

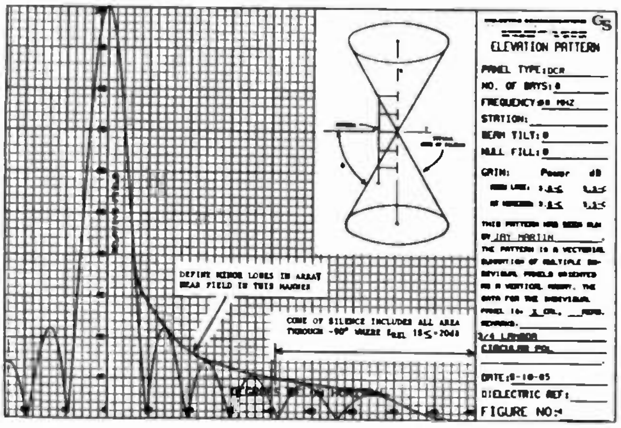


Fig. 8.--Derivation of the cone of silence from an elevation pattern. (8 bays, 3/4λ separation.)

Once the depression angle defining the cone of silence (relative to the horizontal plane) is known, the radius of the cone of silence can be found using Eq. (2), which takes into account the height of the antenna above the ground level. In a similar fashion, the radius of the cone of silence can be selected as required, and a tower height assigned using Eq. (3).

$$r = \frac{h}{\tan \angle d} \qquad (2)$$

$$h = r \tan \angle d \qquad (3)$$

Where: d = depression angle defining cone.
h = effective height of antenna AGL.
r = radius of the "cone of silence".

Obviously, the area contained within the cone of silence is directly related to the antenna height and antenna gain. It is stongly recommended that the broadcaster take whatever steps necessary to obtain as much antenna height above ground level as possible and use it in conjunction with as much antenna gain as is practical. In this way it is possible to minimize the downward radiation from the system. The additional height increases the space losses and in many cases requires a reduction in station ERP. Both effects benifit the overall effort.

The cone of silence is not the only area that requires careful attention when there is concern about excessive downward radiation. The minor lobes radiated from the antenna can contain a substantial amount of energy even when using a modified antenna. The amplitude and location of these lobes can be determined from the elevation pattern in much the same way as the cone of silence was determined. The antenna height and gain are, again, the controlling factors. Fortunately, when maximizing the area within the cone of silence, the probability of an objectional amount of radiation from the minor lobes will be reduced. Exercise caution though, in instances where the ground elevation rises substantially in the vincinity of the transmitter site, and/or low gain antennas are used.

Once the excess downward radiation has been reduced to an acceptable level, the RF fields from the antenna's minor lobes that strike the earth near the transmitter site will then, most likely, be the prodominate source of strong ground reflections. Keep this in mind when estimating probable field strengths near ground level at any site. These reflections can add 6 dB to a calculated E field value at a point of a 100 percent amplitude, in phase reflection.

When either null fill or beam tilt is used on any antenna, the downward radiation situation is further complicated by the effects that these options have on the power distribution in the minor lobes. When null fill is used, there will be additional radiation directed into the first (and sometimes second) null, but there will also be more total power radiated towards the ground at virtually all angles below the main beam. See Fig. 9. The use of beam tilt, on the other hand, results in a redistribution of energy among the minor lobes. (Fig. 10.) Although the total energy (in the minor lobes) does not significantly increase when beam tilt is used, the existing energy can be redirected into a undesired location. When null fill and beam tilt are used together, expect combined effects exceeding those illustrated for either option independently.

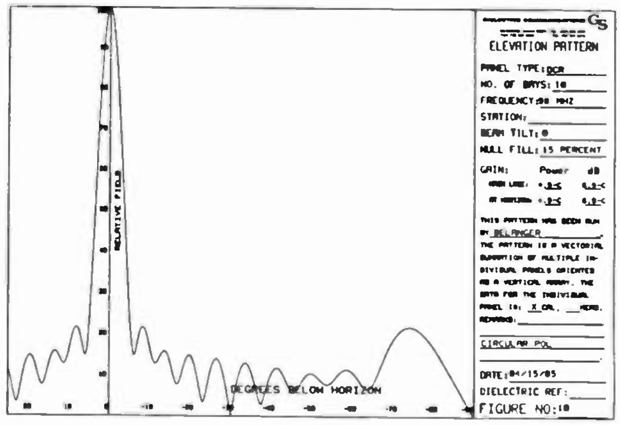


Fig. 9.--A conventional 10 bay antenna with 15 percent null fill.

All of this is not to say that null fill and beam tilt are bad options that should never be used; much to the contrary, they are very useful tools when properly applied. What is stressed, however, is that null fill and beam tilt should not be indiscriminately applied.

There is an interesting point to note about the way an antenna's calculated nulls occur in practice: When in an array near field, i.e., at

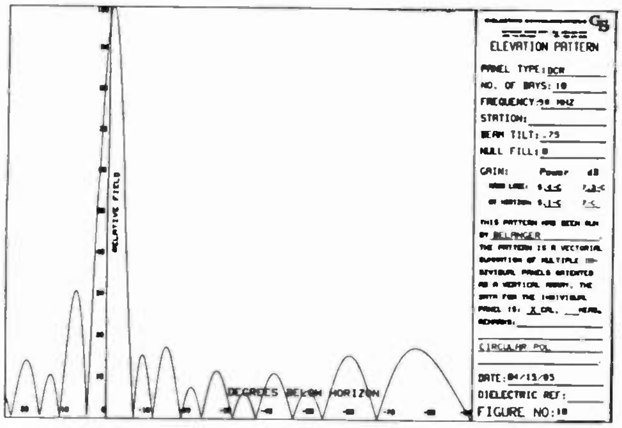


Fig. 10.--A conventional 10 bay antenna with 0.75° beam tilt. Note amplitude of minor lobes.

the transmitter site, the nulls actually encountered are generally quite shallow (if any exist at all) compared to those suggested by the (far field) elevation pattern. For planning purposes, it is practical to ignore the nulls altogether and consider the minor lobes as one broad lobe, defined by the maximas of all the minor lobes. (This is also shown on Fig. 8.)

Improvements resulting from use of a special antenna.--Within the cone of silence, a 10 dB to 20 dB reduction of field strengths over those transmitted from a conventional antenna (of the same gain, ERP, and location) are generally obtained. The author has observed real nulls (as opposed to ground reflection induced nulls) exceeding 30 dB directly below a modified antenna. All of these figures represent a very substantial reduction.

Because of the presence of tower re-radiation and ground reflections, it is unlikely that the improvements theoretically possible beyond the levels given above can be realized. The elevation patterns suggest that complete supression is available at certain depression angles, but don't count on this phenomenon in practice, i.e., at your site!

There are secondary mechanisms that further assist the modified antenna in achieving radiation reduction: When the tower is excited by a conventional antenna, the tower's structural members will radiate a substantial amount of energy towards the ground via the same phase additive process that occurs on the antenna itself. If the tower is instead excited every one-half wavelength, the re-radiation from the tower members will tend to cancel itself as it would on the antenna; although the affect will not be as complete.

Likewise, when parasitic elements are mounted near an antenna bay for pattern correction purposes, they too can radiate a (very) substantial amount of energy towards the ground. This is particularly true if they are horizontally polarized. And once again, a very desirable reduction in the electric fields present below the antenna can be realized when the parasitics' undesired radiation is subject to cancellation through space-phasing.

With all of that power no longer wasted on the ground and up into space, it can be concentrated in the main beam; where it belongs. In fact, most antennas never realize there rated (generally calculated) gain due to various losses; those discussed in this text included. The chances of getting closer to ideal are definitely improved through the employment of a modified antenna design. The typical antenna can lose 0.5 dB to 1.0 dB of gain in all polarizations due to radiation in unwanted directions (excluding radiation normally present in the minor lobes), relative to a one-half wavelength type modified design. With an extremely poor bay, loss of gain due to excessive undesired radiation can substantially exceed these levels.

Additional applications for group one antennas.--The inherit characteristic of an antenna designed to suppress unwanted RF radiation makes it an equally poor receiving antenna in the same directions it was designed to protect, under most circumstances. (The law of reciprocality, as applied to antennas.) Because of this, a special antenna is an ideal tool to increase the coupling loss (i.e., reduce the coupling) into other antennas at many transmitter sites. This, of course, will reduce the likelihood of spurious emission products.

The reduction in antenna coupling that can be achieved for a given situation is not easily defined. Many aspects influence the antenna coupling equation, including: antenna gain, antenna separation, the geometry of the separations, the presence of the tower(s), the polarizations used, frequencies involved, etc.. As a general guideline, when one of the coupled antennas is a one-half wavelength type of design, a nominal 15 dB improvement in coupling losses can be expected compared to those figures attainable with a regular antenna under the same set of circumstances (assumed to be somewhat ideal). The range of improvement to be found under most reasonable circumstances will probably be 10 dB to 20 dB. The use of two similar special antennas will further improve this figure.

The above guidelines regarding the use of a special antenna must be qualified: The maximum amount of loss will occur when the antennas are (1) stacked vertically, e.g., one directly above the other; (2) have a relatively large distance (more than a wavelength) between the two closest bays, and (3) are close in frequency. Note that this last parameter does not apply when two conventional antennas are used.

An undesired increase in coupling will occur whenever one of the parameters described in the above paragraph is compromised. Individual stations' antenna systems should not interleave or partially overlap one another on the same tower. This can lead to incurable coupling problems (among other things) regarless of the type of antenna employed, standard or special. When antennas are adjacent to each other on separate towers located a few hundred feet apart, the antennas with large aperatures will generally exhibit less coupling than their smaller counterparts. Antenna coupling can be further reduced by employing a reverse sense of polarization (cross polarization) for one of the transmitting antennas. This will yield a small to medium improvement (3 dB to 10 dB) in coupling loss.

Maximizing antenna coupling losses from the beginning can result in substantial benifits for a station that is located physically close to another station(s) that is close in frequency; e.g., 800kHz. When situations like these arise, along with the spurious emmissions, the filtering requirements can get very tough--if not impossible. Not convinced. Ask someone who has really battled one of these cases and you will probably change your mind. In cases where every dB of coupling loss counts, a properly applied modified antenna is an excellent place to start.

Finally, the last application for a category one special antenna, to be mentioned here, is so obvious that it is often overlooked. The reduction or elimination of RFI (radio frequency interference), and EMI (electromagnetic interference) at the transmitter site can be readily accomplished with a special antenna. Needless to say, this is a direct result of the reduction of downward radiation. Remember, best results are obtained when the transmitting equipment is located near the base of the tower, the antenna is located on a high tower, and has a relatively large amount of gain.

ANTENNA APPLICATIONS NOT REQUIRING RF RADIATION SUPPRESSION

General.--There are applications for special antennas that are not bound by the same configurations that radiation suppression requires. This allows us to build an antenna with modified interbay spacings, but without regard to exacting requirements necessary for proper space-phasing cancellation. These are the group two antennas refered to previously.

The fact that these antennas are not specifically designed for RF supression does not suggest that the antenna will have a large amount of downward radiation. Whenever an antenna is modified so its interbay separation is a value other than one wavelength, a certain amount of space-phasing cancellation will always take place. In some cases, this advantage can be significant even though it is not a design goal.

There are potentially many cases where an antenna could be custom built to suit a particular requirement. The one application that will be discussed is a situation that will probably prove to be popular. This case involves the use of a special antenna to substantially improve the coverage of a station through improved ability to control the azimuth pattern of the antenna.

The problems of pattern distortion, and the corresponding methods of correction are quite complex. It is beyond the scope of this paper to cover the intricacies of antenna patterning; hence, it is assumed that the reader is already familiar

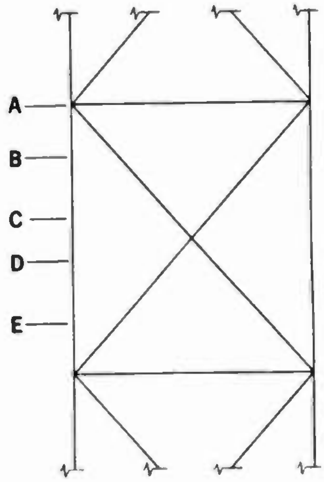
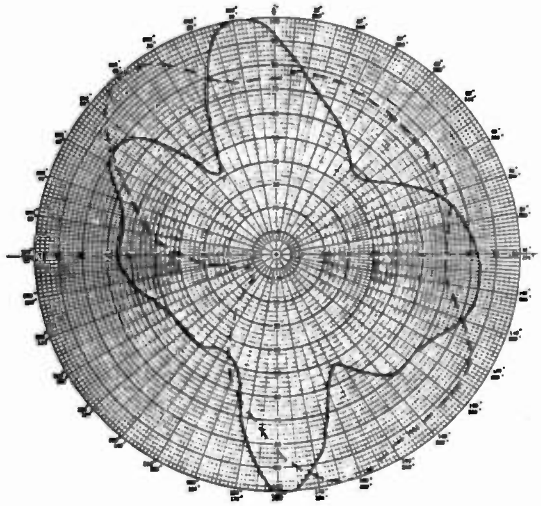
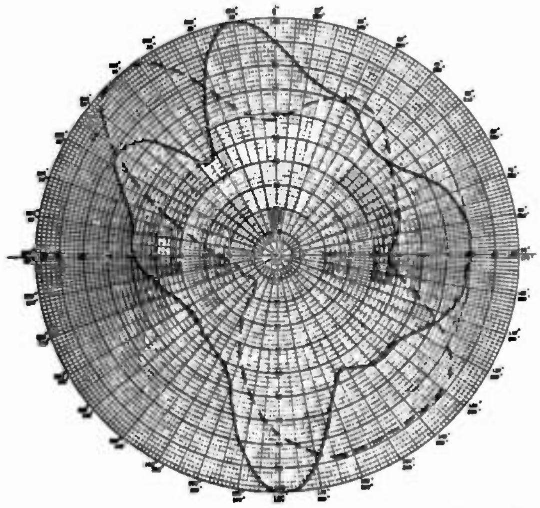


Illustration of tower section showing bay elevations used to obtain the following patterns (a) thru (e).

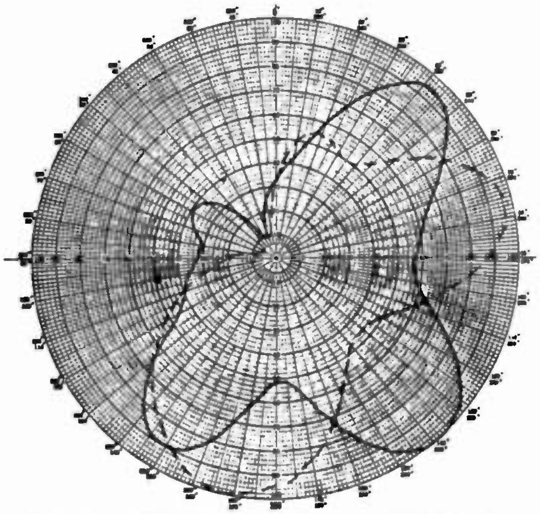


Pattern resulting from bay elevation (a).

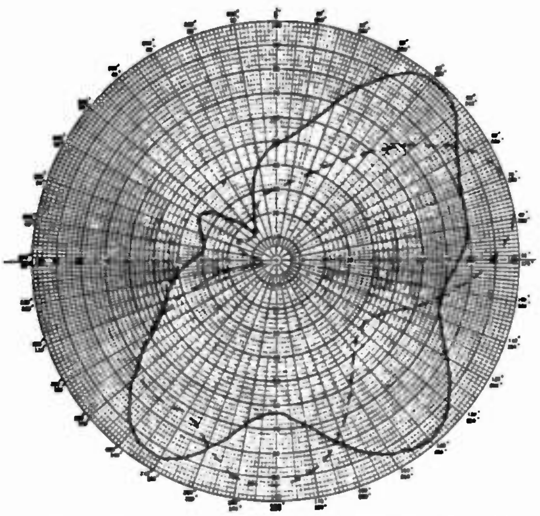


Pattern resulting from bay elevation (b).

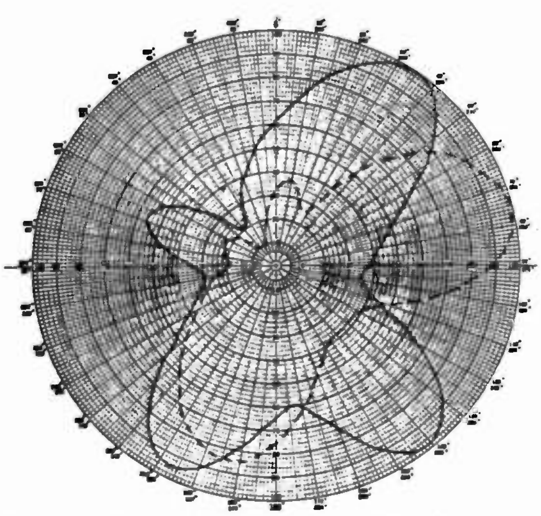
Fig. 11.--Horizontal plane patterns depicting pattern distortion as a function of bay mounting location as shown at top. Figure continued next page.



Pattern resulting from bay elevation (c).



Pattern resulting from bay elevation (d).



Pattern resulting from bay elevation (e).

Fig. 11.--(Continued)
Polarization code:
Horizontal ——— Vertical -----------

with the subject, or can gain access to material that treats antenna patterning in-depth. Therefore, this discussion is limited to background needed to understand the application of the antenna design.

Problem.--Whenever a ring type FM antenna is side mounted on a tower, the azimuth pattern (horizontal plane pattern) actually transmitted from the from the antenna is usually severely distorted. Variations in the relative field strengths at different directions of azimuth will typically exceed 10 dB, and will have different patterns for the horizontal and vertical polarizations. This type of problem can vary from moderate to intolerable depending upon tower size, structural design, antenna mounting location, stand-off from tower, operating frequency, etc..

Several manufacturers have pattern development programs that allow the customer to purchase an anenna that has been modeled on a tower replicating that used by the station. The engineers develop the pattern as best they can according to the requirements, e.g., omni-directional, directional, etc.. Occasionally, parasitic elements are used to aid obtaining the desired pattern. Testing is done either full scale or with scale models. A single bay is usually employed and is generally tested at several points of elevation along the sample tower section to determine what effects the tower's structural members' locations will have on the azimuth pattern, relative to the antenna bay. The manufacturer then takes these patterns and attempts to arrive at an average pattern representative of how the antenna is expected to perform once installed. Since an antenna's bays rarely fall at the same regular interval as the tower's repetitive structural members, the technique of pattern averaging to arrive at a final pattern has been considered a reasonable and proper approach.

Research on the part of at least one manufacturer has revealed that this pattern averaging procedure can introduce large descrepancies between the projected pattern and the actual "installed" pattern. This suggests that the final pattern is generally not the simple average of several patterns given practical circumstances. And there is no known mathematical function or relationship that can be applied in each case to arrive at the correct result. Obviously, the use of pattern averaging to predict the final pattern is inherently flawed, and cannot be relied upon unless the various patterns involved are quite similar to begin with. This is usually not the case when pattern distortion is sufficient to warrant correction. The typical changes that can result to an antenna's azimuth pattern as a function of bay location is shown Fig. 11. It should be evident that it would be difficult to quantify the final pattern for an antenna with n number of bays, and the array arbitrarily attached to the tower.

Solution.--A unique approach can be taken to eliminate the uncertainty of averaging the patterns for the various bay elevations, allowing arrival at the correct pattern with considerable confidence. The technique requires an antenna with altered interbay separation, and is very simple: Just place each bay at a position along the tower that concurs with the repetitive nature of the structure. In this manner, it is possible for each of the bays to illuminate the tower in the exact same way, and in a relative bay location that yields the best overall pattern. Obviously, each bay will radiate the same azimuth pattern, and as a result the final predicted pattern will be equivalent to the bay pattern.

The exact bay separation required to achieve the above set of circumstances is dependent upon the tower. Virtually every tower has girders and braces located every few feet, and it should be possible to locate the bays anywhere from one-half wavelength to one full wavelength apart. Only in rare cases should it be necessary to exceed this recommendation. All bays must be fed in phase, as required by a broadside array, and this can most conveniently be done with a branch feed under most circumstances.

The gain of the antenna is determined after the bay separation and total aperture have been selected. The necessary figures can be derived from the total number of bays to be used, and knowing their respective locations on the tower. Recalling the earlier discussion on gain, it can readily be seen that this is all that is necessary to determine the array pattern, and thus, the gain over a single bay of the same type. How this is translated into the ultimate gain figure is dependent upon the exact antenna configuration (directional, non-directional, etc.) and the methods preferred by the antenna manufacturer. Approximate gain can be determined through the use of Eq. (1), presented earlier in this text.

Resulting benifits.--An antenna employed in the above manner will provide the best overall pattern control possible on a medium or large size tower, without resorting to the use of a costly panel antenna system. These special antennas will produce beamwidth and gain that is similar to that of a conventional antenna of the same approximate length, and will yield some suppression of downward RF radiation. The exact amount of which can be be determined from the antennas specifications.

CONCLUDING REMARKS

The author has had the opportunity to research, design, and have built, a specially modified antenna which made an important transmitter site available to a station that was previously precluded from the site due to operational difficulties.

In this particular instance, a special antenna designed and used as outlined under the group one antenna guidelines in this text, solved several "insurmountable" problems and turned a virtually hopeless situation into one of the best signals in the market. This serves to illustrate one of the many cases where a special antenna could provide the means for solving a difficult problem, a solution that might not be available in any other form.

A modified antenna is best thought of as a tool that can be used to solve a specific problem (or problems), should it be in an existing installation or for one that is on the drawing board.

It is urged that any station interested in utilizing a special antenna first carefully evaluate the exact needs for the particular installation in question. A modified antenna should not be arbitrarily installed, as the results may be both disapointing and costly.

In order to obtain the best results with any antenna installation, the utmost attention to detail is required during all phases of planning, manufacture, installation, operation, and maintenance. This cannot be overstated.

Finally, on a topic as intricate as that presented in this text, it is difficult, if not impossible to cover every potential aspect. In order to keep this paper at a reasonable length, it was not possible to address every situation; such as the use of a modified antenna for multiplexed stations, etc. The author wishes to apologize for any omissions, and hopes that any errors discovered in the text will be brought to his attention so that they may be corrected.

ACKNOWLEDGEMENTS

The author wishes to thank the following persons for their contributions that assisted in the preparation of this paper:

Bob Gonsett
Don Hobson
Chris Holt
Jim Levitt

Special thanks goes to Bill DeCormier at Dielectric Communications for his many valuable suggestions, and to Dielectric Communications for supplying several of the illustations used in this text.

REFERENCES

P. C. Gailey and R. A. Tell, "An Engineering Assessment of the Potential Impact of Federal Radiation Protection Guidance on the AM, FM, and TV Broadcast Services." U.S. Environmental Protection Agency, Nonionizing Radiation Branch, Las Vegas, Nevada.

J. D. Kraus, Antennas, McGraw-Hill Book Company, Copyright 1950.

F. E. Terman, Radio Engineers' Handbook, pp. 776-800, McGraw-Hill Book Company, Copyright 1943.

USING A MICROCOMPUTER TO STUDY FM SHORTSPACING INTERFERENCE

Jon Banks
Chief Engineer
WLTT, W-Lite Radio
Bethesda, Maryland

This paper covers the development of a microcomputer based system to predict the interference effects of shortspacing on FM station coverage. An overview of the shortspacing problem is given and techniques necessary to adapt the problem for computer processing are detailed. Some examples are given.

SHORTSPACING PROBLEMS

When FM stations on the same frequency are too close to each other, their signals will interfere. A listener can't get good reception if the interference is bad enough. The same thing happens if the frequencies are close but not exactly the same. The problem can be serious; some stations lose 40% of their coverage area. But other stations are hardly affected, and many stations are not shortspaced at all.

The problem started when FM stations were allocated, and there weren't enough to go around. Cities aren't evenly spaced, either, so the allocation problem became an impossible jigsaw puzzle. By short-spacing stations here and there, the FCC was able to fit more stations into the heavily populated parts of the country.

The amount of interference depends on the power and height of the stations involved and the frequency difference between them. Most shortspacing is between co-channel, and first- and second-adjacent channel stations. If your station is in or near a top 30 market, the chances are good that it's shortspaced.

I began to study the problem when I was Chief Engineer of WLTW in New York City. Several adjacent channel stations were nearby, and we had reception problems near their transmitters. I found the criteria for interference in section 73.509 of the FCC Rules:

spacing, kHz	ratio undesired/desired
0	1 : 10
200	1 : 2
400	10 : 1
600	100 : 1

(the 600 kHz standard has been deleted)

For example, two full facility class B stations on the same frequency need to be 145 miles apart to be interference free at their 0.5 mV/m contours. Class C stations would need 210 miles of separation.

Drawing the areas of interference onto a map by hand was very tedious work; after finishing the first one, I decided to adapt this problem to run on my Apple computer.

PROGRAM DEVELOPMENT

The first step in writing any computer program is to understand, in great detail, the problem and the methods that will solve it. A computer follows commands blindly, so the program has to anticipate all possibilities and cover every detail of the problem solving sequence.

The Apple's graphic screen is organized on a rectangular coordinate system. Using 115 points (pixels) horizontally and 190 pixels vertically gives a square map field with about one pixel per mile resolution. The aspect ratio of a pixel is not 1:1.

The station being analyzed would always appear at the center of the screen. The central station's coverage would normally extend in roughly a circle to the 0.5 mV/m contour. For each pixel within that circle, the computer would calculate the strength of the central station; then compare that value to the calculated strength of each interfering station at that same pixel (adjusting for the desired to undesired ratio). If any interfering station had a stronger signal the computer would plot that pixel in color to show that it was a problem area.

The program did work in this early version, and it gave accurate results. But it was slow. Calculating the distance to each station, and the field strength at that distance for every one of the 21,850 pixels in the display took almost twelve hours. Now the real programming began -- streamlining the code to improve speed without compromising accuracy.

The first speed enhancement was gained by using a compiler. This translates the program into a simpler computer language that executes about three times faster.

Another improvement was made by scanning every fifth pixel instead of every one. If the computer crosses a boundary between an interference-free area and one with interference then it backs up and tests each pixel to pinpoint the boundary location. This cut the runtime to an hour.

A computational problem like this can be adapted to take advantage of the computer's strengths. Computers process integers quickly. Floating point real numbers are handled much slower. Addition and subtraction are the fastest operations, then multiplication and division. Trigonometric and exponential functions are much slower. When a function is performed in a program loop thousands of times, it's very important to optimize the code in this way.

For example, the formula for computing screen distance (D) from the horizontal (H) and vertical (V) coordinates of a point to the center of the screen is:

$$Z = H^2 + V^2$$

$$D = \sqrt{Z}$$

This will execute faster in this form:

$$Z = H \times H + V \times V$$

choose A_1 to approximate $\sqrt{Z}$

$$A_2 = Z / A_1$$

$$A_3 = (A_1 + A_2) / 2$$

$$A_4 = Z / A_3$$

$$A_5 = (A_4 + A_3) / 2$$

. . . . . .

$$D = A_{last}$$

Multiplying H by itself is faster than raising H to the power of two. And the successive approximation method is faster than the square root function. With a good estimate for A_1 only two iterations are needed to get accuracy within 0.1 miles. These shortcuts doubled the program's speed.

The last improvement incorporated a precalculated look-up table of field strength vs. mileage. This table only has to be set up once for each station. The computer refers to the table instead of calculating the field strength at each pixel. Also, the field strengths were stored as dBu x 10, which can be represented using only integer numbers, and the desired to undesired ratio, in dB, was added to each interfering station's values when the table was created. The execution time was down to just five minutes.

OTHER FEATURES

Making the system fast wasn't enough. It had to be easy and convenient to use, too.

Eventually all the station data was kept on disc in a file format, so it wouldn't have to be entered each time the program was run. This station library has to have certain utilities, to add and delete stations, examine or print the contents of the library, and enter and examine directional patterns. These utilities take a lot of time to program effectively, and they don't really contribute to the engineering results the system produces, but they are essential.

The computer was programmed to search the station data file and identify all potential interfering stations on its own. A special algorithm used the distance to each station's 1.0 mV/m contour and the frequency offset to determine if there was even a chance of interference. A 25% built-in factor insures that any marginal cases will be tested in detail.

A map system was developed so the coverage patterns could be related to geographical areas, even by non-technical personnel. It had to be relocatable, so that it could be centered on the latitude and longitude of any central station chosen. The map scale and coverage pattern scale were automatically selected, based on the coverage radius of the central station.

Adapting the video display of the coverage pattern and map to print in gray shading on a common printer was a problem. The video pixels were not square, and the printer's dots were not evenly spaced horizontally and vertically, so it was difficult to keep the scales true on both. Printing the picture sideways was the key to accurate scales on both displays.

As the program developed, it became a system of several programs, most of which were dedicated to features and conveniences. In final form, there were eight separate programs and over 1800 lines of code.

RESULTS

Four maps are shown to illustrate the kind of information that interference studies reveal. Not shown is the text summary which goes with each map; it lists the stations in the study, whether or not they caused interference, their powers and heights, their distance and bearing from the central station, and their frequency.

The map calculations are accurate $\pm$ one mile. Like all coverage maps, these are not absolute. A knowledgeable engineer familiar with the area can judge when terrain blockage and other factors may reduce or aggravate interference. The population density determines how many listeners will be affected, and the interference will vary with the quality of the receiver. But in general, the maps seem to be quite accurate.

WLTW has much less of a shortspacing problem than WCBS. The difference in coverage is dramatic. WCBS is shortspaced to a co-channel station in Philadelphia, only 82 miles away. (and to stations in Connecticut and upstate New York) Both stations broadcast from the Empire State Building.

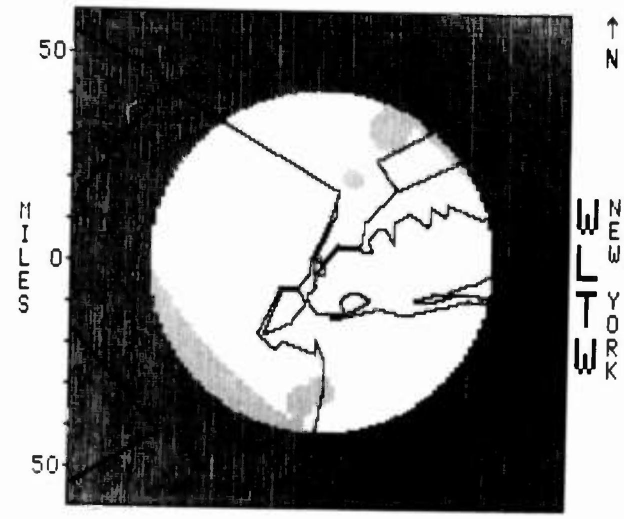
WZFM is a class A station just north of New York City. Note the different map scale. WZFM's coverage to the south is limited by a second-adjacent channel station in the City and a co-channel south of the City.

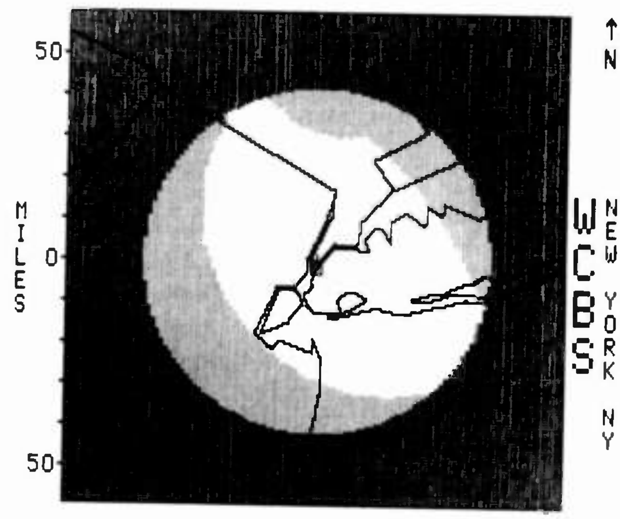
The last example is WPKX, a directional station near Washington, DC. WPKX reduces power to the northeast, protecting a Baltimore station. This is clearly shown, along with the small amount of interference that still exists. If the stations reached an agreement to both operate non-directionally, the area of interference would increase dramatically.

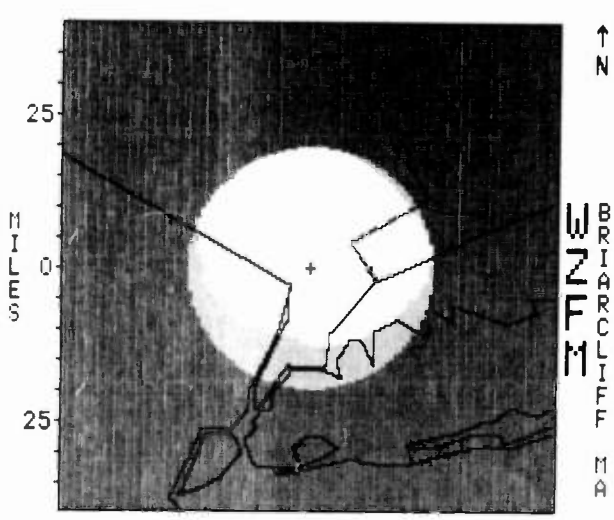
Interference studies can answer many what-if questions that broadcasters ask:

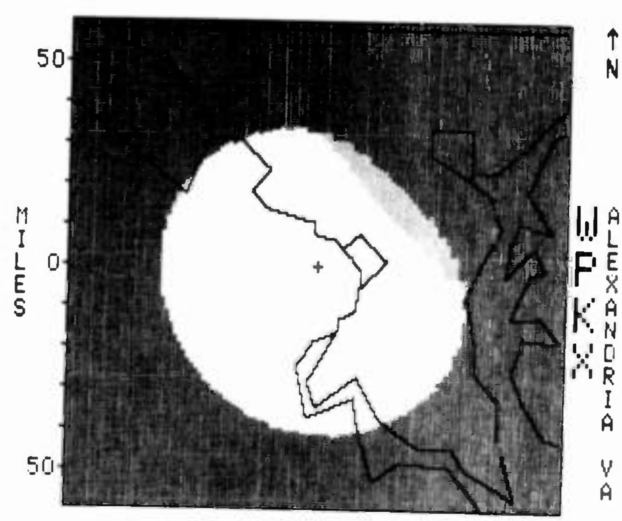
* What if we move the transmitter?
* What if an adjacent channel station gets a power increase?
* What will happen if Arbitron adds new counties to the survey area? Will that help some stations more than others?
* What about a format change? Will our coverage be better than stations already in that format?

Interference studies can reveal major differences in the coverage of stations that seem to have equal facilities. This is a competitive advantage for engineers that understand and use the information.









COMBINING NETWORKS FOR FM MULTIPLEXING

D. Stephen Collins, Chief Engineer, George M. Harris, P.E., Project Engineer
and Robert A. Surette, Manager, RF Engineering
Shively Labs
A Division of Howell Laboratories, Inc.
Bridgeton, Maine

ABSTRACT

Broadcasting FM signals at different frequencies from a single broadband antenna requires the use of a combining network. These combiners can be categorized as branch or star-point in one case, and as constant-impedance, hybrid or balanced in the other. A comparison is made between branch and balanced systems, explaining their relative advantages. Balanced combiners, in turn, may employ either reject or pass filters. A comparison is drawn between the two types. Shively Laboratories recently completed installation of three-channel and eight-channel balanced combiners using pass filters. A theoretical analysis of their performance is given. The predicted performance is compared to the measured performance of the installed systems.

INTRODUCTION

The FCC's recent adoption of Docket 80-90 has caused a flurry of activity in the world of FM broadcasting, as license holders scramble to meet power and antenna height requirements. Beyond the basic high cost of a Class C facility, broadcasters face increasing difficulties in satisfying federal agencies such as the FAA and the EPA, as well as state and local authorities and citizens' groups.

An increasingly popular solution to this dilemma is for two or more broadcasters to share a transmitting facility. This approach reduces construction costs and usually allows the participants to share higher-quality facilities, in terms of tower and antenna.

A shared transmitting plant is implemented by combining the outputs of several transmitters into a single large transmission line, and feeding it into a high power broad-band master antenna. In order to implement such a system, two major building blocks are required. One is the master antenna which is designed specifically not only to handle the high power of several transmitters combined, but also to provide excellent VSWR and radiation pattern characteristics across the entire FM band. The other major block in the system is the transmitter combiner. This interesting network is responsible for connecting each transmitter to a single transmission line for routing to the master antenna, while at the same time providing high isolation between all of the transmitters in the system.

In any combined operation, the isolation between transmitters must be high enough to prevent the energy from one transmitter from entering another. Because of the non-linear nature of transmitters, if this isolation is too small, the units may begin producing high power intermodulation or conversion products that are radiated on frequencies other than those assigned by the FCC. Many broadcast engineers are well familiar with the problems that are caused by transmitter intermods.

The FCC's regulation states that intermodulation and spurious emissions or "spurs" from transmitters must be at least 80 dB below the level of the nominal transmitter's output power. That's a maximum signal power level only one ten-millionth that at carrier!

SOME NETWORK PROPERTIES

When designing a large high power transmitter combining system of this type, there are several important considerations that must be addressed. First, as we just mentioned, there is a minimum transmitter-to transmitter isolation figure that must be met. The reason for this is that whenever two or more signals are impressed on any non-linear network, such as a transmitter final amplifier, spurious signals will be produced that vary in amplitude, depending on the level of the impressed signals, and other criteria such as the degree of network non-linearity in the amplifying systems of the transmitter. The difference in the amplitude of these spurious signals and the amplitude of the signals from the transmitters in the system at carrier is called the conversion factor, and is expressed in dB. This number is generally on the order of 35 dB or more. However, as the active elements in the transmitter such as tubes age, the normal process of gas diffusing across the envelope of the tube will alter the unit's transconductance properties, affecting the amplifier's linearity. This may in turn cause the transmitter conversion factor to change, perhaps increasing its propensity to generate intermods. The amplitude of these intermod products produced depends on the amount of signal power entering the transmitter's output from other transmitters in the system. It is the combiner's job to not only provide a proper impedance match between each transmitter output and the antenna, but to also insure that there is enough isolation between transmitters so that the intermods produced are within FCC specifications.

A properly designed combining system must provide enough isolation to insure FCC compliance with a good safety margin, regardless of amplifier linearity drift within the transmitters. For this reason, we feel that a good stable design mandates a minimum isolation between any two transmitters in the system of 50 dB. In order to achieve this, combining systems usually consist of highly selective filtering networks working in conjunction with each other through other components such as transmission line junctions or high power couplers that route the signal from each transmitter to the antenna.

Another very important design consideration is that the combiner must not introduce any degradation of the transmitted signal whatsoever. This means that the system cannot significantly alter its signal transmission characteristics from the transmitter to the antenna as the frequency varies with modulation within the channel, including stereo and SCA's.

Whenever a signal is passed through any transmission medium or network, there will always be a certain amount of time required for the signal to make the trip from input to output. Also, there will be a reduction in the amplitude of the output signal compared to the input due to losses in the network. The amount of time required for the signal to get from the input to the output is called the delay, and the reduction in the signal amplitude at carrier as it passes through is called the insertion loss of the network.

These are transmission characteristics of a network at a single frequency. In FM broadcasting, any network, such as a filter or coupler, used in a combiner must be completely characterized over a closely-spaced group of frequencies within the FM channel. A filter, such as those used in an FM combiner, is a network whose transmission characteristics, by design, change according to the frequencies being passed through it. Filters are made to offer one set of characteristics to signals at one group of frequencies, while at the same time presenting quite a different set of transmission characteristics to signals at other frequencies.

The delay of a group of signals flowing through a filter is termed group delay. Because of the energy storage nature of the filters used in combiners, the group delay becomes significant, and will change, even within the closely-spaced group of frequencies of an FM channel. The overall group delay is relatively unimportant, however, the difference between the delay of signals at the lower end of an FM channel and the delay at the upper end of the same channel is termed group delay difference in the channel band, and that is extremely important. If great care is not taken in the design of these filters, a high degree of group delay difference within an FM channel will probably occur. This could cause insertion phase variations with modulation, especially at the low and high end of the FM channel. The result could be phase distortion and incidental phase modulation. These in turn, may create stereo and SCA cross-talk and fuzzy audio.

The losses in a filter over the same group of frequencies must also be completely characterized. Again, because of the frequency sensitive nature of a filter, the loss through it will change with frequency, and therefore, the amplitude of the signals appearing at the output will change as the frequency varies with modulation. The amount of loss through the filter resulting in signal amplitude variation over frequency in the channel band is termed the frequency response of the network. Again, unless extreme care is taken in the filter designs to insure a relatively flat frequency response over the channel, other problems such as an increased level of incidental AM could result.

Clearly, these systems must be carefully designed to insure that they do not introduce any significant signal transmission alterations anywhere in the channel, including multiple SCA's. Good design parameters should also include a substantial safety margin on either side of the channel.

TYPES OF SYSTEMS

A combining technique popular in the past was the so-called run-out system. Still in use at several sites, it is now considered obsolete. Currently, there are two major types of combining systems. First, a less involved network, usually reserved for facilities where only two or three transmitters will share a common site, is called a branched or starpoint combiner. The second, a much more elaborate and expandable approach, generally used in an application where there are several stations, (up to nine or more), at a common site is called a balanced or constant impedance combining system.

BRANCHED COMBINING SYSTEMS

A branched system is composed of a network of high power band-pass and/or band-reject filters that are all connected through tuned lengths of transmission line that match impedances to a common transmission line junction that is then routed to the station antenna, as shown in Figure 1 below.

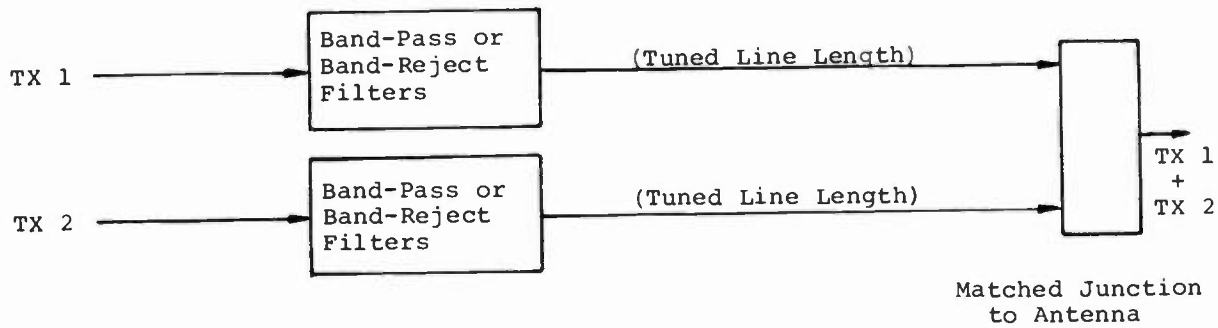


FIGURE 1: Branched Combining System Schematic

Here, the output from each transmitter in the system is passed through filter networks in its branch. These filters are designed to provide all of the necessary isolation between transmitters in the system, while providing an unaltered transmission patch from each transmitter to the station master antenna.

This approach is a good one, as mentioned earlier, when designing a smaller facility. With this type of system, the transmitter frequencies determine some of the very basic design parameters of the network, such as the lengths of transmission line between the filter outputs and the matched junction to the antenna. These and other basic constraints make this approach good for smaller facilities. However, in a large system, such as Guy Gannett Broadcasting Service's "441 Site" in Miami, Florida where an original five stations sharing a common facility have grown to eight, and with another to be added in the future, a branched combiner is entirely impractical. One reason for this is that large systems are generally designed for the addition of several more stations at some point in the future. The operating frequencies of these additional stations may or may not be known at design time. In a branched system, the tuned transmission line sections that connect the filter networks of the combiner to the matched junction of one branch in the system will interact with the tuning of the line section from another. This tuning is done at the factory when the unit is being fabricated and set up. Since each tuned line section will influence the tuning of every other, the addition of future stations to the system once the unit is tuned and in place is a formidable operation.

A second reason is that the filters in a branched system are tuned and coupled to accommodate a particular transmitter frequency spacing. This is done to provide the required specifications for isolation, group delay difference in channel, frequency response and insertion loss at carrier. The addition of another branch to the network once this is done will, in most cases, completely upset these important design parameters, affecting the operation of all stations in the system.

For these reasons, larger systems demand a much more interesting approach to FM combiner design.

BALANCED OR CONSTANT IMPEDANCE COMBINERS

A truly elegant, flexible and expandable approach is the balanced or constant impedance combining system. With this design, the system is built in modular form, so the addition of more stations to the facility may be made at any time, even though the frequencies of future participants are not known. Each time a new station is added, all that is required is the addition of another module to the system. These additions may be made without fear of interaction with other modules in the combiner network.

In a balanced network, each module is composed of specially designed filters working in conjunction with high power quadrature hybrid networks. In the discussion that follows, an attempt will be made to explain, in some detail, the operation of this fascinating design.

In order to understand how a balanced combiner works, it would first be instructive to examine some of the basic properties of hybrid networks.

A hybrid is a 3 dB transmission line directional coupler with four connecting ports, as shown schematically in Figure 2 below.

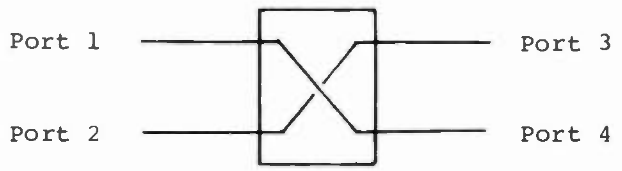


FIGURE 2: Hybrid Divider Schematic

If a signal from a transmitter is connected to Port 1 of the hybrid above, due to the nature of the network, this signal will split and divide equally between Port 3 and Port 4. Here, Port 2 of the hybrid is isolated from Port 1 because of the fact that the unit is a directional network. This "transhybrid isolation" is on the order of 30 dB, if Ports 3 and 4 are terminated in matched loads. The magnitude of the signals coming out of Ports 3 and 4 is equal and just one half of what it is going in at Port 1. And, since the signal from the transmitter is a sine wave, there is not only a magnitude associated with these signals, but a relative phase angle as well. In a quadrature hybrid, as used in a balanced combiner system, the phase angle of the signal at Port 4 lags approximately 90 degrees behind the signal at Port 3. Now, if the matched loads at Ports 3 and 4 are replaced by short or open circuits, the signals coming from Ports 3 and 4 will reflect from these shorts or opens, and go back into the network in such a way that they will combine in Port 2. In order for this to occur, the short or open circuits must be placed at equal distances from the hybrid, producing what is termed "balanced reflections".

Consider now, a second hybrid connected to the first, with Ports 3 and 4 of the first connected to Ports 1 and 2 of the second, as shown in Figure 3, below.

In this configuration, if the same signal from the transmitter is applied to Port 1 of Hybrid #1, it will split into two signals, just as before, and enter Hybrid #2. There, these signals will each be equal in magnitude, with their phases related to each other by 90 degrees because of Hybrid #1. Due to the phase relationship of the two split signals from Hybrid #1, they will combine in Port 4 of Hybrid #2. Here, Port 2 of Hybrid #1 and Port 3 of Hybrid #2 are now isolated.

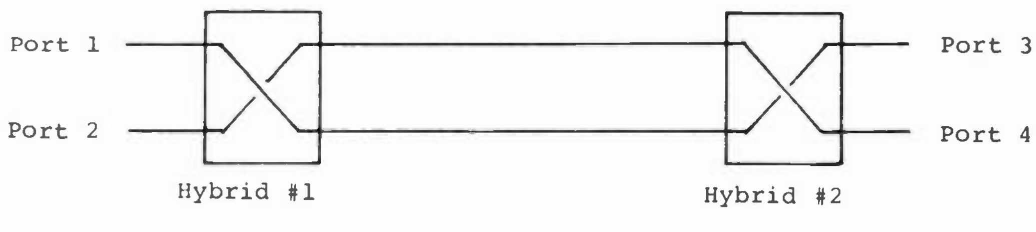


FIGURE 3: Hybrid Network

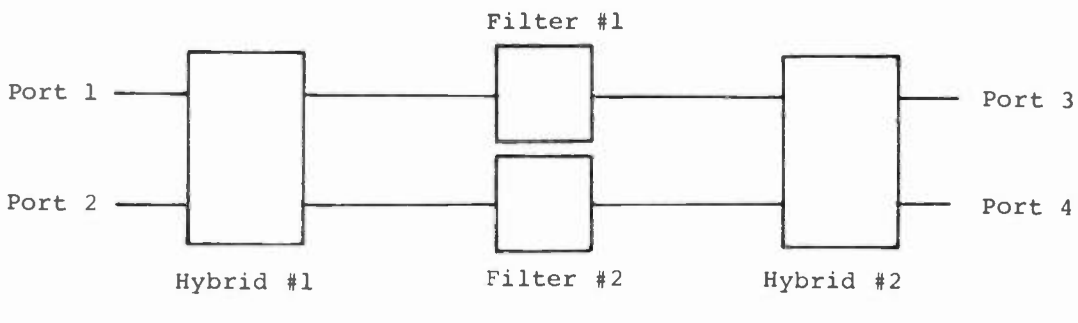


FIGURE 4: Balanced Combining System Schematic

If the same two hybrids are connected together as before, except that this time, two frequency-selective filters are placed at equal distances in the interconnecting transmission lines between the hybrids, a single module of a balanced combiner will result.

This is shown in Figure 4.

BALANCED BAND-REJECT SYSTEMS

Here, if the filters are the band-reject type, they will reflect signals at their center frequency, and pass signals through at all other frequencies. If the two filters are tuned identically to reflect Frequency A, and a transmitter operating on Frequency A is connected to Port 1 of the system above, the filters will produce balanced reflections back toward Hybrid #1 just as the short or open circuits did earlier. These balanced reflections would cause the signals from the transmitter to combine in Port 2. If a second transmitter operating at Frequency B is now connected to Port 3 of the system shown in Figure 4, the signals will split in Hybrid #2, and since the filters reflect signals only on Frequency A and pass other signals straight through, the signal from the second transmitter on Frequency B will combine in Port 2 with Frequency A. In this system, the input of Transmitter A is isolated from that of Transmitter B by only about 30 dB. This is because the only isolation available is the transhybrid isolation. Note that the isolation of B from A will be higher, because of the contribution of the filters.

Because the filters have a finite Q, and because the hybrids have finite directivity, a small amount of signal will appear at Port 4 of the system. For this reason, a termination load is connected to Port 4 to absorb this small amount of signal power. If the system is analyzed, it is easy to see what happens if the frequency of either of the two inputs is varied. In the case of Frequency A, the signals will begin to transfer from the output at Port 2 to the termination load at Port 4. In the case of Frequency B, since the filters are band-reject and reflect only the signals at Frequency A, this second transmitter would always be routed to the output at Port 2, except in the case when this second transmitter is operating on Frequency A. In this case, the signals would be transferred to the termination load at Port 4. It should be apparent that in no case with this design, at any frequency, is either transmitter presented with an impedance other than the termination load, or the impedance at the output at Port 2. The impedance presented to the transmitters on the system is constant over frequency, and hence the name, "constant impedance" combiner. This is a good feature, as the transmitter is never presented with off-channel loads of other than the system's characteristic impedance. This will preclude the build-up of resonances in the transmission line connecting the transmitter to the combiner system. When a third frequency is to be added to this system, another module identical to the one shown in Figure 4 is added. In this case, Port 2 of the first module containing the combined outputs of the first two transmitters is connected to Port 1 of the second module, as shown in Figure 5 below.

In this case, the filters in this second module are tuned to Frequency C. A third transmitter operating at Frequency C is connected to Port 3 of the second module. These filters produce balanced reflections at Frequency C as before, and the signal from this third transmitter will combine at Port 4. At the same time, the first two signals, combined in the first module pass through the filters in the second module, and they also combine at Port 4. This port now contains the outputs of all three transmitters. In this second module, a reject termination is connected to Port 2, thus providing a constant impedance load over frequency to the third transmitter in the system. A fourth transmitter operating at Frequency D may be added to the system at any time by simply adding a third module, its filters tuned to Frequency D, and connecting it to the system as before.

This design is embodied in the Senior Road system in Houston, Texas.

The system just discussed is a balanced system using band-reject filters in the interconnecting transmission lines between the two hybrid couplers. This is a good design compared to the branched combiners, discussed earlier in this paper. However, the band-reject style does have some rather distinct disadvantages. One of this system's major liabilities is that each time another transmitter is added to the network, the combined power of all the transmitters must be passed through the filters and both hybrids in the modules. This poses the problem of building larger and larger networks capable of handling the combined transmitter powers as the system is expanded. A second problem with this design approach is that if the transmitter frequencies are closely spaced, 800 kHz for example, the group delay in a particular FM channel may be increased at one edge of the channel due to presence of the filters in another module of the system. This could lead to group delay differences in the channel that are unacceptable.

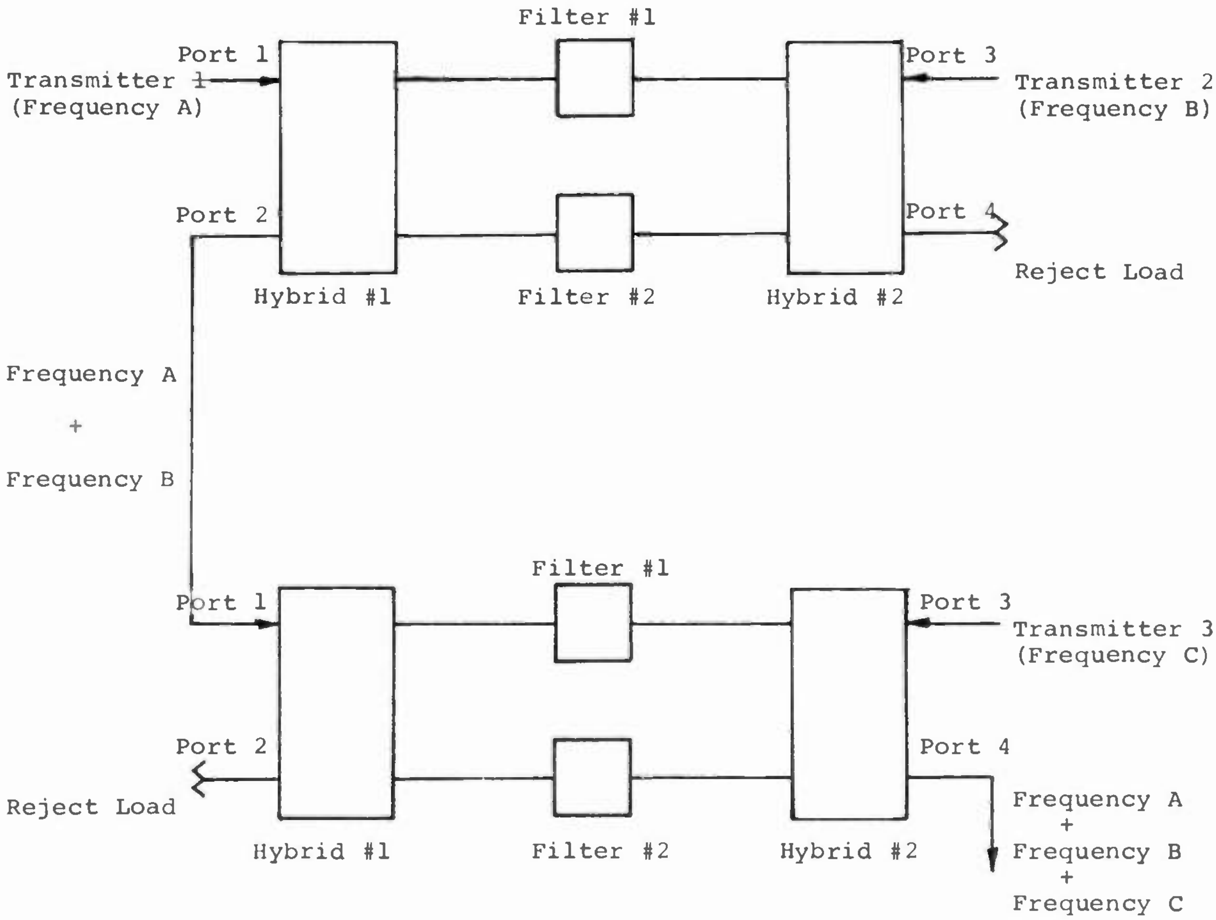


FIGURE 5: Balanced Band-Reject Combiner Schematic

A third problem concerns isolation. As noted above, each transmitter in the chain is isolated only by hybrid isolation of about 30 dB from its neighbors. This is radically lower than the 50 dB dictated by prudent specifications.

BALANCED BAND-PASS SYSTEMS

A system design that addresses all of these problems is the balanced band-pass network. Here, the band-reject filters shown in Figure 4 are replaced with filters that pass only the signals in the FM channel of the transmitter connected to that module. Referring to Figure 4, if the filters are tuned to pass Frequency A, and a transmitter operating on this frequency is connected to Port 1, the signal from this transmitter will split as before, pass straight through the filters, and combine in Port 4. In this system, a termination load is connected to Port 2, and will absorb any reflections from the filters at frequencies other than the pass frequency. Again, the transmitter is always presented with a constant impedance load.

A second transmitter operating on Frequency B is added to the system by simply adding another module, its filters tuned to pass Frequency B, and connecting Port 4 of this module to Port 3 of the first one. Here, the signal from the second transmitter on Frequency B exits Port 4 of the second module and enters Port 3 of the first. It then splits as before and heads for the filters tuned to pass Frequency A. There, because the filters are tuned to pass only Frequency A, it is reflected back and combined in Port 4 of the first module with Frequency A. A third frequency is added in exactly the same way as the second. Then a fourth, fifth and so on, as shown in Figure Six below.

Another transmitter may also be connected to Port 3 of the first module; however, it is good practice to leave that port available for the emergency connection of a transmitter in the unlikely event of failure of one of the modules in the sytem.

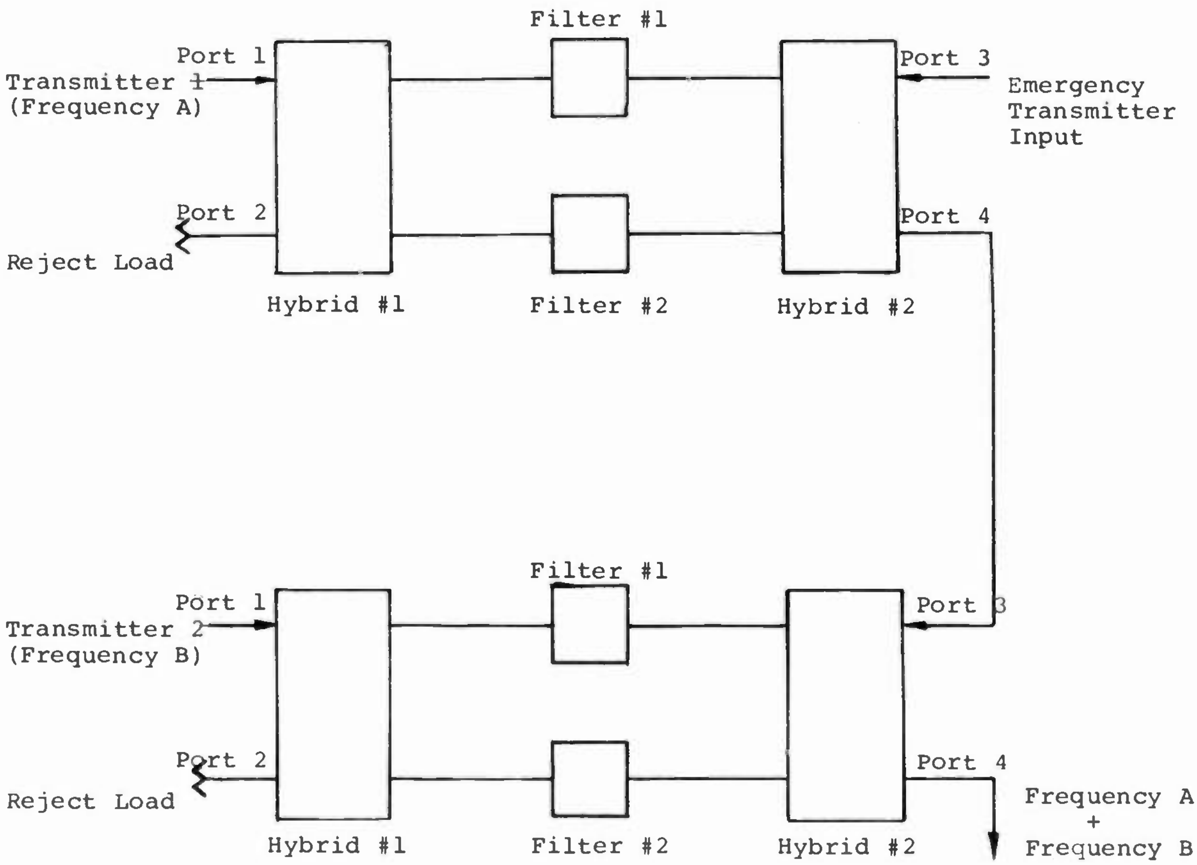


FIGURE 6: Balanced Band-Pass Combiner Schematic

It can be seen that here, the only networks that must handle the combined transmitter power are the module output hybrids and the output filter coupling structures in the first modules of the system.

Still another important advantage is that because the transmitters are band-pass filtered, any spurs or intermods from the transmitters will not pass through the filters. Instead, they will be reflected back and absorbed by the reject load connected to Port 2 of the transmitter input hybrid. This is not the case in a system implemented with band-reject style filters.

SYSTEMS IN THE FLESH

A couple of examples of a balanced band-pass combining system may be found at two shared facilities owned by the Guy Gannett Broadcasting Service in Miami and Orlando, Florida. These two systems were designed and built by Shively Labs in Bridgton, Maine.

At the Miami site, eight 20 kilowatt transmitters are combined to share a master antenna, with the possibility of a ninth one on the way. The Orlando site currently has three 30 kilowatt transmitters, with the capacity for a fourth.

Figure Seven is a photo of a model of the eight-channel system at Miami. Figure Eight is a scene in the combiner room of the transmitter facility.

These systems were carefully designed and built to offer a minimum of 50 dB isolation between transmitters, spaced as closely as 0.8 MHz. Even though the specification called for a rigorous 50 dB, the minimum observed was 58 dB, and that between channels only 800 kHz apart. The isolation of more widely-spaced channels ran 80 to 90 dB. Also, particular attention was paid to group delay difference in the FM channel. The specification called for the group delay to vary no more than 50 nanoseconds at any frequency plus and minus 150 kHz from carrier. This parameter was achieved or topped in every case. In fact, within plus or minus 100 kHz, delay differences were typically 30 to 35 nanoseconds, even in the case of channels spaced only 800 kHz apart. Insertion loss of each module in the system was 0.4 dB or less at carrier. The specification required frequency response parameters less than 1.0 dB at frequencies plus and minus 200 kHz from carrier. Measured values ranged from 0.08 dB to a maximum of 0.5 dB.

These impressive numbers insure a clear distortionless path from each transmitter in the system through the networks to the antenna.

The systems were implemented using large high power hybrid couplers in six and nine inch line at the output end of each module, with three inch couplers at each input. In order to meet the stringent design requirements for low insertion loss, symmetrical, low group delay difference in band and high isolation, very special filters were designed. The application called for natural-convection cooled four-pole modified Tchebyscheff band-pass networks. These units consisted of single four-pole assemblies, iris coupled for the required broad-band Hilbert transformation between resonators in the network to implement the Tchebyscheff design. The four-pole design was selected for the steep susceptance slopes it provides. This control is absolutely essential to meet the tight isolation limits for close-spaced frequencies. In addition, this design makes possible the extraordinary group delay difference performance.

They were fabricated with aluminum for light weight and minimum floor loading, good electrical characteristics and ease of construction. All networks in the system were built with EIA flanged transmission line. The system was also provided with patch panels, allowing any module in the network to be patched out of the system for any reason, while at the same time routing the transmitter of that module to the emergency input, Port 3, of the first module, to be back on the air in a matter of minutes.

Combining transmitters at a common site is certainly an effective way to reduce the cost of operating from a premium transmitter site. And, with balanced band-pass transmitter combining systems of the type just discussed, many years of clear, undistorted station performance can be insured and enjoyed.

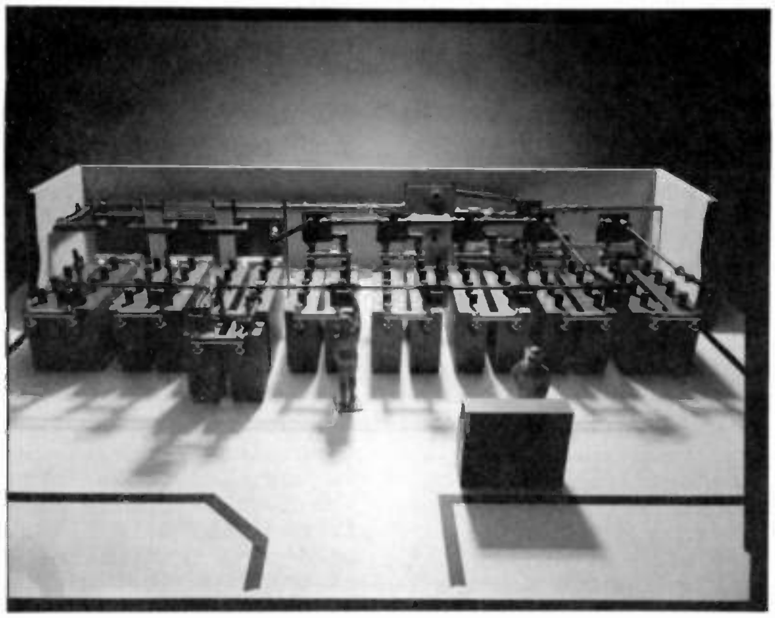


FIGURE 7: Model of Eight-Channel Combiner in Miami, Florida

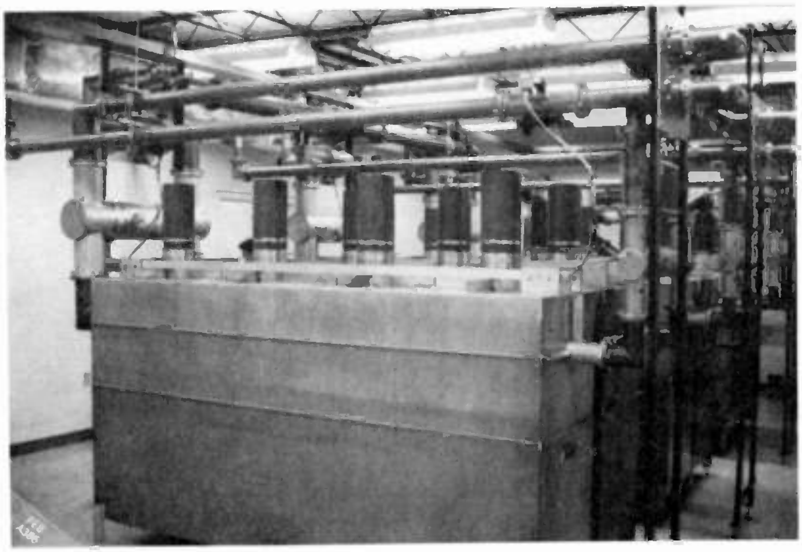


FIGURE 8: View of Combiner Room in Transmitter Facility

DESIGNING VOA ANTENNA SYSTEMS BASED ON BROADCAST AREA COVERAGE REQUIREMENTS

George Lane
Robert L. Everett
Office of Engineering and Technical Operations
Voice of America
Washington, District of Columbia

ABSTRACT

Under the current modernization of the Voice of America, new high frequency radio broadcast stations are being designed with the aid of computer simulation of the broadcast area coverage requirement. The procedure develops the power gain and beam illumination requirement of the broadcast antenna by working backwards from the language service area through the ionosphere to the transmit site. The long-term variations of the ionosphere, as well as the depth of the service area, provide the vertical width of the illumination window and its frequency dependence. A description of the process and the computer programs being used is provided.

INTRODUCTION

The Voice of America (VOA) is the International broadcasting arm of the United States Information Agency. As such it is one of the principal instruments of foreign diplomacy of the United States Government. The VOA currently broadcasts about 1000 program hours per week in 42 languages. Although the VOA operates some Medium Wave broadcasting stations, its principal mode of signal dissemination is via High Frequency (HF) broadcasting.

The VOA is currently undergoing a major modernization and expansion program. In this program, the number of VOA transmitting stations will be increased, and existing facilities upgraded and renovated. Some fourteen or more broadcast facilities of the VOA will operate in an integrated broadcast network providing over lapping coverage of up to sixty language regions around the world.

An integral part of the planning in preparation for the construction of a dynamic HF broadcasting network of worldwide proportions involves the generation of an orderly procedure for establishing the design requirements for the individual radio stations. These design procedures must be established so that a signal of a specified quality will be delivered to a language service area (audience) in a given part of the world, with a determined reliability.

BACKGROUND

MF vs. HF Broadcasting

HF broadcasting is a broadcasting technique considerably different than MW broadcasting. Its primary mode of signal delivery is by way of ionospheric wave propagation (Sky Waves), rather than the very reliable but distance limited mode of ground wave signal delivery most often used by MW radio transmitting stations. The great difficulty with the use of HF ionospheric wave propagation for signal delivery is due to its variability with the time of day of the broadcast, the season, and the state of solar activity during its eleven year cycle. One consequence of this variability is that different frequencies in the international broadcast bands must be used for transmissions. The choice of band for a given broadcast depends on the time the season, and the solar activity. Another consequence is that the signal attenuation between the transmitter and a given point in the signal delivery area is highly variable, depending on the state of the ionosphere.

The VOA is required to deliver reliable signals of high quality to the broadcast service areas. The planning of its transmitting stations must allow for each station to be equipped so that these signals can be delivered, through the expected variation of the ionosphere, during the entire useful life of the station.

Point-to-Point System Planning

An appreciation of the difficulty in the design of HF broadcasting stations can be gained in contrasting the point-to-point communication system case to the broadcasting case. The systematic design of HF point-to-point communication systems, is in itself, complicated, because each point-to-point communication path on the globe is unique. For a given hour, season and level of solar activity, an ideal frequency exists band for each circuit operation. This band is dependent, not only on the state of the ionosphere, but also on the specific locations of the transmit and receive points. At this ideal band, the path attenuation for the signal is the lowest possible. An increase of transmit frequency above this band puts one at the maximum usable frequency (MUF), above which ionospheric reflection rapidly fails, and the signal penetrates the ionosphere and goes off into space. Decreasing the frequency below this ideal band eventually puts one below the lowest useful frequency (LUF). Ionospheric absorption and higher noise levels below this frequency significantly reduces the reliability and quality of signal delivery of the transmission system involved. Thus, in the design of a point-to-point transmission system, one must specify the bands in which the communications link will be operated to achieve the required reliability, the antenna beam specifications at each band, and the transmitter power which will be necessary for operation in each band. If guaranteed signal delivery quality is demanded, the design specifications must meet the worst-case requirements to be encountered over the entire useful lifetime of the system.

Area Coverage Planning

The design of a transmitting station used for broadcast purposes is considerably more difficult than that of a point-to-point system. A language service area is an aggregate of points; with each path from the transmit site to all point within the service area having a unique ideal transmit frequency and a different path attenuation for the signal. If the service area is small and relatively close to the transmit site, there are few complications, and each point within the area may be effectively and reliably served by operation inside a given frequency band, for a given broadcast time, season and solar activity, using reasonable and economical transmitting equipment.

However, as the size of the service area, and its distance from the transmit site increase so do the complications of the analysis required to define its operating parameters and equipment requirements. Up to a certain size and distance from the transmit site, a single band may suffice for operational coverage of the area, for a given time, season and solar activity. However, this band will be a compromise, different than the ideal for any given point. The compromise frequency must be chosen with care so that the desired grade of signal delivery can be accomplished with reasonable and economical transmitting equipment. Over the useful life of the station a variety of transmit frequencies will have to be utilized, and, of course, the transmitting equipment must accommodate them.

The above picture is further complicated by increases in the area size and distance from the transmit point. This can be explained as follows. The behavior of the ionosphere is such that the closer points in the service area usually require the lower frequencies. To reach points farther out in the same coverage area normally one would like to use higher frequencies. However, if the spread of points is large, at certain distances, there may be no acceptable compromise band of operation which would use reasonable and economical transmitting equipment. This results because the lowest usable service band for the farther out points exceeds the MUF for the closer-in points.

In this case, service to the farther points can be accomplished by multiple-hop signal transmission. In this transmission mode, a signal is refracted from the ionosphere down to earth, reflected from the earth, and refracted again from the ionosphere down to the earth, etc., until the signal reaches the farther points of the service area. The steeper angle of incidence at the ionospheric layer for the multiple mode requires the use of the lower frequencies as it did for the close in points in the one hop portion of the service area. In this way it may happen that much of a large service area can be served by a single band, during a given time, season and sunspot activity, despite one part being served with a single-hop transmission, and another part with a two-hop transmission. However, there is a certain part of the area, between the one-hop and the two-hop areas, in which the signal is weak or distorted. Also, in this case, the transmission system requirements may be unreasonable. Often, there is no single compromise band for an entire service area, and multiple broadcast transmission systems are required, each operating on different frequencies.

VOA SYSTEM PLANNING

Approach

The VOA has implemented a system planning procedure which operates much along the lines of the preceding discussion. In this procedure, propagation conditions for the broadcast times, all seasons, and the extremes of sunspot activity are calculated for all the paths from a proposed transmit site to a large array of points describing the projected language service areas. From the data acquired from the propagation predictions, an orderly process of data reduction is pursued so that the worst-case equipment requirements and transmission parameters can be extracted from the broadcast hours over the entire useful lifetime of the broadcast station.

The VOA Test Point File

For the purpose of propagation prediction calculations, all of the VOA worldwide broadcast service areas are broken down into a set of discrete points. Within language areas of highly populated regions in the mid- and low latitude regions, the points are arranged in a more-or-less even grid of 2 degrees in latitude by 2 degrees in longitude; the periphery of the area is delineated with special. In the more sparsely populated regions in the higher latitudes, a coarser grid is used. This density of test points is selected because it represents spacing between test points for which the propagation conditions are semi-correlated. Thus, it can be reasonably expected that propagation conditions are, thereby, determined over the entire language service area with no unpleasant surprises to be discovered after system design and construction.

This layout of points allows for relatively accurate calculation of the width and depth of the language area, as seen from the various transmit sites under consideration. Test points in the interior of the area serve two purposes. One is to force the propagation model, which is a point-to-point model, to assess the ionospheric tilts that come into play when illuminating the area during the sunrise and sunset transition periods. The other is to allow for consideration of the demography of the area. For each test point in the VOA test point file, there is information with respect to the local population density, and a list of all the languages spoken around the test point. This test point file can be sorted and used to list the pertinent locations and demography of any language area to which the VOA broadcasts. It encompasses most of the populated part of the earth and is designed to supply input information to the radio propagation prediction model used by the VOA.

VOA Transmission Quality Standard

The VOA specifies that the minimum acceptable standard of transmission quality in an unjammed environment is a signal-to-noise ratio of 73 dB/Hz at the receiver input. This is a signal-to-noise ratio of 36 dB within the bandwidth of a typical short-wave receiver. The specified signal-to-noise ratio shall be attainable at a minimum of 90% of the language service area, at a minimum of 90% of the time.

VOA Radio Propagation Prediction

The VOA has selected and specified the Ionospheric Communications Analysis and Prediction (IONCAP) program[1/] as the model which must be used in the analyses and design of all VOA broadcast stations. This propagation prediction model is implemented in the form of a computer program, and is a product of the Institute for Telecommunication Sciences, of the National Telecommunications and Information Administration, under the U.S. Department of Commerce.

This program is used to calculate the ionospheric propagation modes, their takeoff angles associated transmission loss for each hour of the day, for the four seasons, and for the extremes of 10 and 120 in the International Smoothed Sunspot number. This program produces 1,728 transmit-to-test-point path predictions, and accounts for the diurnal, seasonal and solar cyclical variations expected to occur over the lifetime of the broadcast station. This program, used with the VOA Test Point File produces all of the information required to characterize propagation from a given transmit site to an entire language service area.

Most Reliable Mode Calculation

The IONCAP program computes the most reliable mode for a given hour, season, sunspot number and frequency band on a circuit specified by the location of the transmit site and the test point. The most reliable mode is defined as the mode (i.e. number of hops and the ionospheric layer concerned) having the highest probability of achieving the signal-to-noise ratio specified by the user of the program.

The IONCAP program defines the propagation probability and predicted performance parameters of a given transmission system. Thus important input system descriptors are the pattern of the receive antenna, that of the transmit antenna, and the power delivered to the transmit antenna by the transmitter.

Transmission Path Angles

The IONCAP computes the takeoff angle of the ray from the transmit site to the test point for the most reliable mode. In addition to this, it computes the azimuthal angles of the great circle routes between transmit and test point locations. A takeoff and azimuth angle pair are computed for each possible frequency band and at each hour of the broadcast.

The Receive Antenna

Any precise knowledge of the receive antennas used by the various worldwide VOA listeners cannot be realistically obtained. Therefore, for planning purposes the VOA uses a model of a typical receive antenna, a short monopole located above a small ground plane, located on the earth's surface. This antenna displays some vertical directivity, with half-power points at 6 and 55° above the horizon. This pattern is applied only for signal reception.

Noise Reception by the Receive Antenna

Noise pickup by the antenna is assumed to be integrated from all angles equally. Thus the signal-to-noise ratio at the receiver input is the same as the ambient ratio of field intensities in the reception area, with the exception that signals arriving at extremely low angles are be penalized by the directivity of the receive antenna. In IONCAP, noise calculations take into account man-made, atmospheric and galactic noise sources.

The System Planning Transmit Antenna

As a system planning tool, the VOA inputs to IONCAP the characteristics of the transmit antenna, which is defined as an isotropic radiator for all angles above 4°. At less than 4°, a cutback factor is applied to the isotropic pattern to effectively simulate the physical low-angle limitations of typical transmitting antennas the VOA is likely to use. For vertical beam takeoff angles of more than 4°, IONCAP with this input will select the least loss mode as the most reliable mode. The cutback factor at angles less than 4° penalizes modes requiring beam takeoff angles which are not efficiently excited by transmitting antennas available to the VOA.

The cut-back factors in the transmit and receive radiation patterns combine to force the transition between the one and two hop modes from the F_2 layer of the ionosphere to occur at ranges of 2600 to 3300 km. This is typical of HF broadcast system performance.

Required Power Gain

The required power gain is the gain, expressed in dB, required relative to the system specified an the input to the IONCAP program. This is the gain needed to achieve the required signal-to-noise ratio with an hourly circuit reliability of 90%. The customary parameters used as input to the IONCAP program during system planning activities are the isotropic transmit antenna, as previously specified, and a 500 kW transmitter, with a -1.5 dB loss factor applied to take into account typical transmission line losses. The usual interpretation of the required power gain expressed by IONCAP is in terms of antenna gain requirements, given constant transmitter power of 500 kW. Each computed required power gain value has an associated most probable mode, takeoff and azimuth angle pair, frequency, hour, month and sunspot number.

The Best Frequency Band Selection Algorithm

In order to enforce minimum power requirements needed to achieve the design goal, it is necessary to assume that the system is operated at the best frequency band. In the case of a point-to-point communication circuit, it is simple to determine the best frequency band, because it corresponds to the frequency having the lowest computed required power gain. For area coverage which consists of a number of point-to-point calculations, the frequency selection process is one of compromise.

Ideally, one would examine the required power gains for each hour and point in the listening area, and select all the of frequencies which meet or exceed the signal-to-noise requirement. From this set of possible frequencies, one would find the subset of usable frequencies which are common to all of the test points at the hour, season and sunspot number. The common frequency or the highest common frequency would represent the best frequency band for broadcasting under the prescribed conditions.

In reality, and especially during the sunrise and sunset transition periods, no single frequency is found which satisfies the design goal over all of the test points in the listening area. Therefore, a best frequency selection algorithm is needed which finds the best frequency under the ideal conditions, and which minimizes the gain requirement for the majority of the listening area when less than ideal conditions prevail.

The VOA procedure is to find the test point, which during a given hour, season and sunspot number, is the hardest to satisfy, even when the best frequency for that point is used. The required power gain needed to satisfy this point, at its best frequency is recorded. This is called the minimum worst-case value. The other eight frequency lists of required power gains for all points are surveyed and eliminated if the hardest to reach point in each frequency list exceeds the minimum worst-case value by more than 6 dB. Thus, the candidate best frequencies are all of those which are within 6 dB of the hardest to reach point, at its best frequency.

Again, the required gain values for the candidate frequency bands are checked against the value of the of the minimum worst-case power gain. Any value which is less than 6 dB below the minimum worst-case power gain is readjusted to exactly 6 dB less than that of the minimum worst-case power gain. This is done so that when the required power gains are summed, a single point having a very low required power gain does not weigh heavily in the frequency selection process.

For each of the remaining candidate frequencies, the adjusted required power gains to all of the test points in a given hour, season and sunspot number are summed. The frequency having the lowest sum is the best frequency band, as defined by the VOA. If a tie occurs, the highest frequency band is selected.

In spite of its apparent complexity, the above process is simply a way to pick a frequency band that will cover the area well, without denying reception to any one or set of points in the service area. The path requirements for the selected best frequency bands define the gains which the transmit antenna must satisfy.

Transmit Antenna Design

The functional design requirements of the transmit antenna are the minimum required antenna power gain and the illumination window i.e., vertical and horizontal angles) through which the required antenna gain must be obtained. From the above described propagation information, these antenna design parameters can be computed for the worst case extremes over a twenty plus year lifetime of the system. The basic process involves running IONCAP, as described, for all the paths between the transmit point and all of the language test points, for the expected broadcast hours, four seasons, 9 possible frequency bands, and the sunspot extremes. The best frequency algorithm is then applied. What is left, at the best frequency band, is information about the required system power gain, with associated vertical and horizontal ray path angles, for the effective coverage of every test point within the language service area, for each hour of broadcast, for the four seasons and the two sunspot numbers. This data can be displayed to give the radiation flux and the angles over which it is required to fulfill the broadcast requirements assuming the use of the best frequency band at each broadcast hour. The required power flux and its associated angles are called the beam illumination requirements.

The required power gain data is arranged in arrays for each of the best frequencies. Each best frequency array has the required power gain values, the associated most reliable mode, elevation and azimuthal angles for each test point in the language service area. These arrays provide the beam illumination requirements at each of the best frequency bands. The arrays contain all of the required power gains needed to satisfy the signal-to-noise requirements at every point in the language service area. They may contain data for one or more hours, seasons or sunspot numbers. The beam illumination requirements for the lowest and the highest frequency bands are the more reliable requirements, since only the extremes of sunspot numbers are used in the propagation analyses. Intermediate frequency bands may have sparse or no data, if that band was not selected by the best frequency algorithm. This does not necessarily mean that the intermediate frequencies are not needed. In fact, they probably are needed during intermediate periods in the solar cycle.

Some of the required system power gains in these arrays can be extremely high, since one frequency, albeit the best for the area, does not reach all points equally well. In order to arrive at an achievable system design, the required power gain value is relaxed to the value that will satisfy the design goal on 90% of the path-hours, where path-hours are the product of the number of broadcast hours, the 4 seasons, 2 sunspot numbers and the number of test points in the language service area. The relaxed gain value is arrived at by selecting the upper decile of the entire population of required power gains for all of the best frequencies. The ten percent of the required power gains that exceed the upper decile value are reduced to this value.

The minimum acceptable antenna design, according to the VOA design procedure, is taken to be this (upper decile) system power gain, effective over all of the angles, vertical and horizontal identified in the above procedure. This requires that the antenna be capable of providing the specified minimum acceptable gain at the required elevation and azimuthal angles from the lowest to the highest of the identified frequency bands. Such an antenna will satisfy the VOA Engineering Standard for the signal level requirements.

DESIGN APPLICATIONS

IONSUM

The VOA, in conjunction with the Institute for Telecommunication Sciences, has prepared a computer program, called IONSUM (IONCAP Summary Program). This program is a computerized implementation of the design methodology described in the preceding section. It formats the voluminous IONCAP output into easy to use tables and charts. The program is user friendly, in that it allows the user to interact easily with the large IONCAP files. The input functions are as follows:

1) Select the proper IONCAP files for the transmit site and language service area;

2) Select the subset of points in the reception area to be serviced by the antenna. These points will be used in the best frequency band algorithm;

3) Place points in the spill-over region. This is optional and points in the spill-over region will not affect the best frequency selection process. The spill-over is used for difficult reception areas where mode splitting may occur;

4) Input the time blocks (hours) of the broadcast;

5) Set the list of frequency bands to be considered.

The output tables which IONSUM produces are as follows:

1) Table of Circuit geometry (great circle route distances and azimuths);

2) Table of required power gain as a function of elevation angle and frequency for all broadcast hours, seasons and sunspot numbers;

3) As above, except for each broadcast hour;

4) Table of the Best Frequency Bands, selected for each time block, season and sunspot number;

5) Table of the Most Reliable Modes by test point (showing total distribution of mode selection and angle range by mode);

6) Table of Occurrence of Required Elevation Angles and Frequencies for all hours, seasons and sunspot numbers;

7) Table of Circuits Having the Highest Required Power Gain by time block, season and sunspot number;

8) Table of the Highest Required Power Gain by hour, season and sunspot number;

9) Tables for each Best Frequency Band, showing required power gain as a function of elevation and azimuth angle;

10) A similar set of tables for the spill-over region if that option was chosen.

EXAMPLE DESIGN

In the design of the new VOA broadcast station south of Tangier, Morocco, it is desired to provide broadcasts to the Hungarian-speaking population of Europe. In the VOA test point file, there are 10 test points designating the location of these people. Nine of the points are in Hungary, and one is in central Romania. The nine points in Hungary are placed in the main reception area, and the one point in Romania is placed in the spill-over region for IONSUM.

The main coverage region is found to fall between 47 degrees and 54 degrees East of True North, as seen from Tangier. The distance requirements are ranges from 2244 km to 2746 km, while the point in Romania is 2900 km, at 55 degrees from True North.

The required power needed to illuminate Hungary on 90% of all path hours is found to be 9 dBi (dB relative to an isotropic source). The elevation angles range from a minimum of 2 to a maximum of 14 degrees above the horizon, with an azimuthal extent of 7 degrees. This gain is needed on frequency bands ranging from 6 to 21 MHz. For 97 % of all path-hours considered, the one hop (1F2) mode is the most reliable. The occurrence of modes is such that 96 percent of the path-hours are predicted to require elevation angles from 4 to 10 degrees, with 42% of the occurrences in the 6-7 degree range.

The antenna design requirement to provide at least 9 dBi from 4 to 10 degrees above the horizon and across 7 degrees of azimuth seems modest. However, from the highest required power gain it is shown that the post-dawn hours of the summer months in low sunspot years require an additional gain of 10 to 14 dBi at 7 degrees above the horizon. Also, the point in Romania, having some 3 million Hungarian speaking residents requires an antenna gain of 21 dBi from 2 to 3 degrees above the horizon and at an azimuth angle of 55 degrees. Radiation at these angles is predicted to provide coverage into the spill-over region on 76% of the hours. Post-dawn and pre-sunset hours (the remaining 24% of the hours)are almost exclusively 2 hop with elevation angles ranging from 14 to 20 degrees.

Taking these points from the IONSUM analysis into account, the optimum antenna at Tangier for coverage of the Hungarian service area is deemed to be one having a main beam gain of 23 dBi at 7 degrees above the horizon, with vertical quarter-power points at plus and minus 4 degrees about this angle. The main beam axis should be at 52 degrees from True North, to favor the harder to reach points in Hungary and Romania. The beamwidth in the horizontal plane should be plus and minus 7 degrees between quarter power points. The antenna system must be operable from 6 to 21 MHz. For the main region of Hungary, an antenna of this gain should permit a reduction in transmitter power from the assumed 500 kW to 100 kW. However, during periods of jamming or for daytime broadcast requirements, the use of the full 500 kW from a variable power transmitter would be quite advantageous.

DISCUSSION AND CONCLUSIONS

The process consisting of simulation of the receiver system use of IONCAP and interpretation from IONSUM, allows VOA engineers to establish the long-term beam illumination requirements for a particular language service area. The beam illumination requirement in terms of gain values, elevation angles and azimuth angles for the lowest and highest frequency bands is used to select an appropriate antenna design. Due to the nature of program scheduling, it may be desirable to combine several language illumination requirements when specifying an antenna design and its beam slewing capacity.

The technique in its present form is a more detailed procedure than previously used by VOA; however, it is not a radical departure from the manual process. The IONSUM program provides the beam illumination requirement that will satisfy the modernization goals over 90% language service area on 90% of the broadcast hours. The technique is based on a statistically large sampling of the broadcast hours in the two years representing the extremes of solar activity, on a sufficiently large number of point-to-point paths in the area to be covered such that the adjacent paths are semi-correlated. The resultant beam illumination requirement is essentially the 11 year "window" that must be satisfied by the transmit antenna for that language service area.

Several areas of improvement in the VOA design procedure are being considered. It is desired to know what the hourly broadcast illumination windows are so that slewable beam antennas can be effectively used in the VOA network. Also improvements need to be made in the prediction model to account for ionospheric anomalies near the equator and in polar regions.

REFERENCES

1/ Teters, L.R., J.L. Lloyd, G.W. Haydon and D.L. Lucas, "Estimating the Performance of Telecommunication Systems using the Ionospheric Transmission Channel Ionospheric Communication Analysis and Predication Program User's Manual", NTIA Report 83-127, July 1983.

SIDEBAND ANALYSIS OF MEDIUM WAVE BROADCAST ANTENNA SYSTEMS

Jerry M. Westberg
Harris Corporation/Broadcast Group
Quincy, Illinois

Most AM directional stations are concerned with improving the quality of the sound received by their listening audience. Although there are several factors which may contribute to an AM directional station achieving a high quality sound, common point impedance bandwidth and sideband pattern bandwidth are among the most significant. This paper will give results of computer analysis done on different power dividers connected to antenna systems of different sensitivity. Alternate phasing schemes will be investigated for optimum common point and pattern bandwidth. The following analyses will show that the common point impedance bandwidth and the sideband pattern bandwidth may be significantly improved by a properly designed phasing system.

Common point impedance bandwidth may be defined as the amount of change in the common point impedance as the frequency is varied from the carrier frequency. Under ideal conditions when a transmitter is modulated 100% with a sine wave, one sixth of the transmitted power is delivered to each sideband. If the loading impedance at the plate of the transmitter changes greatly as the frequency varies from the carrier, the transmitter will not deliver the required power to each sideband. This results in the high audio frequency components being attenuated. On a receiver the station will sound dull, lacking both brilliance and crispness.

If the loading impedance at the plate of the transmitter is asymmetric, the transmitter will deliver more power into one sideband than the other. This will result in a distorted audio signal. VSWR at the 10 kHz sidebands was chosen as a measure of common point impedance bandwidth.

Sideband pattern bandwidth may be defined as the amount of change seen in the antenna pattern as the frequency varies from carrier. (1 MHz is the carrier frequency for all analyses.)

If the patterns produced at the sideband frequencies varies greatly from the carrier pattern, the received carrier and sideband power may not be in the proper proportion. The listener will hear a distorted signal. This is generally referred to as null talk because the effect is usually greatest in the null area. The Pearson product moment r was chosen as a measure of correlation between 10 kHz sideband and carrier patterns. To correlate patterns a sample of field was taken every 10 degrees in the horizontal plane.

Four power dividers were analyzed while connected to 50 ohm resistances. Figure 1 shows schematic drawings of each of these power dividers circuits. The VSWR at the sideband frequencies can be found in Table 1. Also included is the adjustability of each network. Adjustability is defined as the amount of degree change in current phase when changing the power adjustment to produce a current magnitude change of 1%, and the percent change in current magnitude when changing the phase adjustment to produce a current phase change of one degree. The power and phase adjustment components are specified on Figure 1. Maximum adjustability is achieved when: 1. there is no change in current phase when changing the power adjustment and 2. there is no change in current magnitude when changing the phase adjustment.

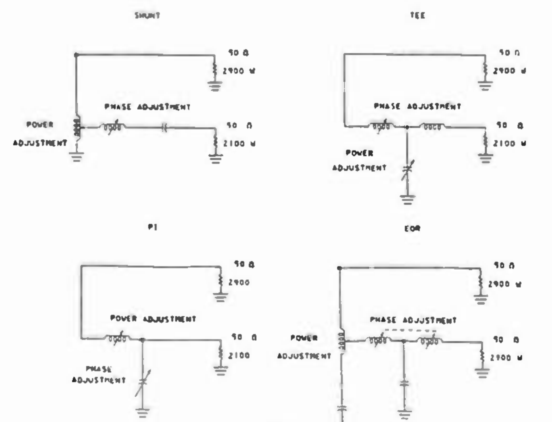


FIGURE 1

Table 1 is a summary of the analysis. It should be noted that some power dividers may perform differently with different power distributions. For example, the shunt power divider will have very little or no change in phase when the power division is such that the tap falls in the center of the divider coil. The power division of 2900W and 2100W was chosen to compare these results with the results of the same dividers operating in a directional antenna system.

POWER DIVIDER	VSWR AT 10 kHz SIDEBAND FREQUENCY	CHANGE IN CURRENT PHASE FOR 1% CHANGE IN CURRENT MAGNITUDE	CHANGE IN CURRENT MAGNITUDE FOR 1° CHANGE IN CURRENT PHASE
SHUNT	1.0081:1	1°	.25%
*EOR	1.0066:1	0°	.044%
PI	1.0087:1	.57°	.0018%
TEE	1.0087:1	.58°	.02%

* EQUAL AND OPPOSITE REACTANCE.

TABLE 1

All of the above power dividers have exceptional impedance bandwidth. The EOR power divider has the best adjustability while the shunt divider did not perform as well in this category. It should be noted that in the field a power divider is not connected to 50 ohm resistors, but to antennas that change impedance when adjustments in current phase or magnitude are made. The following analysis points out this fact.

A shunt divider and an EOR divider were analyzed while connected to a phasing system and tower array model. The power distribution is the same as in the previous analysis. The results of the adjustability analysis can be found in Table 2.

POWER DIVIDER	CHANGE IN CURRENT PHASE FOR 1% CHANGE IN CURRENT MAGNITUDE	CHANGE IN CURRENT MAGNITUDE FOR 1° CHANGE IN CURRENT PHASE
SHUNT	.5°	.8%
EOR	.6°	1.75%

TABLE 2

It can be seen that although the EOR power divider showed superior adjustability into 50 ohm resistors it is not necessarily true that the divider will perform better under normal field conditions. By varying the phasing design using an EOR or shunt power divider the adjustability characteristics will change. The above analysis assumes the transmission lines are matched. Under normal field tuning this is generally not the case.

The ratio between the root-sum-square (RSS) and the root-mean-square (RMS) gives a good indication of the common point and pattern bandwidth to be expected from an antenna system. Arrays with low RSS/RMS ratios (less than 1.2) tend to have good common point and pattern bandwidth. Arrays with large RSS/RMS ratios (above 1.5) have tendencies to exhibit poor common point and pattern bandwidth.

Table 3 shows the antenna design parameters of an array with an RSS/RMS of .91.

TOWER	HEIGHT	FIELD	PHASE	SPACING	ORIENTATION
1	90°	1	0°	0°	0°
2	90°	1.433	135.6°	165°	0°
3	90°	1.934	274.°	330°	0°

TABLE 3

Phasors were designed for this array employing 5 different power divider types. Figures 2-6 (See Page 3) show the schematic drawings of these designs.

Each design was analyzed to determine the VSWR at the 10 kHz sideband frequencies. A correlation was run between the patterns at the 10 kHz sideband frequencies and the pattern at the carrier frequency. The results of this analysis are summarized in Table 4.

POWER DIVIDER	VSWR (1.0:1 BEING IDEAL)	CORRELATION COEFFICIENT (1.0 BEING IDEAL)	
		-10 kHz	+10 kHz
EOR	1.07:1	.9974	.9976
SERIES	1.12:1	.9976	.9975
SHUNT	1.12:1	.9962	.9965
TEE	1.12:1	.9993	.9992
PI	1.08:1	.9994	.9991

TABLE 4

The results of the analysis show only slight differences in common point and pattern bandwidth using different phasor designs. All designs have excellent common point and pattern bandwidth.

Table 5 shows the antenna design parameters of an array with an RSS/RMS of 2.2.

TOWER	HEIGHT	FIELD	PHASE	SPACING	ORIENTATION
1	90°	1	145°	0°	0°
2	90°	2	0°	60°	0°
3	90°	1	-145°	120°	0°

TABLE 5

Phasors were designed employing the 5 different types of power dividers. Figures 7-11 (See Pages 3 & 4) show the schematic drawings of these designs. An analysis was done on each design. The results are found in Table 6.

POWER DIVIDER	VSWR (1.0:1 BEING IDEAL)		CORRELATION COEFFICIENT (1.0 BEING IDEAL)	
	+10 kHz	-10 kHz	-10 kHz	+10 kHz
EOR	1.89:1	1.68:1	.998	.9999
SERIES	1.22:1	4.05:1	.987	.113
SHUNT	1.25:1	3.45:1	.996	.464
TEE	1.28:1	2.96:1	.996	.876
PI	1.39:1	3.08:1	.996	.879

TABLE 6

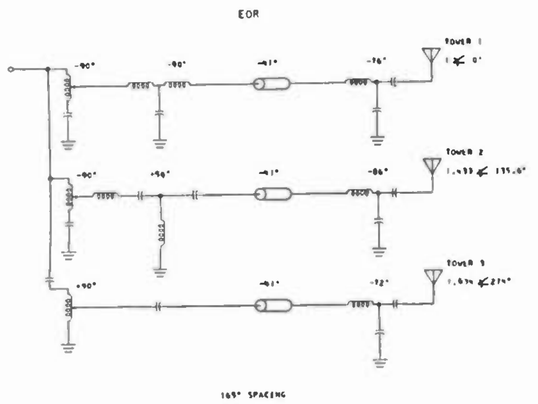


FIGURE 2

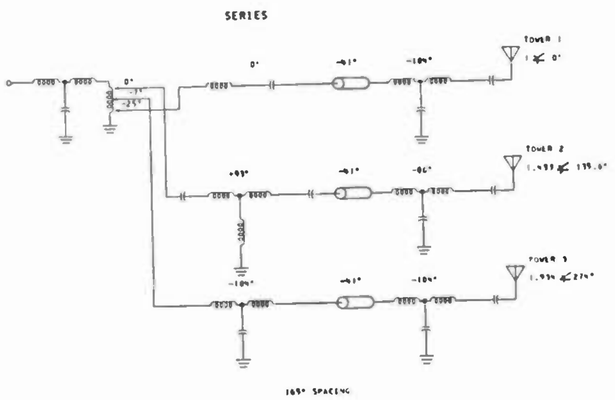


FIGURE 3

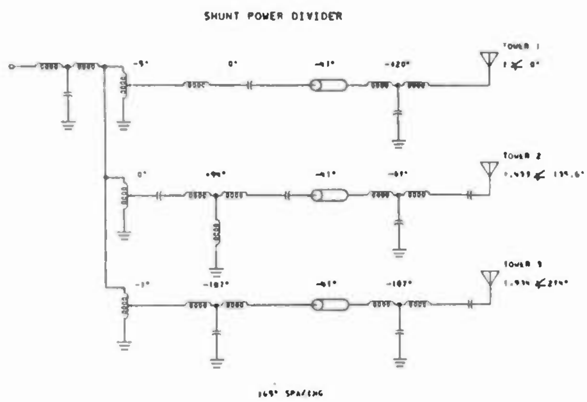


FIGURE 4

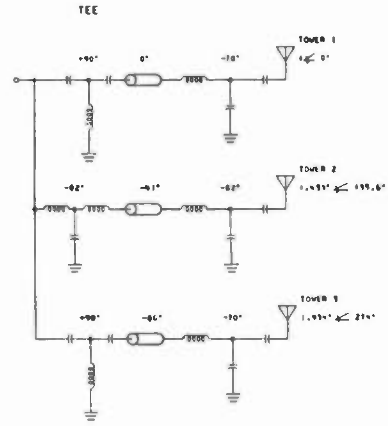


FIGURE 5

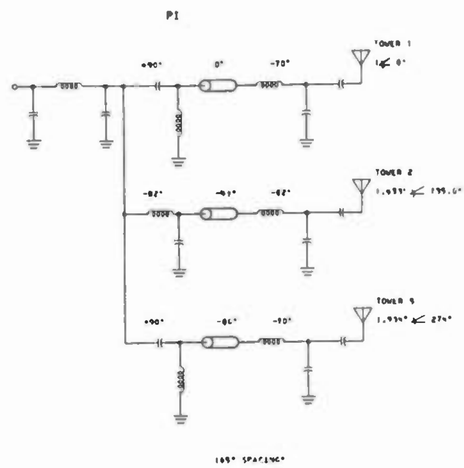


FIGURE 6

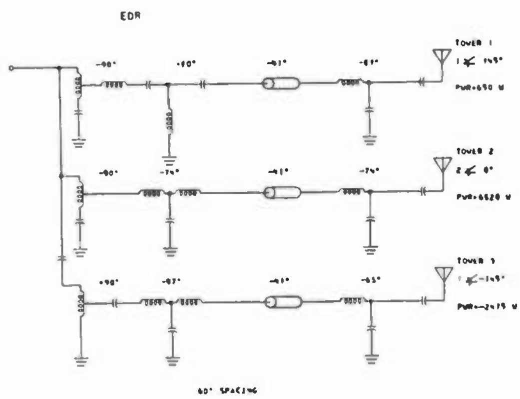


FIGURE 7

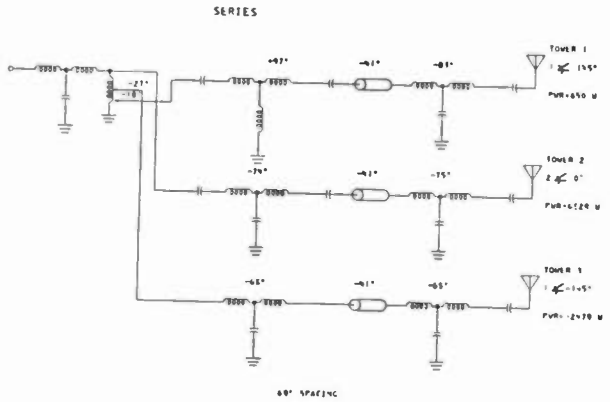


FIGURE 8

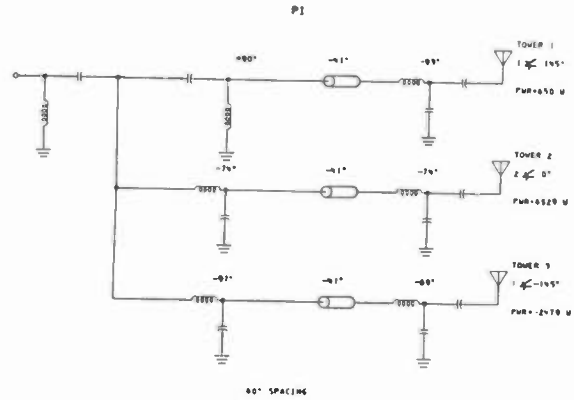


FIGURE 11

Different phasor designs for this antenna system produce very different common point and pattern bandwidths. All designs exhibit poor common point impedance symmetry with the exception of the design employing the EOR divider. The 10 kHz sideband patterns for the above designs can be found in Figures 12-16. All designs show poor correlation between sideband and carrier patterns on the upper sideband except for the design using the EOR divider. To explain this phenomenon the properties of a quarter wavelength transmission line will be examined.

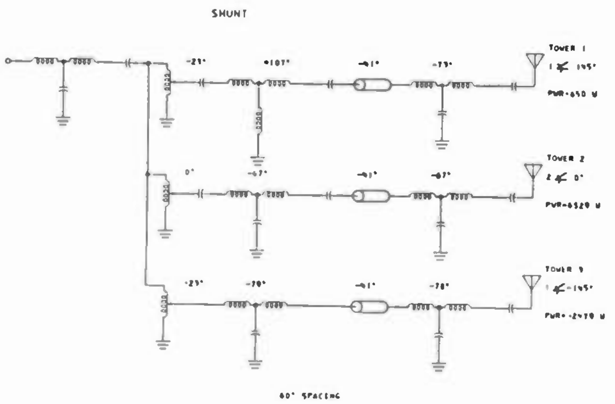


FIGURE 9

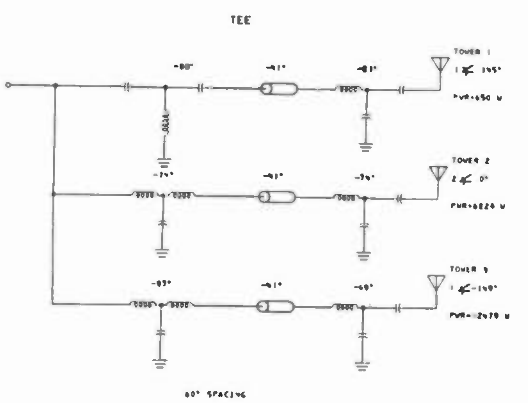


FIGURE 10

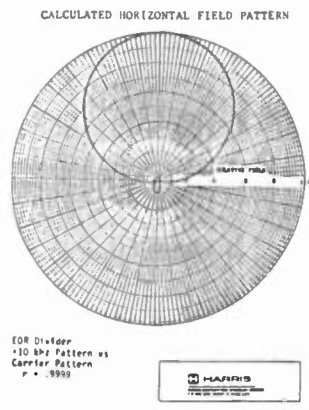


FIGURE 12A

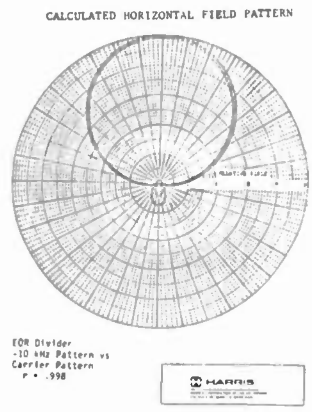


FIGURE 12B

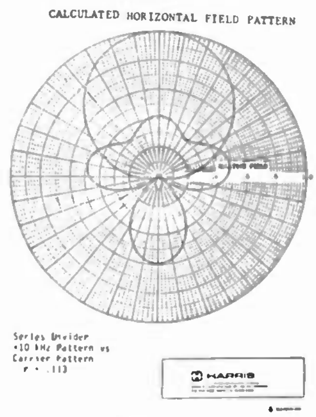


FIGURE 13A

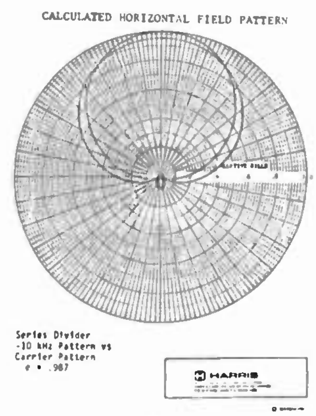


FIGURE 13B

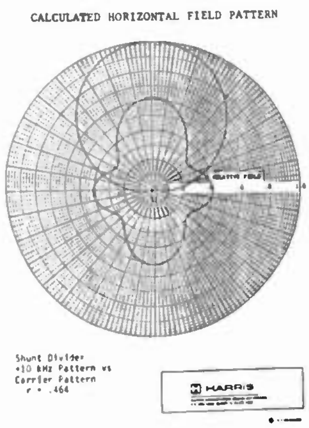


FIGURE 14A

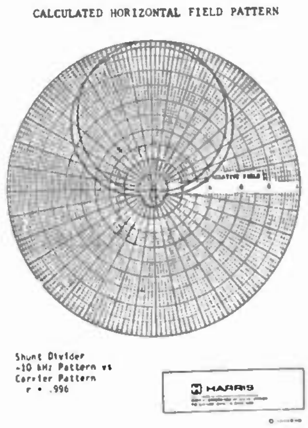


FIGURE 14B

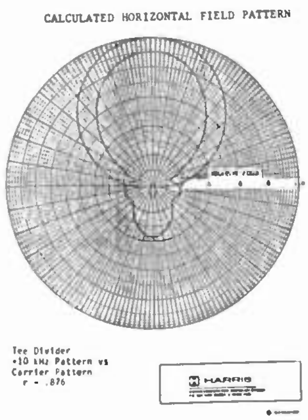


FIGURE 15A

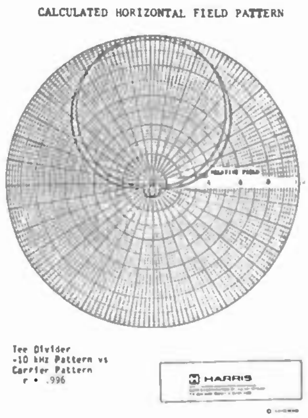


FIGURE 15B

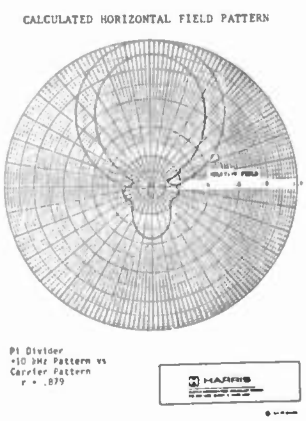


FIGURE 16A

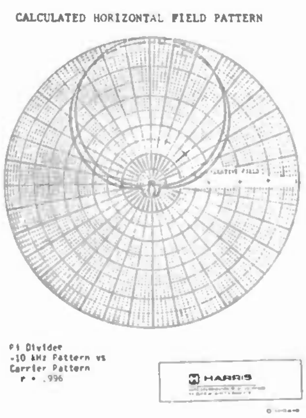


FIGURE 16B

Figure 17 below shows a quarter wavelength transmission line loaded with its characteristic impedance Z_o.

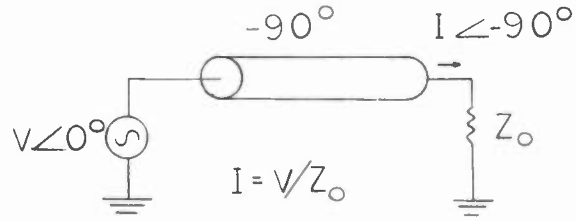


FIGURE 17

When loaded in this way the output current lags the input voltage by 90°.

Figure 18 shows a quarter wavelength transmission line loaded with an unknown impedance.

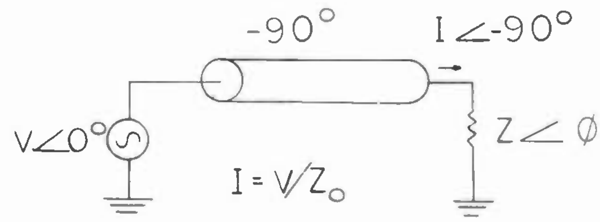


FIGURE 18

Although the load impedance is unknown, the current magnitude 'I' and the phase shift of -90° was preserved. This is not the case for transmission lines that differ from lengths of an odd multiple of 90° (i.e. 90°, 270°, 450°, etc.).

For simplicity a 180° transmission line is studied to demonstrate this point.

Figure 19 shows a half wavelength transmission line loaded with its characteristic impedance.

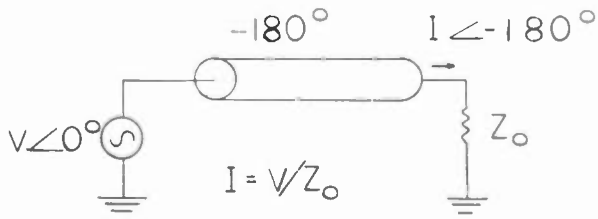


FIGURE 19

When loaded with its characteristic impedance the current phase going into the load lags the input voltage phase by 180°.

This is not the case when the 180° transmission line is loaded with an unknown impedance.

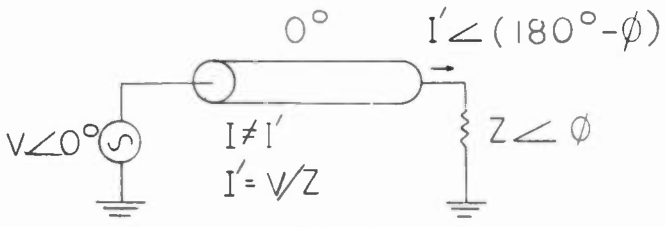


FIGURE 20

For a 180° transmission line the phase of the current going into a load is dependent on the phase of the impedance of the load. The current magnitude is dependent on the magnitude of the unknown impedance. For transmission lines of length other than odd multiples of 90° the magnitude and phase of the current going into a load is typically different than the magnitude and phase of the current entering a load of Z_o.

Consider the antenna system described in Table 5. Tower 2 contributes more than the other towers in forming the pattern. Tower 2 has more power and radiates more field than towers 1 or 3. If the current going into tower 2 was fixed at the sideband frequencies, the patterns at the sideband frequencies will have a tendency to correlate more favorably with the pattern at the carrier frequency.

It was noted earlier that the design employing the EOR power divider gave far greater sideband pattern correlation than the other dividers. The phase shift from the branch point of the phasor to tower 2 is -279° which is very close to an odd multiple of 90°. All other designs did not have this characteristic.

As the frequency varies from the carrier frequency, the impedance of all the towers change. In the case of the EOR design, the current going into tower 2 relative to the voltage at the branch point of the phasor will change little.

Table 7 is the result of the analysis done on three alternate designs. The first two employ a shunt and tee power divider rephased so the phase shift from the branch point to tower 2 is an odd multiple of 90°.

The third design uses an EOR power divider with the sum of the phase shifts from the branch point to tower 2 being 0°.

POWER DIVIDER	VSWR (1.0:1 BEING IDEAL)		CORRELATION COEFFICIENT (1.0 BEING IDEAL)	
	+10 kHz	-10 kHz	-10 kHz	+10 kHz
PROPERLY PHASED SHUNT	1.83:1	1.86:1	.9993	.9983
PROPERLY PHASED TEE	1.71:1	1.75:1	.9995	.9985
POORLY PHASED EOR	1.35:1	3.65:1	.995	.677

TABLE 7

As the above data suggest, for this antenna system high correlation between sideband patterns and the carrier pattern could be achieved using any of the five mentioned power divider schemes if proper phasing is employed. On the other hand, poor sideband and carrier pattern correlation could also result from any of the dividers if phased incorrectly. Pattern bandwidth is a function of the total antenna system. Phasing and matching networks, power divider scheme, and the transmission line size and type can all contribute to or detract from good pattern bandwidth. Figures 21-23 show the pattern plots at the 10 kHz sideband frequencies of the above designs.

For this antenna system it is desirable and practical to rephase the feeder system to improve the correlation between sideband and carrier patterns.

However, this is not always the case. Although quadrature phasing a tower may have significant results as in the previous example, there are many antenna systems where rephasing will not produce the desired results.

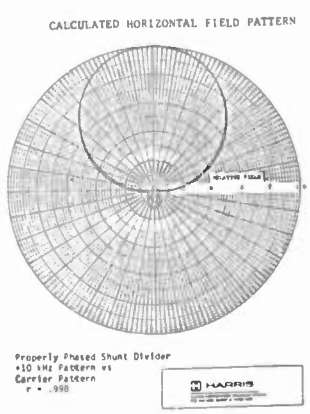


FIGURE 21A

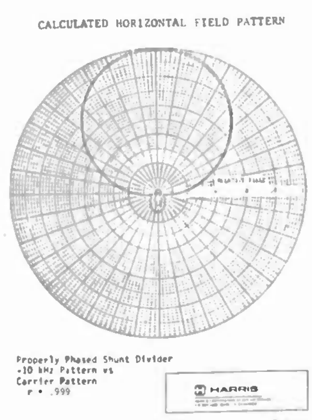
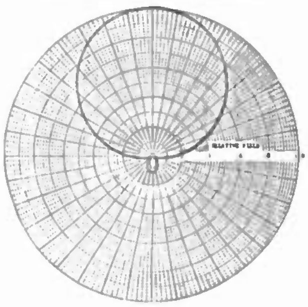


FIGURE 21B

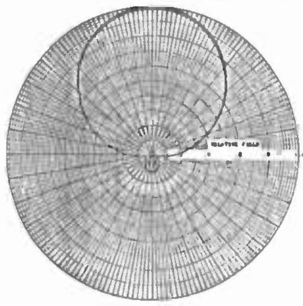
CALCULATED HORIZONTAL FIELD PATTERN



Properly Phased Tee Divider
+10 kHz Pattern vs
Carrier Pattern
r = .9985

FIGURE 22A

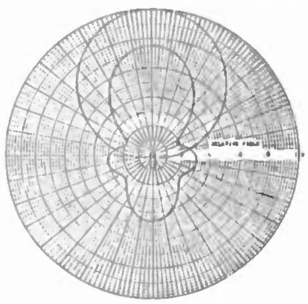
CALCULATED HORIZONTAL FIELD PATTERN



Properly Phased Tee Divider
-10 kHz Pattern vs
Carrier Pattern
r = .9995

FIGURE 22B

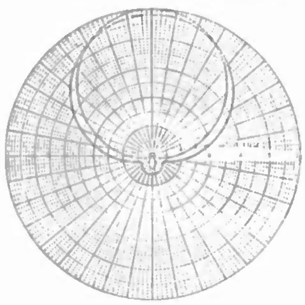
CALCULATED HORIZONTAL FIELD PATTERN



Poorly Phased EOR Divider
+10 kHz Pattern vs
Carrier Pattern
r = .677

FIGURE 23A

CALCULATED HORIZONTAL FIELD PATTERN



Poorly Phased EOR Divider
-10 kHz Pattern vs
Carrier Pattern
r = .995

FIGURE 23B

Table 8 shows the antenna design parameters of an array with an RSS/RMS of 2.43.

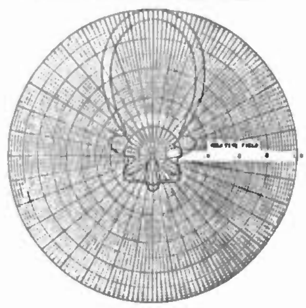
TOWER	HEIGHT	FIELD	PHASE	SPACING	ORIENTATION
1	90°	1	0°	0°	0°
2	90°	2.56	-159°	90°	0°
3	90°	3.22	45°	180°	0°
4	90°	2.44	-114°	270°	0°

TABLE 8

Although the RSS/RMS of above array is close to the RSS/RMS of the array described in Table 5 there is no one dominant tower controlling the pattern. Towers 2 and 3 radiate the most field and are the high power towers. Only one tower can be phased so that the phase shift from the branch point to that tower is an odd multiple of 90°.

Figure 24 shows the sideband pattern plots when the phase shift from the branch point to tower 2 is an odd multiple of 90°. The pattern at -10 kHz shows fair correlation to the carrier pattern. The pattern at +10 kHz has two unwanted deep nulls and the main lobe is smaller than that of the carrier pattern.

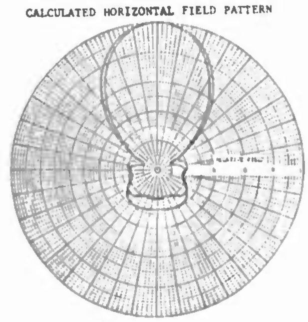
CALCULATED HORIZONTAL FIELD PATTERN



Tower 2 Phased 90°
+10 kHz Pattern vs
Carrier Pattern
r = .953

FIGURE 24A

CALCULATED HORIZONTAL FIELD PATTERN

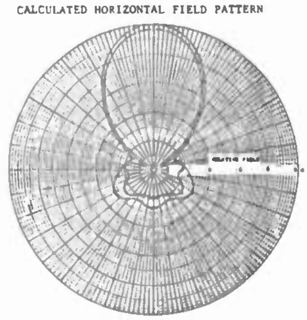


Tower 2 Phased 90°
-10 kHz Pattern vs
Carrier Pattern
r = .987

FIGURE 24B

Figure 25 is the pattern plots of the 10 kHz sideband frequencies when tower 3 is quadrature phased. For this solution the -10 kHz pattern showed poor correlation while the +10 kHz pattern gave fair correlation.

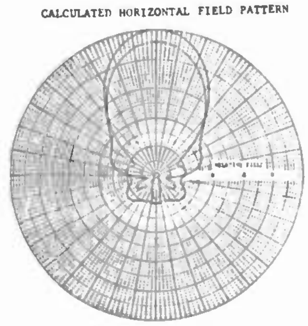
CALCULATED HORIZONTAL FIELD PATTERN



Tower 3 Phased 90°
+10 kHz Pattern vs
Carrier Pattern
r = .976

FIGURE 25A

CALCULATED HORIZONTAL FIELD PATTERN



Tower 3 Phased 90°
-10 kHz Pattern vs
Carrier Pattern
r = .938

FIGURE 25B

Another factor to be considered is how sensitive the sideband patterns are to misadjustment and seasonal variation. When the phase from the branch point to each tower was changed as little as 2°, there was significant changes in the sideband patterns.

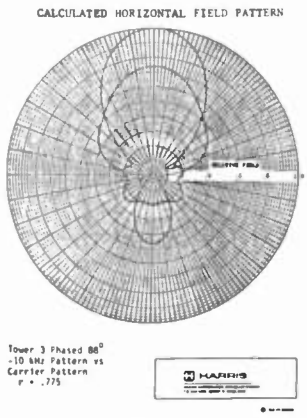


FIGURE 26A

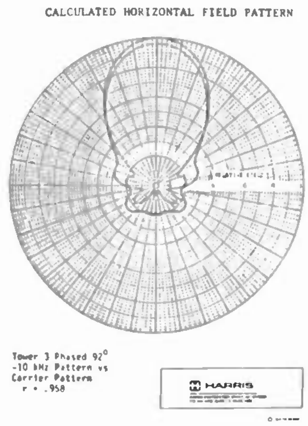


FIGURE 26B

Figure 26 shows the -10 kHz sideband patterns when the phase shift from the branch point to tower 3 is 88° and 92°. These plots can be compared to Figure 25B. The plots show how rapidly the sideband patterns are changing with only slight adjustments in the phasing system.

This is not the case for the antenna system described in Table 5. Figure 12 shows sideband pattern plots of the EOR divider design. As mentioned earlier the phase shift from the branch point to tower 2 in the EOR divider design is 9° different from an odd multiple of 90°. The sideband patterns vary slowly as changes are made in the phasing system.

Another approach to designing a phasing system for good pattern bandwidth is to begin by finding the ideal sideband field and operating parameters. The problem of designing for good pattern bandwidth will become more visible by using this approach. Also, each set of networks between the branch point of the phasor design to a tower can now be analyzed separately. Adjustments can then be made for each tower run separately before analyzing the system. For the previous example, this can be done by decomposing the pattern into its three pattern pairs. If the pattern is such that it will not decompose into pattern pairs, using the carrier field ratios as the field ratios for the sidebands is a good approximation.

Table 9 shows the three pairs for the array described in table 8.

PAIR	PHASE	FIELD	SPACING
1	-161.1	1.5	90°
2	138.2	1.3	90°
3	-91.1	1.3	90°

TABLE 9

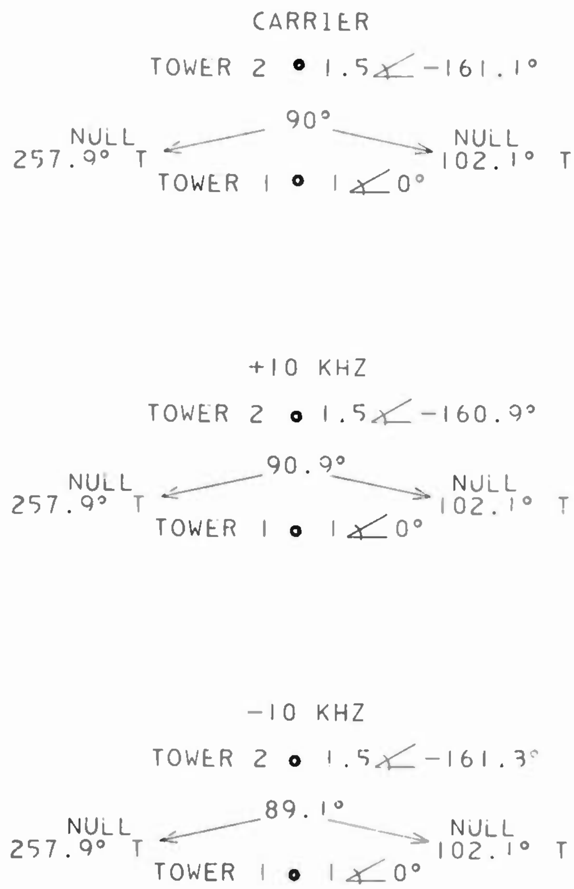


FIGURE 27

Figure 27 is a diagram of the first pair. The nulls for the first pair are at 102.1° T and 257.9° T. To maintain the nulls in the same direction as the frequency is changed, the phase of the pattern pair must also be adjusted. Table 10 shows the desired pattern pairs for ± 10 KHz.

FREQUENCY	FIELD	PHASE	SPACING
-10KHz	1.5	-161.3°	89.1°
CARRIER	1.5	-161.3°	90°
+10KHz	1.5	-160.9°	90.9°

TABLE 10

If this process is repeated for each of the three pattern pairs of Table 9, the desired field parameters can be constructed at the sideband frequencies.

Table 11 gives the reconstructed field parameters at the carrier and sideband frequencies along with the predicted operating parameters. Also included is the VSWR's of each tower's drive point impedance.

-10 KHz

TOWER	HEIGHT	PHASE	FIELD	SPACE
1	89.1	0.000	1.000	0.000
2	89.1	200.810	2.587	89.100
3	89.1	44.513	3.260	178.200
4	89.1	245.340	2.441	267.300

TOWER	BASE R	BASE X	CURRENT	VOLTAGE	POWER	VSWR
1	17.227	46.583	6.058	300.880	632.215	1.32:1
2	8.201	61.381	15.670	970.418	2013.804	1.89:1
3	4.330	86.892	19.749	1718.189	1688.862	4.00:1
4	3.043	82.404	14.785	1219.185	665.119	5.72:1

CARRIER

TOWER	HEIGHT	PHASE	FIELD	SPACE
1	90	0.000	1.000	0.000
2	90	201.000	2.560	90.000
3	90	45.000	3.220	180.000
4	90	246.000	2.440	270.000

TOWER	BASE R	BASE X	CURRENT	VOLTAGE	POWER	VSWR
1	18.238	51.399	5.857	319.453	625.731	1.0:1
2	8.588	66.823	14.995	1010.250	1931.097	1.0:1
3	4.688	93.645	18.861	1768.434	1667.672	1.0:1
4	3.797	89.069	14.292	1274.130	775.500	1.0:1

+ 10 KHz

TOWER	HEIGHT	PHASE	FIELD	SPACE
1	90.9	0.000	1.000	0.000
2	90.9	201.176	2.534	90.900
3	90.9	45.473	3.181	181.800
4	90.9	246.660	2.441	272.700

TOWER	BASE R	BASE X	CURRENT	VOLTAGE	POWER	VSWR
1	19.282	55.370	5.662	331.986	618.207	1.24:1
2	8.995	71.425	14.347	1032.833	1851.565	1.68:1
3	5.067	99.623	18.010	1796.530	1643.622	3.20:1
4	4.642	94.955	13.819	1313.797	886.605	3.74:1

TABLE 11

It should be noted that towers 3 and 4 have drive point impedances that are changing very rapidly. Recall that only one tower may be quadriture phased.

Also recall that the desired current magnitude and phase will be delivered only to the quadriture phased tower independent of tower impedance. However, quadriture phasing any one of these towers could not be expected to compensate for the rapidly changing impedances of the other three towers. This is why satisfactory results were not obtained by quadriture phasing towers 2 or 3 previously.

Recall that the field ratio of each pattern pair could be inverted and still produce the desired pattern. For the above problem, there are eight sets of field parameters that will yield the desired pattern.

Table 12 gives one of the eight alternate sets of field and operating parameters along with the associated sideband parameters.

-10 KHz

TOWER	HEIGHT	PHASE	FIELD	SPACE
1	89.1	0.000	1.000	0.000
2	89.1	201.803	1.756	89.100
3	89.1	45.324	2.354	178.200
4	89.1	245.340	1.086	267.300

TOWER	BASE R	BASE X	CURRENT	VOLTAGE	POWER	VSWR
1	22.986	41.594	9.081	431.551	1895.444	1.22:1
2	-0.372	73.132	15.943	1165.961	-94.522	232.00:1
3	11.791	82.890	21.377	1789.747	5387.838	1.69:1
4	-22.498	90.358	9.863	918.441	-2188.759	1.40:1

CARRIER

TOWER	HEIGHT	PHASE	FIELD	SPACE
1	90.	0.000	1.000	0.000
2	90.	202.008	1.729	90.000
3	90.	45.811	2.336	180.000
4	90.	246.000	1.086	270.000

TOWER	BASE R	BASE X	CURRENT	VOLTAGE	POWER	VSWR
1	24.112	46.235	8.779	457.764	1858.217	1.0:1
2	-0.484	79.225	15.181	1202.742	-111.479	1.0:1
3	12.588	89.295	20.511	1849.594	5295.756	1.0:1
4	-22.461	97.957	9.536	958.359	-2042.495	1.0:1

+ 10KHz

TOWER	HEIGHT	PHASE	FIELD	SPACE
1	90.9	0.000	1.000	0.000
2	90.9	202.194	1.703	90.900
3	90.9	46.289	2.319	181.800
4	90.9	246.660	1.086	272.700

TOWER	BASE R	BASE X	CURRENT	VOLTAGE	POWER	VSWR
1	25.283	50.020	8.488	475.716	1821.446	1.17:1
2	-0.619	84.518	14.452	1221.505	-129.326	106.40:1
3	13.444	94.898	19.681	1886.317	5207.472	1.54:1

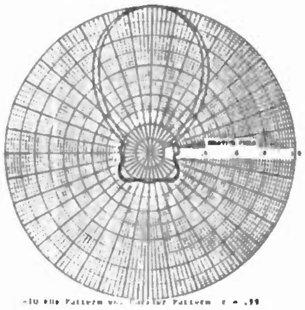
TABLE 12

The impedance of tower 2 changes extremely rapidly as the frequency is varied from the carrier frequency. The VSWR at the sideband frequencies are 232.0:1 and 106.4:1.

However, the impedances of towers 1, 3, and 4 change relatively slow. If tower 2 was quadriture phased, the rapidly changing impedances will be compensated for by this network; thus delivering the proper current, magnitude and phase to the tower independent of tower impedance changes. The other 3 towers will receive current magnitudes and phases close to the desired since the VSWR is low on the networks going to those towers. A phasor was designed employing these principles.

Figure 28 shows the pattern plot at the 10 KHz sideband frequencies. This plot shows high correlation between carrier and sideband patterns.

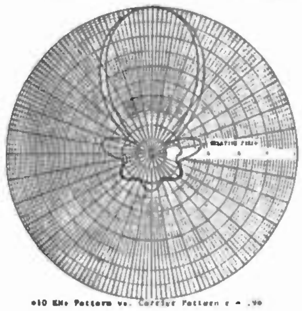
CALCULATED HORIZONTAL FIELD PATTERN



-10 KHz Pattern vs. Carrier Pattern r = .99

Figure 28A

CALCULATED HORIZONTAL FIELD PATTERN



+10 KHz Pattern vs. Carrier Pattern r = .96

Figure 28B

CONCLUSIONS

There are three concepts that can be concluded from this study.

The first is that the performance of a power divider scheme is dependent on the entire antenna system. Transmission line lengths and types, antenna coupling circuitry, phase shifters and array operating parameters all affect the adjustability of a power dividing scheme. A power divider may exhibit different characteristics into 50 ohm resistors than into an antenna system.

Second, pattern bandwidth is a function of the phasing and matching system. By changing phasor designs different sideband pattern characteristics can be expected.

Third, high correlation between carrier and sideband patterns can be achieved in many antenna systems by carefully designing the phasing and matching system. There are two design techniques described in this paper to aid in designing phasing equipment for higher correlation between carrier and sideband patterns. The first is to quadrature phase one of the towers in the array. This technique will allow little change between the ratio of branch point voltage and base current in a tower. This will tend to increase the correlation between carrier and sideband patterns. Secondly, it is desirable to look at the desired operating parameters at the carrier and sideband frequencies. This technique, many times, will make the problem of designing a phasor for good pattern bandwidth more visible. Each set of networks between the branch point of the phasor design to a tower can be analyzed separately. A phasing system can then be designed based on the analysis of these data.

REDUCING RERADIATION AND PATTERN DISTURBANCES OF AM BROADCAST SIGNALS CAUSED BY POWER LINES

C.W. Trueman
S.J. Kubina
Concordia University
Montreal, Canada

ABSTRACT

This paper reviews computer-based tools and techniques for the assessment of the distortion of an AM broadcast antenna's pattern by reradiation from a steel-tower power line. "Detuning" to suppress that reradiation and so restore the station's pattern is discussed, by the method of isolating selected towers from the overhead skywire. A comprehensive case study is presented, comparing computer predictions with full-scale measurements of the azimuth pattern and of the RF current flowing on the bases of the power line towers, for a directional antenna operating at 680 kHz. It is shown that the computer model is helpful in evaluating the magnitude of a reradiation problem, in designing "detuning" for the power line, and in assessing the reduction in the reradiated field to be expected when that detuning is installed.

INTRODUCTION

In recent years computer modelling has been helpful in assessing the distortion of an AM broadcast array's pattern by reradiation of the station's signal from a steel tower power line(1). Computer programs have been used to predict the pattern distortion to be expected from a power line proposed for construction(2), from a power line which has already been built and is suspected of being a reradiator, and in designing and assessing the effectiveness of "detuning" to suppress the reradiation from a power line(3). Reference (4) is a survey of the available literature on reradiation, both from power lines and from other structures, such as free-standing towers, or buildings. This paper briefly reviews the use of computer modelling for the prediction of reradiation from a power line, and for the suppression of reradiation by isolating towers from the skywire. The methods described here are presented in more detail in Reference (5).

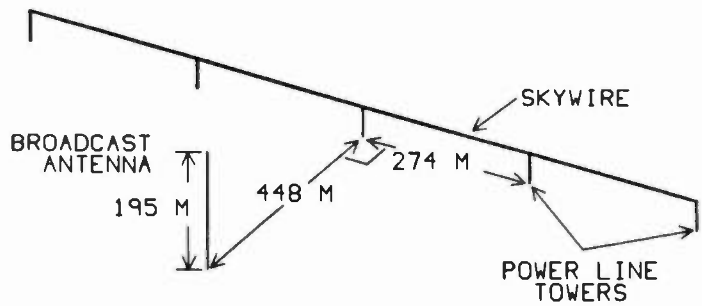


Fig. 1 Straight power line illuminated by an omnidirectional broadcast antenna.

RESONANT BEHAVIOUR

The configuration of Fig. 1 has been used to investigate the resonant behaviour of power lines. A straight power line with uniformly-spaced towers 50.9 m tall and 274 m apart is situated 448 m from an omni-directional broadcast antenna. The power line is resonant when the closed-loop path which includes two adjacent towers, the interconnecting skywire, and their images in ground, is close to an integer multiple of the wavelength. For the line of Fig. 1, the path length is 4x50.9 + 2x274 = 751.6 m, which is one free-space wavelength at 400 kHz, two at 800 kHz, and three at 1200 kHz, and the power line is expected to show resonant response near these frequencies. The antenna of Fig. 1 would have a uniform or "omnidirectional" azimuth pattern in the absence of the power line, but reradiation from the power line introduces lobes where the scattered signal from the power line adds to the broadcast antenna's field, and minima where the scattered field tends to cancel the antenna's field. It is convenient to quantify the amount of reradiation in the azimuth pattern as the ratio of the largest field strength to the smallest, in dB, called the max-to-min ratio. Fig. 2 shows the measured frequency dependence from 300 to 1400 kHz, obtained with a 600 scale factor model of the power line of Fig. 1, with 13 towers, operating over highly-conductive ground(Refs. 6,7). The graph shows three distinct resonance regions, in which the max-to-min ratio takes on values as large as 15 dB, due to minima in the pattern, indicating poor coverage over parts of the service area. The first resonance, termed "one-wavelength loop resonance" occurs between about 400 and about 520 kHz, when the closed-loop path described above is roughly equal to one wavelength. The measured response has three distinct peaks in this frequency range. "Two-wavelength loop resonance" is seen from about 780 to about 1000 kHz. In this range the measured data is incomplete. "Three-wavelength loop resonance" is seen from about 1100 to about 1400 kHz. Power lines of span length and tower height different from that of Fig. 1 would display resonance at frequencies different from those of Fig. 2, but a similar one-, two-, and three-wavelength loop resonance response would be expected.

A simple, useful estimate of the frequencies of resonance is given by

$$f_n = \frac{1.08\ n\ c}{\text{loop path length}} \qquad (1)$$

where "c" is the free-space speed of light, and n is the number of wavelengths which roughly "fit" the loop length at the resonant frequency. With the path length equal to about 752 m, Eqn. 1 estimates the resonant frequencies at about 430, 860 and 1290 kHz, which is in reasonable agreement with the measured data of Fig. 2. A useful, rough estimate for the bandwidth of resonance is that resonance extends from about 60 kHz below the resonant frequency of Eqn. (1), to about 60 kHz above that frequency.

COMPUTER PROGRAMS

The Numerical Electromagnetics Code (NEC,8) gives the user precise control over the details of the model used to represent the power line tower, but requires a large computer system such as a Cyber 835 to analyse a power line with a realistic number of towers, say 30 or more. NEC has been used extensively with quite simple representations of the power line towers, such as that of Fig. 3. Fig. 2 compares the performance of such a NEC model against the measured pattern data, and shows that the model predicts the fine structure of the response in the one-wavelength resonance frequency range quite well, and traces out a narrower peak than the measurement in the two-wavelength resonance range. However, the NEC model predicts

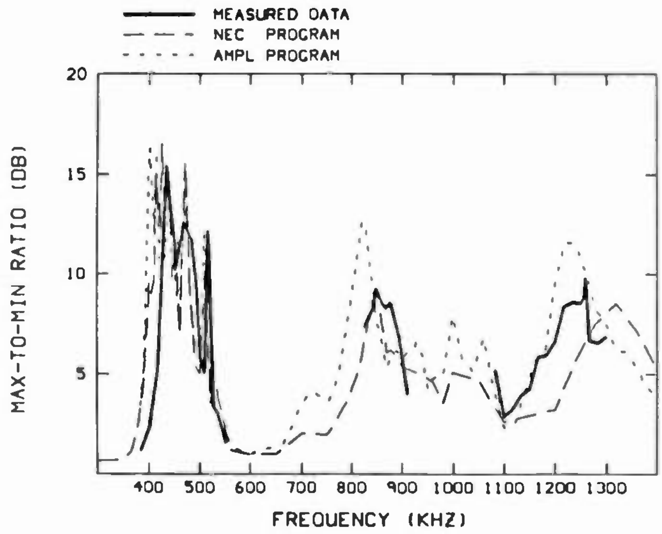


Fig. 2 Max-to-min ratio of the azimuth pattern of the omnidirectional antenna operating near the straight power line of Fig. 1, with 13 towers.

three-wavelength loop resonance centered around about 1300 kHz, whereas the measurement model shows resonance centered at 1200 kHz. Thus the NEC model tends to be poorer toward the top of the frequency range of interest.

The AM Power Line program (AMPL,9) uses transmission-line theory to model the power line, and can be run on a "personal computer". The FORTRAN version of the program uses about 10 minutes of CPU time with 25 towers, using an IBM-PC with an 8087 math coprocessor. Fig. 2 compares the performance of the AMPL model against NEC and the measured data. AMPL predicts resonance at frequencies which are somewhat low in the one- and two-wavelength loop resonance regions, but predicts the frequency of three-wavelength loop resonance much better than does the NEC model. With no ground losses, AMPL tends to predict a larger response than does NEC or the measurement model. Thus AMPL appears to be closer to the measurements toward the top of the frequency range of interest.

GROUND CONDUCTIVITY

The actual conductivity of ground usually lies in the 5 to 20 millimho/metre range, with a relative permittivity of about 15. The effect of less-than-perfect or non-infinite ground conductivity is to introduce losses into the resonant loop path, due to dissipation of energy in the ground. Thus ground conductivity "damps" the resonant response shown in Fig. 2, so that, although the frequency of resonance remains about the same as with "perfect"

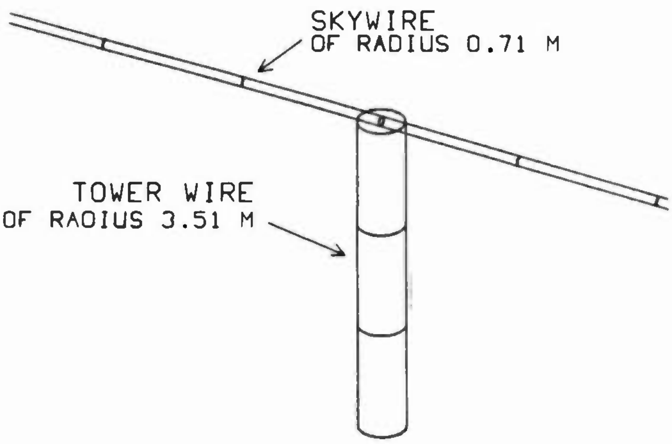


Fig. 3 Computer model of a power line tower connected to an overhead skywire.

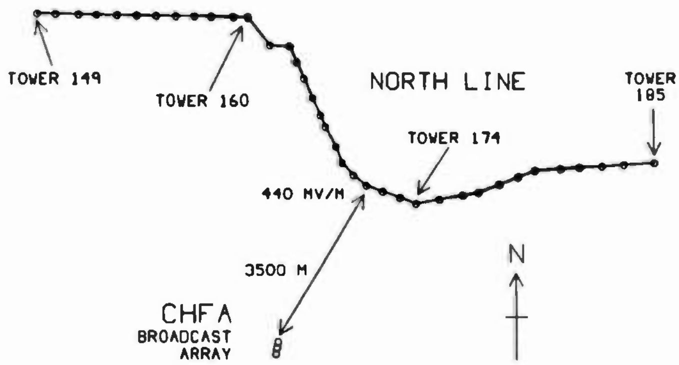


Fig. 4 The CHFA directional array and the "north" power line.

ground, the magnitude of the RF current flow on the power line towers is reduced, and so the magnitude of the reradiated field is also reduced. The most economical means for including losses due to ground conductivity in the computer model is to include a lumped "footing impedance" at the base of each tower(10,11). The footing impedance usually amounts to about 10 ohms resistive plus 5 ohms reactive at the base of each power line tower. It is shown below that inclusion of the "footing impedance" at the base of each power line tower considerably improves the agreement of computer model predictions with full-scale measurements.

INITIAL ASSESSMENT

Fig. 4 shows the directional CHFA broadcast array operating at 680 kHz, situated near the "north" power line, and will be used as a "case study" to illustrate the application of computer modelling to reradiation from steel-tower power lines. When a power line is first proposed for construction, the line is specified by its route and a "nominal" or average value for the height of the towers and for the distance between towers or "span length". To use a computer model to evaluate the power line as a potential reradiator, precise tower positions are required, and are simply not available at this stage. Ref. (2) discusses this "initial assessment" problem. Unfortunately, resonance of the individual spans of the power line is strongly dependent on the lengths of the spans, for which only a "nominal" value is given. On real power lines, the span length is usually quite variable. The prediction of the amount of reradiation to be expected tends to amount to the prediction of how many resonant spans the power line is likely to have.

If a span is taken to be "resonant" if its frequency of resonance lies within 60 kHz of CHFA's operating frequency of 680 kHz, then using the "nominal" span length of 363 and "nominal"tower height of 32.6 m for the "north" line, Eqn. 1 can be used to calculate that spans from 372 to 457 m are "resonant", with a span of length 411 m being resonant exactly at 680 kHz. It was demonstrated in Ref. (2) that the distribution of span lengths is well approximated by a "normal" or "Gaussian" probability distribution with standard deviation 46 m. The "normal" distribution model can be used to estimate the fraction of the spans which are likely to lie in the resonance range from 372 to 457 m in length, by the methods of Ref. (2). Thus evaluating Eqn. (2) of Ref. (2) indicates that the probability that any individual span on the "north" line is resonant is about 40 percent, and so, on a length of 20 spans, there are likely to be on the average 8 resonant spans. Table 1 uses Eqn. (5) of Ref. (2) to estimate the probability that at least "k" of the spans are resonant on the 20 span segment. Thus there will almost certainly be several resonant spans, but it is not likely that there will be more than 14 resonant spans on a 20 span segment of the power line.

To estimate how strong the reradiated field is likely to be when there are "k" resonant spans, it is necessary to do a computation of the reradiated field strength from one resonant-length span located at a distance of 3500 m from the CHFA antenna, being the closest approach of the power line to the array. Accordingly, a computer file describing the CHFA array, and a power line of one 411 m span centred on the position of tower # 171 in Fig. 4, was set up. The CHFA-plus-span configuration was analysed with AMPL to determine the largest possible scattered field from

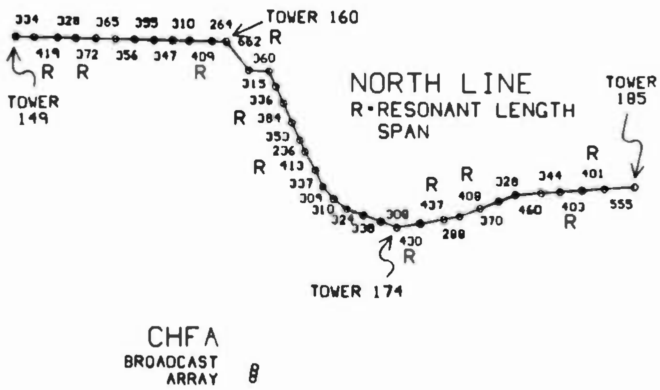


Fig. 5 Diagram showing the actual span lengths on the as-built north line. Spans from 372 to 457 m in length are estimated to be "two-wavelength" resonant at 680 kHz, and are marked with "R".

the span, which was found to be about 35 mV/m at one mile. The R.M.S. level of the scattered field pattern was estimated to be about 23 mV/m. Ref. (2) uses this data to estimate the value of the reradiated field from the whole power line according to

$$E_{net} = \sqrt{k} \; E_{RMS}$$

and results in the field strengths in mV/m at one mile given in Table 1. The table compares the probability of having at least k resonant spans with the likely value of the reradiated field from k resonant spans, and shows that there is a high probability of as many as 7 resonant spans, with a reradiated field of 62 mV/m, but not a very high probability of, say, 12 resonant spans with a reradiated field of 81 mV/m. The station's protection requirement is at a level of about 17 mV/m and hence an estimated reradiated field strength of as much as 62 mV/m is serious cause for concern. Below it is shown that for the "as-built" power line, there are about 5 resonant spans in the 20 spans closest to the antenna, but the reradiated field strength predicted by the computer model is about 115 mV/m.

At the "initial assessment" stage it is sometimes useful to set up a computer model of a power line with perfectly evenly-spaced towers, and analyse it for the given mean span length, and for the nearest resonant value of span length, to obtain sample radiation patterns. Thus if all the spans are of resonant length, it would be expected that a "worst case" pattern would result. Also, as described in Ref. (2), it is possible to carry out a computer simulation involving the construction of "sample" power lines following the

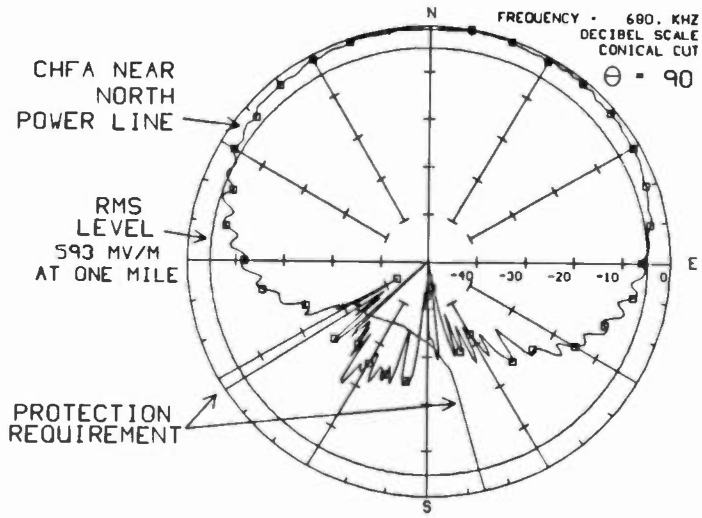


Fig. 6 (a) Azimuth pattern of the CHFA array operating near the "north" power line.

TABLE 1

For a power line with 20 spans, of mean span 363 m, and standard deviation 46 m, this Table estimates how likely it is that there will be at least k resonant spans, and how strong the reradiated field is likely to be from k resonant spans.

Number of Resonant Spans k	Probability that at least k out of 20 spans are resonant	Estimated Reradiated Field from k resonant spans
1	99.99 %	23 mV/m
2	99.95	33
3	99.7	40
4	98.5	47
5	95.1	52
6	87.8	57
7	75.5	62
8	59.1	66
9	41.1	70
10	25.0	74
11	13.1	77
12	5.9	81
13	2.2	84
14	0.7	87

given route, with randomly-chosen span lengths which conform to the given statistics for mean span length and standard deviation. By analysing a set of, say, 40 such power lines, the possible changes in the radiation pattern that the power line might give rise to can be explored. Generally, some patterns will be "good" with little reradiation, some will be "terrible" with high reradiation, and most will reflect the figures of Table 1. Thus, such a study would serve to confirm the rough

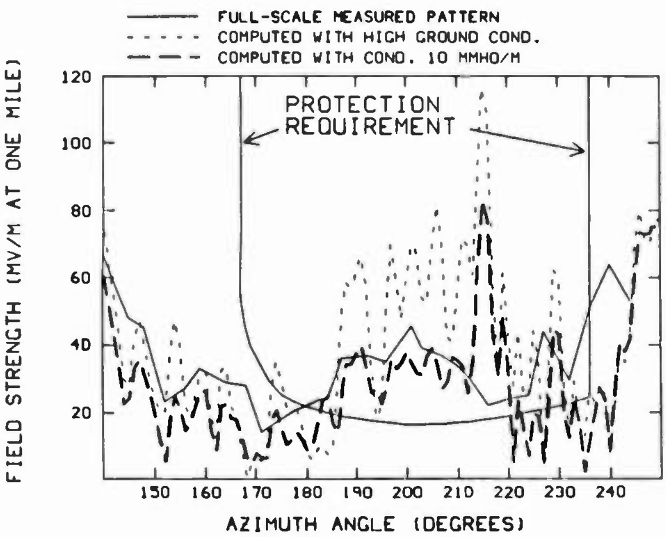


Fig. 6 (b) Field strength in the pattern minimum in comparison with the protection requirement.

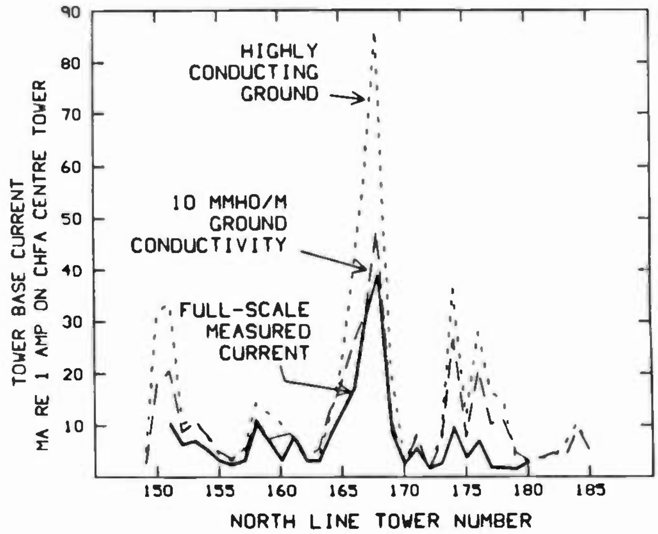


Fig. 7 Comparison of the measured and computed RF current flow on the bases of the towers of the "north" power line.

estimate of Table 1, and to "flesh out" its details more fully.

Once an "initial assessment" has alerted the broadcaster to a potential problem, the pattern of the antenna before the power line is built should be measured as closely as possible. Then, after the power line is built, a further pattern measurement shows the extent of the changes in the pattern. The computer model can help to pinpoint the towers on the power line responsible for those changes.

AS-BUILT POWER LINE

After the power line has actually been constructed, the precise tower positions can be obtained from the hydro utility. For CHFA, the tower positions and hence the span lengths were determined from maps supplied by Trans-Alta(Ref. 12), and are shown in Fig. 5. The power line design can now be inspected for resonant spans. As discussed above, spans of length 372 to 457 m are "two-wavelength" loop resonant within 60 kHz of CHFA's frequency of 680 kHz, and so might respond to CHFA's signal with large currents on the power line towers. Fig. 5 has such spans marked with an "R". The span from tower 160 to tower 161 is especially long, and is "one-wavelength" loop resonant at 680 kHz. Spans 164-165, 167-168, 175-176, and 177-178 are not only resonant, but are also quite close to the broadcast array. The key question is how strongly these resonant spans reradiate.

The tower positions on the "as-built" power line can be used to compute the pattern of the CHFA broadcast array operating near the actual power line, which is shown in Fig. 6(a). The NEC program, using highly-conducting ground was used for the computation. The station's protection requirement is substantially exceeded. Fig. 6(b) shows the field strength in mV/m at one mile throughout the angular region of the protection limit. As discussed above, modelling the ground as highly-conducting exaggerates reradiation effects. The effect of "real" ground, of conductivity typically 5 to 20 millimhos/metre, is to dissipate RF energy coupled into the power line, and thus "damps" the resonance effect. The resonances occur at much the same frequency as over highly-conductive ground, but the magnitude of the resonant response is reduced by losses in ground. The computation was repeated using a ground conductivity of 10 millimhos/metre, by incorporating a "footing impedance" at the base of each power line tower, as discussed above. The value of the footing impedance is readily computed from the formula in Ref. (10), and with a ground conductivity of 10 millimhos/metre at 680 kHz, equals 9.38 + j 4.50 ohms. Fig. 6(b) shows that the computation including ground conductivity "predicts" the measured azimuth field strength (Ref. 13) quite well throughout this angular region, and both the measurement and the computation indicate that the station's protection requirement is substantially exceeded. There is substantial reradiation into the pattern from 180 degrees to 235 degrees azimuth.

The computer model determines the RF current flow on the towers of the power line, as shown in Fig. 7, and the current flow readily identifies those towers principally responsible for the reradiated field as towers 164, 165, 166, 167, 168, and 169. The spans which carry significant RF current flow correlate well with the spans which are resonant in Fig. 5. Spans 164-165, and 167-168 are resonant and respond strongly. Note that towers adjacent to resonant spans, such as tower 166 and 169, often have significant RF current induced on them, and that this current disappears if the nearby resonant span is "detuned". The actual current flow on the towers of the "north" line were measured (Ref. 14) for comparison, and correlates well with the computation when the effect of ground losses is included in terms of the "footing impedance". There is some disagreement on towers 174 and 176, which may be due to a nearby parallel power line, which was not included in the computer model, as discussed in Ref. (5). The measurement confirms towers 164-169 as the sources of reradiation. Thus the computer model provides a useful assessment of both the amount of RF current flow and of the distortion to be expected in the azimuth radiation pattern.

DETUNING BY RESONANCE SUPPRESSION

The reradiation seen in Fig. 6(b) is primarily due to a few spans of the power line which are of resonant length at the operating frequency of 680 kHz. For these spans, the closed loop path consisting of two adjacent towers and the skywire connecting them together, and a return path in ground, is close to two wavelengths in length. The resonant frequency of each span is readily estimated with Eqn. 1, and can be charted as shown in Fig. 8, for towers 164 to 170. Any span resonant within about 60 kHz of 680 kHz is a potential reradiator, and in fact towers 164 through 169 are strong reradiators, due to resonant spans 164-165 and 167-168. The simplest approach to "detuning" such resonant spans is to break the resonant path by "open-circuiting" it. The loop path is readily broken by insulating the overhead skywire from the top of one of the two towers. Although this breaks the path for a lightning strike to be grounded from the skywire via the tower, the "security" of the power line is not seriously degraded provided no more than two or three towers in a row are "isolated" from the skywire in this manner.

"Isolating" a tower from the skywire creates a loop-path spread over two spans which can itself be resonant at the operating frequency, and can thus carry strong, resonant RF current flow. Thus isolating a tower could potentially make a reradiation problem worse than it was with the tower connected to the skywire, and so in selecting towers for isolation, the creation of

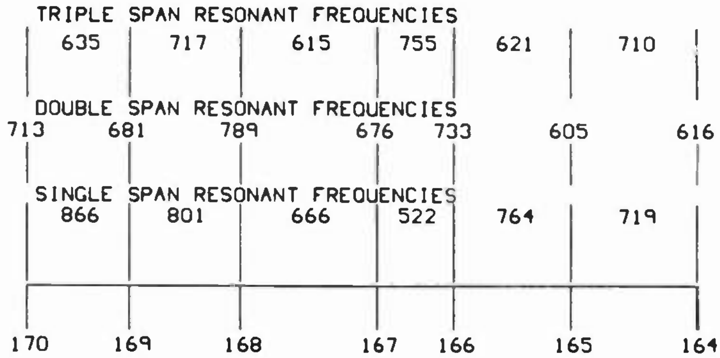


Fig. 8 Resonance chart for the power line from tower 170 to tower 164.

such "double-spans" which are of resonant length must be avoided. Eqn. 1 can be used to estimate the resonant frequency of "double-spans", with the results shown in Fig. 8. Thus isolating tower number 167 will not "cure" the reradiation from the resonant span 167-168, because the "double-span" 166-168 is resonant at 676 kHz, and towers 166 and 168 will carry large RF currents. A better choice is that of isolating tower 168, because the resulting double-span from tower 167 to 169 is resonant at 789 kHz, and will not carry significant RF current flow at 680 kHz.

Isolating two adjacent towers from the skywire creates a three-span loop path, or "triple-span" which can also be resonant at the operating frequency. Fig. 8 shows that if towers 167 and 168 were isolated to suppress the resonant response of span 167-168, then the resulting triple-span from tower 166 to tower 169 is resonant at 615 kHz, which is far enough away from 680 kHz to be "safe". Fig. 8 is a partial "resonance chart" for the north line, and Refs. (3), (5) and (15) present the full "resonance chart" and describe in detail a procedure for its use to select towers for isolation from the skywire so that no resonant "double-" or "triple-spans" are created. Thus to "treat" all the possibly resonant spans, towers 150, 153, 158, 161, 165, 167, 168, 174, 176, 178, 182 and 184 on the "north line" should be isolated from the skywire. The list can be pared down by selecting those towers from the list which actually carry strong RF currents in Fig. 7, rather than treating all possible resonant spans.

DETUNED POWER LINE

When the set of towers specified above is insulated from the skywire, then the NEC computer program predicts that the azimuth pattern will for the most part meet the protection requirement, as shown in Fig. 9. Clearly a large improvement in the azimuth pattern is expected. The value of ground conductivity does not affect the computed

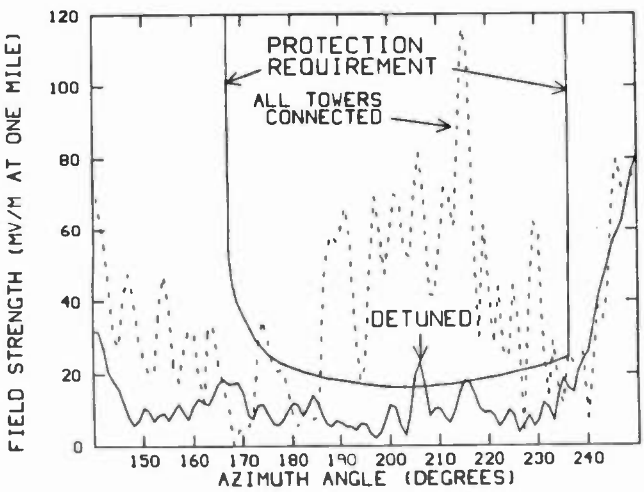


Fig. 9 Field strength in the pattern minimum with the specified set of towers isolated from the overhead skywire.

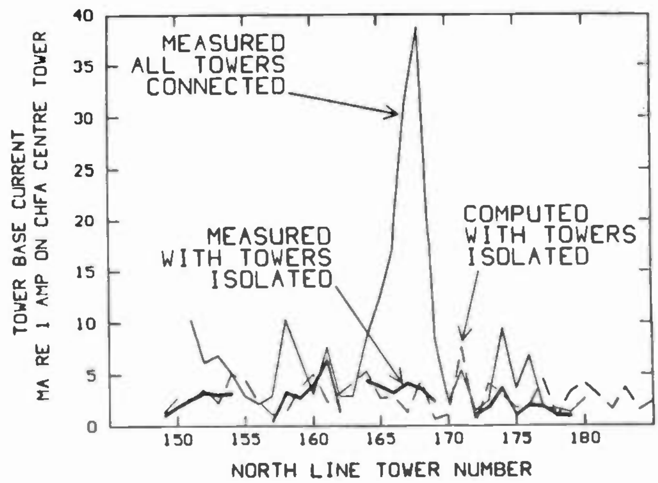


Fig. 10 Base currents on the towers of the power line with the specified set of towers isolated from the skywire.

curve very much, because the power line with the specified towers isolated has no resonant response to be "damped" by ground losses. Thus the computation was repeated with various "footing impedance" values, with no change in the resulting tower currents or azimuth pattern. The specified towers were insulated from the skywire by the hydro utility, and Fig. 10 shows the predicted power line tower base currents in comparison to the actual measured values(Ref. 16). The anticipated reduction in the tower base currents is actually seen in the measured values, and a large improvement has been achieved. In practice, the azimuth pattern may not improve quite as much as anticipated, because there will often be reradiators other than the power line. These have to be identified and "treated" to suppress RF current flow, particularly if a deep null is required in the azimuth pattern, as is the case for the CHFA broadcast array.

CONCLUSION

This paper has summarized the use of computer modelling for the assessment of the reradiation to be expected from a given power line, and for the design of "detuning" for the power line by the isolation of selected towers from the overhead skywire. The "life-cycle" of a reradiation problem has three phases, namely the "proposal" for the construction of a power line, the actual construction, and the "detuning" of the power line. At the "proposal" stage, the exact tower positions are not known, and so resonant spans cannot be pinpointed, and the exact field strength that the power line will reradiate cannot be determined precisely. The computer model can be used to obtain an estimate of how strong the field strength is likely to be, which depends primarily on how likely there are to be resonant spans on the power line. After the power line is constructed, and the exact tower positions are known, the computer model "predicts" a radiation pattern for the broadcast array operating near the power line which, for the case of the CHFA antenna, is reasonably in agreement with the actual measured azimuth pattern. Also, the current flow on the towers of the power line is "predicted" with reasonable accuracy by the computer model. A simple technique has been presented for "detuning" the power line by isolating selected towers from the skywire, and is based on an understanding of the resonant behaviour of power lines. The "resonance chart" does not require major computer resources to construct, and can readily be used to select towers for isolation to "detune" the power line. When the specified set of towers was isolated on the "north" power line near CHFA, a substantial reduction of the measured tower base currents was found. The computer model's prediction of the amount of reduction was in reasonable agreement with the measurement.

The present "state-of-the-art" in modelling power lines by computer analysis allows a computer model to "predict" the azimuth pattern of a directional broadcast antenna operating near a power line with reasonable precision provided that a number of conditions are satisfied. First, care must be taken that the actual azimuth pattern of the broadcast antenna is close to its design values. Thus the pattern must be verified by measurement before the power line is built. Also, in using the NEC program, tower base voltages must be specified for exciting the array, rather than tower base currents, and some adjustment of the excitation may be required before the NEC code yields the expected base currents and radiation patterns. The second condition which must be met is that the precise locations of the power line towers must be known relative to the broadcast array. Thus surveying the site may be necessary. Since knowledge of the precise span lengths on the power line governs the correspondence of the computer model's resonant behaviour to that of the actual power line, precise data on the tower locations is important. Third, the user must be prepared to "run" the computer model for a variety of ground conductivities, since the actual ground conductivity is not usually known precisely, and the available "footing impedance" model is somewhat approximate. If these conditions are met then it is expected that both the AMPL program, and the NEC program can be used with some confidence to assess the power line as a reradiator. Also, the NEC code can then be used with reasonable confidence to predict the effectiveness of measures for "detuning" the power line.

When a power line is proposed for construction near a broadcast array, the computer model serves to alert the broadcaster to a potential problem. If reradiation is anticipated, it is recommended that the antenna's radiation pattern be measured as accurately as possible, before actual construction begins. This can reveal deviations from the antenna's "design" which are not due to the power line and so cannot be eliminated by "detuning" after the line is constructed. Then, after the line is built, the pattern should again be measured, to assess the degree of change that has taken place, in comparison with the predictions of a computer model using the as-built tower positions. The computer model indicates which power line towers are likely to carry strong current flow, and actual measurement of the tower base currents can confirm that those towers are the culprits. The "resonance chart" is used to select towers for isolation, and the computer model predicts the degree of improvement to be expected. Finally, after tower isolation, further pattern measurement and possibly tower base current measurement reveals whether the problem has been resolved satisfactorily. In this way computer modelling and full scale measurement are used together to assess and then resolve reradiation problems.

ACKNOWLEDGEMENTS

This work was funded by the Canadian Electrical Association under Contract No. 023-T-217, the Canadian Broadcasting Corporation, and the Communications Research Centre under Contract OST83-00290. Preparation of this paper was supported by the National Research Council of Canada under Grant No. A1069.

REFERENCES

1. C.W. Trueman and S.J. Kubina, "Numerical Computation of the Reradiation from Power Lines at MF Frequencies," IEEE Trans. on Broadcasting, Vol. BC-27, No. 2, pp. 39-45, June, 1981.

2. C.W. Trueman and S.J. Kubina, "Initial Assessment of Reradiation from Power Lines," to be published in the IEEE Trans. on Broadcasting.

3. C.W. Trueman and S.J. Kubina, "Detuning Power Lines by Isolating Towers for the Suppression of Resonances," 35th Annual Fall Broadcast Symposium, IEEE Broadcast Technology Society, Washington, D.C., Sept. 19-20, 1985.

4. M.A. Tilston, "Final Report of the Working Group on Reradiation Problems in AM Broadcasting," prepared for the Dept. of Communications, DSS Contract 36100-4-4195, Ottawa, Canada, July 12, 1985.

5. C.W. Trueman and S.J. Kubina, "Initial Assessment of Reradiation from a Power Line and Its Detuning by Tower Isolation", Final Report prepared the Communications Research Centre, DSS Contract OST83-00290, Technical Note No. TN-EMC-85-05, Concordia University, Montreal, May 31, 1985.

6. W. Lavrench and J.G. Dunn, reported in "The Effect of Reradiation from Highrise Buildings, Towers and Other Structures upon AM Broadcasting Directional Arrays," Interim Reports No. 4,5 and 6, DOC Project No. 4-284-15010, 1979.

7. W. Lavrench, private communication, Division of Electrical Engineering, National Research Council of Canada, Dec. 16, 1980.

8. G.J. Burke, A.J. Poggio, J.C. Logan and J.W. Rockway, "NEC - Numerical Electromagnetics Code for Antennas and Scattering," 1979 IEEE Int. Symp. on Ant. and Prop., IEEE Pub. No. 79Ch1456-3AP, Seattle, Washington, June, 1979.

9. M.A. Tilston and K.G. Balmain, "A Microcomputer Program for Predicting AM Broadcast Reradiation from Steel-Tower Power Lines," IEEE Trans. on Broadcasting, Vol. BC-30, No. 2, pp. 50-56, June, 1984.

10. M.M. Silva, K.G. Balmain and E.T. Ford, "Effects of Power Line Reradiation on the Patterns of a Dual-Frequency MF Antenna," IEEE Trans. on Broadcasting, Vol. BC-28, No. 3, pp. 94-103, Sept. 1982.

11. M.A. Tilston and K.G. Balmain, "Medium Frequency Reradiation from an Unstrung Steel Power Line," IEEE Trans. on Broadcasting, Vol. BC-29, No. 3, pp. 93-100, Sept. 1983.

12. P.L. Barry, private communication, Trans-Alta Utilities Corp., Calgary, Alberta, June 28, 1983.

13. P. Warmbein and S. Reid, "Effect on CHFA Edmonton of Reradiation from High-Voltage Transmission Lines," Canadian Broadcasting Corporation, Report No. ER-436, January 15, 1985.

14. W.V. Tilston, T. Tralman and M.A. Tilston, "Reradiation Measurements of CHFA's Signal at the TransAlta Utilities Power Line Towers," Final Report, Contract No. E-31786, Til-Tek Limited, P.O. Box 550, Kemptville, Ontario, April, 1984.

15. C.W. Trueman and S.J. Kubina, "Detuning Power Lines by Isolating Towers for the Suppression of Resonances", manuscript in preparation for submission to the IEEE Trans. on Broadcasting.

16. W.V. Tilston and T. Tralman, "Reradiation Measurements of CHFA's Signal at the TransAlta Utilities Power Line Towers," Final Report, Contract No. E-32545, Til-Tek Limited, P.O. Box 550, Kemptville, Ontario, July, 1984.

MICROCOMPUTER APPLICATIONS IN AM ANTENNA SYSTEM ANALYSIS AND ADJUSTMENT

Karl D. Lahm, P.E.
A.D. Ring & Associates, P.C.
Washington, District of Columbia

ABSTRACT

Today's personal computer technology revolutionizes the way AM directional antenna systems are analyzed and adjusted. With appropriate hardware and software, the engineer supervising antenna system adjustment can have available, on site if necessary, the computing power only available in the past from expensive and inconvenient timeshared mini and mainframe computers. Small computers are especially useful in performing different analyses of measured data quickly, providing answers to "what if?" questions. Through the employment of appropriate modeling techniques, the antenna system adjustment procedure may be changed from a "trial and error" procedure involving days of field work to an optimum synthesis problem solved in minutes by computer. The proof of performance report preparation process itself may be automated, as well.

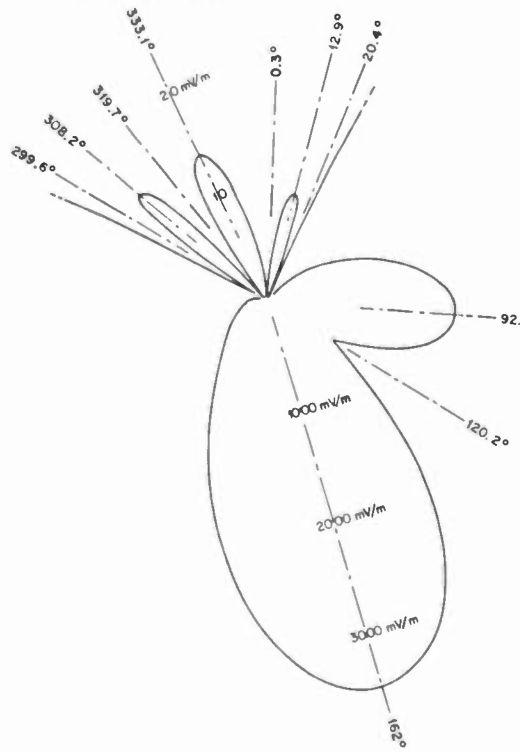
PREPARATORY APPLICATIONS OF MICROCOMPUTERS

Most AM directional antenna field work involves the initial adjustment or later readjustment of the antenna pattern to comply with the groundwave field strength requirements of the Federal Communications Commission (FCC). Prior to conducting any extensive work in the field, the project engineer must first plan the efforts required on site. Computers are useful tools in the selection of measurement radial bearings and field map layout.

Radial Bearing Determination

If the work involves a readjustment of the antenna pattern culminating in the filing of a partial proof of performance to justify new operating parameters (antenna monitor readings, base current ratios, and/or monitor point field strengths), the radial bearings along which field strength measurements are required were established during the last full proof of performance and are not subject to review. However, in the case of a new station proof or new full proof for an existing station (recommended after a major antenna system rehabilitation), the measurements must be taken along all bearings corresponding to pattern minima (usually specified by the FCC in the station construction permit), other bearings corresponding to pattern maxima, and several other pertinent directions, in accordance with Section 73.151 of the Commission's rules.

The radial bearings along which measurements are to be taken could be determined by inspection of a graphical plot of the radiation pattern. Figure 1 illustrates one particular six-tower theoretical radiation pattern, with the radial bearings corresponding to pattern inflections shown.



(FIGURE 1: SIX TOWER RADIATION PATTERN)

The accuracy of the graphic plot is dependent upon drafting errors if it was prepared manually or registration errors if it was prepared by a digital plotter under computer control. A better approach to accurately determining inflection bearings is to employ numerical methods using a computer. The bearings actually shown on Figure 1 were determined using a computer program which resolves them to an accuracy of 0.1 degree. The output from the program is a simple list of inflection bearings and corresponding radiations.

Since it is desired to find these bearings to the nearest 0.1 degree, it would seem logical to write a program which sweeps the pattern over 360 degrees in 0.1 degree increments. The first row of the following table shows the performance of a such a program written for different combinations of BASIC language and hardware, run on the same IBM-PC compatible computer employing an Intel 8088 processor operating at a clock rate of 5 megahertz. The second row shows the corresponding times for a program which achieves the same answers by means of a search algorithm which greatly reduces the number of calculations required. The third row shows the performance improvement factors solely associated with source code efficiency. Timing improvements achieved by the compiled versions of the programs, with respect to the interpreted versions, are shown by the fourth and fifth rows. This table illustrates the principle that greater degrees of performance improvement are generated by writing efficient code than by using faster languages and hardware.

Code Timing Comparison	GWBASIC Interpreter	IBM BASIC Compiler	B7BASIC Compiler
0.1-Oegree Sweep Time	2:59:07	0:29:39	0:21:44
Inflection Finder Time	0:17:37	0:02:07	0:01:08
Code Efficiency Gain	1017%	1401%	1918%
Sweep Improvement	(REF)	604%	824%
Inflection Improvement	(REF)	832%	1554%

(Table 1: Radiation Computation Performance)

Field Map Layout

Once radial bearings have been selected, measurement maps must be laid out for use in locating points in the field. This can be done by graphical means, with reasonable accuracy. However, when theoretical radiation in a particular direction is highly suppressed, very small errors in map drawing and point selection can make substantial differences in measured field strength. Using small computers, the radial lines can be laid out readily by computing the points of intersection of the radial lines and topographic map borders. The process is considerably more accurate than graphical methods and involves no more time.

Map layout can be taken one step farther. Although we have not yet attempted to do so, it is at least theoretically possible for the actual map layout to be performed by a computer driven digital plotter, further minimizing time and chance for errors.

ON-SITE APPLICATIONS OF MICROCOMPUTERS

The project engineer adjusting an AM directional antenna system in the field is continually faced with the question, "where are we," the answer to which must be known before the question, "how do we get this job done," can be considered. It is in these areas that the application of small computers can have the greatest impact. Field strength measurement analysis provides most of the clues to determining the behavior of the antenna system. Optimum parameter synthesis programs can be used to determine the adjustments necessary to complete the project. Operating impedance analysis can be used to anticipate the much-dreaded "ambivalent" tower.

Field Strength Measurement Analysis

An entire presentation could be devoted to the nuances of measurement analysis. Contrary to widely held beliefs, it is not an area where judgment and experience are the only useful tools. Small computers may be used to perform numerous statistical and other analyses of measured data in order to sharpen the precision and accuracy of an engineer's judgment. The closer the analysis of data is to reality, the faster the pattern adjustment problem can be solved.

Several factors may affect field strength readings and the resultant measurement analysis. Reradiation may cause so-called standing wave patterns to be evident along a radial bearing. Wide interelement spacing, high suppression, and/or low operating frequency may result in substantial geometric proximity effects. Power line crossings may result in the field strength meter reading the residual AM station current in the power line rather than the electric field radiated by the station. Road availability and geological formations may result in nonuniform point spacing, perhaps resulting in numerous measurement points being closely spaced with large gaps between such "clusters" of locations.

All these effects may be compensated for in the analysis of measurements. However, to do so manually would involve substantial amounts of time.

Small computers allow the on-site use of analysis programs which go far beyond the simple graphical or ratio analysis methods specified by Section 73.186 of the FCC's rules. The analysis may be performed using integration methods which eliminate analysis weighting caused by nonuniform measurement point spacing. Such a method has been proven to be quite useful in resolving true radiation levels in the presence of reradiation and/or in those situations where topography requires clusters of closely-spaced measurements. Geometric proximity effects may be accounted for by convergence approximation methods which cannot be performed in any reasonable amount of time by manual or programmable calculator means. Points may be selectively deleted from analysis, to consider anomalies expected due to the effects of power lines, water tanks, other stations' transmitter sites, etc. Statistical methods may be used to identify and exclude atypical measurement results from analysis, reducing confusion caused by anomalous scatter.

While the variety of analysis methods available may seem overwhelming, the appropriate method to employ is, in practice, usually obvious after a few parameter trials. The following table illustrates the application of five of twelve possible analysis methods to a particular set of real radial data. As can be seen, the result is quite dependent upon the analysis method employed. Since the ultimate achievement of a correct pattern adjustment is a function of measurement analysis results, finding a solution to the pattern adjustment problem may be entirely dependent upon the analysis method used. Therefore, the prudent project engineer should test several scenarios and prepare alternative analyses based thereon, especially in those cases where data behavior is not obvious. To do this efficiently, a small computer is required.

Log Ratio	Proportionate Integration	Proximity Correction	Statistical Exclusion	Measured Field
N	N	N	N	330
Y	N	N	N	314
Y	N	N	Y	333
Y	N	Y	Y	371
Y	Y	Y	N/A	358

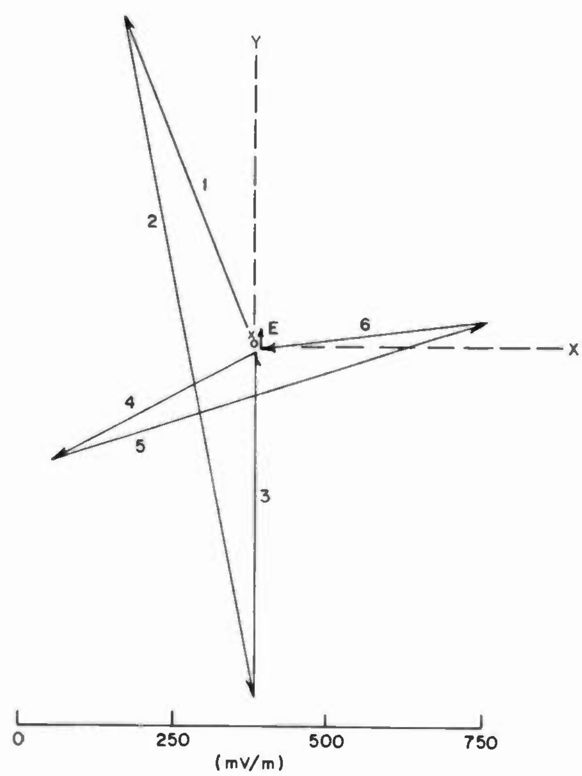
(Table II: Measured Field Results for Different Analyses)

Operating Parameter Synthesis

The most challenging part of a directional antenna field adjustment project, and, therefore, the most satisfying part, is the synthesis of a set of array operating parameters that results in optimal field strength analyses along all important radial bearings. Traditionally, this has required a time consuming, one-step-at-a-time approach. The complexity of adjustment and time required expands with the tower count, as illustrated below.

Number of Towers:	2	3	4	5	6
Parameters Variable:	4	6	8	10	12

Only for arrays of two towers is the evaluation of parameter changes that result in radiation compliance with FCC requirements simple and straightforward. For arrays of more than three towers, it is difficult, at best, to evaluate by inspection a sequence of parameter changes that will solve the pattern. This is especially true for asymmetrical tower layouts.



(FIGURE 2: SIX TOWER VECTOR DIAGRAM)

Figure 2 illustrates the vector diagram in one radial direction for the six-tower array of Figure 1. The origin is shown by the "o" at the intersection of the X and Y axes. The tip of vector "E" represents the coordinates of the present resultant field vector, which is the additive product of all tower vectors plus the error vector. The latter represents the difference between measured field strength and that calculated from the operating parameters shown on the station's antenna monitor. The desired resultant coordinates, to which the array should be adjusted, is shown by point "X."

There are, in this case, 7 radial bearings along which radiation is highly suppressed. If one wishes to evaluate the effects of parameter changes, one must consider 7 such vector diagrams when evaluating the effects of discrete changes. The difficulty in visualizing the effects of a succession of parameter changes is fairly obvious. Furthermore, as parameter changes of more than one or two degrees or percent are made, the pattern multiplying constant will change, modifying the length (size) of each vector shown. Graphical methods cannot readily take into account this effect.

Another approach to performing the same evaluation is to establish a vector sensitivity matrix. The table below illustrates the this matrix for the same radial direction as the previous vector diagram. The values shown represent the anticipated change in measured field strength for a 0.01 change in monitored sample ratio or a one degree change in monitored sample phase. Parameter choices can be made based on an inspection of such a table. Once again, several tables need to be constructed and evaluated, complicating the analysis. Furthermore, when the resultant vector magnitude approaches zero, sensitivities can rapidly change magnitude and sign, requiring establishment of new matrices after each discrete parameter change. The amount of work involved can be truly overwhelming.

Tower	Amplitude	Phase
1	-5.3 mV	+4.0 mV
2	+5.6 mV	-4.3 mV
3	-5.7 mV	+0.3 mV
4	+2.9 mV	+5.6 mV
5	-1.9 mV	-12.2 mV
6	+0.9 mV	+6.4 mV

(Table III: Radiation Vector Sensitivities)

This kind of situation is an ideal candidate for computer modeling and solution. The number of calculations required is substantial and the chance for error is significant when manual methods, including programmable calculators, are used. An appropriate computer program can test all scenarios and select those parameter changes which result in greatest error reduction. Algorithms which operate on such an error minimization basis are known as "steepest descent" methods.

The matrix construction shown by the previous table and the evaluation thereof by the process discussed are implemented readily within a computer program. The computer can evaluate the effects of parameter changes swiftly, with full attention to changes in multiplying constant and sensitivity. A steepest decent control algorithm will usually find the fastest route to a solution, especially if it is modified for error sensing and reversal.

A computer-modeled solution procedure has been used by the author in array adjustment for the past two years. Supercomputers or minis are not required to achieve a solution in a reasonable time frame. In one case, a borrowed bootleg Apple][was used, with modest success, although IBM-PCs and clones are better and the performance of 8 MHz 8086/8087 machines is comparatively awesome. The following table illustrates the time required by various combinations of hardware and software to solve the six-tower example of Figure 1 and a triangular three-tower array. Compiled BASIC was used in all cases shown.

Computer	Processor	Clock	6 Towers 4 Radials	3 Towers 7 Radials
Apple][+ (CP/M)	Z80	2 MHz.	25:45	6:00
AT&T PC-6300	8086	8 MHz.	1:13	0:16
AT&T PC-6300	8086+8087	8 MHz.	0:55	0:12
Corona PPC-22	8088+8087	5 MHz.	2:35	0:33
Oata General One	80C88	4 MHz.	2:41	0:38
IBM-PC	8088	4.8 MHz.	2:34	0:34
IBM-PC	8088+8087	4.8 MHZ.	1:49	0:24

(Table V: Parameter Optimization Performance)

Operating Impedance Prediction

A set of operating parameters desired to be achieved on the antenna monitor which solves the antenna adjustment problem may have been generated quickly. However, actually implementing that parameter set using the antenna phasing and coupling equipment on hand may be another matter entirely. Parameter changes, sometimes even small ones, can cause towers to change from positive to negative resistance or vice versa. If proper precautions have not been taken in equipment design, this may cause much trouble and delay in achieving a desired set of operating parameters.

When an operating impedance computation program adequately takes into account most relevant factors concerning antenna behavior, such as apparent velocity of propagation, non-sinusoidal current distribution, and effective shunt capacitance across the tower base, reasonably accurate predictions of impedances and power division will be obtained. Use of such a program to test prospective operating parameter sets before adjustment is attempted allows the project engineer to anticipate problems before they occur.

Once again, the small computer is a useful tool. The table below shows running times for the author's BASIC impedance approximation program, using various combinations of hardware and software. The first row shows performance in GWBASIC for a modified version of the program which does not eliminate redundant calculations. The second row is for the actual redundancy-avoiding code, in GWBASIC. The remaining times (in seconds) are for compiled BASIC. Once again, writing efficient code results in a significant performance improvement.

Computer Type	CPU Type	Clock	Time
Corona PPC-22	8088	5 MHz.	1:49
Corona PPC-22	8088	5 MHz.	1:30
Apple][+ (CP/M)	Z80	2 MHz.	1:16
AT&T PC-6300	8086	8 MHz.	0:05
AT&T PC-6300	8086+8087	8 MHz.	0:02
Corona PPC-22	8088	5 MHz.	0:15
Corona PPC-22	8088+8087	5 MHz.	0:07
Oata General One	80C88	4 MHz.	0:11
IBM-PC	8088	4.8 MHz.	0:10
IBM-PC	8088+8087	4.8 MHz.	0:05

(Table VI: Impedance Calculation Performance)

Results

The project engineer adjusting a directional array in the field must make complex decisions, all of which take time, in several areas. Measurements must be accurately analyzed. The error vector must be determined when the antenna system exhibits any degree of complexity. Lastly, an optimal set of operating parameters, to be read on the antenna monitor, must be determined.

The application of appropriate microcomputer hardware and software generally leaves the derivation of the error vector as the only activity requiring substantial effort and judgment on the part of the project engineer. Since computer applications in other areas have lessened fatigue, the accuracy of the engineer's evaluation of the error vector is enhanced, resulting in a more accurate model of the array, leading to a rapid solution of the problem. While the computer takes a few minutes or moments to generate a solution, time can be devoted to more relaxing pursuits, such as coffee, lunch, or the latest station gossip.

Experience to date indicates that the time saved in antenna system field adjustment by using a microcomputer on site is from 33 to 67 percent of the total time involved in similar adjustments performed with programmable calculator assistance. Generally, this means an adjustment of the antenna pattern is achieved in three to five working days, with little effect of tower count on adjustment time. Obviously, this procedure is overkill for two tower arrays, where little time saving would result, but is indispensable for arrays of six or more towers.

PROOF OF PERFORMANCE REPORT PREPARATION

There are numerous mundane tasks involved in the proof of performance report preparation process which are readily adapted to computer aided implementation. Time is saved and accuracy is improved if much of the report is generated by appropriate hardware and software.

If the computer is used for data analysis in the field, measured data can be stored on disk for later use back at the office. The analysis result report can be "printed to disk" and incorporated into the written report document by popular word processing programs.

Raw measurement data may be plotted on field strength graph paper using a digital plotter. Even the graphical analysis of measured data by computer aided means is possible. The results of analysis can be stored or otherwise transferred to pattern plotting programs for automated generation of measured radiation patterns. The automation of drafting work has only recently begun, so the efficiency gains are unknown at present.

The tabulation of data need not be done by a custom program written in a high-level language, such as BASIC. Popular spreadsheet programs can be used for data tabulation and statistical analysis, although they do not lend themselves as well to more complicated analysis methods involving integration or proximity correction convergence.

Word processing methods involving "model" forms and report text can be used to greatly reduce report writing and typing time. Although we have only begun to explore the use of such methods, we have been able to reduce the secretarial time required for report preparation by 50 to 75 percent, in a situation where engineering workstations and word processors are not compatible and files must be transferred over wires.

CONCLUSION

Strategic use of small computer hardware and software has been proven to substantially reduce the time required for directional antenna field adjustment and proof of performance report preparation. Popular hardware and software provide most of the features required, at inexpensive cost unimaginable ten years ago. The application of small computer technology to the AM antenna adjustment and reporting process represents a significant AM improvement, one that requires no governmental action or receiver industry cooperation.

MAKING THE BEST USE OF ENGINEERING TIME AND TALENT

Michael D. Callaghan
KIIS AM/FM - Los Angeles, California

ABSTRACT: This paper advances ideas to improve organization. workflow, communication, and save time within engineering dapartments.

It used to be that many stations had so many engineers on staff that they could get everything done just in the process of trying to keep busy. The fewer engineers of today don't have to try to keep busy --- problems and the projects seem to come looking for them.

As the number of engineers we have has decreased, the complexity of our plants has increased. We have more work to do with fewer people. Here are some ideas to help improve efficiency and to extend the amount of the work we can get done with the staffs we do have left.

In the rush to take care of immediate day to day problems, it's easy to lose track of the progress we make in solving them. A good, productive way of keeping tabs on the extent and progress of these tasks is important. This may be done in a number of ways - but one of the best is to generate an effective technical discrepancy form to report equipment problems and to make sure information about them gets to the right people.

Figure 1 is a sample of the form we have evolved - it allows the operator room to clearly indicate what problems he is having and it also allows the engineer taking charge of the repair to provide feedback to the originator. The form includes spaces where the parts required for the work may be entered, along with the order number, scheduled delivery and the state of the work.

When the work is done and the project complete, the engineer signs off the form as the person responsible for the integrity of the work. Copies of the finished form are then passed out to the originator, the chief engineer, and the programming people so that they may be aware of the extent of the work, any special problems it may have involved, and most importantly, the fact that the work is completed.

We have carefully established in the minds of the air staff and those using this report that they must be as explicit as possible - nothing is more frustrating than to have a piece of gear reported out of service with a generic note (" It doesn't work!") and then find the equipment fully operational when the discrepancy report is acted on.

In the rush to take care of immediate day to day problems, it's easy to lose track of the longer term projects. A modest computer database program can be a tremendous help in tracking projects - making sure the engineering staff members are reminded of the work they have left, and in keeping abreast of the total work load. It needn't be run on an expensive computer - even a Commodore 64 with a disc drive will be able to handle it. Any of a number of programs will do the job.

Figure 2 is an example of the daily printout. At the start of his shift each engineer gets a current copy of the projects he has on-line, along with appropriate itemized information. This includes phone numbers, names, circuit numbers, and other facts he needs to move ahead with the work. As each part of a project is completed, he notes the progress on the sheet and these are entered into the database. Some projects may occupy more than one engineer - these are noted by the plural names at the right of the listing.

At the bottom of the sheet, information for the entire technical staff is related - this helps insure that all technicians are aware of forthcoming remotes, network feeds, and other general information.

When a project in the database is finished, it's moved into a 'DONE' file. These are purged each month, stored on disc, and a hard copy is printed for future reference. This lets us go back and review the start and stop dates at some point in the future.

The same program may be used with different files to store and sort specific vendor promised delivery dates and back orders, and for other 'time-intensive' filing tasks. And because it is a database, it will store and sort telephone loop numbers, equipment inventories, and other filing functions.

A second important way of saving time is the documentation of equipment performance using automatic test gear to go through and confirm the performance of various pieces of equipment. An assortment of this new breed of test equipment is attainable for a wide range of prices. Our specific choice, the Audio Precision System One, is based on an IBM (or compatible) computer. It allows individual tests to be written and run, as well as procedures that will automatically link and run a series of different tests to find if the various parameters of a piece of studio equipment are performing within specifications.

The computer may include provisions for 'hard disc' storage of measurements, so that previous test results of a piece of gear may be compared with present performance to see if deterioration is setting in.

Instructional prompt displays may be written into the procedures so that even unskilled help may be instructed about how to hook up various test leads and fixtures - then when the setup is correct, the operator starts the procedure and the tests are performed automatically. The operator needn't understand the operation of the equipment to develop a full set of measurements. A dot matrix printer provides hard copy of the test results for later evaluation by more experienced technicians.

The number and the length of trips to the transmitter may be drastically reduced by expanding the number of metering channels brought back on the remote control. When the transmitter is actually visited, most of the time it's just to check readings that aren't available through the control system, to physically look at the transmitter, and to listen to it. If a full set of transmitter readings (all the way down to driver currents, and exciter outputs) are telemetered back, then the weekly trudge to the transmitter may be avoided, and yet , the transmitter will still be better monitored because all the transmitter parameters may be easily checked at the studio.

A full set of these detailed readings needn't be printed on the log or displayed on the terminal -- they'd probably frighten the air staff if they did appear. We show just enough for the operator to insure the power, phase angles, and frequency are right. The detailed values, including all the driver parameters, are printed on the hard copy every midnight, or more often if desired. A special concealed 'engineers menu' with all the metering channels may be brought up when needed. This display has real value - if the power is dropping or something else is wrong the engineer will have enough data to start thinking over and diagnosing the problem as he drives to the transmitter.

To make the best use of the staff that remains, a development program should be instituted -- just a series of sessions to go over new equipment and trace out new and unfamiliar circuitry. This will upgrade technical knowledge and prepare for the day when the intricate equipment we seem to be endeared to these days is in need of help.

The classes needn't be formal; snap quizzes don't apply here -- it's just a matter of setting aside the time to allow different staff members to share what they have learned. Time invested in these sessions will be well spent - and the returns frequently occur when you least expect them.

Most of these ideas aren't anything new -- but sometimes it's good to clear the air and insure we are getting the greatest performance from the staff members we do have - anything that helps us stay organized an save time will be of benefit, and these steps seem to help.

TECHNICAL DISCREPANCY REPORT

Person Reporting Problem P. ELLIOT Date 2/12 Time 10A Location PROD IV

Nature of Problem (Describe in Detail) NOISE IN TT #1

LEFT CHANNEL - SOUNDS LIKE RAIN

Engineer Accepting Report, Date & Time : MDC 2/12 11:30

+ + + + + + + + + ENGINEERING FOLLOWUP + + + + + + + + + + +

Analysis of Problem: Apparently bad opamp in Russco preamp.

Also found too much ripple in power supply.

Parts Needed to be Ordered: MC 5532 I.C.'s

P.O. Submitted Date/Time : 2/12	Approval Date/Time: 2/12 2:15 PM
Parts Ordered Date/Time : 2/12 3 PM	Vendor's Rep. Name: Cindy / Hamilton
Estimated Arrival Date : 2/17	Followup(s) Due :
Date P.O. Complete : 2/21	Date Parts Installed: 2/21

Work Done: Replaced with spare preamp from syndication room; they won't need it until 2/19.

** Replaced bad MC 5532 2/21 - Replaced filters in Power Supply

S.N.R. now -66 db.

+ +

Date/Time Finished 2/21 Engineer Completing Project MDC

Copy Provided to Person Reporting Problem - Date/Time 2/21 4:30 PM

FIGURE 1

Completed Technical Discrepancy Form

** George **
Project Summary
Mon, Dec 23, 1985

TASKS/TXT 10.38.23

==

7)	Document parameter sample points inside FM transmitters for new R/C; need Final Eg2; Ig2; Ig1 Driver Ig1; Ig2; Eg2 Ik - & VSWR	[ ] George
9)	Decide priorities for AM R/C - do we need another phone line ? Check w/ Ron Trophich (800) 343-7619 for installed cost.	[ ] George
17)	Finish up R/C interface; document needs & parts; order what's needed System due 12/27; install next week	[ ] George
21)	Replace audio patch bay at AM TX. Use bays from KIIS-AM upstairs Needs completion by 1/21 at latest!	[ ] George
22)	Order relays for studio tape deck interface - check MCI manual for contact configurations P/R interfaces not avail in time	[ ] Mike/George
29)	Check w/ Hallikainien re: new R/C channel assignments KIIS - FM and KFSG should match as closely as possible	[ ] George
30)	Pull wires in for new R/C terminal in FM Place on counter next to in/out boxes	[ ] Jerry/George
31)	Order tower flasher fm: Lauderdale Elect. (800) 327-3793 Need FedEx tomorrow - center tower isn't flashing	[ ] George
34)	Need new CK722's for Mike Preamps - check Allied Radio Chicago 5532's too noisy	[ ] George

----

15)	For air conditioning repairs call Trane Service @ (818-961-7181) 24 hrs./7 days. We now have a full service contract with them.	[ ]
32)	New R/C circuits: 7VMNA700246 for FM and 7VMNA712216 for AM Use with new Hallikianien system	[ ]
33)	New studio furniture to be delivered 10:00 AM 1/2 - Building is letting us have freight elevator Wear old clothes - plan on some overtime	[ ]

==

FIGURE 2

Engineers Daily Project Printout

INCREASING TRANSMITTER RELIABILITY THROUGH PREVENTATIVE MAINTENANCE

Jerry Whitaker
Editor, Broadcast Engineering magazine
Overland Park, Kansas

Abstract

Of all the requirements for operation of a broadcast transmitter, reliability is the most important. Reliability can be achieved through: (1) regular preventative maintenance and (2) failure analysis after a problem occurs. This paper describes the requirements of an effective preventative maintenance program for radio transmission equipment. Because of the amount of information to be covered, the failure analysis aspect of transmitter reliability will be examined during the scheduled radio engineering session. Together these presentations provide a thorough examination of how to reduce downtime in a broadcast transmitter.

An equipment failure at a radio station is generally just cause for an instant crisis. All gear in the transmission system, from the cart machines and microphones to the antenna, must work 24 hours a day, 7 days a week, without fail. Every link in the broadcast chain is important, but the transmitter itself is most important. Studio equipment may occasionally fail—and the operators will complain loudly about it—but you can circumvent the problem. The greatest concern on the part of most engineering personnel is keeping the transmission system, particularly the transmitter, in good working order.

Unfortunately, the heart of the broadcast station's technical plant is often located apart from the studio, on some out-of-the-way tract of land or on a mountain top that takes a half-day to reach. It becomes too easy to ignore the transmission gear until a problem occurs. The weekly transmitter inspection visits allow the engineer to give the system a quick "once-over" look, but there is no substitute for walking past the box every day. Engineers who have worked on a particular piece of transmission equipment for any length of time acquire a feeling for how well the unit is working. They know what the blowers should sound like and what meter readings are normal—not by reading the meters individually, but by one glance at the front panel. They know when the PA tube needs replacement, and when there's still some life left in it. They know when the transmitter needs retuning, and when to leave well-enough alone. They know the unit's strong points and weak points.

The only way to gain this knowledge is to know the transmitter—and instruction manual—forward and backward, and to work with the equipment on a regular basis. This translates into a thorough maintenance program. Such an effort can be expensive and time-consuming, but the rewards always outweight the cost.

THE IMPORTANCE OF MAINTENANCE

The transmitter is generally the most expensive piece of equipment at a broadcast station, and one of the units most vulnerable to damage, as well. Whether or not a station has a standby transmitter, the importance of proper maintenance cannot be emphasized too strongly. Many stations unwisely skimp on transmitter maintenance efforts, reasoning, "If it breaks, we can always use the standby." But, will the standby work? Moreover, how much extra downtime and expense will the minimum-maintenance policy cause?

Maintaining a broadcast transmitter is a predictable, necessary expense that all stations must include in their operating budgets. Tubes have to be replaced no matter what the engineer does; components fail every now and then; and time must be allocated for cleaning and adjustments. By planning for these expenses each month, many unpleasant surprises can be avoided.

Although the reason generally given for minimum transmitter maintenance is a lack of money, the cost of such a policy can be deceptively high. Problems that could be solved for a few dollars, if left unattended, may result in considerable damage to the transmitter and a large repair bill. A standby transmitter in the back room often can be a lifesaver. However, its usefulness sometimes is overrated. The best standby transmitter in the world is a main transmitter in good working order.

Contrary to popular belief, equipment failures are not solely dependent on the power company and the will of God. Many failures are preventable. Through accurate observation of the transmission system, degradation of the air product can be avoided.

ROUTINE MAINTENANCE

Most problems in a transmitter can be prevented through regular cleaning and inspection, and close observation. The history of the unit is also important in a thorough maintenance program so that trends can be identified and analyzed.

The front panel can tell a great deal about what is going on inside of the unit. All front-panel meter readings should be recorded on a regular basis in the maintenance log, as well as the positions of critical tuning controls. (See Figure 1.) This information gives the engineer a history of the transmitter and can be a valuable tool in noting problems at an early stage. The most obvious application of this logging is to spot failing tubes, but component changes can be found as well.

PARAMETER	TYPICAL VALUE	MEASURED VALUE
RF power output	18.3kW	
Plate current	2.8A	
Plate voltage	7.55kV	
Screen current	380mA	
Screen voltage	650V	
PA grid current	110mA	
PA bias voltage	490V	
PA filament voltage	6V	
Left driver cathode current	142mA	
Right driver cathode current	142mA	
Driver screen voltage	275V	
Driver screen current	35mA	
Driver grid current	1mA	
Driver plate voltage	1.85kV	
28V power supply	27V	
Reflected power	15W	
Transmission line pressure	3.9psi	
Tank pressure	1500psi	
Transmitter hours	5412	
Exciter AFC	Center scale	

Figure 1. Complete and accurate logging of important transmitter parameters is essential to preventive maintenance and troubleshooting. A complete history of the transmitter allows the engineer to spot trends in the operation of the equipment. Shown is an example of a transmitter parameter form that should be filled out regularly by the station engineer.

For example, consider the case of an IPA and PA stage in an AM transmitter that has lost neutralization. (See Figure 2.) Neutralization adjustment is made by moving taps on a coil, and none have been adjusted. The history of the transmitter (as shown in the maintenance record) reveals, however, that the PA grid tuning adjustment has, over the last two years, been slowly moving into the higher readings. An examination of Figure 2 leads to the conclusion that the problem most likely is C-601.

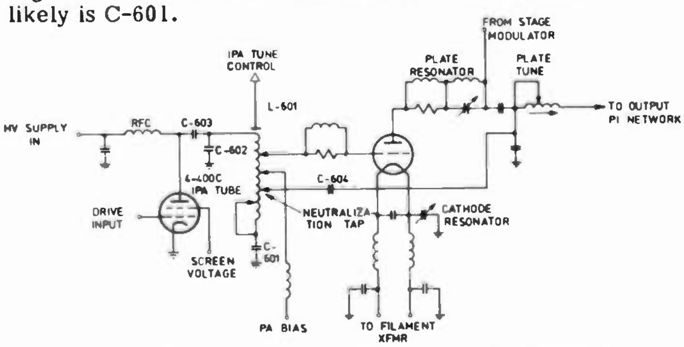


Figure 2. An example of how detailed logging of transmitter readings and tuning control positions can aid in troubleshooting work. The example shown involves an IPA and PA neutralization problem in an AM transmitter. A history of IPA retuning (through adjustment of L-601) helped determine that loss of neutralization was caused by C-601 changing in value.

The tuning change of the stage was so gradual that it was not thought significant, until an examination of the transmitter's history revealed that continual retuning in one direction only was necessary to achieve maximum PA grid drive. Without a record of the history of the unit, time could have been wasted in substituting capacitors in the circuit, one at a time (costing a couple hundred dollars each). Worse yet, the engineer might have changed the tap on coil L-601 to achieve neutralization, further hiding the problem.

Creating a history of the line and tank pressure for pressurized transmission lines helps identify line or antenna problems. Once the regulator is set for a desired line pressure, record the tank and line readings each week and chart the data. If possible, make the observations at about the same time of day each week. Ambient temperature can have a significant effect on line pressure, so note any temperature extremes in the transmission line log when the pressure is recorded. The transmission line pressure usually will change slightly between carrier-on and carrier-off (depending on the power level). The presence of RF can heat the inner conductor of the line, causing the pressure to increase.

After a few months of charting the gradual loss of tank pressure, a pattern should become obvious. Investigate any deviation from the normal amount of tank pressure loss over a given period of time.

Visual inspection

A complete visual inspection of the transmitter on a regular basis is an important part of any preventative maintenance program. Component problems can often be spotted at an early stage by regular inspection of the equipment. Carefully inspect all resistors for signs of overheating, electrolytic or oil-filled capacitors for signs of leakage and feed-through capacitors and other high voltage components for signs of arcing. Also check all high voltage RF capacitors right after signoff for excessive heating.

Transmitting capacitors—mica, vacuum and door-knob types—should never run hot. They may run warm, but generally only because of thermal radiation from other components, such as power tubes in the circuit. An overheated transmitting capacitor is often a sign of incorrect tuning, and should be investigated as soon as possible.

Check all power supply components—transformers, reactors, high voltage rectifiers and transient suppression devices—for overheating. Remember to discharge all capacitors in the circuit with a grounding stick before touching any component in the high voltage sections of the transmitter. Confirm that all primary power has been removed from the transmitter before any maintenance work begins.

Special precautions must be taken with transmitters that receive ac power from two independent feeds. Typically, one ac line provides 208V 3-phase service for the high voltage section of the system and a separate ac line provides 120Vac power for low-voltage circuits. Older transmitters or high-power transmitters often have this arrangement. Check to see that all ac power is removed before you begin maintenance work.

Check modulation transformers and reactors—if used—for excessive heating, and inspect any oil-filled transformers for signs of leakage.

Examine coils and RF transformers for indications of overheating. Such components—operating in a well-tuned transmitter—will rarely heat appreciably. If you notice discoloration on several loops of a coil, consult the factory service department to see if this is normal. Pay particular attention to variable tap inductors, often found in AM transmitters and phasors. Closely inspect the roller element and coil loops of such inductors for signs of overheating or arcing.

Regularly check all fans and blower assemblies for proper operation. Most transmitter instruction manuals include a suggested maintenance schedule for these devices. Follow the schedule closely. Include in your inspection all other portions of the air handling system, such as air intake assemblies, filters and grills. This work is important because dirt particles—or microdust—can collect on the surfaces of the blower cage, blades and ducting, resulting in a significant reduction in air flow.

Cleaning is a large part of a proper maintenance routine. A shop vacuum and clean brush are generally all you need. Use isoproply alcohol and a soft, clean cloth for cleaning high voltage insulators. Cleaning serves a greater purpose than just keeping the transmitter looking nice. You can inspect each component as you clean and observe any changes.

Further, cleaning is important to proper cooling of various components in the system. Dust and dirt of sufficient thickness can create a thermal insulator effect that prevents proper heat exchange from a device into the cabinet.

Clean relay contacts—including high-voltage or high-power RF relays--as often as needed to keep the current-carrying points free of pitting or discoloration. Experience will tell what devices need to be cleaned, and how often. Inspecting certain relays will also show you if operators are using the proper procedures to change transmitter power or antenna patterns. For example, a high voltage relay that should never be changed in the "hot" condition should not show signs of arcing between contact points. Evidence of such arcing would indicate that operators were violating established procedures by making "hot changes" from one mode to another.

Unless problems are experienced with an enclosed relay, do not bother cleaning it. More harm than good can be done by disassembling components that show no signs of problems for detailed inspection. Never be afraid to service a component, but on the other hand, if it's not broken, don't try to fix it.

Check the tightness of wires and connections from time to time, particularly those that may be subjected to vibration. Tightness of connections is critical to the proper operation of high voltage and RF circuits. Also inspect barrier strip and printed circuit board contacts for proper termination. Although it is important that all connections are tight, be careful not to over-tighten. The connection points on some components, such as door-knob capacitors, can be damaged by excessive force.

Cleaning is vital to the proper operation of power tubes. An anode congested with dirt is a poor radiator of heat, possibly leading to shortened tube life.

There is no section of the transmitter where it is more important to keep connections tight and insulators clean than in the PA stage. Loose connections can result in arcing between components and conductors that will not only put you off the air, but also destroy an expensive component. It might appear to the casual observer that the PA cavity is mechanically "overbuilt," that individual sections or components are secured with an unusually large number of screws and nuts.

However, the manufacturer put every component—even down to the smallest screw—there for a reason. It is not enough for most of the hardware to be tight. Everything must be tight.

The cavity access door is a part of the outer conductor of the coaxial transmission line circuit in FM transmitters. High RF circulating currents flow along the inner surface of the door, and it must be fastened securely to prevent arcing.

Cleaning insulators is important to the proper operation of the final amplifier stage because of the high voltages present. Pay particular attention to the insulators used in the PA tube socket. Because the supply of cooling air is passed through the socket, airborn contaminants can be deposited on various sections of the assembly. These can create a high voltage arc path across one of the socket insulators.

A word of caution is in order. Although it is important to keep all components in the PA circuit tight and clean, do not over do it. An engineer who goes overboard on preventative maintenance can wind up causing problems.

POWER TUBES

Plug-in power tubes must be seated firmly in their sockets and the connections to the anodes of the tubes must be tight. Once in place, don't remove a tube assembly for routine inspection unless it is malfunctioning. You can create problems by removing a tube or other component unless you are extremely careful. As a general rule of thumb, if a tuned cavity assembly is set up and working properly, leave it alone.

Whenever a tube is removed from its socket, carefully inspect the fingerstock for signs of overheating or arcing. Keep the socket assembly clean and all connections tight. If any part of a PA tube socket is found to be damaged, replace the defective portion immediately.

In many cases, the specific fingerstock ring can be ordered and replaced. In other cases, however, the entire socket must be replaced. This type of work is a major undertaking, and an inexperienced engineer should consider calling a consultant to help on the project. Replacing a damaged socket should be done immediately, because a bad socket can often damage or even ruin a PA tube. A defective socket can set up high circulating currents within the tube, cause a loss of stage neutralization or contact hot spots between the fingerstock and the tube contact rings. Such hot spots can actually weld a part of the fingerstock to one of the tube contact rings.

Extending tube life

Power transmitting tubes are probably the most expensive replacement part that a system will need on a regular basis. With the cost of new and rebuilt tubes continually rising, engineers must do everything possible to extend tube life.

Inspect each new tube as soon as you receive it for cracks or loose connections (in the case of devices that do not socket-mount). Also check for inter-electrode short circuits with an ohmmeter. Once these preliminary tests have been completed, store the tube in a safe place.

Tubes must be seated firmly in their sockets to allow a good, low resistance contact between the fingerstock and the contact rings. After a new tube—or one that has been on the shelf for some time—is installed in the transmitter, run it with filaments only for at least 30 minutes, after which plate voltage may be applied. Drive (modulation) should next be slowly brough up (in the case of an AM transmitter). Residual gas inside the tube may cause an interelectrode arc (usually indicated by the transmitter as a plate overload) unless it is burned off in such a warm-up procedure.

Keep an accurate record of performance for each tube. Shorter than normal tube life could point to a problem in the transmitter itself. Many engineers wonder what type of average tube life can be expected in a particular transmitter. But with the many variables in operation possible (including filament voltage, ambient temperature, RF power output and frequency of operation), it is difficult to say with any amount of accuracy what to expect in the way of tube life. The best estimate of life expectancy in a particular transmitter at a particular location comes from on-site experience. As a general rule of thumb, however, if a station is not getting at least 12 months service out of a power tube, something is wrong.

Possible problems include improper transmitter tuning; inaccurate panel meters or external wattmeter, resulting in more demand from the tube than is required by the station license; poor filament voltage regulation; insufficient cooling system air flow; and improper stage neutralization.

Once the transmitter is operating properly, the major determining factors of vacuum tube life are cooling system performance and filament voltage management.

To accurately adjust the filament voltage, you need a true-reading rms voltmeter. Make the measurement directly from the tube socket connections. Use a true-reading rms meter instead of the more common average responding rms meter because the former can accurately measure a voltage despite an input waveform that is not a pure sine wave (as would be the case in an SCR-regulated filament supply). The front panel filament voltage meter is seldom a true-reading rms device. (Most are average-responding meters.)

Long tube life requires filament voltage regulation. Many transmitters have regulators built into the filament supply. Older units without such circuits can often be modified to provide a well-regulated supply by adding a ferroresonant transformer or motor-driven auto-transformer. A tube whose filament voltage is allowed to vary along with the primary line voltage will not achieve the life expectancy possible with a tightly regulated supply. This problem is particularly acute at mountain top installations, where utility regulation is generally poor.

To extend tube life, some engineers leave the filaments on at all times, not shutting down at sign-off. If the sign-off period is three hours or less, this practice can often be beneficial. Filament voltage regulation is a must in such situations, because the primary line voltages may vary substantially from the carrier-on to carrier-off value.

By accurately managing the PA filament voltage, you can extend tube life considerably, sometimes to twice the normal life expectancy. For maximum tube life, operate the filament at its full-rated voltage for the first 200 hours. After this burn-in period, reduce the filament voltage—by about a tenth of a volt per step—until power output begins to fall (FM transmitters) or until distortion begins to increase (AM transmitters).

When the emissions floor has been reached, raise the filament voltage about two tenths of a volt. Long-term operation at this voltage can result in a substantial extension in the usable life of the tube. In any event, do not operate the tube with a filament voltage that is at or below 90% of normal. Some tube manufacturers put the minimum level at 95%. At regular intervals, about every three months, check the filament voltage and increase it if power output begins to fall or distortion begins to rise. The filament voltage should never be increased to more than 105% of normal.

When it becomes necessary to boost filament voltage to more than 103%, it's time to order another tube. If you replace the tube while it still has some life remaining, the station will have a standby device that will perform well as a spare.

Check the filament current when the tube is first installed, and at annual intervals thereafter to assure that the filament draws the desired current. Tubes have failed early because of an open filament bar that would have been discovered in warranty if a current check had been made on installation.

For one week of each year of tube operation, run the filament at full-rated voltage. This will operate the getter and clean the tube of gas.

Allow adequate cooling time before turning off transmitter blowers. The metal-to-glass or ceramic seals are under the greatest stress just after system shut down.

Filament voltage supplies should be soft. Make sure that inrush current to the filament is limited by some means.

Why tubes wear out

A tube wears out when the filament emission is inadequate for full power output or acceptable distortion levels. Three primary factors determine the number of hours a tube will operate before reaching this condition: The amount of carbon originally processed into the filament, the quality of the tube vacuum and the filament temperature.

The maximum amount of carbon that can be burned into the filament assembly is limited by the increased fragility that results from high carbon processing levels. The carbon concentration is also limited by the reduction in filament temperature below the level required for adequate emission at the rated filament voltage that occurs with high carbon percentages.

The residual vacuum level affects tube life because the decarbonization rate (the rate at which carbon is burned out of the filament assembly) is a function of the partial pressures of the active gases, primarily oxygen compounds, reacting with the carbon. Good vacuum processing and proper gettering in the tube results in the lowest residual gas levels.

The decarburization rate is closely related to the filament operating temperature. This temperature is determined by the power to the filament and, therefore, is controllable by proper filament voltage management.

These various factors taken together determine the wear-out rate of a tube. Catastrophic failures because of interelectrode shorts or failure of the vacuum envelope are considered abnormal and are usually the result of some external influence.

TUNING UP FOR EFFECIENCY

There are probably as many ways to tune the PA stage of a transmitter as there are types of transmitters. Experience is the best teacher when it comes to adjusting a transmitter for peak efficiency and performance. There are compromises between various operating parameters. Some engineers follow the tuning procedures contained in the transmitter instruction manual to the letter. Others never open the manual, preferring to tune according to their own methods.

Whatever method you use, document the operating parameters and procedures for future reference—yours and your successor's. Do not rely on memory for a listing of the typical operating limits of the system. Write down the readings and post them at the transmitter building. If you are out of town one day and someone else has to service the transmitter, the list will be invaluable.

The factory service department can be an excellent source for information about tuning your particular transmitter. Many times the factory can give you pointers on how to simplify the tuning process, or what interaction of adjustments may be expected. Whatever you learn from conversations with the factory, write it down. Again, a written record will help you and your successor. Table 1 shows a typical tuning procedure for an FM transmitter.

PA tuning adjustment

- Unload the transmitter (switch the loading control to lower) to produce a PA screen current of 400mA to 600mA.
- Peak the PA screen current with the plate-tuning control.
- Maintain screen current at or below 600mA by adjusting the loading control (switch it to raise.)
- Position the plate-tuning control in the center of travel by moving the coarse tune shorting plane up or down as needed. If the screen current peak is reached near the raise end of plate tune travel, raise the shorting plane slightly. If the peak is reached near the lower end of travel, lower the plane slightly.
- After the screen current has been peaked, adjust the loading control for maximum power output and minimum synchronous AM.
- Peak the driver screen current with C37.
- The driver screen peak should coincide with PA screen peak and PA grid peak. Driver screen peak should also coincide with a dip in the left and right driver cathode currents.

Table 1. A sample documented transmitter tuning procedure. Note in your listing of tuning steps the side effects of various actions.

The actual procedures will vary, of course, from transmitter to transmitter. But, if the particular tuning characteristics of the unit are documented in a detailed manner, future repair work is often simplified. This record can be of great value to an engineer who is fortunate enough to have a reliable transmitter that does not require regular service. Many of the tuning tips learned during the last service session may be forgotten by the time transmitter work must be performed again.

When to tune

Tuning can be affected by any number of changes in the PA stage. Replacing the final tube in an AM transmitter usually does not significantly change the stage tuning, although you should go through the tuning procedure just to be sure. Replacing a tube in an FM transmitter, on the other hand, can significantly alter stage tuning. At higher frequencies, normal tolerances and variations in tube construction result in changes in element capacitance and inductance. Likewise, replacing a component in the PA stage may cause tuning changes because of normal device tolerances. Whenever you replace a component in a transmitter RF stage, run through the complete tuning procedure.

One of the primary objectives of transmitter tuning is stability. Avoid tuning positions that do not provide stable operation. Adjust for broad peaks or dips, as required. The transmitter should be stable from a cold startup to normal operating temperature. Readings should not vary after the first few minutes of operation.

Adjust tuning not only for peak efficiency, but also for peak performance. These two elements of transmitter operation, unfortunately, do not always coincide. Trade-offs must sometimes be made in order to ensure proper operation of the system. For example, FM transmitter loading can be critical to wide system bandwidth and low synchronous AM. Loading beyond the point required for peak efficiency must often be used to broaden cavity bandwidth. Heavy loading lowers the PA plate impedance and cavity Q. A low Q also reduces RF circulating currents in the cavity.

Because of the interdependence of transmitter tuning and system performance, the tuning procedures outlined in the instruction manual should be carefully considered. There's nothing wrong with improving on the factory's recommended procedures—just as long as you don't create any new problems in the process.

PREVENTING FAILURES

The sections of a transmitter most vulnerable to failure are those exposed to the outside world: The ac-to-dc power supplies and RF output stage. These circuits are subject to high energy surges from lightning and other sources. For this reason, particular attention must be given to the dc power supplies—especially the high voltage plate supply—and the PA stage. The RF output circuits must also deal with load mismatch problems.

The voltage standing wave ratio (VSWR) of an antenna and its transmission line is a vital parameter that has a considerable effect on the performance and reliability of a transmission system. VSWR is a measure of the amount of power reflected back to the transmitter because of an antenna and/or transmission line mismatch. (See Figure 3 for calculation data.) A mismatched or defective transmission system will result in a high degree of reflected power, or a higher VSWR.

Common practice in FM applications calls for a VSWR of 1.1:1 as the maximum level within the transmission channel that can be tolerated without degrading the quality of the on-air signal. When power is reflected back to the transmitter, it causes the RF output stage to look into a mismatched load with unpredictable phase and impedance characteristics.

Because of the reflective nature of VSWR on a transmission system, the longer the transmission line (assuming the reflection is originating at the antenna), the more severe the problem may be for a given VSWR. A longer line means that reflected power seen at the RF output stage has greater time (phase) delays, increasing the reactive nature of the load.

The effects of transmission line length vary depending on the service. For example, the crosstalk performance of an FM transmission system can be degraded because of a long line. It has been suggested that the maximum VSWR for a system with up to 100 meters (328 feet) of transmission line should be below 1.1:1 for top performance. Systems with lines from 100 to 200 meters should have a VSWR of at least 1.08:1 for equally good performance in FM broadcasting.

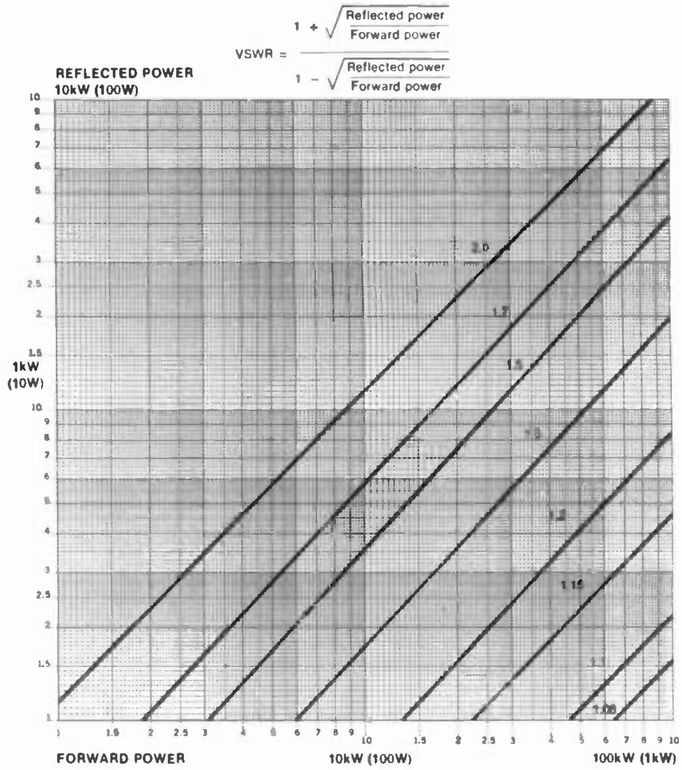


Figure 3. A graph that can be used for determining the VSWR of a transmission system. For low-power operation, use the values in parenthesis.

VSWR is affected not only by the rating of the antenna and transmission line as individual units, but also by the combination of the two as a system. The worst-case system VSWR equals the antenna VSWR multiplied by the transmission line VSWR. For example, if an antenna with a VSWR of 1.05:1 is connected to a line with a VSWR of 1.05:1, the resultant worst-case system VSWR would be 1.1025:1.

Given the right set of conditions, an interesting phenomenon can occur in which the VSWR of the antenna can cancel the transmission line VSWR, resulting in a perfect 1:1 match. The determining factors for this condition are the point of origin of the antenna VSWR, the length of transmission line and the observation point.

The effects of modulation

The VSWR of a transmission system is a function of frequency and changes with carrier modulation. This change may be large or small, but it will occur to some extent. The cause can be traced to the frequency dependance of the VSWR of the antenna (and to a much lesser extent the transmission line), as demonstrated in Figure 4.

Although this plot—showing VSWR-vs.-frequency for a common FM antenna—is good, notice that with no modulation the system VSWR is one figure. VSWR measurements are different with positive modulation (carrier plus modulation) and negative modulation (carrier minus modulation).

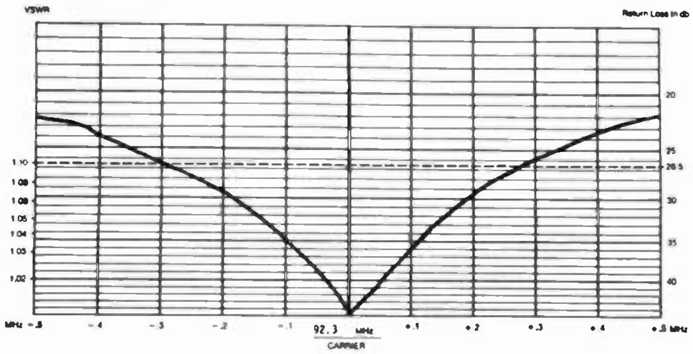


Figure 4. The measured preformance of a single-channel FM antenna (tuned to 92.3MHz). This antenna — a 10-bay circularly polarized unit — gives a VSWR of below 1.1:1 over a frequency range of nearly ± 300kHz.

VSWR is further complicated because power reflected back to the transmitter from the antenna may not come from a single point, but instead from a number of different points. One reflection might be caused by the antenna-matching unit, another by various flanges in the line and a third by a part of the antenna system that has been damaged. Because these reflection points are different lengths from the transmitter PA plate, a variety of standing waves can be generated along the line, varying with modulating frequency.

Energy reflected back to the transmitter from the antenna is not all lost. A small percentage of the energy is turned into heat, but the majority of it is radiated by the antenna, delayed in time by the length of the transmission line.

In order to maintain low VSWR, service the transmission line and antenna system regularly. Inspect the antenna elements, interconnecting cables, impedance transformers and support braces at least one each year. Falling ice can often damage FM antenna elements if proper precautions are not taken.

Icing on the elements of an FM antenna will degrade the antenna VSWR because the ice lowers the frequency of the electrical resonance of the antenna. Two methods are commonly used to prevent a buildup of ice on an antenna: Electrical de-icers and radomes.

Check AM antennas regularly for structural integrity. Because the tower itself is the radiator, each section of the structure should be bonded together for a good electrical contact. Clean base insulators and guy insulators (if used) as often as required. Obviously, it is only practical to clean the guy insulators near the tower and near the ground. Keep lightning ball gaps clean and properly adjusted.

Inspect the transmission line for signs of damage. Check supporting hardware and investigate any indication of abnormal heating of the line immediately. Keep a detailed record of VSWR in the station's maintenance log and investigate any increase above the norm.

High voltage power supply

The second section of a transmitter most vulnerable to damage because of outside influences is the high voltage plate power supply.

Figure 5 shows a high-reliability power supply of the type common in broadcast transmission equipment. Many transmitters use simpler designs, without some of the protection devices shown, but the principles of preventative maintenance are the same.

Thoroughly examine every component in the high-voltage power supply. Look for signs of leakage on the main filter capacitors (C1 and C2). Check all current-carrying meter/overload shunt resistors (R1-R3) for signs of overheating. Carefully examine the wiring throughout the power supply for loose connections. Examine the condition of the filter capacitor series resistors (R4 and R5), if used, for indications of overheating. Excessive current through these resistors could spell a pending failure in the associated filter capacitor. Examine the condition of the bleeder resistors (R6-R8). A failure in one of the bleeder resistors could result in a potentially dangerous situation for maintenance personnel by leaving the main power-supply capacitor (C2) charged after the removal of ac input power. Examine the plate voltage meter multiplier assemply (A1) for signs of resistor overheating. Replace any resistors that are discolored.

When changing components in the transmitter high-voltage power supply, be certain to use parts that meet with the approval of the manufacturer. Do not settle for a close match of a replacement part. Use the exact replacement part. This ensures that the component will work as intended and will fit in the space provided.

During each maintenance session (after all ac power has been removed from the unit), check all connections in the primary power system for tightness. Because of the high currents normally associated with the primary ac supply, secure connections are important. Inspect the system wiring for signs of overheating or insulation breakdown. Gently tug on wires terminated in crimp connectors to confirm tightness. Be careful, however, not to stress the connectors.

Inspect all power contactors for signs of wear. Experience will tell how often (if at all) the contact points of each contactor need to be cleaned. Whenever cleaning relays or contactors, be certain to use the proper tools. Cleaning kits are available that make the job quick and easy. Inspect the mechanical linkage of all power contactors to confirm proper operation. The contactor arm should move freely, without undue mechanical resistance.

Inspect vacuum contactors for free operation of their mechanical linkages and for indications of excessive dissipation at the contact points and metal-to-glass (or metal-to-ceramic) seals. Contactors, vacuum or conventional, should never run hot.

Just after signoff (and after all ac power has been removed) carefully check individual components in the primary ac supply for overheating. Most devices will run

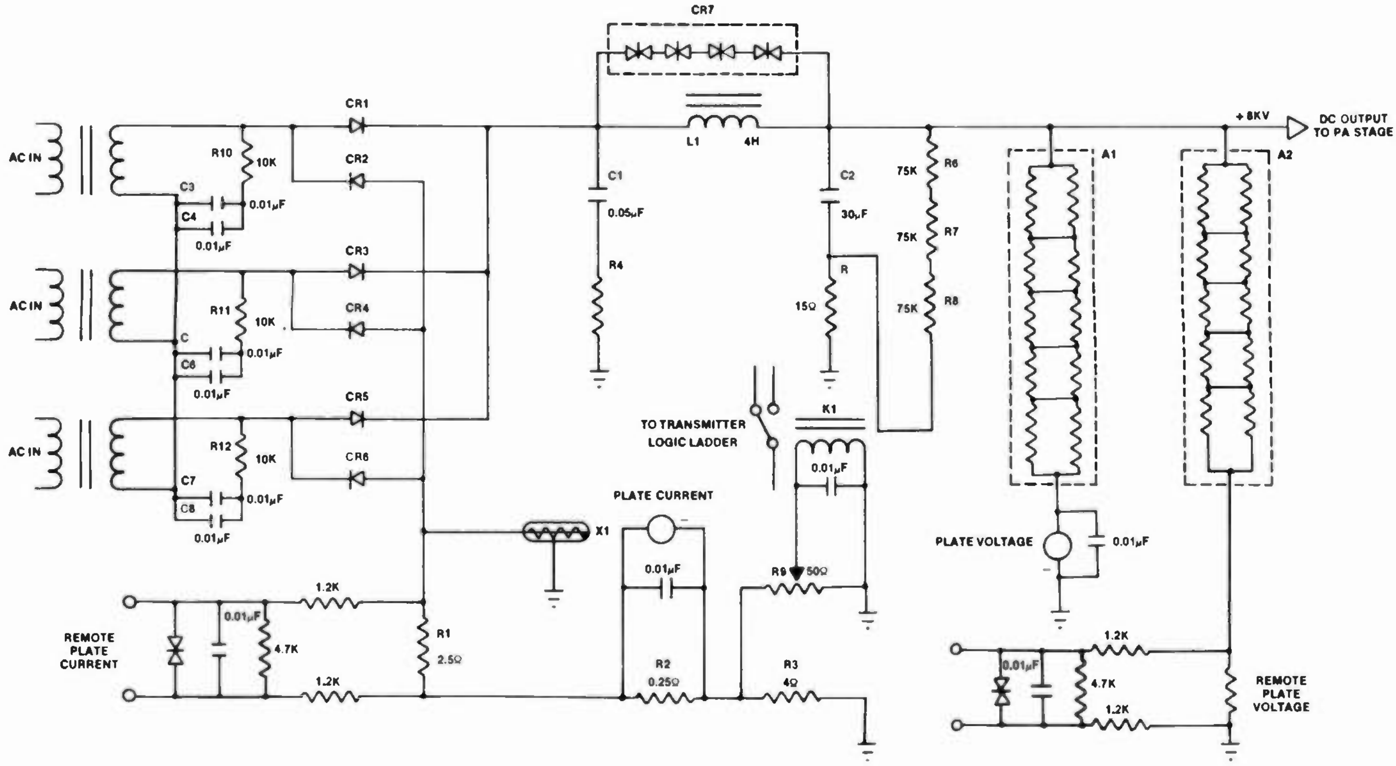


Figure 5 A common high-voltage transmitter power supply circuit design.

warm, but not hot, to the touch. Check vacuum and conventional contactors, transient suppression components, fuse holders and circuit breakers. Excessive heating of a circuit breaker can be an indication of impending failure. If appreciable heating is detected, contact the factory to ask whether this condition is normal. Replace any parts found to be defective or damaged.

Power transformers and reactors normally run hot to the touch. Check both the transformer frame and the individual windings. On a 3-phase transformer, each winding should produce about the same amount of heat. If one winding is found to run hotter than the other two, further investigation is warranted. Be careful when checking transformer heating because some units can run quite hot. For this reason, stations that sign off at night should run the transmitter for 15 minutes or more with filaments only to allow controlled cooling of the power transformers.

Check the mechanical operation of circuit breakers. They should provide a definite snap to the off position (all ac power should, of course, be removed for this test) and they should firmly reseat when reset. A circuit breaker that is difficult to reset should be replaced.

Metering

Proper metering is one of the best ways to prevent failures in broadcast transmission equipment. Accurate readings of plate voltage and current are fundamental to transmitter maintenance. Check each meter for proper mechanical and electrical operation. Replace any meter that sticks or will not zero.

With most transmitter plate current meters, accuracy of the reading can be verified by measuring the voltage drop across the shunt element (R2) and using Ohm's law to determine the actual current in the circuit. Be certain to take into consideration the effects of the meter coil itself. Contact the transmitter manufacturer for suggestions on how best to confirm the accuracy of the plate current meter.

The plate voltage meter can be checked for accuracy by using a high-voltage probe and a high-accuracy external voltmeter. Be extremely careful when making such a measurement. Follow instructions for use of the high-voltage probe to the letter. Do not defeat transmitter interlocks to make this measurement. Instead, fashion a secure connection to the point of measurement and route the meter cables carefully out of the transmitter. Never use common test leads to measure a voltage of more than 600V. Test lead insulation for most meters is not rated for use above 600V.

Overload sensor

The plate supply overload sensor in most transmitters is arranged as shown in Figure 5. An adjustable resistor—either a fixed resistor with a movable tap or a potentiometer—is used to set the sensitivity of the plate overload relay. Potentiometer-type adjustments should be checked periodically. Fixed-resistor-type adjustments rarely require additional attention. Most manufacturers have a chart or mathematical formula that may be used to determine the proper setting of the adjustment resistor (R9) by measuring the voltage across the overload relay coil (K1) and observing the operating plate current value.

Clean the overload relay contacts periodically to ensure proper operation. If any mechanical problems are encountered with a relay, replace it.

Transient disturbances

Different types and makes of transmitters have varying degrees of transient overvoltage protection. Given the experience of the computer industry, it is hard to overprotect electronic equipment from ac line disturbances.

Figure 5 shows surge suppression at two points in the power supply circuit. C1 and R4 make up an R/C snubber network that is effective in shunting high-energy, fast-rise time spikes that may appear at the output of the rectifier assembly (CR1-CR6). Similar R/C snubber networks (R10-R12 and C3-C8) are placed across the secondary windings of each section of the 3-phase power transformer. Any signs of resistor overheating or capacitor failure are an indication of excessive transient activity on the ac power line. Transient disturbances should be suppressed before the ac input point of the transmitter.

Assembly CR7 is a surge suppression device that should be given careful attention during each maintenance session. CR7 is typically a selenium thyrector assembly that is essentially inactive until the voltage across the device exceeds a predetermined level. At the trip point, the device will break over into a conducting state, shunting the transient overvoltage.

CR7 is placed in parallel with L1 to prevent damage to other components in the transmitter in the event of a loss of RF excitation to the final stage. A sudden drop in excitation will cause the stored energy of L1 to be discharged into the power supply and PA circuits in the form of a high-potential pulse. The results of this transient can be damaged or destroyed filter, feedthrough or bypass capacitors, damaged wiring or PA tube arcing. CR7 prevents this by dissipating the stored energy in L1 as heat.

Discoloration or other outward signs of damage to CR7 should be investigated. Such an occurrence could indicate a problem in the exciter or IPA stage of the transmitter. Immediately replace CR7 if it appears to have been stressed.

Check spark gap surge suppressor X1 periodically for signs of overheating. X1 is designed to prevent damage to circuit wiring in the event that one of the meter/overload shunt resistors (R1-R3) opens. Because the spark gap device is nearly impossible to accurately test in the field and is relatively inexpensive, it is an advisable precautionary measure to replace the component every few years.

Single phasing

Any transmitter using a 3-phase ac power supply is subject to the problem of single-phasing, the loss of one of the three wires from the primary ac power distribution source. Single phasing is usually a utility company problem, caused by a downed line or a blown pole-mounted fuse.

The loss of one leg of a 3-phase line results in a particularly dangerous situation for 3-phase motors, which will overheat and sometimes fail. Figure 6 shows a simple protection scheme that has been used to protect transmission equipment from damage caused by single phasing. Although at first glance the system looks as if

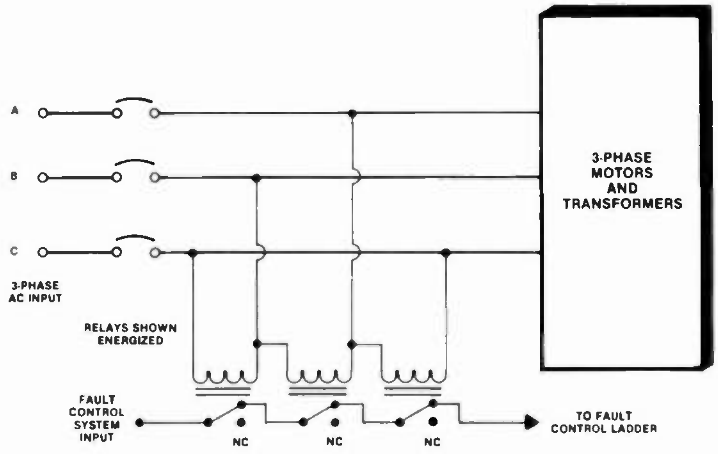


Figure 6. Using relays for utility company ac phase loss protection.

it would easily handle the job, operational problems can result.

The loss of one leg of a 3-phase line rarely results in zero (or near-zero) voltages in the legs associated with the problem line. Instead, a combination of leakage currents caused by regeneration of the missing legs in inductive loads and the system load distribution usually results in voltages of some sort on the fault legs of the 3-phase line.

It is possible, for example, to have phase-to-phase voltages of 220V, 185V and 95V on the legs of a 3-phase, 208V ac line experiencing a single-phasing problem. These voltages often change, depending upon the equipment turned on at the transmitter site.

Integrated circuit technology has provided a cost-effective solution to this common design problem in medium- and high-power transmitting equipment. Phase-loss protection modules are available from at least one manufacturer that provide a contact closure when voltages of proper magnitude and phase are present on the monitored line. The relay contacts can be wired into the logic control ladder of the transmitter to prevent the application of primary ac power during a single-phasing condition.

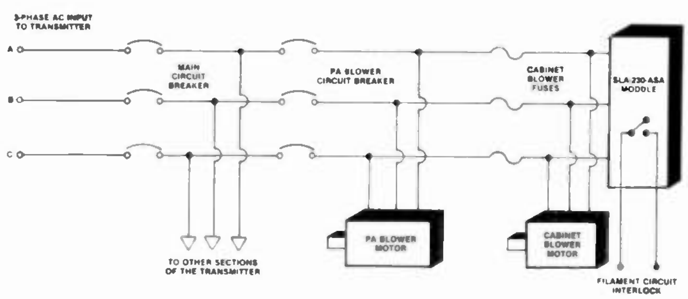


Figure 7. A high-performance single-phasing protection circuit using a phase-loss module as the sensor. (Note: The device shown in this diagram is a model SLA-230-ASA phase-loss protector module manufactured by Diversified Electronics of Evansville, IN. Units performing comparable functions are also available from other manufacturers.)

Figure 7 shows the recommended connection method. Note that the input to the phase monitor module is taken from the final set of 3-phase blower motor fuses. In this way, any failure inside the transmitter that might result in a single-phasing condition is taken into account. Because 3-phase motors are most sensitive to single-phasing faults, the relay interlock is tied into the filament circuit logic ladder.

The phase-loss protector shown in Figure 7 includes a sensitivity adjustment for various nominal line voltages. The unit is small and relatively inexpensive (about $55).

Modifications and updates

If you experience a problem, examine what can be done to prevent the failure from occurring again. You can often avoid a repeat by installing various protection devices or consulting the factory for updates to your equipment. If the transmitter is several years old, the factory service department can detail any changes that may have been made in the unit to provide more reliable operation. Many of these modifications are minor and can be incorporated into older models with little cost or effort.

These modifications could include items such as changing a variable capacitor in a critical tuning stage to a vacuum variable for more stability; installing additional filtering in the high voltage power supply; replacing older technology transistorized circuit boards with newer IC and power semiconductor PCBs; improving the overload protection circuitry; or adding protection against transient overvoltages in various stages of the transmitter.

Temperature control

The environment in which the transmitter is operated is an important factor in improving system reliability. Proper temperature control must be provided for the transmitter to prevent thermal fatigue in semiconductor components and shortened life in vacuum tubes. Thermal fatigue occurs in semiconductor power devices because of differential expansion and contraction of the individual parts of the device itself (the silicon pellet, solder and case.) Some semiconductor manufacturers have been able to predict the actual number of thermal cycles that their devices will be able to withstand without failure.

For example, RCA's RC-5258 NPN power transistor has a life expectancy of nearly 2 million thermal cycles from ambient temperature to 50°C above ambient. At 100°C above ambient, however, the number of thermal cycles possible before device failure drops to about 40,000. At 150°C above ambient, the number of thermal cycles is only 800. Removing heat is vital to the long-term survival of semiconductor devices.

Transmitter room cooling requirements vary considerably from one location to another, but some general statements on cooling apply to all installations.

A transmitter greater than 1kW must have its exhaust ducted to the outside whenever the outside temperature is more than 50°F. Transmitter buildings must be equipped with refrigerated air conditioning units when the outside temperature is higher than 80°F. The exact amount of cooling capacity needed is subject to a variety of factors, such as actual transmitter efficiency, thermal insulation of the building itself and size of the transmitter room. Here again, though, some generalizations can be made. Radio transmitters up to and including 5kW usually can be cooled (if the exhaust is efficiently ducted outside) by a 10,000 BTU air conditioner. 10kW installations should have 17,500 BTU of air conditioning and 20kW plants should be provided with at least 25,000 BTU of air conditioning. Larger installations should be studied by an air conditioning expert.

Figure 8 shows a typical 20kW FM transmitter plant installation. The building is oriented so that the cooling activity of the blowers is aided by normal wind currents during the summer months. Air brought in from the outside for cooling is well-filtered in a hooded air intake assembly that holds several filter panels.

This layout includes two air conditioners, one 15,000 BTU and the other 10,000 BTU. The thermostat for the smaller unit is set for slightly higher sensitivity than the larger air conditioner, allowing small temperature increases to be handled more economically.

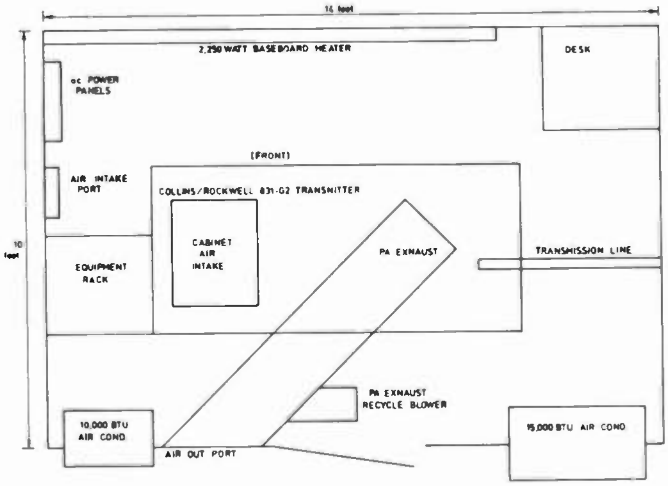


Figure 8. A typical heating and cooling arrangement for a 20kW FM transmitter installation. Ducting of PA exhaust air should be arranged so that it offers minimum resistance to air flow. Ideally, the transmitter PA exhaust would go straight up through the roof of the building.

It is important to keep the transmitter room warm during the winter, as well as cool during the summer. Provisions should be made for heaters and PA exhaust recycling blowers. A transmitter that runs 24 hours a day should not need additional heating equipment, but stations that sign off for several hours during the night should be equipped with electric room heaters (baseboard types, for example) to keep the room temperature above 50°.

PA exhaust recycling can be accomplished by using a thermostat, some relay logic and a solenoid-operated register or electric blower. By controlling the room temperature to between 60°F and 70°F, tube and component life will be improved substantially.

Once the transmitter is clean, keeping it that way for long periods of time may require improving the air filtering system. Most filters are inadequate to keep out very small dirt particles (microdust), which can become a serious problem in an unusually dirty environment. Microdust also can become a problem in a relatively clean environment after a number of years of operation.

In addition to providing a well-filtered air intake port for the transmitter building, an additional air filter can be placed in front of the normal transmitter filter assembly. Computer system filter panels can be secured to the air intake port to provide additional protection. With the extra filter in place, it generally is necessary only to replace or clean the outer filter panel. The transmitter's integral filter assembly will stay clean, eliminating the work and problems associated with pulling the filter assembly out while the transmitter is operating. Be certain that the addition of supplemental filtering does not restrict airflow into the transmitter.

SAFETY CONSIDERATIONS

Any work on a transmitter should be approached with extreme caution. High voltages that exist in a transmitter can be lethal. Such work should be performed only when a second engineer is in the room.

Perform work inside the transmitter only after all ac power has been removed and after all capacitors have been discharged using the ground stick provided with the transmitter. Remove primary power from the unit by tripping the appropriate power distribution circuit breakers at the transmitter building. Do not rely on internal contactors or SCRs to remove all dangerous ac.

Be familiar with first aid treatment for electrical shock and burns. Always keep a first aid kit on hand at the transmitter site.

Do not defeat protective interlock circuits. Although defeating an access panel interlock switch may save work time, the consequences can be tragic.

IN CONCLUSION

Regardless of the age or type of transmitter, an aggressive maintenance program easily will pay for itself in reduced downtime and failures, and increased performance.

Transmitter failures can damage productivity, station image and advertising revenues. When that's at stake, good maintenance is good business.

Acknowledgments:

The author wishes to thank the following individuals who helped in the preparation of this paper:

- Gil Housewright and Mark Fryer of Broadcast Electronics
- Dave May and Terry Bonkowski of Harris Broadcast
- Dave Chenoweth and Ken Branton of Continental Electronics

HOW RECENT CCIR TECHNICAL DECISIONS AFFECT U.S. AM & FM BROADCASTING

Ralph H. Justus
Department of Science & Technology
National Association of Broadcasters
Washington, District of Columbia

INTRODUCTION

Recent decisions of the International Radio Consultative Committee (CCIR) , the permanent technical arm of the International Telecommunications Union (ITU) will affect the audio quality, the access to spectrum, and in some cases the way current spectrum is used for AM and FM broadcast operations in the United States. This paper describes some of the decisions made at the Final Meetings of the CCIR Study Group 10 -- Sound Broadcasting, held in Geneva, October 16-November 1, 1985, and discusses the implications those decision hold for U.S. broadcasters.

CCIR Activities and Organization

The CCIR is the standing technical committee of the ITU and performs the technical studies which form the bases of negotiations at World and Regional Administrative Radio Conferences (WARC's and RARC's) held by the ITU.[1] The CCIR consolidates the results of work conducted over a four-year cycle into Study Programs, Reports and Recommendations. Of particular concern are its Recommendations, statements of agreed system characteristics, which are tantamount to international standards. Two other major activities of CCIR concern studies on spectrum utilization, and providing technical assistance to ITU member countries with handbooks and special reports. Outside of its normal cycle of Interim and Final Meetings, CCIR gathers technical information through meetings of Interim Working Parties (IWP's) which study specific problem areas.

The most recent Final Meetings of CCIR Study Group 10 (Sound Broadcasting) were held in Geneva from October 16-November 1, 1985. The output of these meetings now goes before a Plenary Assembly in May, 1986 for final approval and subsequent publication and distribution.

Major Decisions of Study Group 10 Final Meetings Concerning AM and FM Broadcasting

1. A new Recommendation was discussed concerning the reduction of the necessary bandwidth of emission for AM broadcasting to more closely match the narrow bandwidth of AM receivers. Such an approach would provide more available AM channels, but at the cost of limiting the available audio-frequency bandwidth. While this may be appropriate for European systems -- where smaller channels are used -- it would be inconsistent with the U.S. developments in AM Improvement -- where the production of wideband receivers is seen as a critical element of improving AM broadcast sound quality. After considerable discussion, the approved Recommendation reads:

> ...that where required for optimizing spectrum utilization or for providing an improved overall system AF response, the overall system can be optimized and planning problems can be reduced by taking advantage of the existing knowledge of the interrelationship between system bandwidth, channel spacing and adjacent channel protection ratio...[2]

and refers to an existing report. This end result was considered acceptable and provides the lee-way for some European countries to eventually "squeeze in" more channels, while at the same time providing for the U.S. desire to maximize overall system quality.

2. Interim Working Party 10/7 is continuing its work to develop performance specifications for reference AM and FM

receivers, which will subsequently be used for planning (allocation) purposes. This IWP is seeking to characterize specifications on antennas, sensitivity, selectivity, large signal performance, automatic frequency control, intermediate frequency, and local oscillator radiation. The U.S. is now participating actively in this IWP and hopes to provide it with updated information as our domestic AM improvement activities continue.

3. FM compatibility with the aeronautical mobile service (in 108-137 MHz) has been studied extensively by a Joint Interim Working Party (JIWP 8-10/1), with particular concern in Region 1 (Europe and Africa) where the FM band has been extend from 100 MHz to 108 MHz. This JIWP continues its studies which may seek world-wide compatibility standards. This matter is also being studied by the Federal Communications Commission in its outstanding MM Docket No. 85-108, which addresses a number of testing programs yet to be concluded. The U.S. will have considerable input to this JIWP at its subsequent meetings.

Related to this issue was a proposed Recommendation to modify the International Radio Regulations to specify a more stringent spurious emission limitation for FM broadcast stations. One element of this JIWP's Report to a Region 1 Planning Conference was a spurious emission limit of 85 dB. (The U.S. maximum requirement is 80 dB.) That value was adopted by the Region 1 Conference, and it was sought to make it a world-wide requirement. If adopted, this would mean that, eventually, all U.S. FM broadcast stations would be required to retrofit their transmitters with filters necessary to comply. After considerable U.S. opposition to this proposal, this proposed Recommendation was withdrawn.

4. The Radio Data System (RDS) proposed by the European Broadcasting Union (and described more fully elsewhere in these Proceedings by Kopitz) was adopted as a new Recommendation. RDS is a system for automatic tuning of receivers, program identification, and other applications (e.g. data tranmissions), which uses a specific protocol on a 57 KHz FM subcarrier.

Recent concerns have been raised in the U.S. regarding compatibility of RDS with other subcarriers now in use or being tested. Further, it is unclear what regulatory weight can be given domestically to a CCIR RDS Recommendation. Upon adoption by the Plenary Assembly in May, this would have the status of an international standard. Yet, FM subcarrier operations have been deregulated by the FCC.

5. Finally, a number of Recommendations were approved concerning audio frequency characteristics of sound broadcasting. First, a recommended sampling frequency for digital encoding of sound signals of 48 KHz, with a maximum tolerance of 1 part in 10^5, without using preemphasis, was adopted. Second, the Audio Engineering Society-developed standard for a digital audio interface for broadcasting studios was adopted. And third, audio quality parameters were adopted for the performance of a high quality sound-program transmission chain. These Recommendations are a very significant step in bringing digital audio studio of age.

Implications for U.S. Broadcasters

A recommended reduction of AM bandwidth of emissions to match that of narrowband receivers would be devastating to our domestic AM technical improvement efforts. Similarly, an AM reference receiver used for international allocations planning could give rise to a second-rate service if the performance specifications of that receiver does not incorporate current trends in receiver technology.

Conversely, the audio quality parameters for transmission chains and the digital audio standards will benefit all broadcasters as these Recommendations are reflected in new equipment.

Domestic FM broadcast transmitter siting restrictions are already being considered by the FCC to avoid potential interference to aeronautical radionavigation. However, those restrictions are an order of magnitude less restrictive than those proposed by JIWP 8-10/1. Further study is ongoing in this area, and world-wide compatibility criteria may yet evolve. Yet how such criteria would be implemented internationally remains to be seen.

It is unclear exactly what status a CCIR-adopted Recommendation enjoys domestically. In some countries they have the weight of the law, however in other countries they are recognized, as the word implies, simply as "recommendations". The extent of the U.S. treaty obligation to the ITU has yet to be definitively applied to CCIR Recommendations.

Whatever its regulatory status is now, there is a window of opportunity in the CCIR process that broadcasters may yet use to their advantage. With the current philosophy of the FCC to not develop, or even adopt, technical standards -- preferring to leave this function to "marketplace forces" -- there may be an alternative avenue (the CCIR Recommendation) to pursue technical standards development. Questions remain on this approach, such as: Would the FCC, as a member of the U.S. CCIR National Committee, endorse an industry-developed standard as a proposed CCIR Recommendation, while at the same time refuse to adopt such a standard domestically? Regardless of the answer to this question, the CCIR forum may offer some relief and needs further study.

U.S. Participation in CCIR

CCIR is a unique technical forum of experts. It touches upon all forms of telecommunications. The advantages to broadcasters of participation are easily understood when one examines the outcome of agreements (such as NARBA, Rio, and bilaterals between the U.S. and Canada and Mexico, as well as the outcome of the Region 2 AM Band Expansion RARC of April, 1986) which define the opportunities for domestic broadcasting. If evidence of this advantage were needed, one has only to look at the extent of commitment now being given to CCIR activities by NAB, the major U.S. networks and by manufacturers. The State Department has the administrative machinery in place with its reorganized Bureau of International Communications and Information Policy which oversees U.S. participation in CCIR. It is now left to broadcasters to participate for the betterment of our industry. This will happen if an appreciation of the results of CCIR activities can be understood clearly. Participation in CCIR does not directly result in a bottom line profit. However, as Ambassador Diana Lady Dougan recently expressed, "we need to get the CEO's past a third-quarter-balance mentality," and look toward the long-term future of our industry.

END NOTES

[1]For a more complete discussion of the ITU and its structure, the reader is referred to "How International Spectrum Decisions Affect Broadcasting in the United States," by A. James Ebel, NAB Proceedings of the 37th Annual Broadcast Engineering Conference, 1983.

[2]Document 10/346, Working Group 10-A, Draft New Recommendation, "Necessary Bandwidth of Emission in LF, MF and HF Broadcasting."

SOLUTIONS TO THE FM RADIO/AERONAUTICAL INTERFERENCE PROBLEM

John F. X. Browne, P.E.
John F. X. Browne & Associates, P.C.
Bloomfield Hills, Michigan

Abstract

The FCC has instituted a Rule Making Proceeding to study the implementation of rules governing the operation of FM broadcast stations designed to protect aeronautical navigation facilities. The need for these regulations has been created by claims made by the FAA that high power broadcast facilities--particularly FM--are creating havoc and hazardous situations because of interference to airborne communications and navigation receivers. The FAA has adopted ad-hoc standards which it is believed are overly conservative and which would--if applied universally--have the effect of seriously limiting the power and siting of FM broadcast facilities. This paper discusses the issues involved and proposes alternative approaches to the problem of compatibility between the services.

Recently, some broadcasters have had the unfortunate experience of receiving from the FAA a notice of determination of Hazard to Air Navigation--or the threat of receipt of such a determination--on the basis that their proposed facilities would create an electromagnetic interference problem for aeronautical services. These situations have arisen where the station--and, in particular, an FM station--was seeking to increase power even without a change in site or tower height--the "traditional" areas where the FAA exercised its authority to disapprove broadcast facilities. Similarly, UHF television broadcasters have also received notices from the FAA that their proposed facilities could cause interference to FAA aeronautical facilities, particularly ground based receivers, in the VHF bands!

There are cases on record where FM broadcast stations have been ordered to greatly reduce power or cease operation because their signals have, allegedly, caused interference to airborne receivers. The typical situation would come to light when a station's programming--like readily identifiable rock music--would be reported as being heard by pilots on a tower communications frequency--sometimes severe enough to interfere with air traffic control communications. These incidents, and others, have caused the FAA and the FCC to voice concern over the problems and to propose, through the Rule Making process, various methods for identifying, calculating and dealing with them. The FAA is proposing major revisions to Part 77 of the FAR's - dealing with Objects Affecting Use of the Navigable Airspace--which heretofore dealt primarily with physical obstructions--to include notification to the Administration of proposed electromagnetic changes in the facilities even though no physical change in the supporting antenna structure is contemplated.

The FCC, on its own motion, instituted a Rule Making Proceeding, (MM Docket 85-108), which proposes to adopt Rules requiring studies of potential interference to aeronautical facilities from proposed broadcast facilities--either new or modified--and which would set thresholds for determining the existence of theoretical interference. It is interesting to note that the FCC--in the NPRM--has limited its primary concern to FM facilities because it believes that other broadcast services have low potentials for causing interference. The FAA, on the other hand, would include TV broadcast facilities within the scope of the proposed Part 77 revisions.

The FCC's proposition to limit concern to FM facilities is supported by various studies and analyses that demonstrate that the aeronautical services have a great immunity to TV signals because of factors such as spectral separations between TV and aeronautical bands, out-of-band performance characteristics of TV transmitters, and the rejection characteristics of aeronautical receiving systems at TV frequencies. This morning's discussion will, therefore, be generally limited to the potential problems between FM broadcast facilities and various aeronautical services.

We are all aware that the FM broadcast band extends from 88 MHz to 108 MHz. Perhaps unfortunately, the VHF aeronautical band starts at 108 MHz and extends to 118 MHz for navigational facilities and to 136 MHz for communications facilities. In addition, there are government/military facilities in the band 136 MHz to 144 MHz and 225 MHz to 400 MHz.

The types of interference have been classified by both the FAA and FCC as falling into two general categories, that is, radiated interference in the aeronautical band and interference that is caused by radiation on frequencies outside of the aeronautical bands. The first category includes radiated intermodulation or other spurious products from a broadcast station; such as from multiple station antenna sites or community antennas and interference due to out-of-band emissions from broadcast stations which fall in the aeronautical bands. Interference caused by signals outside of the aeronautical band which generate intermodulation in the receiver and interference which results from desensitization of the receiver by strong signals are in the second category.

There is a great deal of disagreement in the industry as to what conditions will cause the interference effects: that is, what combinations of power, frequency, and receiver characteristics will result in the creation of one or more types of interference. Studies conducted by the FAA in 1978, - The International Civil Aviation Organization, - The Radio Technical Commission on Aeronautics, and the CCIR all arrived at similar but different conclusions. However, one underlying fact in all studies is that the characteristics of the airborne navigation and communications receivers are quite variable and, to a large measure, they are the controlling factors on perceived interference effects.

Much of the disagreement today centers on this issue: What are the characteristics of the ideal, the median, and the worst case airborne receiver and which should be used for the reference calculation of potential interference? A theme which can be found in all studies and reports is that improved aeronautical receiver equipment would all but eliminate the problems. However, the FAA has apparently taken the approach that the receiver problem can only be resolved on a long-term basis because it will take many years to phase out the old equipment. The ICAO proposes new receiver standards to take effect by 1998...yes, 1998. Therefore, the short-term solution must lie with placing restrictions on broadcast stations according to these bodies.

Since it is most likely that interference from FM stations will occur in the lower portion of the aeronautical band (108-118 MHz) because of its proximity to the FM broadcast band, the FCC has proposed to limit aeronautical interference concerns to this portion of the band. In fact, some aspects of the FCC's proposal would only consider effects on aeronautical frequencies between 108 and 112 MHz on the assumption that the communications frequencies above 118 MHz would be relatively immune and the frequencies between 112 MHz and 118 MHz are used only in the enroute phase of air navigation by aircraft at relatively high altitudes. While it is true that the band between 108 and 112 MHz is used primarily for terminal navigation and instrument landing systems, it is also true that some of the facilities such as terminal VOR's--VHF omnirange station--are also used in the low altitude airway system and that many standard VOR's (in the band between 112 MHz and 118 MHz) are also used for instrument approaches to airports and this position may require modification.

In any event, it appears that the greatest concern is over the impact of FM broadcast facilities on airborne navigation receivers.

As noted earlier, the characteristics of the actual receivers in use vary widely from high quality relatively immune airline equipment to obsolete equipment in older general aviation aircraft. The protection standards being proposed by the FAA and FCC differ. Factors such as the overall gain or loss of the assumed aircraft antenna system need further clarification because a 3 dB difference in this value is of great significance to a broadcaster attempting to site a new FM facility and a 3 dB factor from his perspective might mean the difference between operating with 50 kW or 100 kW.

It has also been determined that an outboard filter at the input of the VHF navigation receiver could achieve greatly improved same performance on most existing equipment. The FAA and the aviation industry do not agree that the addition of filters to existing equipment is a practical approach. Reasons cited include cost, performance, stability and effectiveness. It is our belief that these concerns are unfounded and, in cases where a particularly poor receiver design is subject to interference, it can in most cases be simply and economically retrofitted with such a filter. It should also be noted that most of the poorer airborne equipment will be found in older general aviation aircraft where the owner has not upgraded the equipment. Generally, because these aircraft are used solely for flight under visual conditions and visual flight miles and not under instrument conditions and requirements, the need for upgrading has not been apparent to the owner.

The standards used for assessing interference from FM stations will require that the interference areas be determined in relation to the service volumes of the FAA navigational facilities. The service volume is defined as the three-dimensional airspace in which an aircraft can be expected to use a navaid on an operational basis. These service volumes are quite large as shown in the diagrams for ILS and VOR facilities.

As mentioned earlier, one type of interference will generally be caused by spurious products generated within the transmitter. This type has been dubbed A-1 by the FAA/FCC. Even though they are attenuated in accordance with FCC requirements to a maximum of 80 dB, out of band emissions which could theoretically fall anywhere in the aeronautical bands, can cause interference to aeronautical service receivers. For example, a 100 kW Class C facility just barely meeting the 80 dB requirements would have to be located nearly 20 miles away from the service volume of the ILS facility to guarantee immunity from the interference according to the FCC. As the FCC has noted, reducing these spurs to -100 dB would reduce the separation requirements dramatically to a few miles. Because the FAA's terminal and enroute facility service volumes cover virtually the entire country--particularly east of the Mississippi--any new or modified high power FM station can have a problem finding a site which will satisfy the FAA requirements.

Type A2 interference is a transmitter generated problem generally restricted to cases where FM stations on 107.9 MHz cause problems for airborne navigation receiveers on 108.1 or 108.2 MHz. The first of these frequencies is allocated for ILS system localizers and the second for terminal VOR stations. (It is also noted that channels spaced 50 kHz from each of these frequencies are also available in the frequency plan.) Using the protection ratios proposed, a Class C station with 100 kW would have to be located over sixty miles from an ILS facility on 108.1 MHz. The VOR facility's signal would fare much better because of the greater frequency separation. An FCC study, however, reveals that the FAA has not assigned 108.1 to any civil ILS systems in the U.S. The Commission proposes, therefore, to coordinate these cases on an individual basis. TVOR facilities will still require protection, however.

Of more concern to broadcasters, at least insofar as the new regulations are concerned, will be receiver generated interference. The first kind of interference in this category is called B-1 and is 3rd order intermodulation generated in the receiver by the presence of two or three carriers, particularly where one of the signals is very strong and "triggers" an overload condition. Where the intermodulation product falls directly on the desired aeronautical frequency, it can render the receiver useless.

The FAA has adopted the so-called VENN diagram approach to analyzing the potential for interference. In this analysis the contours from FM stations corresponding to free space power levels as received by an isotropic antenna of -20 dBm for the prime signal and -30 dBm for the other signal or signals are drawn in relation to the aeronautical service volumes. The intersection of the prime contour will one or two off the other contours will, theoretically, define an area where interference will result.

B2 interference occurs when an aeronautical receiver is exposed to a strong FM signal which produces brute-force overload. The FAA defines an area described by a -10 dBm contour while the FCC proposes to protect the aeronautical facilities--again, primarily airborne navigational receivers--by specifying minimum distance criteria between FM stations above 104 MHz and aeronautical facility service volumes. These distances would range from 1 to 12 miles depending on FM frequency and power.

A study conducted by this firm under the auspices of the NAB evaluated the application of the proposed FAA criteria to the ILS approach facilities at nine existing major airports in the USA including:

New York Kennedy
Washington National
Detroit Metropolitan
Denver Stapleton
Miami International
Boeing Field/King County International
San Diego Lindbergh
Seattle Jackson International
St. Louis Lambert

For these studies, the characteristics of all licensed FM facilities were used. The results of the studies indicate 385 cases of interference at those airports. Except where a high power facility is located near the centerline of the approach course most cases of interference involve two or three station intermodulation products. The only conclusions that one can draw from these findings is that either the proposed standards are grossly overconservative or that virtually every major airport in the United States is being seriously affected by existing FM stations and operational safety is in serious jeopardy. Since we have not been able to identify any cases where operational use of these ILS facilities has been diminished or where the FAA has issued warnings to the pilots using these facilities (by Notices to Airmen or NOTAMS) that even the potential for a hazard or operational limitation exists, it can only be concluded that the proposed standards are grossly overconservative. For example, using FAA criteria, one of the most seriously impacted facilities would be the ILS serving Runway 21R at Detroit Metropolitan Airport. This is one of the most heavily used facilities at Detroit. Discussions with tower personnel, flight service station personnel and a review of NOTAMS reveal no cases of reported interference or published restrictions.

The impact of these restrictions, if adopted as proposed by either the FAA or FCC, would be to seriously limit site changes or changes in operating parameters of existing stations if those changes increased the predicted interference areas.

If the new receiver performance standards were assumed--or if "fixes" for actually impacted receivers could be effected--the predicted interference area would be reduced. The FCC proposes to use the better receiver performance since it is assumed that aircraft operating under IFR will have higher quality receivers.

The FCC proposes that the vertical pattern characteristics of FM antennas be considered in the interference analysis. A preliminary review indicates that this will affect only the situation where an FM facility is located on or near the centerline of NAVAID based approach. In actual practice, little is known about the typical FM antenna vertical pattern characteristics or side lobe energy beyond 10 or 15 degrees of the horizontal plane. It is known, however, that many FM arrays with one wavelength element spacings have very large lobes at plus or minus 90 degrees--a condition which will not help mitigate a problem interference calculation.

One final comment regarding the Rules as now proposed by the FCC. The Field Operations Bureau would be given authority to suspend operation of broadcast stations deemed to be causing aeronautical interference. Broadcasters should follow this rule making aspect closely as the "shut down" order could be based solely on alleged interference by the FAA. The FOB should be required to confirm existence of interference prior to ordering a station to suspend operation.

(As this paper goes to press, the FCC rule making procedure is still in process. Many organizations--including the NAB and AFCCE--have called for additional receiver testing and further study to be considered in a Notice of Further Rule Making. An update of the status of rule making will be provided at the time of paper presentation.)

A SYSTEMS APPROACH TO IMPROVING SUBCARRIER PERFORMANCE

Geoffrey N. Mendenhall, P.E.
Vice President-Engineering
Broadcast Electronics, Inc.
Quincy, Illinois

ABSTRACT

This technical paper is oriented toward helping the radio or TV station engineer better understand how each individual element in the transmission system affects subcarrier performance. By breaking the transmission system down into its individual parts, the contribution of each subsystem can be measured and specified into an overall error budget for the complete transmission system.

The following components affect subcarrier performance through the system:

1. SCA / SAP / PRO generator.
2. Stereo generator.
3. FM exciter.
4. Composite STL (when used).
5. All transmitter RF amplifiers.
6. Antenna system (including diplexers and combiners).
7. Multipath and other propagation phenomena.
8. Receiving antenna, IF passband, and demodulators.

This paper will concentrate on the components which are part of the transmission system.

Topics covered in this presentation are:

1. Basic theory of subcarrier transmission.
2. Spurious frequency components interfering with the subcarrier spectrum.
3. Stereo generator effects.
4. Baseband and STL requirements.
5. Effects of composite baseband processing.
6. FM modulator linearity requirements.
7. FM / Aural power amplifier bandwidth requirements.
8. Optimization of power amplifier tuning.
9. System test procedure and setup.
10. Subcarrier receiver characteristics.

The information in this paper is equally applicable to FM broadcast subcarriers or TV-MTS subcarriers.

INTRODUCTION

The recent de-regulation of broadcast subcarrier usage has spurred a new interest in using subcarriers for data transmission and paging services in addition to the more conventional audio services. FM and TV broadcast stations are permitted to "piggy-back" up to two additional audio or data channels on the main carrier of the station. Subcarriers added to FM broadcast stations are Subsidiary Communications Authorizations (SCA) while subcarriers added to a TV stations's aural carrier can be either a Secondary Audio Program (SAP) or a non-public channel for Professional use (PRO).

HOW SUBCARRIERS ARE ADDED TO THE BROADCAST SIGNAL

Subcarriers are added to the main broadcast FM or TV aural carrier by a technique called frequency domain multiplexing, which allows the additional subchannels to be separated from each other and from the main channel by use of specific frequency bands for each subchannel. In the case of an FM station broadcasting in stereo with two subcarriers, the frequencies typically used are 67kHz and 92kHz for the two subcarriers. The main channel and stereophonic information are transmitted in the frequency band extending from 30Hz to 53kHz while the subcarrier information is transmitted above this frequency range in a band extending from 54kHz to 99kHz. The subcarriers each modulate the main FM carrier by a maximum of 10% of the total modulation or about 20dB below main program levels. This means that the effective coverage of each subcarrier will not be as great as the main channel since the subcarrier does not have the full use of the transmitted power. The sum of all the different components being transmitted is called the composite baseband.

Each subcarrier is frequency modulated, which in turn, then frequency modulates the main transmitter carrier. This type of "FM on FM" system is not easy to analyze and fully understand. For example, the main carrier is typically deviating a constant plus and minus 7.5KHz (10% of the total carrier deviation) by a subcarrier while the subcarrier's frequency is itself being deviated up to plus and minus 6KHz by the audio or data being fed into the subcarrier modulator. Figure-1 depicts the "FM-ON-FM" system used for subcarrier transmission.

The key points to remember are that the deviation of the main carrier is dependent only on the level of the subcarrier and is not effected by the modulation applied to the subcarrier while the deviation of the subcarrier is dependent only on the modulation applied to the subcarrier and is not related to main channel deviation.

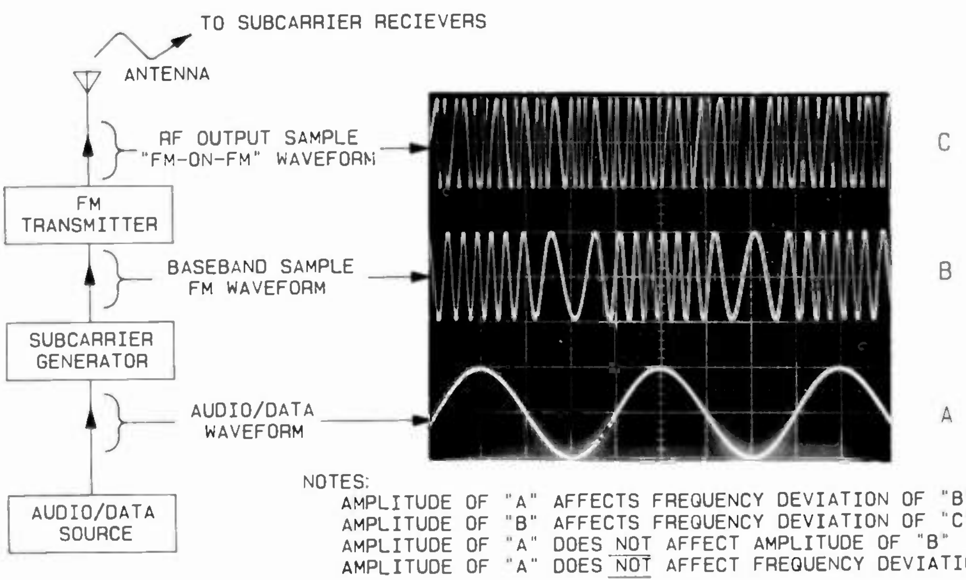
Transmitting the Subcarrier

The subcarrier is added to the broadcast signal by connecting a subcarrier generator to the FM (aural) exciter located in the broadcast transmitter. The subcarrier generator accepts audio and/or DC coupled data inputs and provides a frequency modulated subcarrier at its output. This generator may also have additional features which allow automatic muting of the subcarrier transmission under certain conditions, multiple audio/data inputs, active filtering of the inputs, and modulation indicators. Since the subcarrier generator is located at the broadcast transmitter, it is usually supplied by the broadcaster. The FM exciter must have a wideband input to accept the subcarrier and add it to the rest of the baseband for FM modulation onto the main radio frequency carrier.

Compatibility of Subcarriers with Stereo Channel

The center frequency and modulation index of each FM subcarrier must be selected and controlled so that the occupied bandwidths of the subcarriers do not interfere with the stereo subchannel which extends to 53kHz in the FM stereo system (47kHz in TV-MTS) or with each other. Figure-2 illustrates the frequency spectrum allocations for the various components within the composite baseband.

The modulation index is usually controlled by restricting the audio or data input bandwidth to the subcarrier modulator with a low pass filter. The lower sidebands of the subcarrier are thereby restricted from extending down into the stereo subchannel where crosstalk from the subcarrier into the stereo channel would otherwise occur. In some cases the modulated subcarrier is fed through a bandpass filter to further restrict its occupied bandwidth. The use of a subcarrier bandpass filter after FM modulation introduces harmonic and intermodulation distortion to the subcarrier information in addition to affecting its amplitude and phase response. The use of a lowpass filter before modulation changes only the amplitude and phase response of the subcarrier information near the filter cut-off frequency. A properly designed subcarrier generator should provide adequate protection to the stereo subchannel using only lowpass filtering before the subcarrier modulator.



NOTES:
AMPLITUDE OF "A" AFFECTS FREQUENCY DEVIATION OF "B"
AMPLITUDE OF "B" AFFECTS FREQUENCY DEVIATION OF "C"
AMPLITUDE OF "A" DOES NOT AFFECT AMPLITUDE OF "B"
AMPLITUDE OF "A" DOES NOT AFFECT FREQUENCY DEVIATION OF "C"

FIGURE 1. "FM-ON-FM"

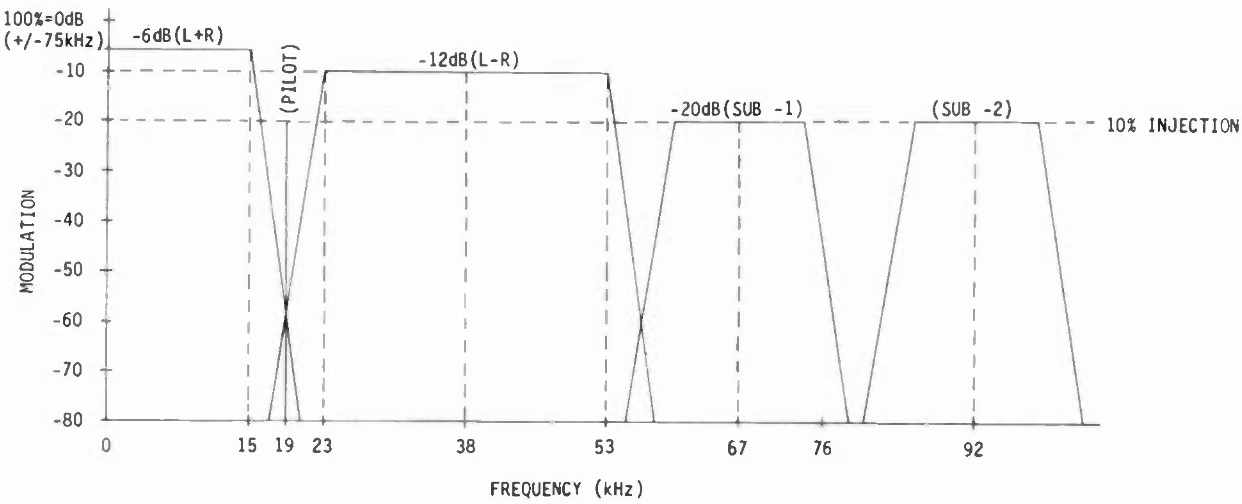


FIGURE 2 BASEBAND SPECTRUM ALLOCATIONS

Crosstalk into the Subcarriers

Just as the subcarrier sidebands must be prevented from extending down into the stereo subchannel, the stereo subchannel sidebands and their harmonics must be prevented from extending up into the spectrum allocated to the subcarriers where crosstalk into the subcarriers will take place. Minimization of crosstalk from the main and stereo subchannels into the subcarriers requires careful attention to the stereo encoding process, handling of the composite baseband, FM modulator linearity, and RF transmission bandwidth.

STEREO GENERATOR PERFORMANCE REQUIREMENTS

The stereo generator's characteristics play an important role in preventing interference to the subcarrier.

Audio Input Filtering

Audio lowpass filters before the stereo modulator are necessary in all stereo generators. These sharp cut-off filters protect the mono subchannel, pilot, and stereo subchannel from spilling into each other by greatly attenuating audio components above 15kHz. Audio input lowpass filters also restrict the upper sidebands of the stereo subchannel from extending up into the subcarrier frequency spectrum and are essential to preventing crosstalk into the subcarriers. If the pilot level is observed to be fluctuating on the stereo modulation monitor during modulation, the audio input filtering may be inadequate. Audio lowpass filters with delay equalization will keep overshoot to a minimum, while providing adequate protection to the pilot, stereophonic subchannel, and any additional subcarriers.

Stereo Subchannel Modulator

The second harmonic components of the stereophonic subchannel may fall directly on top of the subcarrier, so it is important to use a stereo generator that suppresses these undesirable components. The stereo generator must have good 38kHz (2Fh for TV) subcarrier suppression with modulation applied. Excessive 38kHz leakage may cause additional 76kHz regeneration in the system. The stereo generator must also have good 76kHz (second harmonic) suppression. The second harmonic modulation sidebands should be attenuated as well, because they add crosstalk into the subcarriers. If crosstalk into a subcarrier operating at 20dB below 100% modulation is to be 50dB or better, the stereophonic subchannel harmonics must be suppressed by at least -70 dB allowing for some degradation through the entire system.

Manufacturers of stereo generators have traditionally chosen either linear or switching modulators. The linear modulators use balanced analog circuits that may require periodic adjustment of 38kHz and 76kHz null controls. These adjustments should be maintained if excessive 76kHz becomes evident during spectrum analysis of the composite baseband. The switching modulator is popular because of better long-term stability. The modulator switching waveform requires filtering with a sharp cut-off 53kHz linear-phase lowpass filter. This filter is a major design problem, because the passband amplitude ripple and phase non-linearities cause degraded high frequency stereo separation by adversely affecting the upper sideband of the L-R subchannel. A third type of stereo generator shown in Figure-3 uses a digital stairstep generator to synthesize the subcarrier and pilot simultaneously, eliminating any pilot phase variation. Digital synthesis produces an approximation to a sinewave with low harmonic content throughout the frequency range of interest. The composite lowpass filter only needs to provide a gradual rolloff beyond 100kHz. Stereo separation is still better than 50dB at 15kHz while suppression of harmonic and spurious components that would ordinarily interfere with the subcarriers is better than other types of stereo generators. Second harmonic sidebands, pilot harmonics, and spurious products in the subcarrier spectrum are 80dB below 100% modulation reducing crosstalk into the subcarriers by as much as 20dB.

COMPOSITE STUDIO TO TRANSMITTER LINKS

The composite STL is really a transmission subsystem within a system. STL transmitter requirements are identical to those of the FM exciter. Since the STL has its own modulated oscillator, the same modulator linearity considerations that apply to FM exciters also apply to the STL transmitter. The IF bandwidth and demodulator characteristics of the STL receiver will also affect subcarrier crosstalk. If possible, is recommended that all subcarriers be fed directly into the FM exciter at the transmitter. Telephone lines or other narrowband radio links (including separate high frequency STL subcarriers above 100kHz) can usually handle the program bandwidths used to feed the subcarrier generators. This technique reduces the burden of maintaining very low intermodulation performance through the entire STL modulation/demodulation process.

Distortion of the composite baseband signal can also be caused by harmonic (THD), steady state intermodulation (IMD), and transient intermodulation (TIM) distortion within any composite amplifier stages. These types of distortion have the greatest effect on subcarriers because the resulting harmonic and intermodulation products interfere with the subcarriers. The composite amplifiers must have sufficient feedback bandwidth to accept baseband frequencies to 100kHz and should slew symmetrically to minimize slew-induced distortion.

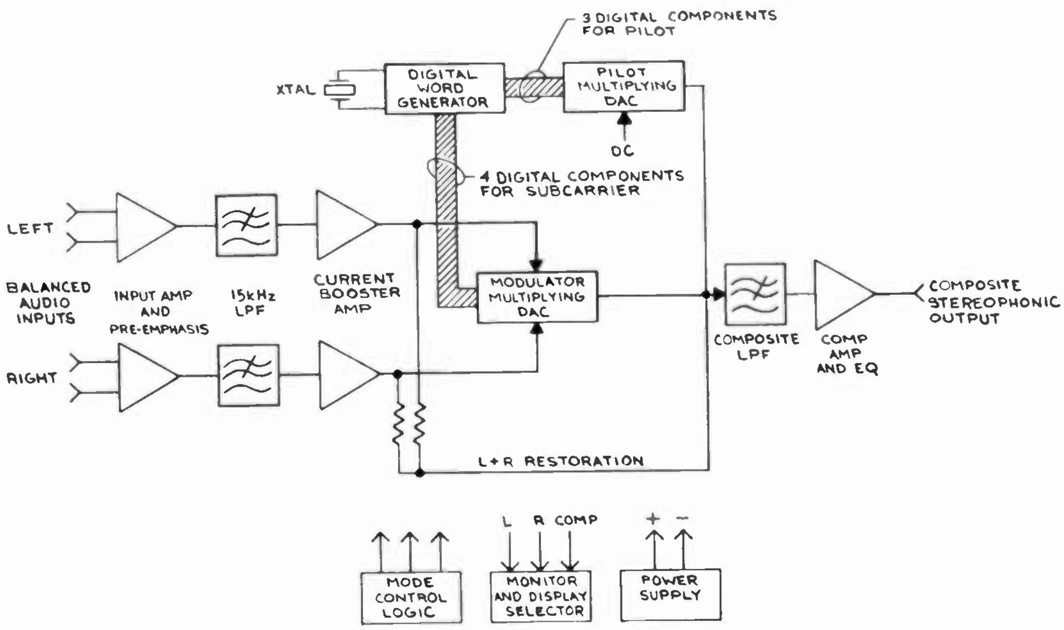


FIGURE 3. SIMPLIFIED BLOCK DIAGRAM OF FS-30 STEREO GENERATOR

The TIM performance becomes largely a matter of operational amplifier selection and circuit configuration.

Although flat composite amplitude and phase response is very critical to maintaining stereo separation, subcarriers are not affected by moderate ripple in the amplitude and phase response. This is because the information in the subcarriers is transmitted in a relatively narrow bandwidth and is not time dependent on the main channel.

COMPOSITE BASEBAND PROCESSING

In an effort to achieve maximum modulation density (loudness), some FM broadcasters use composite processing (after the stereo generator and STL) to remove the low energy overshoots in the amplitude of the composite waveform caused by complex audio input filtering. Overshoots have no effect on any audio performance parameter other than achieving the last dB in loudness. Composite processing is not recommended for use with subcarriers. The use of any non-linear devices, such as clippers or limiters in the composite line will alter not only the peak amplitude of the baseband, but also the frequency spectrum of the baseband. This generates several types of distortion at the stereo receiver and increases crosstalk into the subcarriers. Figure-4A and Figure-4B show the waveform and spectrum of unprocessed baseband while Figure-4C and Figure-4D show the same waveform and spectrum after 1.25dB of composite clipping. Figure-4D shows harmonic and intermodulation products filling the spectrum reserved for the subcarriers. Also note that during clipping the stereo pilot has been stripped from the composite waveform.

Effects of Composite Processing on Subcarriers

1. Intermodulation of all baseband frequency components causing extraneous spectral components which interfere with the subcarriers.
2. Harmonic distortion of baseband causing regeneration of stereo subchannel second harmonic sidebands with resulting degradation of crosstalk.
3. Generation of harmonics of the pilot causing interference to subcarriers.

The received stereo audio is high in intermodulation distortion and non-correlated information due to aliasing of the extraneous spectral components added by composite processing. Crosstalk and interference to the subcarriers has also increased due to composite processing. If minimum crosstalk into the subcarriers is the goal, composite processing should not be used. Audio processing should be performed before the audio is multiplexed into baseband.

FM EXCITER PERFORMANCE REQUIREMENTS

The exciter characteristics are important for good subcarrier performance.

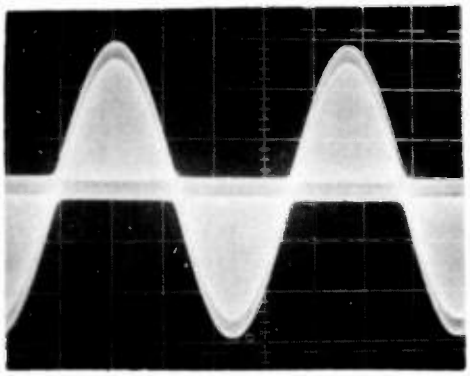
The composite baseband signal is translated onto a frequency modulated carrier by the modulated oscillator. Frequency modulation is produced by applying the composite baseband signal to a voltage tunable RF oscillator. The modulated oscillator usually operates at the carrier frequency and is voltage tuned by varactor diodes, operating in an LC circuit.

To have perfect modulation linearity, the RF output frequency must change in direct proportion to the composite modulating voltage applied to the varactor diodes. This requirement implies that the capacitance of the varactor diodes must change as nearly the square of the modulating voltage. Unfortunately, the voltage versus capacitance characteristic of practical varactor diodes is not the desired square law relationship. All varactor-tuned oscillators have an inherently non-linear modulating characteristic. This non-linearity is very predictable and repeatable for a given circuit configuration, making correction by complementary predistortion of the modulating signal feasible. Suitable predistortion can be applied by using a piece-wise linear approximation to the desired complementary transfer function. The predistortion network is cascaded with a non-linear voltage-tuned oscillator to produce a linearized FM modulator.

Non-linearities in the FM oscillator can, by altering the waveform of the baseband signal, create distortion in the demodulated output at the receiver. Any distortion of the baseband signal caused by the modulated oscillator will have secondary effects on stereo and subcarrier crosstalk, which are quite noticeable at the receiver in spite of the rather small amounts of distortion to the baseband. For example, if the harmonic distortion to the baseband is increased from .05% to 1.0%, as much as 26dB additional crosstalk into the subcarrier can be expected.

For illustrative purposes, Figure-5A, 5B, and 5C give representations of the fundamental and second order terms in the composite baseband spectrum with increasing amounts of harmonic distortion in the modulated oscillator. Figure-5B shows this spectrum after 0.05% harmonic distortion has been added to each component. Note that the second order stereo (L-R) sidebands are 78dB below 100% modulation or about 58dB below a 67KHz SCA subcarrier with a 10% (-20dB) injection level. With normal energy distributions in L-R and the subcarrier, crosstalk from stereo into the SCA will be more than 60dB below the SCA subcarrier. Figure-5C shows the same baseband spectrum with 1.0% harmonic distortion. The second order stereo sidebands are only 32dB below the subcarrier.

BASEBAND WITHOUT CLIPPING



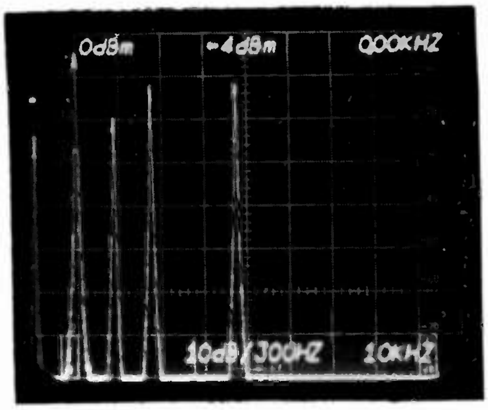
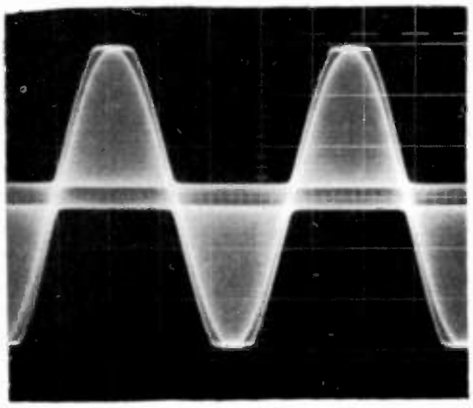


Figure 4A

Figure 4B

(OUTPUT FROM BEI FS-30 STEREO GENERATOR
ONE CHANNEL ONLY MODULATED @ 10KHz)

BASEBAND AFTER 1.25dB COMPOSITE CLIPPING



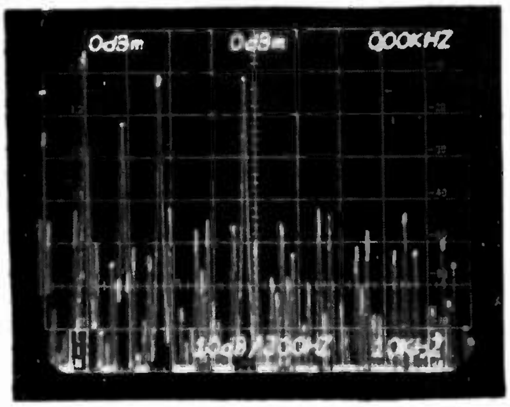
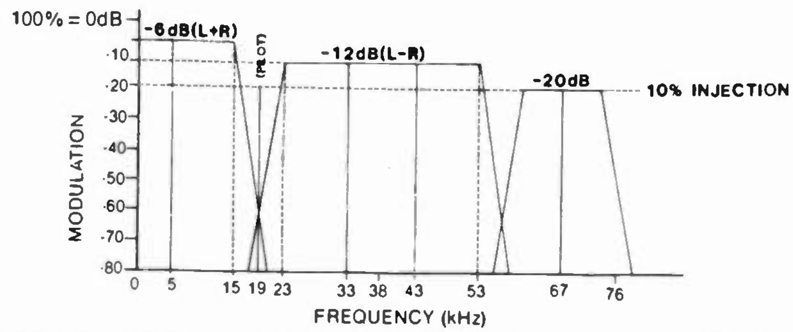


Figure 4C

Figure 4D

(OUTPUT FROM BEI FS-30 STEREO GENERATOR FOLLOWED BY 1.25dB
OF COMPOSITE CLIPPING-ONE CHANNEL ONLY MODULATED @ 10KHz)

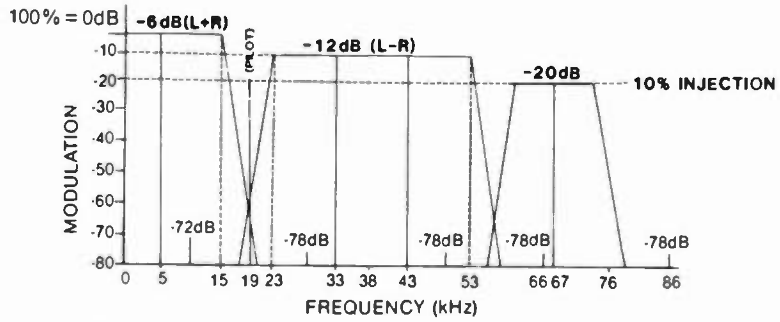
FIGURE 5A.



L OR R ONLY MODULATED 100% @ 5 kHz. UNMODULATED SCA @ 10% INJECTION

Ideal demodulated composite baseband spectrum with no modulator distortion.

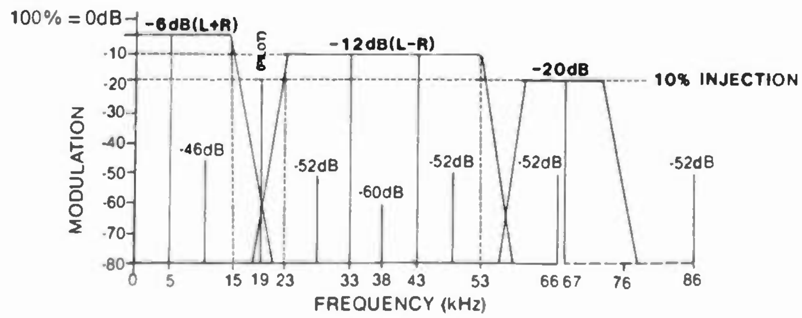
FIGURE 5B.



L OR R ONLY MODULATED 100% @ 5 kHz. UNMODULATED SCA @ 10% INJECTION.
INTERFERING SECOND HARMONIC STEREO SIDEBANDS ARE 58 dB BELOW SCA.
ONLY FUNDAMENTAL AND SECOND HARMONIC TERMS ARE SHOWN.

Demodulated composite baseband spectrum with 0.05% harmonic distortion in modulator.

FIGURE 5C.



L OR R ONLY MODULATED 100% @ 5 kHz. UNMODULATED SCA @ 10% INJECTION.
INTERFERING SECOND HARMONIC STEREO SIDEBANDS ARE 32 dB BELOW SCA.
ONLY FUNDAMENTAL AND SECOND HARMONIC TERMS ARE SHOWN.

Demodulated composite baseband spectrum with 1.0 % harmonic distortion in modulator.

Crosstalk may now increase as much as 26dB, depending on the respective energy distributions in (L-R) and the SCA subcarrier. Modulator linearization using a piecewise approximation pre-distortion network has reduced harmonic and intermodulation distortion to less than 0.05% in state of the art equipment. TIM distortion is usually not a factor in varactor tuned modulated oscillators. The modulation bandwidth capability is generally more than ten times the composite bandwidth and no negative feedback is used to maintain linearity.

Assuring that the composite baseband signal undergoes minimal distortion in the modulation process will suppress undesired harmonic and intermodulation products in the baseband, making the FM exciter transparent to the signals coupled into it.

THE RF PATH

The FM modulator converts the composite baseband signal into the frequency modulated RF signal containing a complex array of sidebands. The amplitude and phase of the FM sidebands are determined by the modulation index, while the frequencies of the sidebands are determined by the modulating frequencies.

The remainder of the FM transmitter consists of a chain of power amplifiers, each having from 6 to 20 dB of power gain. Ideally, the transmitter should have as wide a bandwidth as practical with a minimum of tuned stages. Broadband solid-state amplifiers are preferred to eliminate tuned networks in the RF path. Tuned output bandpass filters may still be necessary when broadband amplifiers are operated in a dense RF environment to prevent RF intermodulation products from being generated within the amplifier output stage. Higher powered transmitters in the multi-kilowatt range may use a single tube PA stage with high efficiency. The dollars/watt economics of single-tube transmitters outweigh the bandwidth benefits of solid-state transmitters at the higher power levels with present technology. Design improvements in tube-type power amplifiers have concentrated on improving bandwidth, reliability, and cost effectiveness.

The FM Sideband Structure

The frequency modulated RF output spectrum contains many sideband frequency components, theoretically an infinite number. They consist of pairs of sideband components spaced from the carrier frequency by multiples of the modulating frequency. The total transmitter RF output power remains constant with modulation, but the distribution of that power into the sidebands varies with the modulation index so that power at the carrier frequency is reduced by the amount of power added to the sidebands.

Occupied Bandwidth

The occupied bandwidth of an FM signal is far greater than the amount of deviation from the carrier that one might incorrectly assume as the bandwidth. In fact, the occupied bandwidth is infinite if all the sidebands are taken into account, so that a frequency modulation system requires the transmission of all of these sidebands for perfect demodulation of information. In practice, a signal of acceptable quality can be transmitted in a limited bandwidth, by allowing truncation of the insignificant sidebands (typically less than 1 percent of the carrier level) and accepting a certain degree of signal degradation. Design considerations in the transmitter RF circuitry make it necessary to restrict the RF bandwidth to less than infinity. As a result, the higher order sidebands will be altered in amplitude and phase. Bandwidth limitation will add to the distortion in any FM system. The amount of distortion in any practical FM system will depend on the amount of bandwidth available versus the modulation index being transmitted.

Consider the system shown in Figure-6A, where a perfect FM modulator is connected to a perfect demodulator via an RF path of infinite bandwidth. The demodulated baseband shown in Figure-6C contains no distortion components.

Figure-6B shows the effects of an RF bandpass filter on the RF spectrum of composite baseband consisting of stereophonic baseband modulated at 4.5kHz only on one channel along with an unmodulated 67kHz SCA subcarrier. The only distortion evident on the RF spectrogram is the attenuation of sidebands greater than 200kHz from the center frequency and the amplitude differences between the lower and upper sideband pairs. Figure-6D shows the corresponding effects observed on the demodulated baseband spectrum for the same signal. Note the creation of many undesired intermodulation terms which will cause crosstalk into subcarrier bands.

As you can clearly see, the distortion in this FM system does depend on the amount of bandwidth available versus the modulation index being transmitted.

Limiting Factors Within the FM Transmitter

Relating the specific quantitative effect of the bandwidth limitations imposed by a particular transmitter to the actual interference to the subcarriers is a complicated problem indeed. Some of the factors involved are:

1. Total number of tuned circuits.
2. Amplitude and phase response of the total combination of tuned circuits in the RF path.
3. Amount of drive (saturation effects) to each amplifier stage.
4. Non-linear transfer function within each amplifier stage.

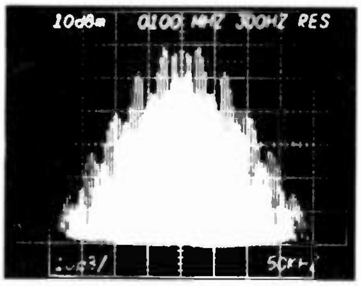


FIGURE 6A.
WIDEBAND RF SPECTRUM TO DEMODULATOR

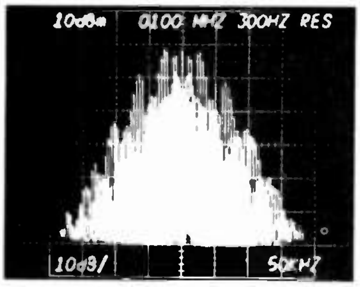


FIGURE 6B.
BANDWIDTH LIMITED RF SPECTRUM TO DEMODULATOR

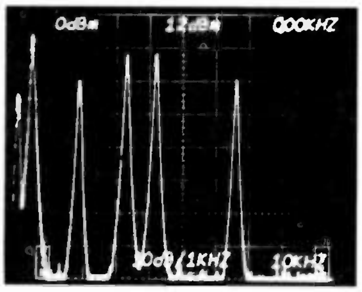


FIGURE 6C.
DEMODULATED BASEBAND SPECTRUM FOR WIDEBAND RF SPECTRUM

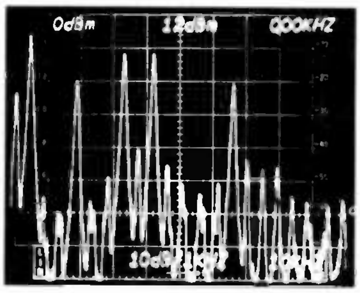


FIGURE 6D.
DEMODULATED BASEBAND SPECTRUM FOR BANDWIDTH LIMITED RF SPECTRUM SHOWING DISTORTION PRODUCTS

The degree of bandwidth reduction is a design constraint which affects the gain and efficiency in all tuned PA stages. The bandwidth of an amplifier is determined by the load resistance across the tuned circuit and the output or input capacitance of the amplifier. The high input capacitance of a grid-driven final power amplifier is usually the limiting factor for the entire transmitter. As a result, the input tuning to final amplifier usually has a greater effect on subcarrier performance than the output tuning. Bandwidth limitations in a grid-driven PA can be partially overcome by resistive swamping in the input circuit and by utilizing a broadband input impedance matching device to achieve optimum transfer of power from the driver stage into the PA.

Broadband Impedance Matching

A broadband impedance matching circuit has been developed to match the high grid input (parallel) impedance of a tetrode RF power amplifier to the 50 Ohm impedance of a solid-state driver. Conventional L, PI, or T network matching circuits are normally used for this purpose. All of these circuits require interactive adjustment of one or more circuit elements to provide a satisfactory impedance match at each frequency and RF power level. The newly developed broadband impedance-matching circuit * consists of a combination of series inductor (L) and shunt capacitor (C) circuit elements, implemented as a printed circuit with inductors and capacitors etched into a copper-clad laminate. Multiple LC sections match the 50 Ohm source impedance to the high input impedance of the grid-driven RF power amplifier over a wide bandwidth by making the required transformation in a series of many small steps. This device is shown in Figure-7A and B. (*) PATENTED BY BROADCAST ELECTRONICS.

The broadband impedance matching circuit improves transmitter operation and stability, compared to previous methods. A single tuning control in the input circuit is sufficient to tune and match the 50 Ohm driver impedance to the high input impedance of the grid over the 88-108MHz FM broadcast band with a 4:1 range in RF power level.

IMPROVEMENT OF THE RF PATH

Some RF bandwidth related factors which will improve subcarrier performance are:

1. Maximize bandwidth by using a broadband exciter and a broadband IPA stage.
2. Use a transmitter of single tube design or broadband solid state design where feasible.
3. Minimize the number of interactive tuned networks.
4. Optimize both the input circuit and plate circuit tuning for best possible bandwidth.
5. Use a broadband antenna system with low standing wave ratio on the transmission line.

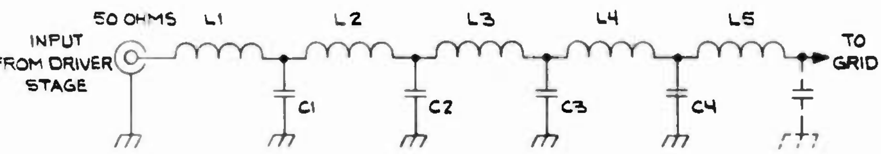


FIGURE 7A. CIRCUIT DIAGRAM OF PA INPUT IMPEDANCE MATCHING DEVICE

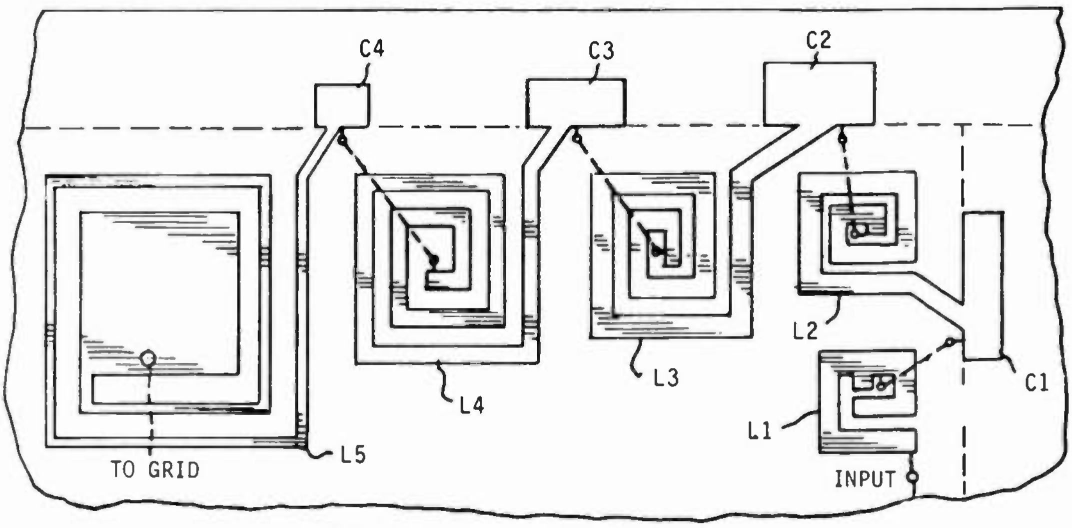


FIGURE 7B. INPUT MATCHING DEVICE

ADJUSTING THE TRANSMITTER

All optimization should be done with the transmitter connected to the normal antenna system. The transmitter is first tuned for normal output power and proper efficiency according to the manufacturer's instruction manual. The meter readings should closely agree with those listed on the manufacturer's final test data sheet.

A simple method for centering the transmitter passband on the carrier frequency involves adjustment for minimum synchronous AM. Synchronous AM is a measure of the amount of incidental amplitude modulation introduced onto the carrier by the presence of FM modulation. This measurement is very useful for determining the proper tuning of the transmitter. Since all transmitters have limited bandwidth, there will be a slight drop-off in power output as the carrier frequency is swept to either side of the center frequency. This slight change in RF output level follows the waveform of the signal being applied to the FM modulator causing AM modulation in synchronization with the FM modulation. Minimizing synchronous AM will assure that the transmitter passband is centered on the channel.

Care must be taken when making these measurements that the test setup does not introduce synchronous AM and give erroneous readings which would cause the operator to mistune the transmitter to compensate for errors in the measuring equipment.

The input impedance of the envelope detector must provide a nearly perfect match so that there is a very low VSWR on the sampling line. Any significant VSWR on the sampling line will produce synchronous AM at the detector because the position of the voltage peak caused by the standing wave moves along this line with FM modulation. Unfortunately, the AM detectors supplied with some modulation monitors do not provide a good enough match to be useful for this measurement. Precision envelope detectors are available that present a good match (30dB return loss) to the sampling line.

A typical adjustment procedure is to FM modulate 100% at 400Hz and fine-adjust the transmitter's input tuning and output tuning controls for minimum 400Hz AM modulation as detected by a wideband envelope detector (diode and line probe). It is helpful to display the demodulated output from the AM detector on an oscilloscope while making this adjustment.

Note that as the minimum point of synchronous AM is reached, the demodulated output from the AM detector will double in frequency to 800Hz, because the fall-off in output power is symmetrical about the center frequency causing the amplitude variations to go through two complete cycles for every one FM sweep cycle. This effect is illustrated in Figure-8. It should be possible to minimize synchronous AM while maintaining output power and efficiency in a properly designed power amplifier.

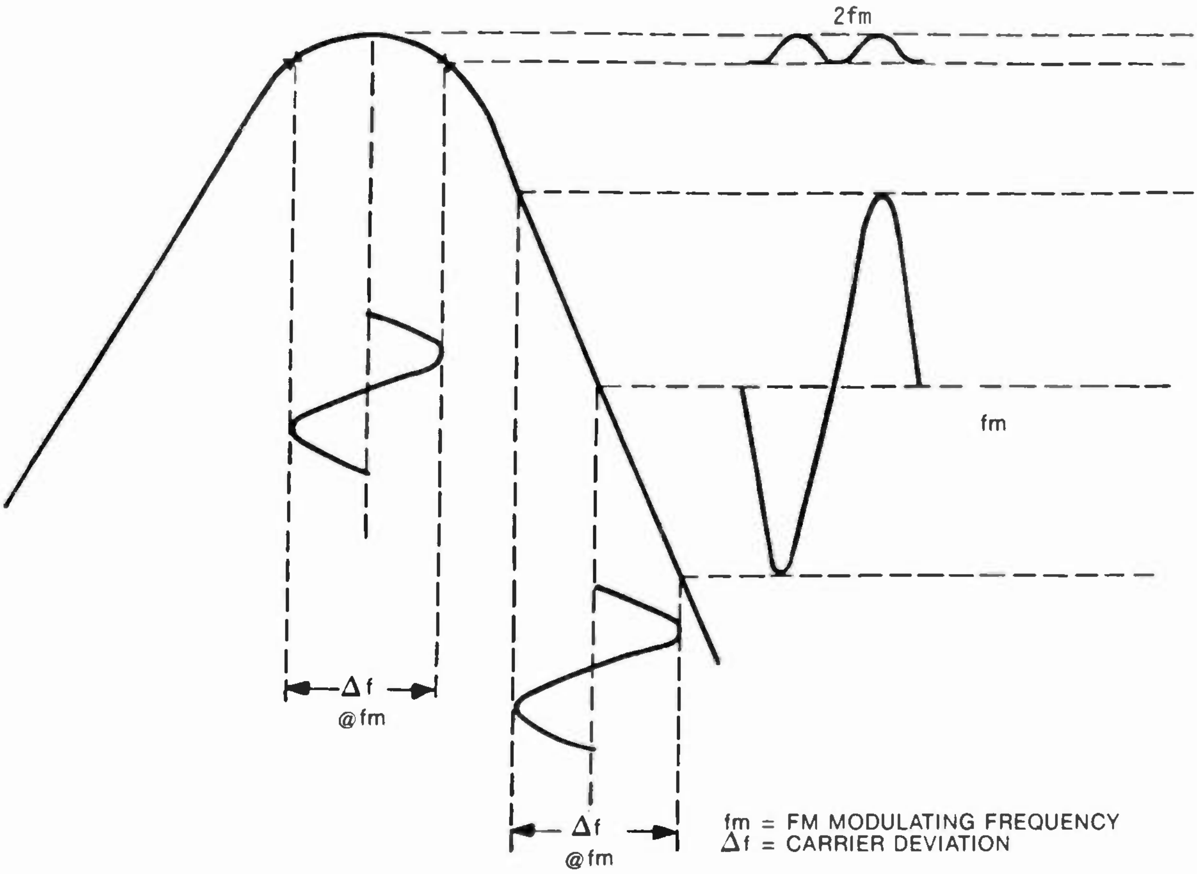


FIGURE 8. SYNCHRONOUS AM WAVEFORMS

The most sensitive test is to tune for minimum crosstalk into the subcarrier. Transmitter tuning becomes very critical to minimizing crosstalk into the subcarriers. Modulate one channel only on the stereo generator to 100% with a 4,500Hz (7,867Hz for TV) tone. This will place the lower second harmonic (L-R) stereo sideband on top of a 67.00kHz SCA subcarrier (upper second harmonic (L-R) TV stereo sideband on top of a 78.67kHz SAP). Activate the subcarrier at normal injection level without modulation. Tune the transmitter for minimum output from the subcarrier demodulator. This adjustment can also be made by listening to the residual subcarrier audio while normal stereo programming is being broadcast.

Field Adjustment Techniques

1. Tune for minimum synchronous AM noise.
2. Tune for minimum crosstalk into unmodulated subcarrier.

As mentioned previously, the input tuning is frequently more critical than the plate tuning. This is because the impedance match into the final amplifier tube's input capacitance becomes the bandwidth limiting factor. Even though the amplitude response appears flattened when the input is heavily driven into saturation, the phase response still has a serious effect on the higher order FM sidebands.

TEST EQUIPMENT SET-UP

Figure-9 shows a block diagram of the required test equipment setup for making composite spectrum and crosstalk measurements. Note that the composite baseband spectrum is checked at various points along the transmission path in order to verify the performance of each subsystem. Most of the measurements center around the use of a low frequency (10Hz to 200kHz) spectrum analyzer to determine the amount and location of distortion products added to the baseband signal as it passes through each stage of the overall system.

The modulation monitor or modulation analyzer used to demodulate the RF to composite baseband must have a highly linear pulse counting discriminator in order to avoid the introduction of distortion products during the demodulation process. The wideband subcarrier demodulator is essential to make crosstalk comparisons throughout the system. A narrower bandwidth subcarrier receiver is also useful in determining the amount of crosstalk introduced by the typical receiver.

A precision envelope detector with low input VSWR is included in the test setup so that the accurate synchronous AM waveforms can be observed while tuning the transmitter.

TEST SET-UP FOR COMPOSITE WAVEFORM AND SPECTRUM MEASUREMENTS

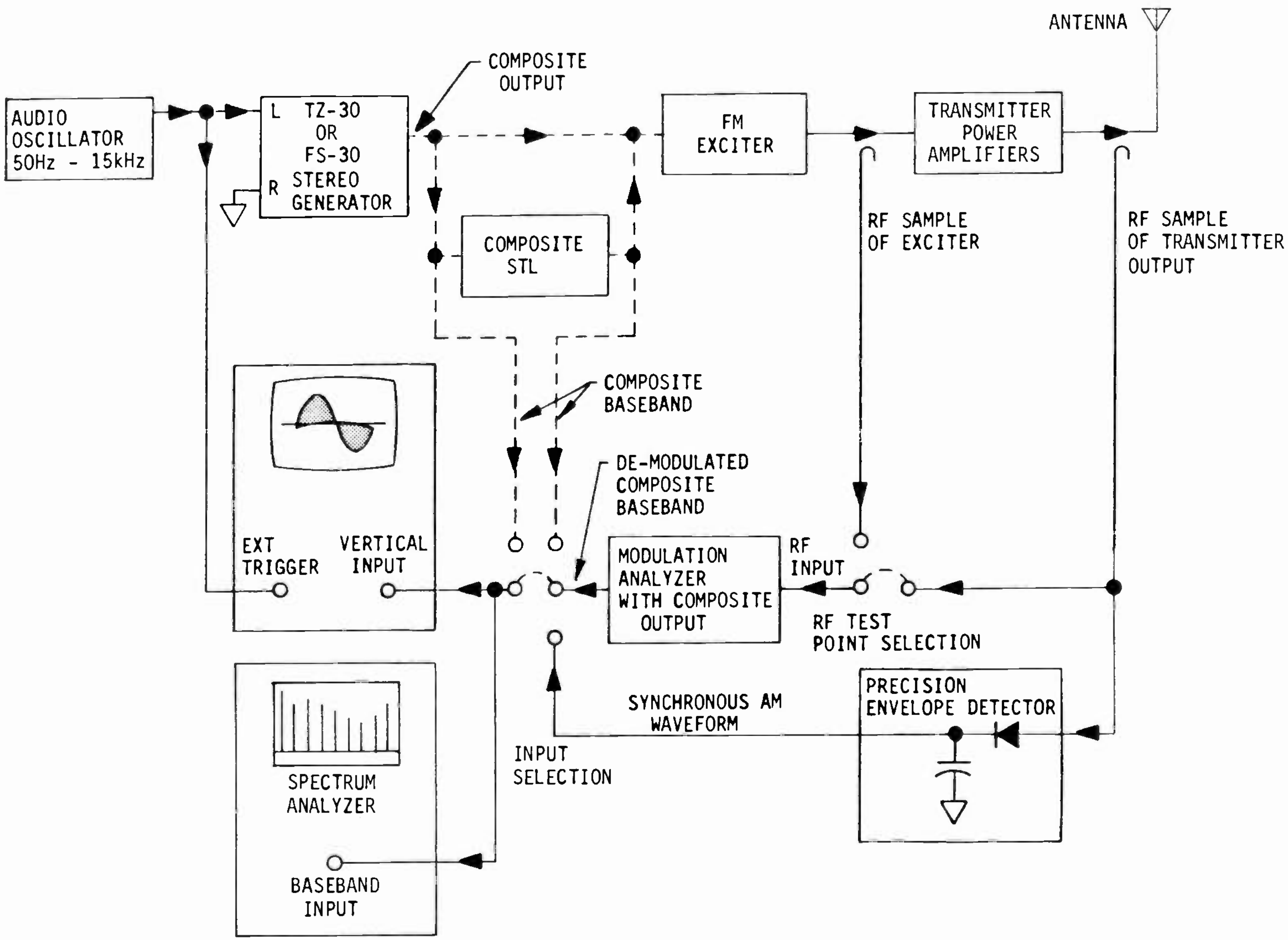


FIGURE 9

RECEIVING THE SUBCARRIER

The subcarrier receiver must first FM demodulate the entire baseband, filter out the desired subcarrier from the rest of the baseband components, and then FM demodulate the subcarrier information. This requires two IF strips and two FM demodulators. The first IF strip is usually operated at 10.7MHz with a bandwidth of at least 250kHz while the second IF strip is located at the subcarrier frequency (67kHz, 78.67kHz, 92kHz, or 102.27kHz) with a narrower bandwidth (typically 25KHz or less). The first FM demodulator is usually a quadrature or pulse counting type while the second FM demodulator is usually a Phase-Locked-Loop to minimize interference from the main and stereo channels.

This dual demodulation process places some limitations on the performance of the subcarrier receiver. The amplitude and phase response of the IF filters will have a significant effect on the crosstalk into the subcarrier from the main and stereo channels. For instance, the crosstalk into the subcarrier can be improved by increasing the first IF bandwidth to 500kHz or greater when receiving conditions permit. The trade-off is reduced rejection of other RF signals. A highly linear first demodulator will help reduce regeneration of spurious products which interfere with the subcarrier. The second IF bandpass filter will reduce crosstalk into the subcarrier at the expense of increased distortion to the demodulated subcarrier information. This type of receiving system is also more susceptible to multipath than a simple FM system. The subcarrier being received only has access to a maximum of 10% of the transmitter power. The additional noise factors introduced by the "FM on FM" nature of the system cause further degradation of the signal to noise ratio which may yield a total penalty in coverage of more than 20dB when compared to main channel.

SUGGESTED SYSTEM ERROR BUDGET

The broadcast engineer is often faced with the problem of meeting subcarrier performance objectives without knowing exactly where to begin. The concept of breaking the entire transmission system (subcarrier generator to subcarrier receiver) into its parts is very useful in "zeroing in" on the problem areas. Systematic, step-by-step evaluation of each subsystem will allow development of an "error budget" for each point along the transmission path. The total system performance will depend on the sum of the individual errors along the way. Once acceptable performance parameters have been assigned to each subsystem (error budget), periodic checks will direct attention to the areas where the biggest gains can be made.

For example, if the desired total system performance is:

1. Subcarrier crosstalk into stereo of better than 60dB.
2. Subcarrier signal to noise ratio (including crosstalk) of 50dB and distortion of less than 1.0% at an injection level of 10% (-20dB).

The following error budget of key parameters effecting subcarrier performance might be appropriate.

Subcarrier generator:
  Lower sideband suppression of 60dB at upper limit of (L-R) subchannel. Distortion of less than 0.5%.
Stereo generator:
  Upper and harmonic (L-R) sidebands suppressed 75dB in the subcarrier occupied bandwidth. Spurious suppression of 80dB or better.
Composite baseband distortion:
  THD and IMD of less than 0.025% (including STL)(no composite clipping).
FM exciter linearity:
  THD and IMD of less than 0.025%.
Transmitter bandwidth:
  3dB amplitude bandwidth of at least 800kHz. (modulated oscillator to transmitter output)
Antenna bandwidth:
  1.5:1 VSWR bandwidth of at least 1MHz.

BRINGING IT ALL TOGETHER

Subcarriers do offer an important new opportunity to transmit additional information over existing FM broadcast facilities. Whether subcarriers are used primarily for paging, data transmission to fixed points, or other applications remains to be seen. In any case, it is important that each subsystem be individually optimized before the complete transmission and reception system can perform properly. The complexity and technical limitations of the subcarrier system makes attention to details critical to the success of the operation.

RADIO DATA SYSTEM PERMITS RECEIVER ADJUSTMENTS AND SPECIAL SIGNALING BY THE FM BROADCASTER

Dietmar Kopitz
European Broadcasting Union, Technical Centre
Brussels, Belgium

ABSTRACT

The EBU (European Broadcasting Union) is a professional association of broadcasting organizations of national importance. It has its headquarters in Geneva (Switzerland) and its Technical Centre in Brussels (Belgium). The Radio Data System "RDS", which is the topic of this presentation, is the result of coordinated research efforts that started more than ten years ago with the aim of specifying the method and codes for adding to any FM broadcast inaudible auxiliary data signals that would offer a variety of methods for identifying the transmissions. On the basis of such a technique, the receiver manufacturing industry could then design more "intelligent" radios, particularly for use in cars, where retuning to any given programme and preprogramming could be simplified to the extent that the listener would not need to know the frequencies of the transmitters. The implementation of the new functions which RDS would offer should lead to only small increases in receiver costs, assuming the use of new technologies (large-scale integration, frequency synthesis, microprocessors, utilisation of small displays and memory chips) in the production of these new receivers. Obviously, an international standard was necessary to support the mass-production of such receivers, and when in 1983 the EBU published the technical specification of RDS[1], the basis for an industrial standard was indeed achieved. Two years later, the CCIR agreed to use this specification as a reference for a world standard[2], which will be published in its final form later this year.

ADVANTAGES WHICH RDS WILL OFFER TO LISTENERS

Due to the ever-growing density of transmissions and the number of radio programmes which are receivable, particularly in urban areas, tuning to any given programme (or network) is becoming increasingly difficult on conventional FM radios, even if they can already be preprogrammed to a certain extent. On a car radio, in particular, the listener will not easily find for any given programme the best signal for reception in the area where he is travelling, and retuning to a given programme when moving to another area is even more difficult. Furthermore, it is at present not easily possible for the listener to identify the name of the programme (or the call sign) to which the radio is arbitrarily tuned, even if that receiver already has a digital frequency display.

A new generation of RDS receivers will therefore enhance the comfort of manual tuning, and also permit automatic tuning or retuning. For each station received, an eight-character ASCII code would appear on a small display, showing the programme-service name or call sign. Additionally, a number of new applications would be provided, such as identification of programmes giving information to motorists, and identification of traffic announcements so that these can be switched on even if the listener is using his cassette player or compact-disc component in his car-radio installation. There is also a code to identify 32 predetermined types of programme: e.g. news, sport, pop and rock music, "for children", etc., so that the radio can be set to seek any of these categories. A programme-item number will identify any particular programme, so that the receiver can be preprogrammed, either to switch to that programme when it is on the air, or to record it. Music and speech will be identified with a special switching code so that new receivers with separate volume controls could allow the listener to achieve his own balance. Clock time and date would also be broadcast, so that a traveller would not have to set the clock each time he enters a new time zone. The time shown on the clock would always be correct, since the area to which it would apply can also be identified. The distribution of comprehensive traffic information in coded form which would not interrupt the radio programme is now also under study. Such information could be output on a language channel chosen by the listener, and as an outlet, either a speech synthesizer or a small printer could be used. The RDS standard is flexible enough to allow a number of still unknown applications to be defined and to be added to the specification. For home receivers radiotext could be broadcast for display on a small LCD screen having either 32 or 64 characters to give details of music, programme title, news flash and even advertisements. On a transparent data channel even tele-software could be broadcast. Efforts are now being made in Europe to define the necessary interface for the connection of peripheral equipment to the radio so that the data could be directed to a number of devices. The matter is being studied in collaboration with the radio manufacturers.

PRESENT POSITION OF MANUFACTURERS

Already in the early stages of the development of the radio-data system, the experts within the EBU contacted the European receiver-manufacturing industry with a view to finding out what applications would be desirable from their point of view. All the ideas which were collected were also presented to radio programme directors so that they could give their opinion and set priorities for the implementation. This resulted in the definition of four different groups of applications, i.e. tuning information, switching information, radiotext and additional features. All interested parties agreed to put the priority on the distribution of tuning information (programme identification, programme-service name, alternative frequencies, traffic programme identification, etc.), so that radios and in particular car receivers could be manufactured which would offer the listener a much greater comfort in tuning to any wanted programme.

When field trials of the RDS system were carried out to test the transmission reliability in the mobile reception mode under the most difficult conditions (multipath propagation and reception at various speeds and various signal levels), representatives of the European manufacturers participated as observers, and their advice on testing also the compatibility with the existing receivers, car radios as well as home hi-fi sets, was most welcome. Now, at the stage where the EBU is recommending to its Member organizations the introduction of RDS, we are in a typical "chicken and egg" situation. What should come first, RDS transmissions or RDS receivers? Since manufacturers need the market to sell these new receivers, the broadcasters must obviously take the first step. RDS will thus now be introduced in Europe, country after country. The first countries to use this system will be Sweden (1985), FR of Germany and the United Kingdom (1987), and others, to follow not much later, will be Italy, France, Austria, Switzerland and the Netherlands. Apart from the basic tuning signals, each broadcaster may choose the applications which he would require from the standardized list. The applications for each network or local station may thus vary from case to case, and from country to country. For the receiver manufacturers, however, there will be, thanks to the EBU specification, a unified European market, which might well be extended at a later stage also to other parts of the world.

As already said, the RDS specification is flexible enough to be adapted to other situations than those prevailing in Europe, such as, for example, those in the United States. Nevertheless, a relatively small standardization effort would be necessary to ensure that future RDS receivers produced by the industry for any such particular market would not malfunction, a case which could otherwise occur if the particular radio was not designed to work with, or even ignore, any of the already defined applications, and particularly those which are even not yet defined.

Contacts were also made with car-radio manufacturers in Japan and the United States, and in both countries a number of important manufacturers are known that have already developed prototypes of RDS radios for the European market. Later this year, it will be possible to buy such radios in Swedish shops, and the first companies known to market them are Volvo and Clarion, followed probably not much later by Philips, Bosch-Blaupunkt, Ford, Pioneer, Sony and many others. By mid-1987 it is expected that such receivers will also become available in those other European countries that are going to introduce RDS first.

SOME TECHNICAL DETAILS ON RDS

RDS data signals are defined for being transmitted within the well-known constraints set by national and international standards for the distribution of auxiliary subcarrier signals, authorised to be distributed within the multiplex signal of an FM broadcast in monophony or stereophony using the pilot-tone system. To avoid interference to the stereophonic main channels, the position of the subcarrier to be used is critical, as well as the bandwidth that such auxiliary signals may occupy. For these reasons, the subcarrier chosen is the third harmonic of the pilot-tone, which is 19 kHz, so that the subcarrier used for RDS will be 57 kHz. The bandwidth of the amplitude-modulated and bi-phase coded RDS signal, with a suppressed subcarrier, is limited to ± 2.4 kHz. The basic data rate is relatively small, i.e. 1187.5 bit/s. The clock frequency is obtained by dividing 57 kHz by 48. The recommended nominal deviation of the main FM carrier due to the modulated subcarrier is ± 2.0 kHz. The decoder should however be designed to work with subcarrier levels corresponding to between ± 1 and 7.5 kHz deviation. If used simultaneously with the ARI traffic-broadcast identification system, the ARI (Broadcast information for motorists) and the RDS subcarriers will have a phase difference of 90° ± 10°, and the recommended nominal deviation of the main carrier will be ± 1.2 kHz due to the RDS signal and ± 3.5 kHz due to the unmodulated ARI subcarrier[2].

The RDS data signals use a novel framing, or baseband-coding structure, that ensures an optimum protection of the data transmission under extremely difficult reception conditions as encountered in moving vehicles. The largest element in the structure is called a "group" of 104 bits. As shown in Fig. 1, each group comprises 4 blocks of 26 bits, where the first 16 bits are the information bits, and the remaining 10 bits form a cyclic redundancy checkword. For synchronisation purposes, different 10-bit offset words are added to the respective checkwords to identify the four blocks within each group. As shown in Fig. 2, the second block contains a 5-bit group address so that in total 32 different group types may be identified. At this stage the EBU has only defined 14 different groups, so that there is still sufficient flexibility for adapting RDS to other regions than Europe.

Table 1 gives the minimum recommended repetition rates for some of the main applications and Table 2 shows the typical proportions of the respective groups that need to be transmitted within a given time interval to achieve these repetition rates. As an example, using the information in Table 2, Fig. 3 shows, in the form of a pie chart, the channel usage in per cent. It can be seen from this figure that more than half of the transmission capacity is indeed utilised for the tuning functions (PI/programme identification, PS/programme-service name, AF/alternative frequencies, ON/information on other networks), to which priority was given by the European broadcasters.

As far as the RDS receiver design is concerned, some principles were published at an earlier occasion[3]. Decoding the radio-data signal would consist of the following stages:

- Demodulation of the suppressed 57 kHz subcarrier amplitude-modulated signal to recover the biphase symbols.
- Demodulation of the biphase symbols to recover the data signal.
- Recovery of the bit-rate clock.
- Recovery of the group and block synchronisation.
- Identification of information and check-bits.
- Performance of error correction and detection.
- Decoding of address information and messages codes.

One possible process of demodulating the 57 kHz subcarrier consists of a synchronous demodulator using a special kind of phase-locked loop, i.e. the Costas-loop. A simple phase-locked loop would not work here, because we have no coherent 57 kHz reference signal. This particular loop therefore synthesizes the reference signal from the sideband energy of the data-modulated subcarrier. This technique has a considerable advantage: it locks the recovered subcarrier exactly in phase with the wanted sidebands, even under conditions of multipath propagation. If, on the contrary, the 19 kHz pilot were the reference signal, this could not be achieved.

The bit-rate clock is then derived from the subcarrier by simple division, together with some additional logic circuitry which helps to achieve correct phase-locking to the biphase coded symbols.

The remainder of the data-demodulation process is then achieved by software which is implemented in a microprocessor.

Perhaps, at the end, a few remarks may be useful to receiver designers on the subject of error detection and correction. The error-protecting code which is used in RDS is an optimal single-burst error-correcting code, capable of correcting any burst of errors which spans 5 bits or less. In field trials it was observed that the data stream was generally corrupted by short bursts of usually 1 to 10 bits, with the length decreasing with driving speed. Tests made on a motorway at the upper speed limit showed that such bursts were usually shorter than 5 bits.

Recent field trials in the FR of Germany have shown that the transmission reliability can be improved by optimizing the error-detection/correction strategy in the receiver. This is done by switching off the error correction when the percentage of detected blocks with errors exceeds a certain limit. Additionally, the periodically repeated information can be compared and be used for further processing, only if the message was received correctly more than once. Also, a possibility was found that is quite independent of the data contents: neighbouring blocks were checked for errors. Only if a particular block, and the blocks immediately preceding and following it, were free of errors, would that particular block be used for further processing[4].

REFERENCES

1. EBU doc. Tech 3244 (March 1984), "Specifications of the radio-data system RDS for VHF/FM sound broadcasting", published by the European Broadcasting Union, Avenue A. Lancaster 32, B-1180 Brussels, Belgium.

2. CCIR Draft Recommendation <AX/10> (1985), "System for automatic tuning and other applications in FM radio receivers for use with the pilot tone system", published by the International Telecommunication Union, Place des Nations, CH-1211 Geneva, Switzerland.

3. S. R. Ely and D. Kopitz, "Design principles for VHF/FM radio receivers using the EBU radio-data system RDS" (1984), EBU Review (Technical) No. 204, pp. 50-58.

4. J. Mielke and K. H. Schwaiger, "Radio-Daten System RDS - Gegenwärtiger Entwicklungsstand und Versuchsergebnisse (Radio-Data System RDS - Present state of development and results of field trials) (1985), NTG-Fachberichte Hörrundfunk 7, published by VDE-Verlag GmbH, D-1000 Berlin 12, Bismarckstr. 33, Germany, FR (ISBN 3-8007-1439-6), pp. 93-103.

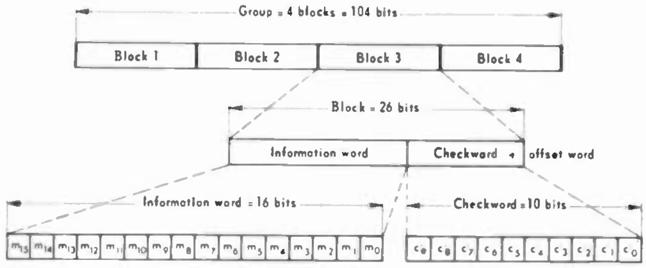


Fig. 1: Structure of baseband coding

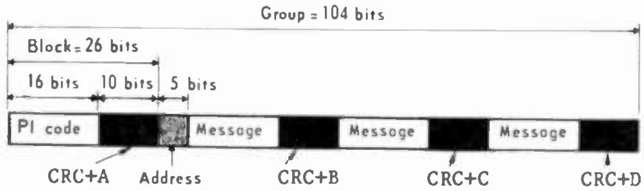


Fig. 2: Coding format used to transmit 1187.5 bits, corresponding to 11.4 groups, i.e. 45.7 blocks or 726 usable information bits per second

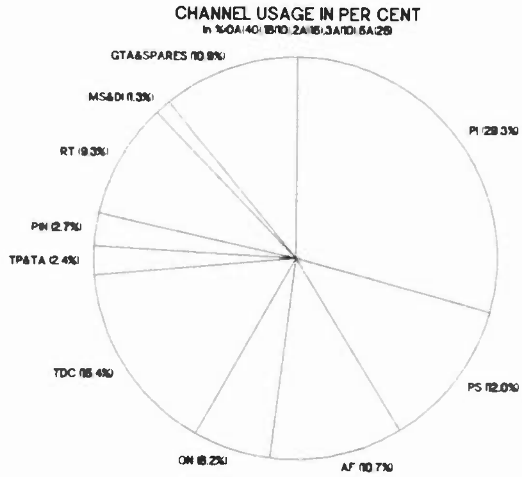


Fig. 3: Example for the transmission capacity used by various applications assuming the mixture of groups recommended in Table 2, below

Applications	Group types which contain this information	Recommended minimum repetition rate per second
Programme identification (PI) code	all	11*
Programme service (PS) name	0A, 0B	1*
Programme type (PTY) code	all	11
Traffic programme (TP) identification code	all	11
Alternative frequency (AF) code	0A	4**
Traffic announcement (TA) code	0A, 0B, 15B	4
Decoder identification (DI) code	0A, 0B, 15B	1
Music/speech (M/S) code	0A, 0B, 15B	4
Programme item number (PIN) code	1A, 1B	1
Radiotext (RT) message	2A, 2B	0.2

* Valid codes for these two items will be transmitted with at least these recommended minimum repetition rates whenever the transmitter carries a normal broadcast programme.

** The alternative frequencies (if any) for transmitters carrying the same programme signal will be transmitted cyclically from a list of up to 25. When no alternative frequencies are transmitted, type 0B groups (which do not contain the alternative frequency information) should be used instead of type 0A.

Table 1: Recommended minimum repetition rates

Group type	Applications	Typical proportion of groups of this type transmitted
0A or 0B	PI, PS, PTY, TP, AF*, TA, DI, M/S	40%
1A or 1B	PI, PTY, TP, PIN	10%
2A or 2B	PI, PTY, TP, RT	15%**
3A or 3B	PI, PTY, TP, ON	10%
Any	Optional applications	25%

* Group type 0A only.

** Assuming that type 2A groups are used to transmit a 32-character radiotext message. A mixture of type 2A and 2B groups in any given message should be avoided (see § 1.3.3).

Table 2: Recommended mixture of groups to achieve minimum repetition rates

HIGH SPEED DATA TRANSMISSION OVER BROADCAST AM AND FM SUBCARRIERS

William D. Loveless and Gary Robinson
Bonneville International Corporation
Salt Lake City, Utah

Abstract:

Part I - Progress report - KSL tests a higher data rate AM sub-carrier with Kahn AM stereo.

Part II - A single 18% data sub-carrier is superior to two 9% sub-carriers. A description of Bonneville's 9.6 kilobaud satellite fed FM data sub-carrier network deployed in 40 markets.

Part III - Bonneville engineers are working with RTT in testing a high rate 2-way data system with experimental license on adjacent TV Ch-6 in Salt Lake City, Utah.

Part I - Progress Report: AM Data Sub-carriers

The Kahn AM data sub-carrier system is being tested at KSL in Salt Lake City. A proprietary sub-carrier modulation system is used with baseband data encoding. The data sub-carrier is concealed within an unused portion of the Kahn AM stereo spectrum.

The AM data sub-carrier fits within the spurious radiation requirements of Section 73.44 of the Commission's rules for AM transmitters. Cross-talk into the main channel is not audible on a conventional AM receiver with envelope detector or on a wide-band AM stereo receiver with an adjacent channel whistle filter.

The Kahn AM data sub-carrier receiver delivers buffered ASCII characters across its standard RS-232 interface at 1,200 baud. The AM data receiver simulates a standard 1,200 baud asynchronous modem in the receive only mode. The data rate through the system ranges between 300 to 600 baud depending upon main channel modulation. Bit error counts average 1 bit error in 100,000 bits.

On February 12, at 5:30 pm, 600 baud data was transmitted over-the-air on KSL using the data sub-carrier with the Kahn AM stereo system. The following repeating data message was received without error through a window on the 8th floor at Broadcast House, a distance of 10 miles.

"This is a test of the Bonneville/Kahn data system. This is the KSL radio data stream. This is a test of the KSL sub-carrier data system. February 12, 1986"

On-air announcers monitored their voice from the audio console "line" instead of the "air" monitor because of the delay in the audio chain while using the data system.

KSL's main channel stereo or mono modulation performance was not affected by the presence of the data sub-carrier. As average main channel stereo modulation dropped below a set threshhold, data transmission halted and started again gracefully, without error.

Bonneville engineers are considering the AM data sub-carrier to deliver a KSL news and information service called TeleText-5 to home computers. The free ad supported service is presently operating via 4 dial-up phone lines and receives 600 to 700 computer modem calls a day on (801) 575-5911. The AM data sub-carrier would be modulated by the TeleText-5 data stream in repeating cycles for continous wide area distribution. Data sub-carrier receivers have been designed for large scale integration (LSI) on hand-held or wrist-watch style AM radio data terminals.

Further testing on KSL will determine the data coverage area for the KSL ground-wave and sky-wave signals.

Part II - High Speed FM Data Sub-Carriers

FM broadcast channels are spaced at 200 kHz with 20 times more bandwidth than AM channels. Guard bands prevent FM sidebands from overlapping into adjacent FM channels. FM data sub-carriers in the FM guard bands have been used for a number of years.

Except near U.S. borders, FCC rules allow 110% total modulation (82.5 kHz deviation) of the main RF carrier when fully loaded sub-carriers are used. Two sub-carriers, at 67 kHz and 92 kHz, each with 9% injection are allowed. Injection is the percent of 75 kHz deviation used.

There is however a +2.67 dB gain in total sideband power that can be achieved by using an 18% sub-carrier at 79.5 kHz instead of two 9% sub-carriers at 67 and 92 kHz as shown in the following examples:

Example 1: A 100 kW FM station with a single 9% sub-carrier at 67 kHz produces a pair of 253 watt carriers for a total sideband power of 506 watts.

Example 2: The same transmitter with a single 9% sub-carrier at 92 kHz produces a pair of 134 watt carriers for a total sideband power of 268 watts.

Example 3: The same transmitter with both 67 and 92 kHz sub-carriers, each at 9% injection, produces 2 pairs of sidebands. The sum of 1 and 2 is 774 watts.

Example 4: The same FM transmitter with a single 18% sub-carrier at 79.5 kHz would produce a pair of 716 watt sidebands for a total sideband power of 1,432 watts, an increase in power of 618 watts or +2.63 dB. The sideband power is subtracted from the 100 kW RF carrier.

With separate 67 and 92 kHz sub-carriers operating, additional guard bands for band-pass filters are required between the two sub-carriers which segments and reduces the bandwidth. Greater bandwidth with higher sideband power from a single 18% 79.5 kHz sub-carrier would allow greater signal-to-noise ratio and higher speed data to be transmitted. (Wider bandwidth also receives more noise)

Side-band power computed using Bessel functions for various single sub-carriers and 100 kW ERP.

Subcarrier	Injection	2-Sidebands	Ref	100kW 0dB
76 (4x19)	18%	1,566 watts	0dB	-18.06dB
79.5 (mid)	18%	1,432	-0.38	-18.44
67 (lower)	9%	506	-4.90	-22.96
76 (4x19)	9%	394	-6.00	-24.06
79.5 (mid)	9%	360	-6.38	-24.44
92 (upper)	9%	268	-7.66	-25.72
57 (3x19 ARI)	3%	78	-16.04	-34.10
57 (3x19 RDS)	2%	34	-16.63	-34.69

During the past 6 months, Bonneville engineers tested data rates up to 38.4 kbs with good results, but the 19.2 kbps rate seems to be more reliable and robust. Data crosstalk into main channel programming with "Easy Listening" format is not audible, and extensive testing reveals no adjacent channel interference.

Bonneville's existing, 9.6 kbps packet multiplexed data stream is transported to satellite via an up-link in Salt Lake City and then down to 2 foot satellite dishes at each FM station. The satellite data signal modulates the FM station's sub-carrier which is delivered locally over-the-air to thousands of Bonneville FM data receivers connected to computers and terminals in customer offices. A number of packet multiplexed data services are presently running interleaved on the Bonneville network.

Bonneville's FM data receiver contains a sub-carrier de-modulator and packet de-multiplexor with forward error correction to form an addressable radio modem. Down-loaded customer authorization codes, individual FM receiver addresses and virtual circuits allow each customer to receive only those electronic mail messages and data services that have been authorized. Messages are input to the head-end computer via dedicated data lines and low-cost dial-up value added network lines (VANs).

The Bonneville data network is presently deployed and operating on 40 FM stations in major U.S. markets. In remote areas without FM service, customers use 2 foot satellite dishes to receive the same data service. The principle advantage of the Bonneville data network is its low message cost that is not sensitive to distance.

Depending on the FM signal quality, bit error counts measured at various locations in New York City from station WRFM atop the Empire State building range from less than 1 bit error in 1 billion bits to 1 bit error in 100 thousand bits. Forward error correction is used to improve the raw-error count by a factor of 100 but depends upon the quality of FM reception and the degree of multipath in the signal. Bonneville's data receiver has a built-in test mode for real time measurement and documentation of the actual raw and corrected error counts.

Part III - Two-way Data Tests on Adjacent TV Ch-6

Bonneville engineers in Salt Lake City, Utah, are working with Radio Telecom Technology (RTT) in testing their T-Net System, a true 2-way radio data system with high potential capacity. RTT holds an experimental license to use TV Channel 6, adjacent to Bonneville's KSL-TV Ch 5, on a non interference basis in the Salt Lake metro area.

RTT's T-Net system, promises low-cost, high-capacity, private 2-way data channels by using an adjacent or taboo TV channel. With T-Net, 300,000 individual 2-way data terminals are assigned to an unused TV channel in a given market. 75,000 of the 300,000 can be in active, 2-way, independent communication at the same time.

Outbound and return data signals are received and transmitted at the customer location using an existing roof-top TV receiving antenna connected to an operating TV set while receiving normal TV programs on the adjacent TV channel, all without interference.

The outbound data rate can be up to 65,536 bits per second while return data signals from the customer's terminal can be 300, 1,200 or 4,800 bits per second. The adjacent TV channel used for data transmission is sub-divided into a number of multiplexed data channels. The X.25 packet protocol provides for dynamic channel allocation, customer location verification, addressability, authorization, de-authorization and billing.

The RTT 2-way radio modem, receives and transmits data at a few milliwatts of average power while connected to the same TV antenna used by the TV set tuned to the adjacent TV channel program, all without interference. Several phases of testing and verification of the T-Net system will continue through 1986 in Salt Lake City.

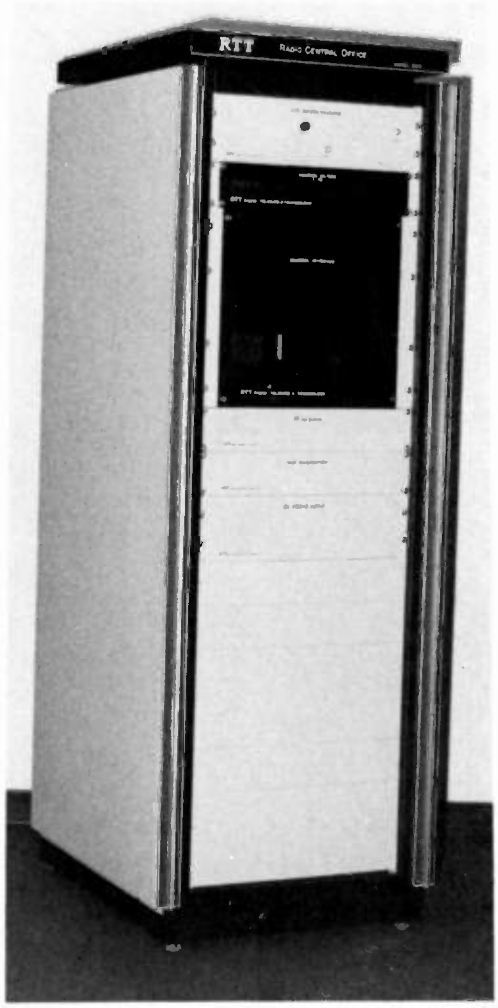
Acknowledgments:

The authors wish to thank and acknowledge Leonard Kahn of Kahn Communications Inc, John Dehnel, Peter Hughes and Randy Finch of KSL, Gordon Smith of Bonneville Telecommunications and Lewis Martinez of Radio Telecom Technology, for their many hours of help and assistance on these projects.

Kahn Communications Inc.
AM sub-carrier data receiver prototype

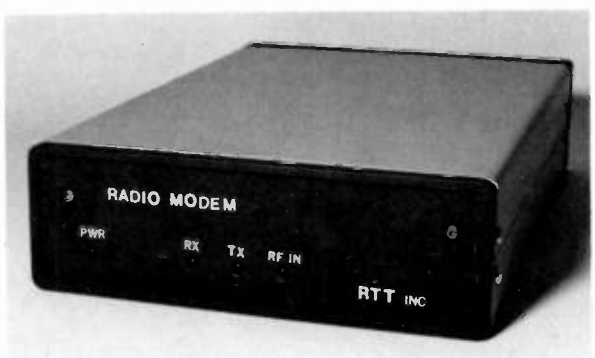
Bonneville Telecommunications
FM sub-carrier data receiver

Ch-6 antenna for RTT Radio Central Office, 18 miles S.W. of Salt Lake City, at KSL-TV transmitter site, 9,054 foot Farnsworth Peak.



Radio Telecom Technology Inc.
2-way Radio Central Office Farnsworth Peak

Radio Telecom Technology Inc.
2-way Radio Modem Prototype on TV Ch-6



DIAL TELEPHONE TRANSMITTER REMOTE CONTROL

John E. Leonard, Jr., President
Gentner RF Products
San Jose, California

AFFORDABLE TELEPHONE REMOTE CONTROL

- ☐ Use dial telephone system
- ☐ Use Touch-Tone (R)
- ☐ Use synthesized voice
- ☐ Let any telephone be an access point
- ☐ Observe all FCC requirements

Transmitter remote control systems stem from the early 1950's. In the intervening years the ability to handle directional AM stations as well as VHF television facilities have sequentially been added. A large variety of Rules and Regulations existed in the past that provided guidance as to the various techniques and methods for remote control, or unattended operation of broadcast transmitters. With the adoption on November 19, 1984 by the FCC of Docket 84-110, a drastic revision to these Rules occured. The Rules were amended such that the use of the switched or dial telephone system could now be used for operation of a remote control system in place of the previous mandatory dedicated circuits.

The principal advantage offered by the use of the dial telephone system for remote control of broadcast transmitter is the reduction in operating costs. A dedicated telephone line, with the deregulation of the telephone industry, has undergone a substantial increase in cost. As an example, from our offices in San Jose, California to the nearest FM Broadcast transmitter, an unconditioned data circuit as provided by the local telephone operating company would have a monthly cost of some $135.00. This represents a distance of some 5 miles and involves two central offices. This type of circuit is commonly used by remote control equipment designed to function on dedicated circuits. A conventional business telephone line to that transmitter site would have a cost of some $15.00 to $20.00 a month. This represents a potential savings of over a $100.00 a month when dial access is used instead of a dedicated circuit. This is a substantial savings in operating costs.

The reliability and repairability of conventional telephone service must also be considered. With many operating telephone companies, installation and servicing of a dedicated data circuit is more difficult to obtain than the standard service. Reliability must not be overlooked. In many instances with a national disaster or other general disruption of services, the dial telephone system is among the last to cease functioning. How many times have we all gone to a transmitter site to see why the transmitter is off the air, only to find that the telephone works, but there is no AC power present at the site.

Flexibility maybe the ultimate factor in utilizing the dial telephone system for transmitter remote control. If a system is established that will function with the dial system, it is then possible to access it from any location having a telephone.

In approaching the use of dial telephone system, consideration must first be given to the requirements of the current FCC Rules and Regulations. For AM, FM and TV the Rules are now contained in two sections of Part 73. These are 73.1400 and 73.1410.

In reviewing the Report and Order for Docket 84-110, the first point mentioned relates to the previous requirement for fail-safe. In this proceeding the Commission stated that nearly all the response to the docket expressed that the primary difficulty with remote control operation was the fail-safe requirement. The requirement for fail-safe circuitry where thus removed and are not included in the new Rules. In the Docket the Commission took note that the Communications Act of 1934 requires that a licensed operator have supervisory control over the transmitter during all periods of operation. The proceedings note that the operator need only be able to terminate the stations operation should it be a source of harmful interferance or be operating inconsistantly with law or treaty. It is to be noted that the new Rules are devoid of "how to" methodology provisions.

The new Rules do not require notification if the remote control point is the studio or transmitter location. Section 73.68 (a) is to be noted when a directional AM array is involved. This does require the filing of Form 301-A. Other than that requirement, no authorization is required for non-directional AM, FM or television stations to use remote control. Notification is also not required if responsible station personnel may be contacted at the studio or transmitter site during hours of operation when the remote control operator is elsewhere. If a remote control point is elsewhere and no one will be at the studio or transmitter, then notification is required within three days of initial use.

These new rules do not stipulate what parameters need to be observed at the remote control point, only that sufficient control and operating parameter monitoring capability to allow compliance are needed at the remote control point. AM stations that must change modes during the broadcast day, are to have sufficient redundancy to insure that such mode changes actually occur.

A remote control system is to be designed, installed and protected so that the transmitter can be activated or controlled only by licensed transmitter operators authorized by the licensee. The system need only be calibrated and tested as often as necessary to insure proper operation and it is to be designed so that malfunctions in the circuits between the control point and the transmitter site do not cause inadvertent activision of the transmitter or the changing of operating modes or powers. Whenever a malfunction causes loss of accurate indications of transmitter operating parameters, remote control operation must be discontinued within three hours after the malfunction is first detected. It is to be noted that if the station is found to be operating beyond the terms of the station authorization and such malfunction can not be corrected by remote control, station operation must be immediately terminated. Finally, the Rules permit a variety of auxiliary modulation schemes, such as subcarriers, to be used as interconnecting circuits.

Two additional points that must be carefully observed are EBS and tower light monitoring. Although these go beyond the scope of this paper, they are mentioned so as not to be overlooked in considering remote control operation. It must not be forgotten that all stations, including non-EBS stations, are required, given an national Emergency Action Notification to discontinue normal programming.

As the Rules do not provide specific guidance, such as been the case in the past, for this type of operation, efforts have to be made to insure that the intent of the rules are met. The Communications Act requires that a station have the ability to terminate operation. This is considered the ability of having absolute carrier control. While not a fail-safe, as existed in the past, it is to have the ability to cease radiation at will. From discussions with members of the Commission's staff and from presentations made elsewhere by members of the FCC staff, absolute carrier control can be accomplished in a number of ways. The dial telephone system, however, can not be construed as given absolute carrier control. This is based upon the assumption the use of the dial telephone system is only of an intermittent nature. That is the dial telephone is used in an automatic dial/automatic answer mode and is not normally left off-hook where it would resemble a dedicated circuit. Rather the dial telephone circuit would only be used when it was desired to observe transmitter operating parameters or when the control system wished to report a problem by initiating a telephone call.

It is practical to state that if programming is not present at the transmitter site there is no need to have that transmitter on the air. Thus, absolute carrier control can be established by the presense or the lack of program material to the transmitter. In the simplest terms the carrier operated squelch relay of an aural STL receiver or the simple presence of program audio will provide an acceptable means of providing absolute carrier control.

The new Rules also do not tell us what form of monitoring to use, not even that meters are needed or required. The general guidelines from this proceeding are for the operation by remote control were that the licensee be assured that: (1) an operator is on duty, (2) the transmitting system operates properly, and (3) the Commission can contact station personnel during hours of operation. Given all of the above a careful accessment must be made of "how to" use the dial telephone system.

Looking at the dial system there are several basic characteristics: (1) the use of signaling (2) the ability to carry voice traffic. Signaling refers to the ability to transmit or various telephone numbers. This is accomplished in the dial system through the use of either sequential interruptions of the circuit, most times referred to as pulse dialing. In most places of the country the more common way is through the use of Touch-Tone (R) signals.

The principal thing that this system is designed to carry is voice traffic. In other words, the spoken word. While the system is currently being used for this, successful transmission of slow and medium speed digital data, freeze-frame video, and the like are also possible.

In contemplating the use of the dial telephone system for transmitter remote control, the use of Touch-Tone (R) and voice make the most amount of sense. This would permit accessing the system from any standard telephone. With microprocessors it is now quite possible to implement a system that takes full advantage of these two parameters - voice and Touch-Tone (R).

The use of synthesized voice for outputting data enables the use of any telephone as a remote control unit. Touch-Tone (R) when used for the command input permits the greatest versatility. When voice is used as output for a system, careful consideration must be given to the words that are actually spoken. For a remote control system to function, the ability to observe analog parameters (metering channels), as well as go/no-go indications, is virtually mandatory . Such a system needs to have the ability to scale metering channels in a number of ways. Verbally the presentation of numbers in the form of small numeric values is most recognizeable. A plate voltage of "twenty eight hundred fifty volts" is much more difficult to comprehend or understand, than a presentation of "2.85 kilo Volts". Various verbal presentations to identify functions must be considered. From our work we have determined that just for identification, excluding numeric presentations, over 500 words are needed to present, all common transmitter operating parameters.

The system must also have the ability to issue control functions. With the verbal feedback, command functions existing either independently or in association with metering or status channels become virtually mandatory. Such a combining of capabilities permits the tailoring of a system to meet individuals station requirements.

A self-monitoring of correct system operation is very desirable when the dial telephone network serves as the interconnecting circuit. Checking the accuracy of metering (analog) presentations can be viewed as mandatory to assist in compliance with the verification of observation ability under the new Rules. Likewise, a system that can automatically confirm its operation every three hours can help meet the intent of the Rules. This could be accomplished by a system automatically dialing to report its presence and correct functioning.

An area of equal concern is the correct handling of the dial telephone system. The FCC provides some direction with the requirements established under Part 68 of the Rules and Regulations. Specifically these relate to electrical characteristics but also cover the number of times a system can automatically dial a sequence of more than one telephone number. Combine with this the possibility of catastrophic alarm situations that could produce sequential attempts at automatic dialing, such as icing of an FM transmitting antenna, and the requirements become more stringent. All of these create a situation where it is desirable to have multiple telephone numbers that can be automatically dialed. In automatic dialing, time gaps should exist between the dialing of each telephone number. Further, a remote shut down of automatic dialing can be very desirable. The use of microprocessor technology makes all these possible.

Microprocessor technology enables the combining of data collection (Metering and status) and command capability, while accommodating all dial telephone functions in one system. A system that is affordable, both in acquisition costs and operating costs.

APPENDIX

The following are the current FCC Rules for transmitter remote control.

73.1400 Remote control authorizations.

(a) An AM, FM, or TV station transmission system may be operated by remote control using the procedures described in 73.1410.

(b) No authorization from the FCC is required to operate the transmission system of an AM station operating with a nondirectional antenna, FM station, or TV station by remote control. Authority to operate an AM station using a directional antenna system by remote control is obtained using the following procedures:

(1) An application for a construction permit to erect a new directional antenna or make modifications in an existing directional antenna, subject to the sampling system requirements of 73.68, may request remote control authorization on the permit application FCC Form 301 (FCC Form 340 for noncommercial educational stations).

(2) A licensee or permittee having a sampling system in compliance with the provisions of 73.68(a) must request remote control authorization on FCC Form 301-A, and submit information showing that the directional antenna sampling system has been constructed according to the specifications of 73.68(a).

(3) A licensee or permittee of a station not having an approved directional sampling system in compliance with the provisions of 73.68(a) must request remote control authorization on FCC Form 301-A, and submit information showing that the directional antenna is in proper adjustment and further showing the stability of the antenna system during the 1-year period specified in Section II of Form 301-A.

(c) Whenever a remote control point is established at a location other than at the main studio or transmitter, notification of that remote location must be sent to the FCC in Washington, D.C, within 3 days of initial use of that point. This notification is not required if responsible station personnel may be contacted at the transmitter or studio site during hours of operation when the remote control operator is elsewhere.

73.1410 Remote control operation.

(a) Broadcast stations operated by remote control must provide at remote control points sufficient control and operating parameter monitoring capability to allow technical operation in compliance with the Rules applicable to that station and the terms of the station authorization. AM stations that are required to change modes of operation during the broadcast day must provide sufficient redundancy to assure that such mode changes actually occur.

(b) The remote control system must be designed, installed, and protected so that the transmitter can be activated or controlled only by licensed transmitter operators authorized by the licensee.

(c) The remote control and monitoring equipment must be calibrated and tested as often as necessary to ensure proper operation.

(d) The remote control system must be designed so that malfunctions in the circuits between the control point and transmitter will not cause the transmitter to be inadvertently activated or to change operating modes or output power.

(e) Whenever a malfunction causes loss of accurate indications of the transmitter operating parameters, use of remote control must be discontinued within 3 hours after the malfunction is first detected. If the station is found to be operating beyond the terms of the station authorization and such malfunction cannot be corrected by remote control, station operation must be immediately terminated.

(f) AM stations may use amplitude or phase modulation of the carrier wave for remote control telemetry and alarm purposes. FM stations may use aural subcarriers and TV stations may use either aural subcarriers or signals within the vertical blanking interval for telemetry and alarm purposes. Use of such remote control signals must be in accordance with the technical standards for the particular class of station.

OFF-PREMISE REMOTE CONTROL OF A RADIO STATION USING A PERSONAL COMPUTER

P. Michael Zeimann, Station Manager
WKDN-FM
Family Stations, Inc.
Camden, New Jersey

Abstract
While many radio stations use computer-based program automation systems to control the continuity and flow of their programming, few stations have integrated a technical control system into their operation.

Such a control system has many inherent advantages, not the least of which is an unattended operation for part of the broadcast day. The cost of some dedicated, packaged systems is prohibitive for some stations, but with the advent of inexpensive personal computers and a "real world" interface, WKDN has developed a complete control package for under $1200 that provides unattended, off-studio operation and improved control of its transmitter.

System Function and Description

The system at WKDN was designed around the Commodore 64 computer and its related equipment (printer, disk drive, monitor, and phone modem). In addition, the C-64 was interfaced to an existing transmitter remote control system (TFT, Inc.) using the Innovative Technology 1020 interface board.

The host (studio) computer calls (via the phone modem) the off-premise control point (terminal) every 2 hours to report all conditions are normal during unattended studio operation. The terminal operator is then assured the host computer is working properly and has not "crashed".

If an alarm occurs at the station, the terminal operator is immediately notified via the auto-dial/auto-answer modem. The terminal operator can then reset and verify the alarm condition and take appropriate action.

The computer system performs the following functions:

1. Monitors and controls WKDN's transmitter and provides a printed log of transmitter readings and alarm conditions such as high and low power.

2. Monitors various radio station functions such as tower lights, transmitter building and studio burglar alarms, and the Emergency Broadcast System receiver.

3. Provides audible and visual indications when any monitored function is out of tolerance and notifies the terminal location during unattended studio operation.

4. Provides WKDN with off-premise, studio-unattended operation from 12 midnight to 6 a.m. weekdays using the phone modem as the studio-to-remote-location link and a dial-up phone line. A similar Commodore computer system at the off-premise or terminal location is used.

WKDN's Computer System meets or exceeds all remote control requirements as set forth in Federal Communications Commission (FCC) Report and Order MM Docket No. 84-110, RM 3046 adopted November 19, 1984.

It should be noted that the system described is a real-time control system for controlling and monitoring technical functions -- it is not a program automation system. Programming at WKDN is delivered via Satcom IV satellite and is produced by Family Radio in Oakland, California of which WKDN is an owned and operated station. The local station insert programs and announcements are done with a spot inserter and Carousel cart machine.

The Commodore 64 and Commodore peripherals were chosen for their 1) cost effectiveness 2) outstanding graphics and sound 3) ease of programming 4) availability, and 5) good documentation including many helpful articles in computer magazines.

System Features

1. Continuous full-color graphic display of transmitter parameters, alarm conditions, and status of various system conditions.

2. Automatic printout of transmitter readings at regular intervals.

3. Audible and color-coded visual indications of alarm conditions.

4. Logging of all alarm conditions.

5. Self-correcting real-time clock for programmable events.

6. Automatic date advance and log heading.

7. Disk-based memory protection.

8. Menu-driven system functions:
   a. Time and date set
   b. Operator initials
   c. Alarm reset and disable
   d. Transmitter efficiency calculation for indirect power calculations
   e. Terminal location selection and terminal mode on/off
   f. Monitor volume level
   g. Printer on/off
   h. Auto/manual selection

9. Password security for host and terminal computers.

10. Off-premise (terminal operator) has the capability of controlling and monitoring all transmitter functions using the TFT remote system.

11. Terminal location provides a printed log and history of all alarm and normal indications.

12. "Homebrew" interface box provides isolated contact closure outputs for miscellaneous functions.

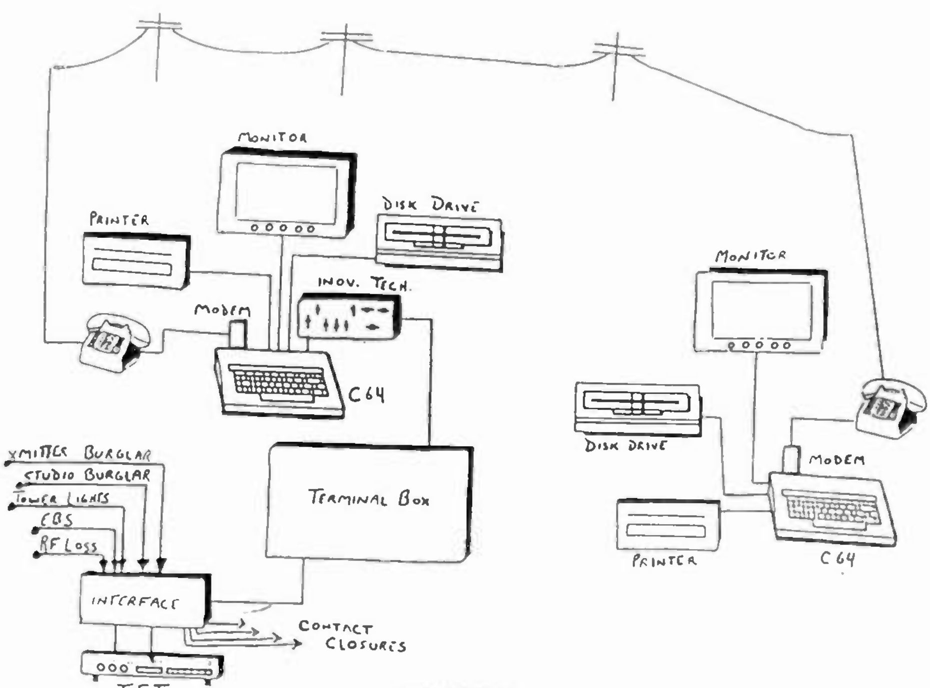
13. Minimal computer system downtime is due to low cost and easily-obtained system components.

<u>Conclusion</u>
The WKDN Computer System:

1. Allows us to operate with no studio personnel from 12 midnight to 6 a.m. weekdays. Another Family Radio station (WFME in Newark, New Jersey) monitors our air signal and computer alarms with a Commodore 64 used as a terminal during this time. Big cost savings!

2. Provides a continuous printed log of transmitter readings and station alarm conditions and has removed the tedium of regular transmitter readings. While transmitter operating logs are no longer required by the FCC, smart station operators continue to log as proof of proper operation and for maintenance reasons.

3. Provides for better control of transmit-



SYSTEM OVERVIEW

ter than an operator making periodic adjustments (if at all).

4. Provides key station employees access to transmitter functions from remote locations.

Based on our experience at WKDN, a cost-effective, flexible, and "user-friendly" microcomputer control system that can operate a radio station from an off-studio location is a reality.

The Commodore 64 and Commodore peripherals and Innovative Technology interface board (also available with Analog to Digital conversion) made software and hardware development relatively easy.

The software using BASIC is very flexible and can be customized easily to almost any FM station. Family Radio is presently exploring the possibility of incorporating other Family Radio owned and operated stations into the existing computer network for off-premise remote control operation. Since transmitter status and control as well as building alarm conditions are only as far away as a telephone call, the system is accessible from virtually any location using a password.

For more information or an on-line demonstration of our computer system, don't hesitate to call me during business hours at 609-854-5300.

USING PACKET RADIO TECHNIQUES TO RELIEVE "P" CHANNEL CONGESTION

Harold Hallikainen - Hallikainen & Friends - San Luis Obispo
Michael D. Callaghan - KIIS AM/FM - Los Angeles, California

ABSTRACT: This paper presents a concept whereby existing 'P' channels and new digital packet techniques are combined to link studio and transmitter sites for transmitter control and telemetry return.

Transmitter remote control systems require two data links - one from the studio to the transmitter, and another from the transmitter to the studio.

A number of choices are available to accomplish these links; two-way telephone lines may be leased from the phone company, or the necessary signals may be piggybacked on the studio to transmitter uplink, with the return telemetry brought back by an aural subcarrier riding down on the main carrier in the case of FM stations, or as a subaudible tone on AM stations.

There is a distinct disadvantage to this; part of the primary signal and part of its modulation capability is being used for simple point-to-point communications. We are sending the data a lot of places it doesn't need to go. Since the transmitter readings matter only to the transmitter operator, we can avoid this waste by using a less encompassing link to return the data.

Another disadvantage of using the STL/broadcast transmitter communications link for control/telemetry is that we are relying on the "equipment under test" (the broadcast system) to carry data necessary to debug the system. If your station is off the air, and you are relying on the STL/broadcast transmitter link, you cannot tell if the problem is that the STL signal is not arriving at the transmitter site, or there is a problem in the broadcast transmitter system itself. Your remote control efforts to get the station back on the air are "shooting in the dark" by trying various control combinations to see if one will get the station back up. You do not know what is wrong, and you do not even know if the control signals you are sending are getting there. This problem is avoided with an independent control/telemetry link, such as the previously mentioned dedicated or dial-up wire line, or a separate radio system.

Also, it's not entirely clear that the apprehensions many FM broadcasters have about subcarrier use are totally unwarranted. Given the benefit of the doubt, it would probably be preferable that the subcarrier not be used.

This leaves phone lines as the next most common alternative. However, due to the recent deregulation of the telecommunications industry, local telephone companies are being forced to adjust their prices to reflect the actual cost of service. These price adjustments have shown up as a decrease in long distance rates and an increase in local and private line rates. The increase in private line rates has encouraged broadcasters to move to alternate technologies, including the use of dial-up lines to acquire data and exercise control on an "as needed" basis and the use of radio links.

For years the Commission has set aside eight special U.H.F. radio channels for use in bringing telemetry back from the transmitter site. These are known as 'P' or 'control' channels. However, the existing usage is such that each station interested in using a one of these assignments for its telemetry is assigned one frequency. This means only eight broadcast stations may be accommodated before all the channels are gone.

In terms of efficient spectral usage, it makes little sense to have one station per channel, especially considering that remote control readings are rarely taken continuously. More often than not, they're sampled at set intervals.

Spectral utilization could be tremendously increased if more than one station were to share the same frequency. Establishing a system to do this would be a major undertaking if it weren't for the fact that the system of packet radio had already been brought into widespread use by radio amateurs.

In packet radio one frequency is 'time-shared' by a rather large number of users. Certain protocols and priorities are established in terms of who uses the frequency at a given time, and to attempt to insure more than one station is not transmitting at the same time.

Using existing two way remote control systems, this might take the form of the addition of some simple circuitry to the existing telemetry return link equipment. At each 'P' channel transmitter site would be a receiver monitoring the output channel. If a carrier is present, operation of the transmitter would be suppressed. When the carrier goes away, the transmitter would be brought up after some "random delay". The random delay is necessary to insure that a dozen transmitters don't all come up at the same time after they've noticed that the one original interfering carrier has gone away. The random delay could be replaced with a fixed delay that varies between transmitters, but this would give the station with the shortest delay priority access to the system. Finally, each transmitter would include a timer that would allow it to transmit a maximum of one minute, or perhaps ten or twenty seconds after the last metering channel change or raise or lower command. Twenty seconds after one of these had been sent, we would assume that the operator had walked away from the studio unit of the remote control system and that further updates of its display serve no purpose.

As an illustration, there are eight major FM stations with studios in Hollywood and transmitters on Mt. Wilson. All these stations could share the same 'P' channel. When a particular station were interested in learning the status of its transmitter plant the remote control would be punched up or dialed the same way it is now. The digital information representing the inquiry would be sent to Mt. Wilson as a burst of data on the shared channel, which would contain a digital address for the intended transmitter.

The appropriate transmitter plant would decode the address, verify the data had been received correctly, act on the signal, return an acknowledgement, quickly interrogate the data registers within its own remote control and provide a return burst of data back to the studio, which would also send back an acknowledge.

The entire procedure - the inquiry going to the transmitter and the information returning - would occupy just a few seconds, depending on the controller, response time, channel useage and the baud rate. Then the carrier would go dead until another station started an inquiry.

If an inquiry is made for a metering parameter that requires some settling time to measure, (such as directional antenna phase angles), then the return data will obviously be delayed, but not appreciably more than would happen if a phone link were still employed.

If a collision does happen, the receive parity test will fail, and no acknowledgement will come back. One of the systems will automatically come on again, resend the inquiry, and the second will follow when that system finishes.

Because the data moves at such a rapid rate this should never take more than a few seconds.

In the event of a power failure at a common shared transmitter site, it's likely that a number of stations would all be trying to trying to interrogate their control systems at the same time. In order to avoid collisions the 'delay before transmit' scheme would probably be rather active, but, even so, all it would mean in the end is that some stations might have to wait a few more seconds for their readings to appear.

In theory, there is no limit to the number of stations that could use the same channel. However, if it exceeded twenty or thirty it could mean delays of consequence in the return of the data.

Another possible application for the concept would be a television station with a number of E.N.G. receive sites to control. They could use one frequency and transmitter to access their different sites. aim antennas, and bring back telemetry. A number of stations could share the same channel if the demands weren't too heavy.

An operation using one of these systems would then need just a pair of U.H.F. transceivers, antennas, two packet controllers, two simple interfaces and a "P" channel to put the concept into practice. 'P' channels are currently frequency coordinated by local coordinating committees.

The only other prerequisite is that they all use the same packet scheme, most likely the AX.25 Version 2 system which has become the de facto standard in amateur usage, with the associated low cost of the equipment.

In this protocol, the transmit burst is made up of a series of frames, each of which starts with a series of framing bytes, to synchronize the controllers. These are followed by the source and destination address bytes, who establish which receive controllers will use the data. Next comes a series of bytes which carry internal information to the controllers relating to control status, procedure, and system operation. Following are the actual eight bit data bytes, which may range in quantity from 1 to 256 per frame. Finally the CRC, or Cyclic Redundancy Check is sent. This is a number derived by a complex algorithm using the values of the bytes in the data frame. The same computations are performed by the receiving controller. The value it derives is compared with the value sent by the transmitting controller to insure that the data arrived intact. As many as 7 of these frames can be included in one packet burst, giving a total packet capacity of about 1.8 K of data - more than enough to completely fill a screen. If everything checks out properly, then an acknowledge burst is returned to the originating controller.

The packet controllers themselves can accept any of a number of inputs. Because of low cost, one of the favorite interfaces in current use is the one for the Commodore 64 computer. For remote control operation, however, we would be more likely to select a controller that is 'RS-232 transparent'. This means the remote control terminals talk back and forth in the same fashion they would if they were connected with leased phone lines and regular data modems. They don't know the difference - the transmit addresses, receive acknowledgements, parity checks and transmission parameters are all handled by the two packet controllers. The RS-232 loops from the remote controls to the controllers through a simple interface board which inhibits the system control data from bothering the remote control system. The other requirement is to connect the controller audio inputs and outputs, keying circuits, and the U.H.F. antennas to the transceivers.

If a simplex frequency is intended, the antennas should be non - directional. (By receiving the signals from all the other users, a specific transmitter will know when to inhibit transmissions if the channel is occupied). If the stations sharing the channel are far enough removed that they cannot receive each other, a repeater would be needed to serve all of them. There are a couple of fashions in which it may operate: the single frequency (simplex) sequential repeater and the two frequency (duplex) simultaneous repeater.

Since digital data is easy to store, a repeater could pick up messages, store them, then transmit them on the same frequency it was receiving on when the channel goes clear. This appears to save spectrum, since only one frequency is used. However, since each message appears on the frequency twice, the throughput is reduced to half of what would be available without the repeater. In addition, if the various stations in the system cannot hear each other directly (which is quite likely, for if they could, there would be no need for the repeater), there is a possibility of a collision due to a station not knowing that the channel is busy.

The two frequency simultaneous repeater is the same repeater technology that has been used for voice technology for a long time. Although this uses two frequencies, resulting in more spectrum being consumed, the message is transmitted simultaneously (except for propogation delays) on both frequencies. This allows the same throughput that would be available without the repeater, or double that of the single frequency sequential repeater. The spectrum efficiency of the two repeater techniques ends up the same since the single frequency system has half the throughput of the double frequency system. In addition, if all units transmit on the repeater input frequency and listen on the transmitter output frequency, all units know when the system is busy, allowing efficient collision avoidance, again increasing system throughput.

In any case, the repeater needs to have very short squelch and key delays, since these delays are added to the other delays in the system reducing system throughput and potentially increasing the possibility of collisions. In addition, since several stations are sharing the repeater, it needs to be very reliable. Redundant circuitry and battery backup operation are suggested.

The two frequency simultaneous repeater could use one of several repeater techniques. The first would be the standard receiver output to transmitter input circuit. If this is used, it is suggested that deemphasis in the receiver and preemphasis in the transmitter be removed to eliminate the frequency response and envelope delay distortion effects of mismatching of these two networks.

The repeater may also use direct hetrodyne techniques similar to FM translators (as authorized by 74.436(d)). This technique would cause the least alteration of the signal to be retransmitted.

Another repeater technique available for digital packet transmission would be to do the digital data recovery, and retransmit it using locally generated clocks and tones. This would eliminate some non-error causing distortions in the signal path from the station to the repeater before retransmission of the data. This would also, however, prohibit the intercom operation on the H&F DRC190, which relies on the data going through a voice grade circuit. In addition, digital data regeneration would require all stations to use the same data format.

Packet stations using a repeater would also employ directional antennas. The gain these provided would further insure interference-free operation.

There are some points to consider when selecting the radios - several restrictions in the current FCC rules regarding the use of 'P' channels prevent broadcast stations from using the exact same equipment that amateurs are using for packet communications.

74.451 requires equipment to be used under part 74 to be type accepted for use under parts 74, 21 or 90. Not much amateur equipment is type accepted under these parts.

74.462 restricts the deviation of transmitters used on 'P' channels to 1.5 KHz peak and restricts the bandwidth to 10 KHz. Most amateur (and most commercial) equipment is designed for wider deviations and bandwidths. The transmit deviation and bandwidth can easily be reduced through a minor transmitter adjustment, however, the receiver bandwidth cannot be reduced to offer sufficient adjacent channel rejection (adjacent channels are only 10 KHz away) without modification of the receiver I.F. strip.

74.464 restricts the transmit frequency tolerance to 2.5 ppm. Many amateur and low power commercial transceivers have a frequency tolerance of 5 ppm, which is sufficient for mobile operation under part 74. Unless your transmitter site or studio qualifies as mobile, the tighter frequency tolerance specification is required.

74.482 places a station identification requirement on part 74 transmitters. Amateur transceivers and packet network controllers do not have the required 20 to 25 word per minute, 750 Hz tone Morse code identifier. These identifiers, however, are readily available from companies supplying the mobile radio field for their repeater applications, and is available from standard broadcast TRL suppliers (Moseley and Marti), and is inlcuded as an option in the H&F DRC190.

Finally, improved throughput and a reduction in the number of collisions that occur results when the delay between sending a "key up" request to the transmitter and the "breaking of squelch" at the receiver is as short as possible. A 250 mS delay is insignificant for voice traffic, but with standard data packet techniques, that is 250 mS when this unit is not listening for another carrier and another unit does not hear a carrier from this unit. The chances of a collision increase as this delay increases. Further, that 250 mS could be used to send 300 bits of data using standard techniques. That might be our whole message!

There are no stations currently on the air using either of these two concepts - RS-232 packet controllers are just now becoming available. However, manufacturers have expressed interest in the inclusion of such a controller in their systems. One has even proposed packaging a remote control system, the packet controller, the U.H.F. radio, and a narrow-deviation S.T.L. system in one chassis. Sort of a universal replacement for the phone company.

At present, the cost of implementing packet radio as a control link may be approximated by the figures shown in Figure 1.

Figure 1

Two Packet Controllers	@ 250	$ 500
Two U.H.F. Transceivers	1200	2,400
Two Interface Boards	100	200
Two Antennas w/Coax	300	600
Total		$ 3,700

This translates to about $ 30/mo. over the expected 10 year life of the equipment. Obviously, the price of the controllers will soon come down, and the rest of the equipment may well be less.

Implementing this development could provide a station relief from telephone bills, better control over the operation of the station plant, and would allow substantially better use of available spectrum. That profits us all. Research and experiments continue vigorously on this concept. Manufacturers and the Society of Broadcast Engineers are encouraging additional tests and studies. The Commission has indicated it is very interested in helping licensees make use of this concept. From the present viewpoint, things look very exciting.

SETTING UP A REGIONAL SPORTS NETWORK

Robert M. Smith Jr.
WRKO/WROR Radio
Boston, Massachusetts

ABSTRACT

A review of the options available when setting up a network to carry sports play by play broadcasts. These options are investigated for both "backhaul" to the flagship station and distribution to the affiliates.

The options reviewed are; leased satellite channels, dedicated equalized service from a common carrier, FM subcarriers, dial-up phone service and dial-up service with frequency response enhancement. The selection criteria for these methods are availability, performance, reliability and cost.

The Boston Celtics Basketball Network, operated by WRKO, is analyzed as an example of how the various options can be integrated.

INTRODUCTION

The RKO - Boston Celtics Basketball Network has full-time affiliates in nine states and provides occasional service to other locations and Armed Forces Radio. The game broadcasts originate in twenty three cities, as nearby as Boston and as distant as Los Angeles or Seattle. Interconnecting the appropriate city with the network control station and the network control station with all of the affiliates is accomplished with a mix of various transmission facilities. Each of the facilities was chosen based on a number of criteria.

FACILITY SELECTION CRITERIA

When choosing which of the various methods of transmission is to be utilized for each of the backhaul and distribution requirements, four characteristics of each of the transmission methods are considered. The four characteristics are: availability, performance, reliability and cost.

Availability

The first criteria to consider when selecting a mode of transmission is its availability. The performance, reliability and cost are not important if the facility is not available when and where it is needed. At an arena in large cities like Boston, New York, or Los Angeles almost all modes of transmission are available on short notice. The only transmission facility available to send network programming to an affiliate in a small town in Maine or New Hampshire may be a dial-up circuit.

Performance

The frequency passband of the facilities to be discussed varies from 15kHz to less than 3kHz. At the top end of the quality scale is the digital audio satellite transmission service available from some of the radio networks. At the other end of the scale lies the low cost, easily available dial-up circuit. Between these two extremes are the quality provided by the various grades of common carrier provided leased circuits, FM subcarriers and dial-up circuits with frequency response enhancement equipment.

Reliability

Sports broadcasts are one time only events, the commercial time within the broadcasts is usually quite expensive, and affiliates are depending on receiving and rebroadcasting the game. Given this, the reliability of the transmission facility from the gamesite to the network control and from network control to the affiliates is of great importance. Much like availability, the reliability of facilities varies from location to location, from day to day, and sometimes it appears with luck.

Cost

Two types of costs are involved in setting up a network and backhaul transmission system. The first of these is the one-time capital investment for equipment. The second type, and probably the higher cost, is the recurring cost of facility rental or usage fee. Over the past four years the costs for transmission equipment have held fairly steady. During this same period the circuit rental fees and usage charges have varied greatly. Everyone is aware of the dramatic increases, recently made, in the charges for leased circuits from the common carriers. During this same period, however, the charges for satellite space have decreased. Due, in part, to the new era of competition in long distance telephone service, the rate for dial-up service in most of the country has been declining. The cost of transmission service is ever changing. Only frequent review of the actual costs incurred for each of the methods of transmission can assure continuing cost effective distribution.

FACILITY OPTIONS

Six different methods of transmission are presently or have been utilized in the production and distribution of the Boston Celtics broadcasts. The facilities are: digital satellite, analog SCPC satellite, leased equalized circuits, FM subcarriers, frequency response enhanced dial-up and straight dial-up.

Digital Satellite

Available for only the last half dozen years, the digital audio satellite transmission system has revolutionized the distribution of the large radio networks. All of the digital audio transmission is presently sent through Satcom 1R. Over one thousand radio and television stations throughout the country now have receiving dishes aimed at this satellite. A large proportion of the affiliates of the major networks using this system have their own antennas and receivers. The remainder of the stations receive their network programming via a leased circuit from a nearby downlink. With this much penetration, the availability of downlinks for the digital audio transmission system is very good.

Presently the digital audio system can only be uplinked from Vernon Vally, New Jersey, and Los Angeles. Utilizing this system requires that the audio be carried to one of these two uplink locations for transmission to the satellite.

The widespread availability of downlinks, and the very limited availability of uplink locations makes the digital satellite system well suited sports network distribution, but not as convenient for use in backhauling from the gamesite.The digital audio transmission system has two audio passbands available; 15kHz and 7.5kHz. The wider channel has specifications that exceed those of the best FM exciters and transmitters, and is overkill for a sports broadcast which consists primarily of voice information. The 7.5kHz channel has more than sufficient quality for the type of programming we are interested in distributing.

This transmission system is the backbone of the distribution system for ABC, CBS, NBC and USN. This system was designed to perform reliably and has met that design goal. Since uplinking is available only in New Jersey and California, an additional potential source of failure is added due to the necessity of transmission facilities between the source and one of the uplink locations.

Most of the digital audio channels available are owned by one of the major radio networks, so the cost of utilizing this method of transmission depends on what type of deal you can cut with the network leasing you the space. The major factor controlling this cost is supply and demand. The supply has and will most likely remain stable while we can expect the demand to increase.

Analog (SCPC) Satellite

The technology for the transmission of audio in analog fashion over geosynchronous satellites has been available for a longer period than has the digital technology. Some of the major radio networks are using this system for distributing their programming. The Mutual Radio Network and National Public Radio are utilizing space on Westar III for their distribution. A majority of the affiliates of these two networks have receiving systems aimed at this satellite, giving a regional sports network a good base for receiving locations.

Unlike the digital system, the analog system is comprised of a single carrier per channel (SCPC). SCPC technology allows for the simultaneous transmission from many widely spaced locations through a single satellite transponder. With a permanent or even portable uplink installed at the gamesite, backhaul to the network control can be made with no intermediate links. In 1985 a transponder on Satcom 1R was opened for SCPC use. This allows users of the digital system to receive SCPC signals with the addition of only a receiver. The antenna and LNA in use with the digital receiver will also serve the SCPC receiver.

The widespread availability of downlinks and the ability to uplink from nearly anywhere makes the SCPC system well suited to both network distribution and broadcast backhaul.

These SCPC channels are offered by a number of vendors in 5kHz, 8kHz and 15kHz bandwidths. Most users find that even the 5kHz wide channel is adequate for sports broadcasts.

The reliability of SCPC equipment is very good. Most failed broadcasts using SCPC transmission are due to set up problems because of a breakdown in communications between the user and the equipment and space supplier. Once installed and checked out, an actual equipment failure should be quite rare.

More than any other system of transmission, the cost of SCPC facilities is negotiable. The wide variation in charges is due to the large availability of channels, ever increasing numbers of uplinks, and heavier competition among companies providing the services. When purchasing SCPC equipment, channel space or turnkey services it is important to shop around and negotiate for price. Prices are volatile and any quotation of typical costs here could be meaningless by the time they were read.

Leased Lines

Equalized lines leased from "the phone company" have been the main method of program transmission for many years. Every radio station in the country has at one time utilized this service for a studio to transmitter link, remote broadcast transmission or network reception. This service has traditionally been dominant because it adequately met the four selection criteria of availability, performance, reliability and cost. "The phone company" entered a new era a few years ago and at about the same time the availability and cost of leased circuits began to change.

The availability of equalized leased circuits is variable upon a number of conditions. To obtain an equalized circuit between two locations it is necessary that the proper physical facilities be present between each end and its central office, and between the two central offices. In many of the major cities the number of "unloaded" and "untapped" pairs has decreased as the pressure for voice and data communication services has increased. This decrease in suitable transmission pairs has decreased the availability of equalized service. In many rural locations all of the physical facilities are loaded Due to the long distance of the cable runs. Generally the availability of equalized leased loops is still good, but in some areas this is changing rapidly. When ordering equalized service to or from a location outside your local calling area there are a number of suppliers able and willing to supply the service. When the service originates and terminates within your local area, your local telephone company is the only option.

Subject to the availability of adequate physical facilities, equalized service can be leased with bandwidths ranging from 3.5kHz to 15kHz. The 5kHz and 8kHz service is quite adequate for sports broadcast, while the 15kHz is probably overkill. The 3.5kHz service may be adequate for backhaul where only the announcer's voice is to transmitted, but may not be adequate for transmission to the affiliates of the full program with musical commercial material.

All broadcast engineers have, at least once, complained about the reliability of equalized leased lines. If an objective look is taken at the overall record of reliability, this service deserves a very high rating. The facilities are usually installed when and where requested. Once the service is activated and tested, failures during a broadcast are fairly rare.

Among all of the different transmission facilities considered, the equalized leased line has increased in cost the most in recent years. Some stations have reported increases of up to 800% in their line charges in the last year alone. Most of these services are available on a one time only or full-time basis and it is usually worthwhile to price the services out both ways. The costs for installation and usage vary widely from supplier to supplier. Only by checking with the supplier at the time of ordering can you be assured of getting an accurate price for this type of service.

FM Subcarriers

Every FM broadcast station has the ability to include in its transmission one or more subcarriers. These subcarriers can be used to transmit sports broadcast audio to affiliates equipped with the required receivers.

As more uses for FM subcarriers have been developed (including digital data transmission) the availability of subcarrier space has begun to decrease. Many of the users of subcarriers require full-time service. A sports network will require only a few hours of service a week but would prohibit the use of the subcarrier by some service needing full-time operation. The possibility of obtaining a subcarrier where and when it will be needed will vary greatly from market to market.

The performance of a subcarrier sports distribution system can be very acceptable with 5kHz bandwidth and good signal to noise ratios, but solid reception of the FM signal by the affiliate is required. Because strong signals are needed, the area of reception is somewhat limited.

The reliability of the actual subcarrier is as good as the reliability of the FM station transmitting the subcarrier. The overall reliability of a subcarrier distribution system will depend on a number of factors. These factors include: receiver location, interference, receiver reliability and the reliability of the link between the network control and the subcarrier transmitter.

There are initial capital costs as well as ongoing rental fees when using a subcarrier for network distribution. The transmitting station will need a subcarrier generator and subcarrier modulation monitor. All affiliates will need subcarrier receivers and antenna systems. Rental fees will vary from market to market but, in general, the charges for use of FM subcarriers have increased sharply in recent years.

Dial-up Service
The most available, cheapest and lowest quality of any of the methods is the standard dial telephone circuit.

For both backhaul and distribution nothing beats the availability of the standard dial-up telephone circuit. Every sports arena and radio station in the country is equipped with at least one phone and ordering extra phones installed for a broadcast is a simple matter. For backhaul use the talent or tech needs only some way to couple the mixer output into the telephone. For distribution use the affiliate must be able to air audio from a phone and the network control must have a method of feeding multiple dial-up lines simultaneously.

The performance of the dial-up circuit is not up to the performance of any of the preceeding transmission methods. The frequency response of the typical dial-up circuit is around 300Hz to 3.5kHz. While this falls far short of the preceeding methods of transmission, it may be adequate for some affiliates and is certainly adequate for emergency backup use.

The reliability of this service is very good. Rarely does any operating company make an error in installing a dial circuit in an arena. The transmission reliability of this type of facility is enhanced by the ability of the operator to secure a new circuit by merely redialing the number at the destination. Changing facilities with any other transmission method is far more complicated and time consuming.

The dial-up circuit is truly one of the best bargains in the transmission of audio between two points. Game length calls from coast to coast are under fifty dollars. With the arrival of competition to long distance service the rates have decreased and shopping for a long distance carrier can result in some very low cost service.

Dial-up with Frequency Extension
With equipment available from Comrex, Kahn or Rood it is possible to take advantage of all of the good qualities (low cost, availability, reliability) of the standard dial-up circuit while improving its performance significantly. Two types of frequency response extension equipment are presently available: the single line and dual line systems. The single line type system will convert a standard dial-up circuit to a broadcast circuit with a frequency response of 50 HZ to 3250 Hz. With the sacrifice of 1/7 of an octave of response at the high end you can gain a 2 1/2 octave increase in the low end response. The two line type systems use two standard dial-up circuits and convert them into a broadcast circuit with frequency response approximating that of a 5 kHz equalized loop.

A PRACTICAL EXAMPLE

An analysis of the present RKO/Celtics Basketball Radio Network will show how the various methods of transmission discussed can be integrated. Separating the facilities into their two functions, backhaul and distribution, will enable a simpler analysis.

Backhaul
The backhaul facilities serve two purposes, transmitting the announcers voice from the gamesite to the WRKO studios and sending an IFB from the studio to the gamesite. The IFB is required to enable the announcers to hear actuality material during the pre-game show, commercial material during the broadcast

and telephone callers during the talkshow style halftime show. Since this IFB is interruptible by intercom it also allows communication from the network control board operator to the announcers. WRKO has, for the last five years, utilized dial-up circuits for backhaul of all games played outside the Boston Garden. Boston Garden games are transmitted via equalized leased lines. Figure 1 shows the backhaul arrangement for an away game. At the remote gamesite, on the left, the announcers use a Comrex SLX sports console. This console has built-in telephone couplers, single line low frequency extender, and monitoring facilities. Set-up consists of connecting microphones and headphones then plugging in two modular plugs into the RJ-11C jacks provided on the dial-up circuits. Using a phone connected to the SLX, the announcer then dials two automatic answering telephone couplers at the studio. These couplers are wired to answer when they sense incoming ringing current. When the couplers have answered the incoming call the studio is presented with two audio circuits. The first circuit has the gamesite audio, encoded with Comrex low frequency extension, and the second circuit is wired into the monitoring channels of the SLX console at the gamesite.

At the studio, the output of the receiving coupler is decoded by a Comrex RLX, amplified and fed into the network control room console. All pre-recorded commercial and promotional material is inserted into the broadcast at this console.

A monitor output of this console is modified to allow insertion of an intercom microphone into the circuit. This output is connected to the transmit coupler and provides the IFB. During a commercial break in the broadcast, the announcer and board operator or producer can conduct a two way conversation by dropping the gamesite audio into cue. During the broadcast the board operator or producer can talk to the announcers through their headphones by momentarily interrupting the monitor audio. When not hearing the operator or producer the announcers are listening to the complete broadcast audio. This system has worked very well for us and allows for all necessary transmission between the game and the network control to be accomplished with only two dial-ups.

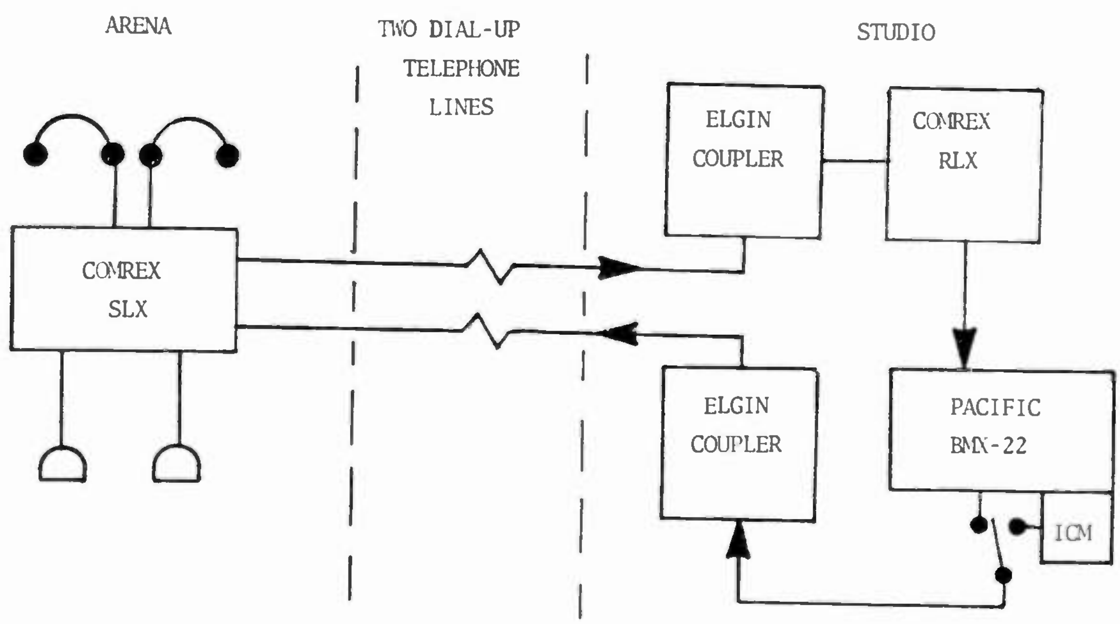


FIGURE 1

Game Origination Facilities

When examined in light of our four selection criteria we find availability is second to none. The National Basketball Association requires all teams to provide two phones to visiting team flagship radio stations. The reliability of this system has been excellent. In nearly five hundred game broadcasts we have missed less than ten minutes of action. The cost is less than thirty percent of the cost for a satellite or leased line facility. The performance, while not equal to a satellite or leased line, is adequate for the voice transmission required. WRKO owns two line extension equipment and has considered using this equipment for backhaul, but the difference in quality does not justify the additional dial circuit installation and usage charges.

Home games, played in the Boston Garden, are transmitted over a leased line, feedback is sent over a leased line, and the intercom function is performed over a dial-up circuit. This dial-up circuit is available for backup use if either of the leased loops should fail.

<u>Network Distribution</u>
Distribution of the finished product to the network affiliates involves the use of all but one of the transmission methods previously discussed. At this time only the analog (SCPC) satellite is not being utilized for distribution.

The primary method of distribution and our first choice for new affiliates is digital satellite on Satcom 1R. Over one half of the present Network affiliates now receive their game broadcasts from this source. As explained earlier, when utilizing the digital satellite it is necessary to send your audio to the uplink in either New Jersey or California. Our network control is in Boston so we use the uplink in New Jersey. The broadcast is sent to New Jersey via New York over an 8 kHz circuit leased from Western Union. As shown in Figure 2, below, the leased circuit is backed up by a dual line Comrex 2X system. If the 8 kHz circuit should fail, two telephone calls can put the system back in service within three minutes.

The digital satellite transmission system was chosen for the primary distribution based on the four criteria used to select the backhaul, and all other facilities. Foremost among the considerations when

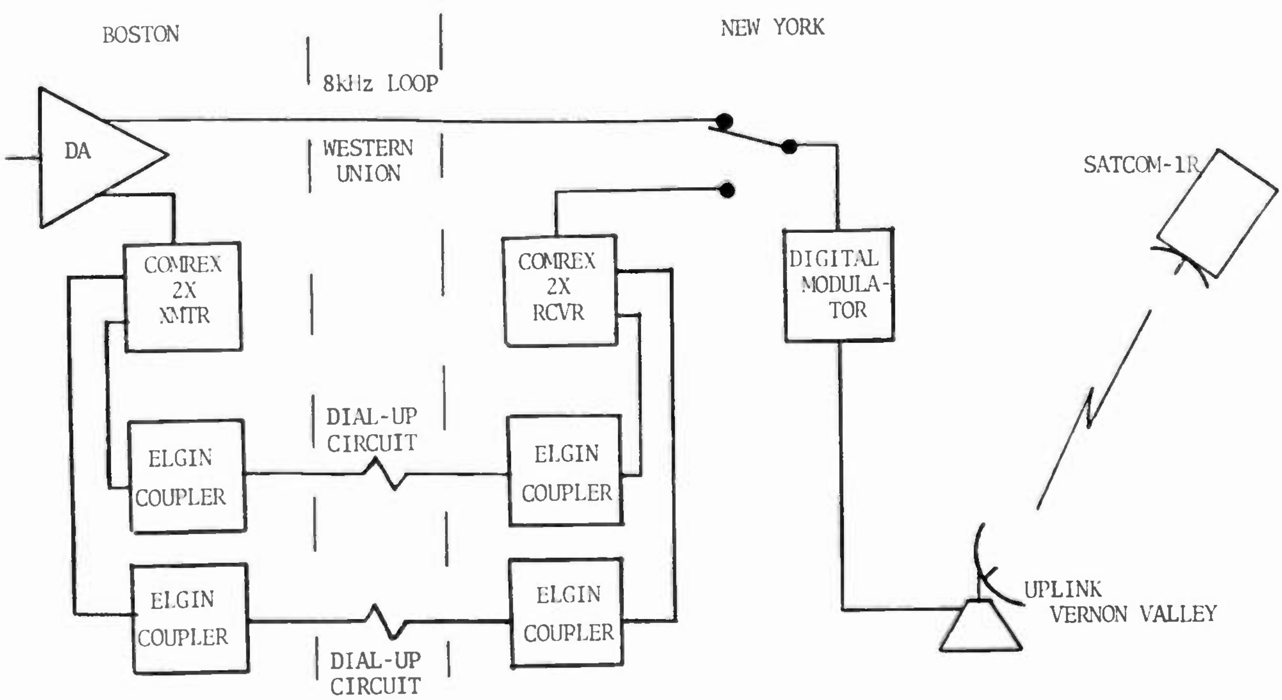


FIGURE 2

Satellite Distribution Facilities

deciding to distribute by satellite was picking the satellite. It seemed unreasonable to expect an affiliate to install a dish and receiver just to receive basketball game broadcasts. Over half of our affiliates already had receivers listening to Satcom 1R, so the choice of satellites was obvious. All of the affiliates looking at Satcom 1R were equipped with digital receivers, so the choice of system was obvious. The only remaining decision on the satellite system was which transponder to use. This decision was dictated by availability and cost.

With the majority of the network now connected we still faced the necessity of feeding broadcasts to affiliates without access to Satcom 1R receivers. Four of the affiliates are within receiving distance of an FM station in Worcester, Mass. and we have a rental agreement for use of that station's 67 kHz subcarrier. Feeding the subcarrier generator from a Satcom 1R receiver and installing subcarrier receivers at the studios of these affiliates completed this portion of the network. This method of distribution is far less costly than leased line service and provides better performance than dial-up or enhanced dial-up service. Due to the possibility of subcarrier failure or reception problems, each of the affiliates receiving this service is also given a dial-up access facility for backup use.

The few remaining affiliates have no access to a Satcom 1R receiver and are outside the reception area of the subcarrier. In addition, leased line facilities are not financially viable due to the long distances to the affiliates from Boston. For these few remaining stations a frequency enhanced dial-up service is provided. Each station is provided with a telephone number which is connected to a coupler. Each coupler is wired for automatic answer and provided with a Comrex single line enhanced audio feed. Spare couplers fed with enhanced and normal audio are installed to allow for one-time-only feeds and emergency backups.

Operational Details

The network control studio is busy from about one hour prior to game broadcast through the end of the post-game show. Because of the necessity to pre-feed audio from the gamesite to the studio and to send a closed circuit information feed to the affiliates the network control is performed in a separate studio from the WRKO on air operation. WRKO handles the game just like any other affiliate by joining the game from its air studio. To eliminate the requirement for both a network operator and WRKO operator to be on duty simultaneously, all of the WRKO IDs and local commercials are run from the network control studio. The multichannel console in the network control studio allows the network to receive the game feed without also receiving the WRKO local material. During IDs, rejoiners and local commercials all affiliates receive silence or crowd noise.

Prior to each game the 8kHz loop between Boston and the uplink in New York is checked for continuity and quality. If any problems are encountered with this checkout the backup Comrex 2X is prepared by dialing two telephone couplers at the New York end. Approximately thirty minutes before the beginning of the pre-game show a closed circuit continuous loop announcement is transmitted. This taped announcement contains information on last minute changes and other reminders to affiliates. In addition to transmitting necessary information the closed circuit allows affiliates to check the continuity and quality of their feeds prior to the pre-game show and arrange for alternate feeds if required.

CONCLUSION

Changes in satellite technology, new techniques for enhancing the quality of dial-up telephone lines and frequent changes in the rates for leased line circuits combine to complicate the distribution of a regional sports network. Adapting to these changing conditions and mixing the various transmission options allows construction of a reliable and cost effective network distribution system. The WRKO/Boston Celtics Basketball Network has been in operation for five years. Each year has seen changes in the distribution system that have kept the network cost effective.

TELNOX L-O: ON AIR COMPUTERIZED TELEPHONE SYSTEM FOR BROADCASTERS

Jacques Coutellier
Normex Ltd
Montreal, Canada

ABSTRACT

This paper discusses the concept philosophy and general design of the **Telnox L-O** product.

The system has been designed to solve old technical problems in placing telephone calls on the air, improve the quality of On Air result, incorporate new and practical features as well as the automation of tedious operations.

Although very complex, its operation is "**user friendly**".

This paper also covers the operational dimension of the product for a good reason: Besides being technically innovative, it is operationaly innovative as well.

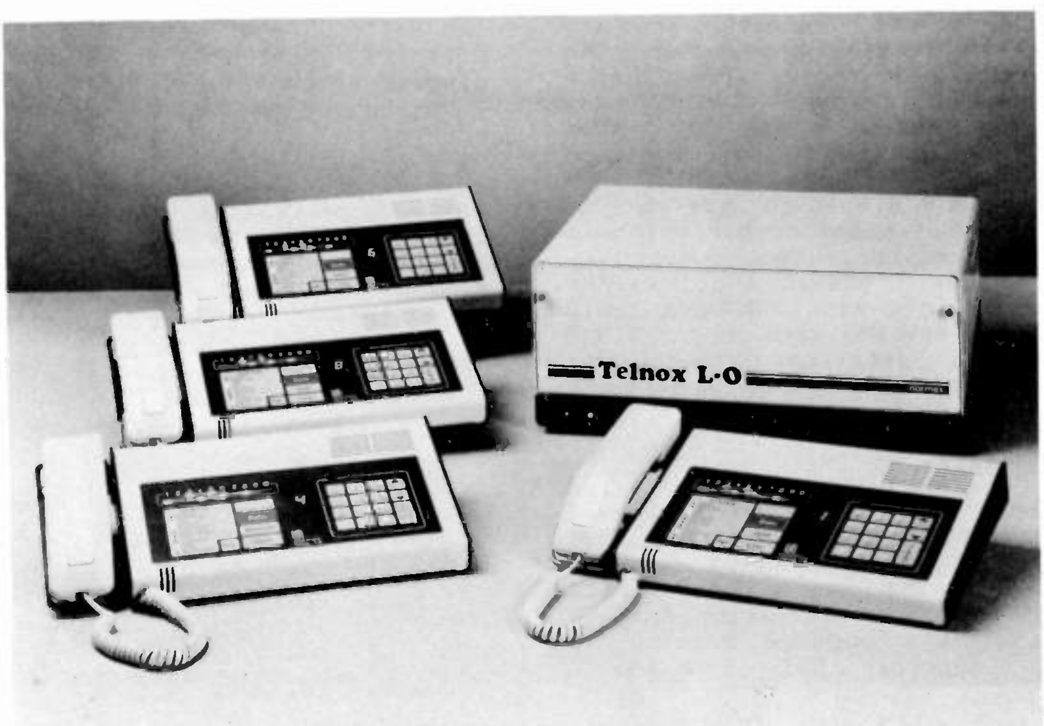
INTRODUCTION

In the world of high technology surrounding the broadcast experts, the telephone equipment has been, until recently, one of the least evolved piece of equipment in the station .

When the telephone call made its debut on the air, the broadcaster had to interface the two technologies himself.

Through the years, some products on the market appeared to do the basic job but limiting the broadcaster to the basic.

The product described hereinafter provides more than just the basic. It is above all an important tool designed especially for the



broadcaster, using today's technology which makes a dramatic difference in studio workload and provides a mean to develop new program formats.

Our philosophy was to design and develop a product with these following goals in mind:

First, it would do the basic job. **Second**, it would solve long lasting problems. **Third**, new features would be introduced. **Fourth**, Automation and security would be maximized. **Fifth**, the product containing the above was going to be "user friendly". **Sixth**, the configuration of the system would be flexible to **suit** the needs of small and large broadcasters.

The design has been oriented towards performance with simplicity of operation. Wanting to solve long lasting problems and introduce new and automatic features to provide the broadcaster with a performing tool with which, he too, could innovate in his specialty "broadcasting good programs" required **microprocessor technology**.

Figure 1 shows the general block diagram of the **Communication Processor Unit** (**CPU**).

Each block is linked with the **master microprocessor** through the **digital bus**. The sole function of the master microprocessor is to control and keep track of all the system's operations. To manage the activities in **real time**, it is helped by **Co-Processors** on the **Console Interface Cards** and the **microprocessor** located in each **control console** as shown in figure 2.

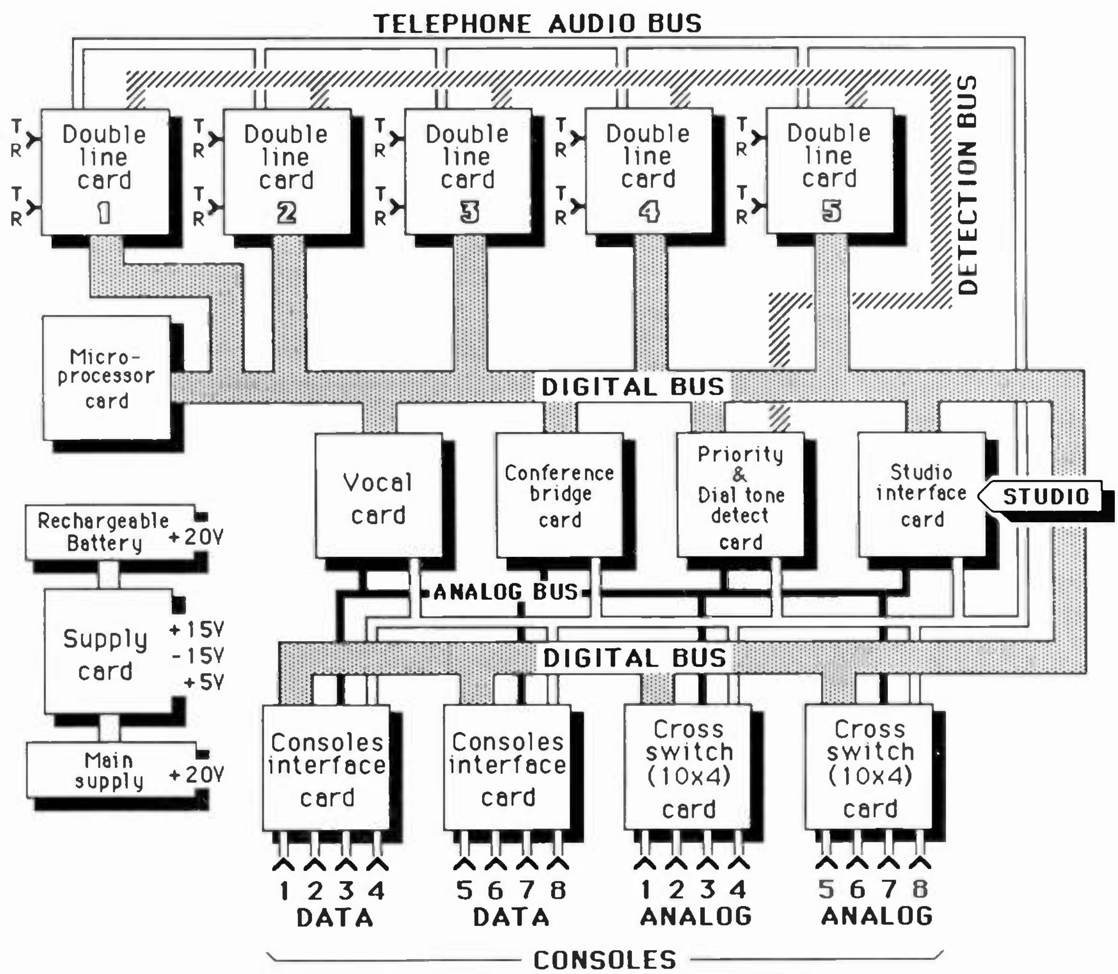


FIGURE 1

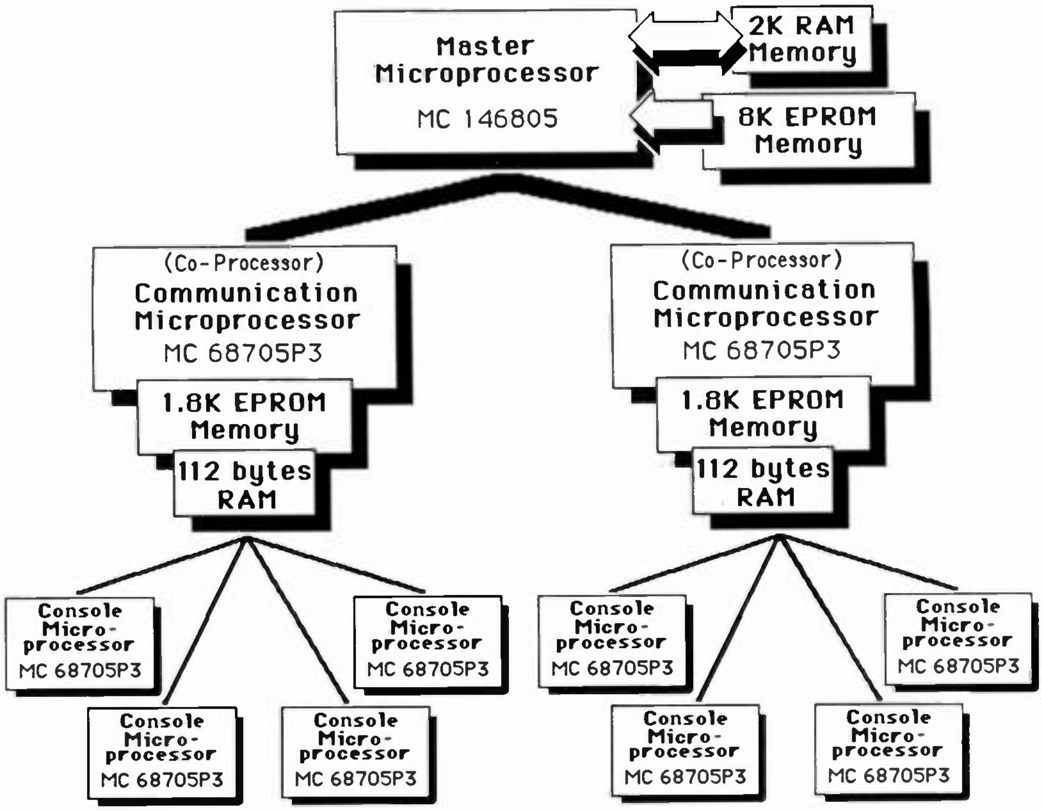


FIGURE 2

THE AUDIO NETWORK

The audio network is formed by three circuit cards; the line card, the conference bridge card and the studio interface card.

Signals separation ...

Telephone lines are coupled to the Communication Processor circuits through isolating transformers. A 2 to 4 wire converter (TTF converter) removes the **transmit** signal from the **receive** signal. **No adjustment** is required since the **TTF converter** is a new philosophy in separating signals.

Level correction ...

In the **receive** path of the telephone signal, a programmable amplifier controlled by the master microprocessor, gives a **19 dB gain** adjustable by steps of 2 db. This programmable amplifier is also used by the master microprocessor to create the **priority** effect described below.

An other programmable amplifier, also controlled by the master microprocessor, gives the user the opportunity to adjust the signal level in the **transmit** path as well within a range of **-14 dB and +5 dB** by steps of 2 dB.

Quality protection ...

To prevent distortion problems, **dynamic limitors** are used in each audio signal input and output stages. (See figure 3).

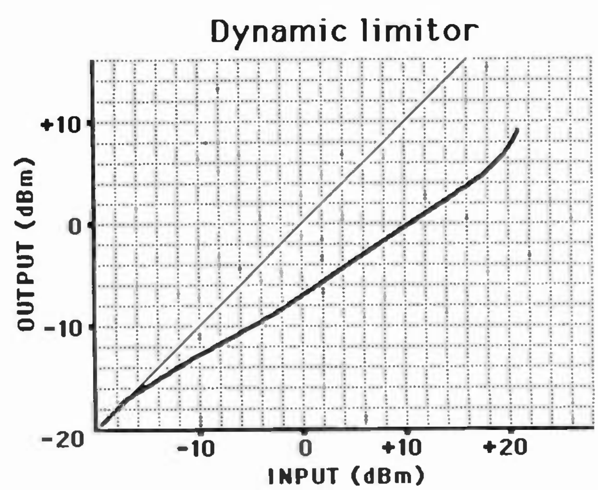


FIGURE 3

An **equalizer** compensates for the frequency response loss characteristics of the telephone line (See figure 4). The voice is richer and sounds more natural on the air.

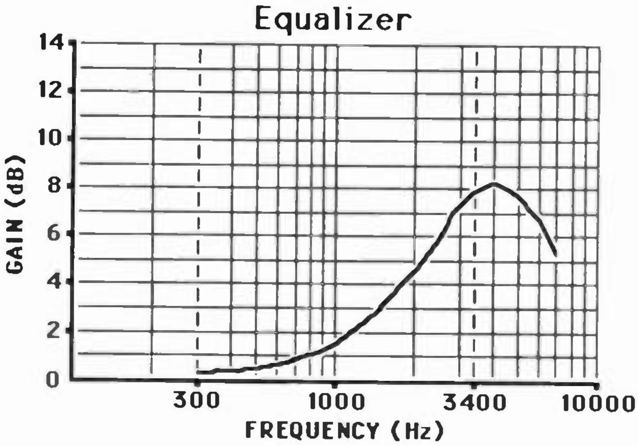


FIGURE 4

Noise elimination ...
To eliminate the background noise inherent to a telephone line, there is a "**Conference filter**" used in each line circuit.

The natural noise on a telephone line is a **white noise** and cannot be removed by the use of a frequency filter. It is normally low but when mixed with other lines in a conference, each individual line noise adds up and the end result becomes quite noticeable and annoying.

The role of the conference filter is to decrease the signal level of the line by **50 dB** in the absence of a telephone voice signal. The action of the conference filter is practically invisible.

It is applicable individually to each line and to obtain a **telephone line effect** on the air, the user should leave at least one line without the conference filter on.

Silent On Air switching ...
Calls go on and off the air without "**CLICS**" for three reasons: **First**, the audio switching is made electronically. **Second**, the impedance of the switching gates is very low (100 ohms). **Third**, the audio network is only resistive (without inductance or capacity effects).

Lab tests & results ...
Evaluation tests made by major broadcasters have shown a **signal/noise ratio of 59 dB** and a **maximum harmonic distortion of 0.5%** across the bandwidth.

AUTOMATIC & NEW FEATURES

The product is especially designed to eliminate most tedious manual tasks. Example;

The automatic **LINE FEEDER** passes incoming calls to the telephone receptionist in the order in which they've arrived.

The automatic **LINE FINDER** provides an idle line to place an outgoing call.

A system configuration of 2 control consoles and the CPU equiped with 5 double line cards in option (10 telephone lines)

An **AUTOMATIC DIALER** stores up to 9 telephone numbers (15 digits max.) for each console and the last number dialed can be **redialed**. The numbers are memorized in the Communication Processor's memory, thus allowing the user to replace or reconfigure the studio set-up without loosing the telephone numbers stored in the memory.

AUTO HOLD places calls automatically on hold after a number of desired rings and the callers hear the **Program On Hold**. When the **Vocal card** option is present, an **encode it yourself message** introduces the caller to the station and warns the person that he or she is next to go on air.

A **PRE-PROGRAM** stage is designed to allow the operator to plan and set-up in advance his next On Air move and obtain error-free On Air action each time.

With **AUTO ON AIR**, calls go on air in the order in which they've arrived, one after the other, by simply pressing the "**Exec.**" key each time. It is also possible to lock certain lines on the air and execute a **rotation of calls** on air, one by one with the remaining lines.

The system can **conference** up to **10 lines in full duplex**. This is due to the efficiency of the **TTF converter** to isolate and reject the transmit signal from the receive signal and this **without calibration and line balancing**. The incoming signal is re-transmitted amplified to all the other conferencing parties to the conference bridge in a "**Mix minus one**" configuration.

The role of the **priority** feature is to fade down non-priority caller(s) when the priority party speaks. The priority can be given to anyone line or to the studio and the threshold point can be adjusted within a range of **+12 dB** and **-12 dB** by steps of 3 dB from a reference point. The attenuation then applied is adjustable from **6** to **24 dB** by steps of 6 db.

The **line level adjustment**, in the **transmit** and **receive** direction, is adjustable in each direction **independently** and allows the user to balance the signals without causing feedback problems. When conferencing many lines together, it gives the possibility to obtain a uniform signal strength at the output. Inversely, the signal transmitted on one particular line may be raised or decreased without modifying all the other lines.

SAFETY FEATURES & PROTECTIONS

The **LINE DETECTOR** continually analyses the conditions of the telephone lines and disregards an absent or defective lines.

The **DIAL TONE DETECTOR** has two functions. The first task is to release the telephone line on hold that has been abandoned. It allows a greater rotation of incoming calls. The second task is to release a telephone line from the air if a dial tone appears.

The **ACCESS** feature determines the access level of a console. A 4 key password is required to change the level of a console locally or remotely from an other console.

The 4 console modes or levels are:

MONITOR:	The keyboard is locked and only the read out lights are active.
OPERATOR:	The console is limited to a regular telephone use. Line levels can be adjusted and the **SKIP** function is active.
STUDIO:	All of the operator's functions plus the possibility of executing **PRE-PROGRAMS** with the "**EXEC.**" key.
CONTROL ROOM:	Has full access to all the system's functions and features.

When an operation **error** is made, the system warns the operator three ways:

1 - A special **sound** is heard
2 - The error status **light** blinks
3 - An **error number** code on the numerical display indicates the type of error made.

There are built-in **TESTS** which informs the user of the general conditions of the system. A dozen tests or so are presently integrated into the product with expansion capabilities.

The **BATTERY BACKUP** provides the system with **20** to **30 minutes** of full operating capacity when a power failure occurs. The batteries are self rechargeable and care free.

The system is equipped with " **PTC** " **resistors (Positive Temperature Coefficient)** which protects the system's circuits from **short circuits** in the cables between the Communication Processor Unit and its consoles. The use of " **PTC** " resistors eliminates the replacement of fuses. They reactivate themselves automatically once the short circuit is removed.

Transient suppression devices are widely used to protect internal circuits from external sources of **high peak voltages** and/or **static discharges**.

FLEXIBILITY & GROWTH

The data communication between the Console Interface Card and each control console is transmitted by using **MODEM** technique with **BELL 103** standard. It has the advantage of working perfectly with several hundreds of feet of cable between the units. This communication technique also allows to control the studio telephone equipment remotely.

A **statistic package** option gives information on the system's activities.

Each console port can be configured **RS-232**. A Line Printer and other devices using this standard can be linked.

GENERAL

The Telnox L-O system has these following characteristics:

- Microprocessor technology
- Compatible with regular Tip & Ring, loop start, 600 ohms telephone lines and equivalent P.B.X. station ports
- 10/20 pps and Tone dialing with last number redial and auto-dialer
- Expandable from 2 to 10 telephone lines with plug-in double line card
- Automatic Line Feeder for incoming calls
- Automatic Line Finder for outgoing calls
- Line presence detector
- Auto Hold feature
- 10 lines conferencing capacity
- Priority feature with threshold adjustment from the console
- Full duplex communication
- Line level adjustment, Tx & Rx separately
- Hands free built-in feature in each console
- Automatic "Dial Tone Disconnect" feature on "Hold" and "On Air" position
- Vocal card option for automatic answering with messages
- Input and output audio levels of +8, 0, -20 dBm 600 ohms, balanced ("XLR" connectors)
- Expandable from 1 to 8 control consoles
- "On AIR" Pre-Programming stage (Pre-selection)
- Manual On Air execution
- "Auto On Air" feature
- Automatic "On Air" line sequencer
- On air conferencing feature
- Line noise "Conference Filter" feature
- Silent ON / OFF AIR moves
- Four control Console Access Levels
- Membrane keyboard
- L.E.D. display lights
- ERROR codes with warning sound
- "Bip" and "ring" adjustable sounds
- Battery back-up
- Statistic package option
- Remote package option
- P.T.C. (Positive temperature coefficient) resistor protection on power leads
- Transient suppressor protection on all inputs
- Long haul Modem transmission between control consoles and C.P.U.
- Data transmission compatibility with Bell 103 standard/RS232 standard.

WRAP UP

Looking at the **TELNOX L-O**'s automatic features, a typical case is to visualize a night program host alone in the studio. This is where the automatic and new features come in handy.

Telephone answering with the "**AUTO HOLD**" is eliminated. The system answers incoming calls and places them on hold automatically. When the system is equipped with the optional "**VOCAL**" card, a welcome message is given automatically to each caller before being placed on hold to receive the program content while the person waits, with the "**DIAL TONE DETECT**", the system automatically releases lines with dial tones on hold and on the air.

With the "**AUTO ON AIR**", he does'nt have to remember who's next, the "**EXEC.**" key is the only key to press. This command brings the first caller on air with him and when he presses it again, the line is dropped out and replaced by the next and this **in the order in which the calls come in**.

Should the calls require screening before, the "**TEMPORARY SKIP**" can be used to skip a particular line until the caller has dropped out.

Should he wish to reserve lines for gathering comments "OFF AIR", the "**PERMANENT SKIP**" will remove all the automatic features.

When the talking becomes a debate, the priority feature helps the program host. By activating the "**PRIORITY**" on the special guest's line, the other party is faded out every time the priority party speaks.

The "**PRIORITY**" becomes more than useful when conferencing many parties.

Looking again at the "**DIAL TONE DETECT**", it takes its importance on "ON AIR" lines. First, **frees the lines on hold** that have been abandoned. Second, it prevents **turning dial tones on the air** and third, it eliminates the need to know which of the conferencing party dropped out.

Rear view showing connectors
(telephone lines, control consoles, audio)

We foresee the conferencing capacity of the **TELNOX L-O** to transform present programming. Although the system does conference all of the **ten (10) lines**, it is intended to conference any of the ten (10) lines with the studio.

One way to benefit from the "**AUTO ON AIR**", is to "**PERMANENT SKIP**" a line and call a special guest with the later, place him "ON AIR" manually. This procedure locks the special guest "ON AIR". Then, activate the "**AUTO ON AIR**" to allow the audience to speak alternatively with this guest, just by pressing "**EXEC.**".

CONCLUSION

A short conclusion on the **TELNOX L-O**'s design and performances can be as simple as saying: "You can now run the show with one key and one finger !"

This is innovation. Isn't it ?

THE WLS RADIO REMOTE VEHICLE

Edward J. Glab
WLS Radio, Chicago Illinois

In 1985 WLS Radio in Chicago began construction of a remote broadcast vehicle designed to provide a self-contained facility for out-of-studio origination. Such a vehicle increases station exposure because it makes remotes possible in locations before impractical. It makes an impression that people will remember. As more people see the "Silver Bullet", as the vehicle has been nicknamed, they will remember that WLS was there. The vehicle also provides a more comfortable broadcast location for station personnel. In this paper we will look at the WLS remote vehicle as we designed and built it. We will look at some of the reasons we built it as we did. We hope this will be of assistance to anyone building their own remote vehicle.

WLS REMOTES

History

Before 1960 WLS was the Prairie Farmer station. Remote broadcasts were common from state and county fairs. The National Barn Dance was broadcast from locations all over the country. The farm format and live music lent themselves well to remotes as listeners could see their favorite radio performers in person. In 1960 WLS was purchased by ABC. The format became rock and roll, and remotes came to an end. DJs made personal appearances at "hops" which must have provided the exposure they needed. Why spend money to do remotes if the listeners could see the DJs at hops?

In 1968 when I joined WLS we had only one remote. It was every Sunday night from the People's Church on Lawerence Avenue. That ended in 1969. In 1975 we were approached by Mariott's Great America, a brand new "Theme" amusement park North of Chicago, with the idea of doing a remote broadcast from their park. The Program Director, John Gehron, was concerned that such a broadcast might disrupt the format. After all there would only be a handful of people at the remote site listening compared to the hundreds of thousands listening on the radio. We offered to build a remote set-up using an old RCA BC-3C console and 6 old ATC cart machines. The idea was to bring a whole radio studio to the remote site so the viewer at the remote could see what a radio show looked like. At the same time we would make the DJ's operation as much like the studio as we could so that the disturbance to the format would be minimized. Everybody seemed satisfied by this solution so we went ahead. With the BC-3 on a table, the cart machines and PA amps in a full-sized rack, and some column speakers on stands we set up in a gazebo in the middle of "Hometown Square". Set up took about 3 hours. The only complaint we heard was, "It sounded just like it was in the studio." I remember we talked about how nice it would be to have a studio in a vehicle that we could just drive up and put on the air without a lengthy set-up.

The WLS "TeePee"

WLS began doing more remotes in addition to the Great America remotes. Another regular remote became the annual "ChicagoFest", two weeks of music, food, and fun on Navy Pier. The first three years we had a nice inside location, but in 1983 the "Fest" was moved to Soldier Field and our location was moved outside. In order to provide a "sheltered" broadcast location we had a structure built. This thing was sort of portable. A crew of 4 carpenters could set it up in about a day, and in another day they could break it down into about a thousand pieces and haul it away. This "Broadcast booth" had a few problems. First, it was rather unique in appearance. It was made of black plywood, and sort of a cross between the Eiffel Tower, the John Handcock Building, and Darth Vadar's helmet. It stood 30 feet high and measuresd 15 feet on a side at the base.

It became known as the "WLS Darth Vadar TeePee". Besides being somewhat less than portable and less than attractive, the "TeePee" had another major problem: it leaked like a sieve. We used the TeePee for at least 5 remotes, and it rained at least one day at each and every one of these remotes. I remember times it was raining harder inside than outside. It became obvious that WLS needed something better for outside remotes. After all, a DJ sitting under a tent of plastic inside a black plywood teepee didn't do much for the image of WLS. We had been trying for several years to get the money to build some kind of remote vehicle, but management never went along with the idea. The Program Director was in favor of it, but it never got past the "front office". Then two things happened which swung the decision in our favor. No, the TeePee wasn't hit by a train and burned to the ground. Our Program Director became the General Manager, and WABC, NewYork, got a remote vehicle. We now had the ammunition to convince both the local front office and ABC in New York that we needed a remote vehicle. Armed with unlimited funds (No, not really) we began to build the WLS REMOTE VEHICLE!

BASIC VEHICLE

Motor Home or Trailer

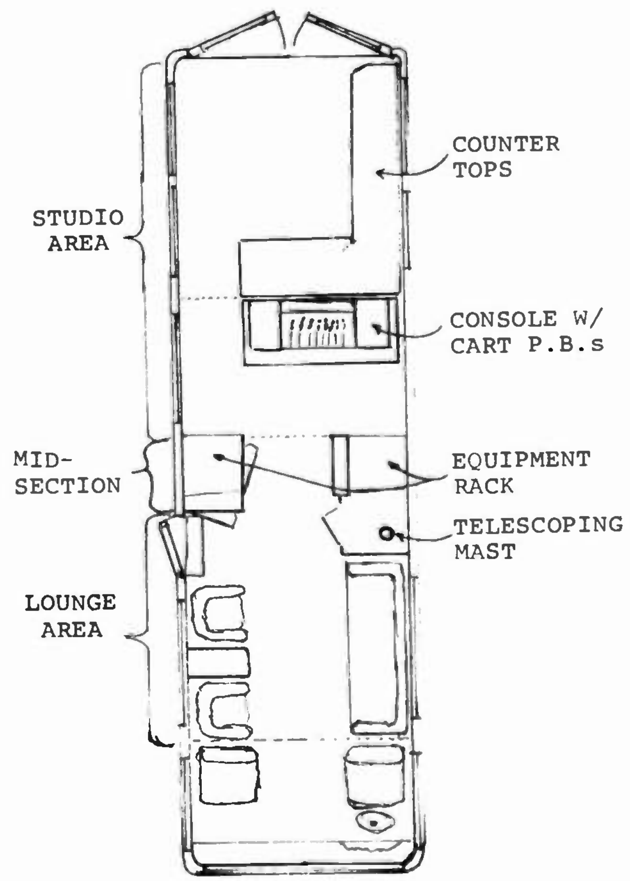
The first decision to be made was what kind of vehicle would the WLS remote studio be built in? We decided against a trailer because we would need a tow vehicle in addition to the trailer. We had, however, rented R.V. motor homes in the past for some one and two day outdoor remotes. (Yes, folks, the leaky TeePee was saved for those special occasions which ran several days...when the chance of rain was always greatest.) The idea of a motor home seemed attractive. A motor home is self-contained. All you have to do is drive it up and park it, and you are on-site. When we rented we would set up our remote equipment on the dinette table. The "talent" would sit in the "living room" area. The problem was that there was very little contact with the outside spectators. We looked at the space in the back that was the bedroom. It was wasted space for our use, but in our own vehicle the whole back end could become the studio. We decided a motor home was the way to go.

Custom Build or Modify

Since we had rented some motor homes we thought about modifying an existing vehicle. We thought about what would have to be changed:

1. Remove the bedroom in the rear and convert it into a studio.
2. Cut large windows into the studio so that the spectators could see the DJ.
3. Install a door in the rear so the DJ could go outside and talk to the people.
4. Install a second AC generator and probably upgrade the existing generator.
5. Install a telescoping mast for RPU antennas.
6. Install cable raceways and a connection panel on the outside for connection to telco, etc.
7. Remove the kitchen area to make room for equipment racks...

And that was just the beginning of the list. It was about then that we decided to look into a custom built vehicle. We found Barth, Inc. in Milford, Indiana. They were willing and able to build a custom motor home. We toured the plant and talked at length about what we were looking for in the vehicle. The company has built custom vehicles for TV, industry, and government agencies, so we felt we had made a good choice. The plans were signed off and the WLS Remote Vehicle began rolling down the assembly line.



FLOOR PLAN
Fig. 1

FLOOR PLAN

Lounge Area

Fig. 1 shows the floor plan of the WLS Remote Vehicle as it was built. The front of the vehicle is a lounge area. There are two chairs and a couch for talent, guests, and station personnel. The driver's seat and "co-pilot's" seat swivel so seven people can sit in this area. The entry door is in this area so that the air operation suffers minimal disturbance from people entering and leaving. Why such a large area devoted to a lounge? I don't know about your remotes, but we seem to always have a lot of people at ours. The talent brings his wife/girlfriend(s), there is a person or two from the promotion department, a couple from engineering, the sponsor(s) of the remote, etc. At a recent remote we did from an outdoor rally welcoming home the Super Bowl Champion Bears our vehicle was host to the Mayor of Chicago, his fiancee, body guards, and press aids. At one time I counted 12 people in the lounge area while the broadcast went on undisturbed in the back of the vehicle. Maybe I should mention that the wind chill was 15 below outside and we had the only warm place near the stage for the Mayor to hide, but I like to think His Honor wanted to see our new vehicle. The lounge area is also just a nice place to crash after getting up at 4AM to do 18 hours of remote. Located under the couch is one of the AC generators. The 12 volt batteries are in the area under the swivel chairs.

Midsection

Behind the lounge area on the roadside there is a small room which provides access to the back of the main equipment rack. The base of the 40 foot telescoping antenna mast is also in this room. This room also allows some storage space for tools, ladders, speaker covers, etc. A 66 inch high equipment rack forms the back wall of this room. This is the main rack which houses P.A. amplifiers, RF gear, etc. Below this rack and the mast room is our main cable storage locker. This locker opens to the outside and serves as our main connection point to the outside world. A 4 inch square door allows the cables for telephone, speakers, etc. to pass outside without leaving the main door open. A corridor connects the lounge area with the studio area. On the curbside of this corridor is a half rack which will house our satellite uplink equipment. Below this half rack is a refrigerator which opens into the corridor. Below the refrigerator is the second AC generator.

Studio Area

The studio area is the back half of the vehicle, and is divided into two areas. The front portion is elevated to clear the wheelwells and serves as a "control room" area. The fronts of the equipment racks open into this area. To the right of the main rack is the power metering/control panel. A McCurdy console is set up in this area so that an engineer seated at the console has a good view of the studio area. The back half of the studio area is surrounded by large windows to allow maximum visual contact with the outside spectators. The back is fitted with double "cargo doors" so that the talent can enter and leave the studio directly. The doors can also be left open if the DJ wishes. We made no attempt to soundproof the studio area since we don't want remotes to sound too much like the studio. The listener should be able to hear some of the outside sound from the remote location.

Creature Comforts

The entire vehicle is air conditioned by two roof mounted RV type air conditioners. There is a roof mounted "power vent" in the corridor to exhaust stale air. Heat is provided by five electric baseboard heaters. We selected electric heat over LP gas for several reasons. First we wouldn't have to make room for an LP storage tank which left more room for equipment lockers. We have only one type of fuel to buy for the vehicle since both the automotive engine and the generators run from the same 75 gallon gasoline tank. The most important reason is that we have used the vehicle for some remotes inside buildings (such as convention centers like McCormick Place.) The fire inspector will not allow LP gas inside such buildings. At some locations we have even had to drain some of the gasoline and disconnect the batteries. I was surprised to find out that Champaign, Illinois will not allow vehicles carrying LP gas in the downtown area. So, eliminating LP gas from the vehicle allows us to go many places we otherwise couldn't. "What about the bathroom?" I was waiting for someone to ask that question. We didn't provide one. Why? Well, space was a problem, but I'm sure we could have made the space if we really wanted to. A bathroom brings with it many problems. Now you need water tanks, holding tanks, and pumps. All of these can freeze in the winter. You say you won't be doing any winter remotes? We have done remotes in 15 below temperatures. The big problem with a bathroom is that it needs to be cleaned. And guess who gets to clean it.

Yes, it's the engineer. Since I don't want to be the one to clean the bathroom, and I'm the one who designed the vehicle, it does not have a bathroom. Most of the remotes we do are in places where bathrooms are nearby. If we ever do a remote in a desolate area we can trailer a chemical john behind the vehicle. I have talked to a couple of other stations who have had bathrooms in their vehicles. One guy told me they closed the thing up and use it only for storage. A bathroom is more trouble than it is worth.

ELECTRIC POWER SYSTEMS

Shore Power

For some strange reason we seem to need electricity to make our broadcast equipment work, so we decided to make some provision for power in the WLS remote vehicle. When we originally designed the vehicle we thought we would be able to use outside power at most of our remotes. At this writing we have used the vehicle for nine remotes. We have had power available at only two of these. Our provisions for outside power (or "shore power" as we call it) allows for two separate sources. We like to have separate power for the technical equipment and a separate power feed for the heat, A/C, and lights. It is also possible to run everything from one power feed. It is nice to be able to use shore power where possible because the voltage is usually pretty stable, the frequency is always 60 Hz, and it saves wear on the generators. The disadvantage of shore power is that someone can always turn it off. Why would someone turn your power off? It could be accidental, but I'm sure you always make sure that the breakers and plugs are protected like we do. It could be deliberate. We used to have an afternoon drive team that people either loved or hated with a passion. One of the two remotes we did where we had shore power was with this team. One of the guys doing the lighting on a stage near our location apparently didn't like the boys on the air, so somehow our power got turned off "by mistake" no less than five times during a four and a half hour remote. Shore power is nice, but be sure you can switch to a generator fast if the shore power goes out.

Generators

The WLS Remote Vehicle has two on-board AC generators. One is under the sofa in the forward lounge area. It is a 7.5Kw Kohler powered by a four cylinder water cooled engine. The second generator is located under the refrigerator on the curbside midsection of the vehicle. It is a 7.0Kw Kohler powered by a two cylinder air cooled engine. Either of the generators is capable of powering the entire vehicle by itself. Originally we designed two of the 7.5Kw water cooled units into the vehicle, but space limitations dictated the air cooled unit on the curbside. The air cooled is somewhat louder than the water cooled, so it is used as the back-up and for times we are not on the air but still need power. The water cooled is the unit of choice for on-air times. If you can make room for two water cooled units I recommend you do it. Under any circumstances I would have two generators in the vehicle. We made sure that there was plenty of ventilation for the generators to prevent overheating. I talked to another station once who told me that they had to pull their generator out of the vehicle any time they had to use it for more than a few minutes. This is a problem that good design from the beginning should avoid.

Inverter

There is one overwhelming problem with the gasoline powered AC generator: Frequency Stability. With mechanical governors on the generators and A/C or heating units cycling on and off stable 60Hz is simply not possible. Since we have cart machines on board the vehicle with synchronous motors the tape speed will vary with the generator speed. In order to provide a stable source of power for frequency sensitive equipment we have provided an inverter. The TrippLite PV1000FC inverter we used is "frequency controlled" according to the manufacturer. This means that the oscillator which supplies the 60Hz reference for the inverter is a 555 timer. In order to achieve greater accuracy for the inverter we have modified the unit to use a 60Hz output from a Kinemetrics Model 60-DC WWVB Synchronized Clock as an ultra-stable 60Hz reference. Even when WWVB is not being received by the clock the 60Hz output is crystal controlled. If this outside source is lost the inverter will automatically fall back to the internal 555 timer frequency source. The output of the inverter is conditioned by a Sola type CVS harmonic neutralized constant voltage transformer to provide a clean 1KVA for broadcast equipment. The 12 volt DC input for the inverter is supplied by the "RV" batteries. These batteries are charged by the automotive engine alternator when that engine is running and by a 75 amp DC converter which runs whenever AC voltage is present. We find that we run the critical equipment on the inverter most of the time even if shore power is available. Then if the shore power is somehow cut off the batteries will carry the broadcast equipment until AC power is restored.

Power Switching

Power selection and monitoring is available on a panel to the right of the main equipment rack at the forward end of the studio area. On this panel we have both voltage and frequency metering for the shore power inputs, generators, and inverter outputs. In addition we meter the inverter input DC current, the converter DC output, and both RV and automotive battery voltages. Both generator start/stop controls are located here. AC power is selected by rotary switches which operate power contactors. Inverter power routing is through relays selected by front panel toggle switches. The console, individual racks, and P.A. amplifiers can be put on the inverter buss. In the event the inverter fails the relays will fall back to the selected AC power source. This panel provides in one location convenient to the operator all the power control and metering needed for the vehicle.

CONNECTING TO THE OUTSIDE WORLD

Telephone Circuits

Connections to telephone circuits are made on blocks located in the cable storage locker under the main equipment rack on the roadside midsection of the vehicle. The vehicle is equipped to use both equalized telephone circuits or dial-up circuits. We often use dial-ups for remotes from distant cities. We use the Rood bandwidth extension system which takes two dial-up circuits to make one 5KHz channel. The quality of the Rood is surprisingly good. We have used it as far away as Maui with good results.

RPU Link

The WLS remote vehicle is also equipped with Moseley 450MHz RPU transmitters. We are licensed on the wideband "S" channels. The antenna is a 10 Db gain yagi mounted on top of the 40 foot mast. With receivers on the Sears Tower we can cover a large area. We can also use a 3Db gain roof mounted antenna. We haven't tried this one yet, but it should be possible to transmit from the vehicle while in motion. We can also use other 450 frequencies for "cues and orders", and our cellular telephone for additional communication with the studio to do a totally wireless remote.

Satellite Uplink

Future plans call for an uplink to be installed in the vehicle. The antenna would most likely be a five meter trailered behind the vehicle. The modulators, up/down converter, demodulator, and TWTAs would be mounted in the half rack above the refrigerator. This rack is removable (by two strong men and a small elephant) so the uplink can be located some distance from the vehicle.

AUDIO EQUIPMENT

Main Console

The main audio console is a McCurdy SS8800 eight input console. It is equipped with six cart machines so that carts can be played from the remote site. There are two mic inputs which are associated with two talent "turrets". From these positions the talent can operate their own mics as well as talk to the studio or the engineer. These turrets can also be moved outside the vehicle on extension cables up to 200 feet away. These turrets also have remote displays for the WWVB clock and the cart running time timer. The console is also equipped to handle two wireless microphones, a 450MHz receiver and both stereo and mono line level inputs. At one remote, for example, we carried parts of a live concert while doing a show from in front of the theatre. The stereo mix from the house system was brought through the McCurdy console through one of the stereo line inputs. One of our DJs also roamed with a wireless mic. To provide this coverage we used two wireless mic receivers, one in the vehicle and another inside the theatre which was brought through one of the mono line level inputs. This console can also be used as an emergency air studio. In the event of total loss of the use of our normal studios the remote vehicle can be parked at the transmitter and used on the air.

Combo Console

At simple remotes we often operate combo. A small combo console is then located in the talent area of the studio. This console provides talkback to the studio where all carts are played. A tone signaling system cues the studio for the next cart as well as alerts the remote end when the cart is ending. This consoled has four mic inputs so that both local and wireless mics can be used. The talent has control of the PA as well as studio monitors at this location.

Outside mics

The WLS remote vehicle is equipped with two Vega wireless mic systems with diversity receivers. The antennas are located one on the roof and one on the 40 foot mast for each receiver. The antenna locations can be changed if the situation dictates. Monitor for the talent on wireless can either be via Walkman receivers when we are within the station coverage area or via a VHF IFB transmitter located in the vehicle. The IFB feed can be interrupted at the vehicle console to communicate with the talent outside the vehicle.

Wired Mics

We also carry two thousand feet of three pair cable in the vehicle for locations where we cannot use wireless mics. At the far end we can use two EV line level mics. Monitor and talkback are via an RTS intercom on the third pair of the cable. This "wired outside mic" scheme was used, for instance, at the FARM-AID concert. The RF envrionment was too crowded with all the radio and TV stations on site, so we used the wire mics to provide coverage from the stadium press box while also providing coverage from the vehicle outside the stadium.

Additional Audio Equipment

The vehicle can provide public address at remotes. We carry four Bose 802 speakers and stands on the vehicle. The speakers are driven by two Crown MT-1000 power amps. These amplifiers are capable of driving more than the four speakers if needed. We have had good results placing the speakers on stands on the roof of the vehicle. This keeps them out of the reach of spectators, provides wide coverage, and keeps feedback to a minimum. The PA feed can be equalized using a UREI 535 graphic equalizer. An Orban 424 dual limiter provides overload protection for the program output from the vehicle. A WLS built monitor/PA mixer can be used to "re-construct" the monitor from local and mix-minus feeds when using satellite circuits. For some reason the talent doesn't like hearing their own voice coming back at them half a second later, so the studio feeds a "mix-minus", that is everything but the remote back to the remote. We then mix the local audio back with the mix-minus to give the talent at the remote an idea of what it sounds like on the air.

CONCLUSION

The WLS remote vehicle has been accepted with rave reviews by talent, sales, programming, and promotion. We are now doing many more remotes than we used to do which comes as a mixed blessing. The station is getting more exposure, but I have been putting in so much overtime that I had to post my picture above the dogs' dishes so they don't forget who I am and attack me when I do come home. The new vehicle has been so well received that we have had trouble getting time to work on it. This brings us to:

ED'S FIRST RULE OF REMOTE VEHICLES

"Don't let sales or promotion know you've got the new vehicle until you've finished installing your equipment!"

When we took delivery of the vehicle the promotion department had two remotes lined up within the first week. This was before the first piece of equipment could be installed. Try to give yourself some time to work on the vehicle before you have the grand opening.

The WLS remote vehicle has allowed us to do remotes from locations we couldn't use before. We feel it has been well worth the investment in time and money.

THE NEW ABC RADIO NETWORKS BROADCAST CENTER

Richard Martinez
Director, Engineering and Program Operations
ABC Radio Networks
New York, New York

WHY A NEW BROADCAST CENTER?

When growth bumps against production limits and transmission capacity, where do you go? The ABC Radio Networks found itself in this unique position entering the 1980's. Programming was threatening to overflow our transmission capacity over the single thread land line then in use. Multichannel satellite delivery was obviously the vehicle to accomodate this business growth. ABC chose not simply to provide for long term growth, but also new and in some cases, as yet, unidentified ventures.

Digital Audio Transmission System

ABC selected the RCA DATS system after exploring digital satellite transmission with a number of vendors during the late 1970's. The final selection was a full transponder capable of 20-15 Kilohertz audio channels. Each of these channels could be subdivided into 7.5kz channels. A 15kz channel could further be divided into 12-32 kilobit voice cue or data channels. As implemented, ABC Radio currently operates 19-15 khz program channels with the 20th channel sub-divided into 5-32 kb voice grade and 7-32 kb data channels. (Figure 1.)

Production Facilities for a Multi-Channel Delivery System

Now that ABC had a DATS program underway, attention was drawn to an outdated production facility. The vintage 1968 studios in use were hard pressed to handle the current program load and would be inadequate for future expansion plans. The objective, as always, would be to design a broadcast center which would survive change over the next decade or two.

Figure 2 graphically shows how a production center traditionally geared to a single 24 hour channel, had to change in order to cope with up to 19-24 hour channels. The comparison of these three broadcast centers over three decades demonstrates the major programming changes occurring during those periods.

The 1966 era facility had to contend with only one network. This single service provided programming to all affiliated stationsalike. Demographic distinctions were not yet a network priority. Feed time availability therefore exceeded available programming. There was little contention for feed time.

The 1976 facility had to accomodate an expansion to 4 demographically unique networks with an attendant growth of 50%. This facility still handled program transmission by serially time sharing one 5 kilohertz land line. Contention for desirable feed time by four network services started creating problems for the networks and stations.

In contrast, the new broadcast center now programs 6 full service, demographically targeted networks, a talk radio service, ad-hoc networks such as concerts and special programming and a variety of syndications. Feed time is now spread out over several satellite channels.

The Design Problem!

A network production center can be broken down into three basic elements:

1. Real Time Program Origination Facilities
Typically, these consist of studios or sub-centers largely dedicated to on-air programming such as news, sports, special events, etc. For planning purposes, on-air use of these facilities usually precludes their use for off-line production.

2. Off-Line Production
These facilities support real-time programming by producing either, elements for integration in real-time programming, or complete packaged programs for later broadcast such as series programming, features, special programming, etc.

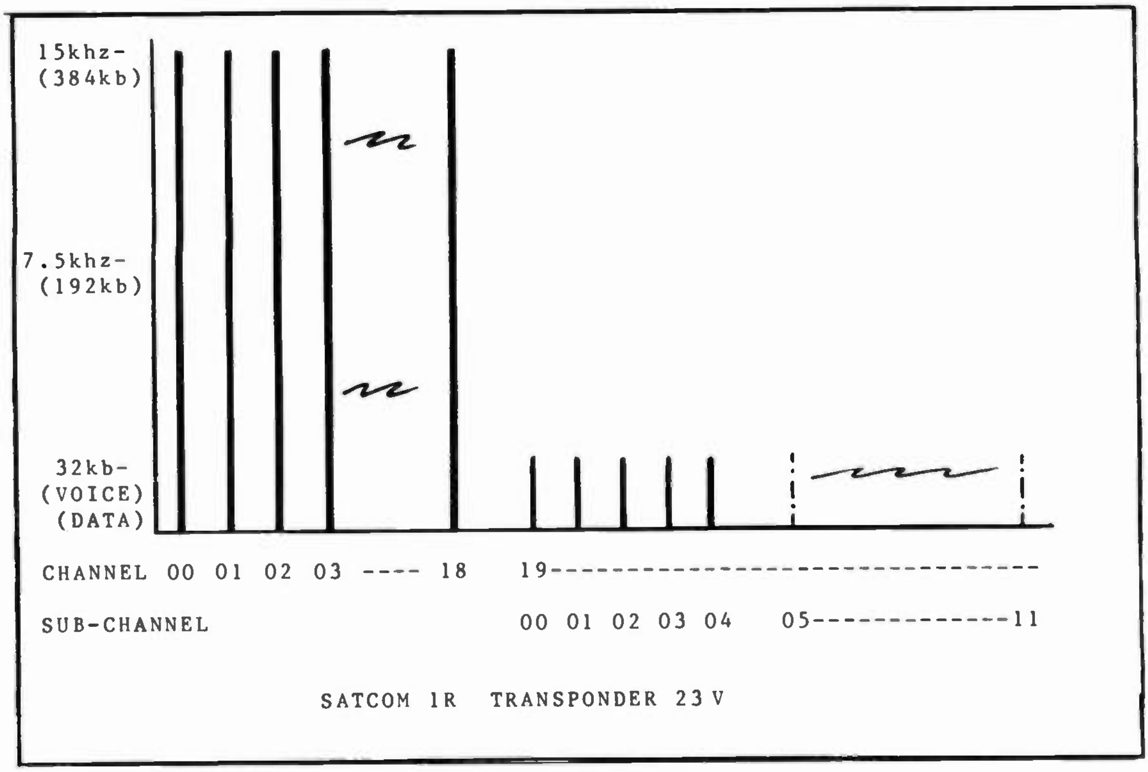


Figure 1.

3. Program Transmission Facilities
This facility provides the means and control over the affiliate program delivery system. It must be able to deliver multiple, concurrent program channels.In addition it must be flexible enough to switch 100 sources of programs to 30 program channels in any combination. All switching would have to be accomplished in one second or less and switching could occur as often as once every second. This facility would also provide program automation over previously prepared tape programs and syndications. Within two years, 1982-1984, the old Radio Master Control would be renamed as the "Technical Operations Center" to better describe it's new global responsibilty. In addition to traditional duties, the facility was taking on the appearance of a major common carrier central office similiar to NY NR or Chicago CQ.

With this last requirement we entered the world of computer controlled program transmission.

The Challenge And Some Answers

How do you design a new facility to accomodate as yet undefined "new programming and opportunities"? Flexibility, interchangeability, modular construction became the new buzz words.

1. Flexibilty - Although we knew our current business well, new formats might be constricted by new facility planning. Software control of hardware seemed to offer a solution. Reprogrammable, software driven hardware was utilized at every level as one answer to the flexibility problem. Examples: Tape recorder parameters were modified to our specifications by PROM changes; a new networked computer traffic system solved the problem of preparing and updating increasingly larger, complex multi-channel broadcast schedules; a networked, mini-computer based automation system solved the much more complex satellite audio switching matrix, while allowing rapid changes in formats or daily schedule changes. New studio microcomputers gave operators the ability to follow late changes, query the master computer for schedule and switching information as well as to buffer manual switching and automation control. A new affiliate automation encoder computer handled look up tables for simultaneous transmission of automation controls for concurrent programs over multiple channels.

Communications and program feedback has traditionally been a problem area. As soon as you install a system, requirements change.Now the expensive and time consuming process of modifying

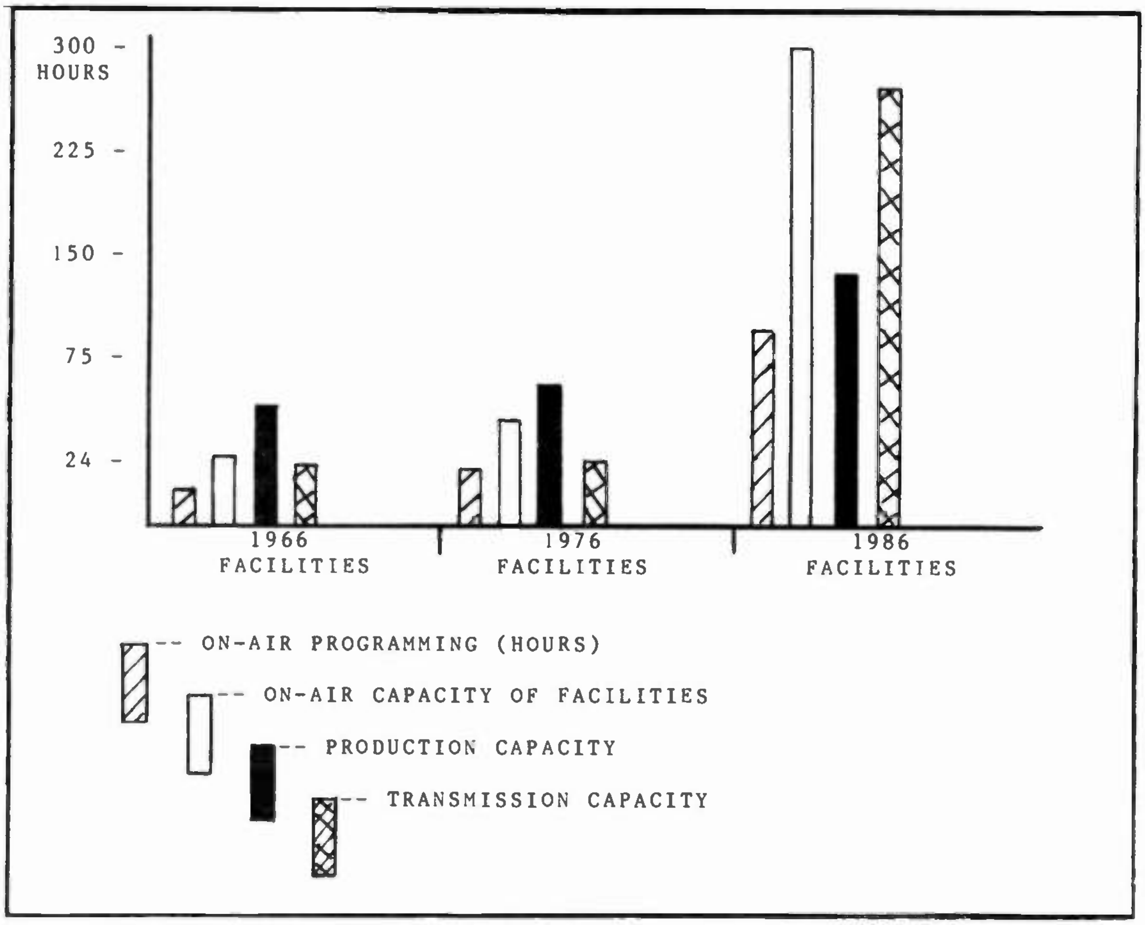


Figure 2.

hardware begins. This problem was also solved by choosing a large plant intercom which is software based. Permanent changes can be made in software overnight. Immediate changes are made at terminal keypads.

As simple an item as office monitoring was dealt with in the same manner. DTMF switched, microprocessor controlled CMOS switch cards provide flexible and expandable monitoring. Past history showed that monitor systems and the dynamics of change were synonymous. Software control and addressing has eliminated the daily rewire syndrome.

2.Interchangeability - Heretofore, radio network studio construction relied on similiar but functionally tailored rooms. An edit room might use the same console as an air studio or production studio, but the number and configuration of input/output channels would be tailored to the rooms intended use. This type of design often resulted in outdated rooms before the new facility air date, since production plans might change during construction.

The new broadcast center was conceived with each room designed to accomodate air, news edit or production interchangeably. Only in this way would we hope to span the changes of a decade.

3. Modular construction - Change is inevitable! By following modular construction techniques throughout the plant, ABC planned to respond easily to equipment changes brought on by new production techniques. In addition to extra rack space, provisions for change and expansion were included by the extensive use of high density connectors and cross-connect frames at either end of all studio cabling. Within subsystems the same philosphy was used. All systems were designed with future expansion and change in mind. For example, the present microprocessor controlled 200 input by 150 output studio audio routing switcher was designed to expand to either 200 stereo or 400 mono inputs and an additional 50 outputs (200).

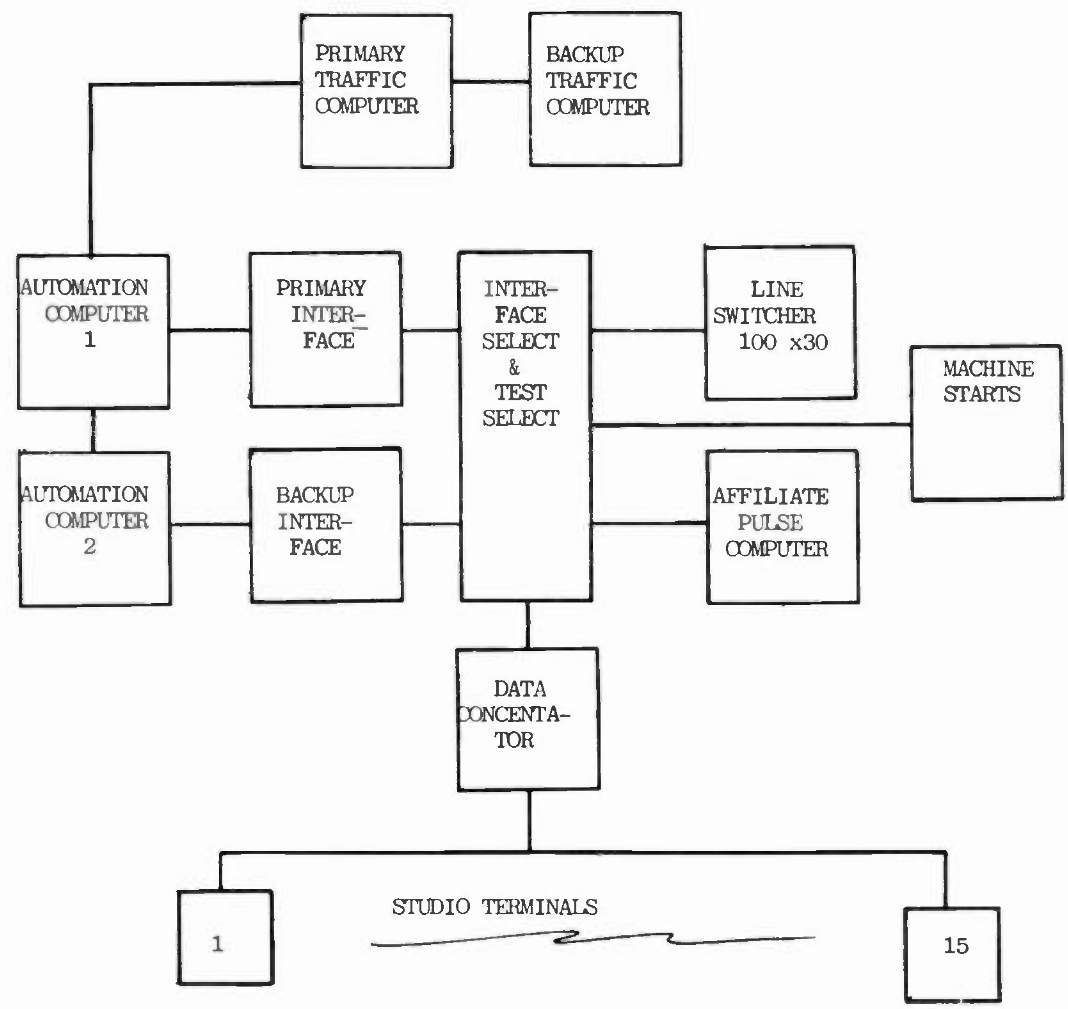


FIGURE 3.

All of the above are typical good engineering answers to traditional programming problems. What follows is the innovative answer to how you control all these in a closed loop automated system.

THE ABC RADIO AUTOMATION SYSTEM

The magnitude of imminent programming expansion dictated the need for a better way to handle daily operations. The method in place in 1982 relied on operators performing real time transmission switching, affiliate automation switching, machine starts, and other actions during even the briefest of programs. Most of these operations were prescribed in the daily operations schedule published each day. It became obvious that this schedule could be replaced by a data file which an automation system would execute. Reviewing the potential 1,000% increase of program allowed by the new transmission system, a closed loop system became mandatory. In the future, all scheduled, routine operations would be performed for the operator. In this way the operator would be released from repetitive, non-discretionary tasks and allowed fuller concentration on production or supervision of on-air programming.

Side benefits were now possible. A computer issued, program tape list was now possible thereby eliminating

THE TECHNICAL OPERATIONS CENTER (T.O.C.)

typographically generated errors on-air. Random access selection of commercial inventory could now be realized. But more importantly, a test verification of commercial traffic scheduled vs traffic aired is now possible.

Figure 3. shows a block diagram of the ABC Radio Network Automation System and the network of traffic, affiliate automation, and studio computers. Figure 4. outlines the flow of information in the operations loop. This flow of executable program instructions and information would now allow a higher degree of quality control.

AFFILIATE BENEFITS

Once more one should ask the question "Why a New Broadcast Center?". A network is guided by multiple market forces. Among these are the requirement to deliver an audience for the advertiser. Symbiotically, the network must have an affiliate base accepting or "clearing" advertiser supported programming. Under this system it becomes clear that affiliate clearances depend on many factors not least of which is the ease in which the station is able to air or tape delay programming. This ease of program integration at the local level had to receive high priority attention in the new facility.

Multiple Channel, Simultaneous Programming

Local stations program for their local markets. Sounds simple enough! But what happens when that 1 hour network special is fed in real time and conflicts with the local station schedule? What if the staff can't conveniently record and delay broadcast that special or a prefeed of your favorite commentator or sportscaster? Multi-channel feeding takes on new significance. Not only does it serve the needs of multiple concurrent networks, but it also can be used to feed packaged programs at times more convenient for local recordings as well as repeat feeds.

Affiliate Automation System

Since 1982, the ABC Radio Networks have operated a serially encoded FSK pulsed system for affiliate, program automation control. All regularly scheduled programs are preceded and followed by a unique series of sub-audible pulsed codes. These are used at the affiliate station in a number of ways consistent with their unique needs. Automated stations can use this system to either air programs such as newscasts in real time or automatically record, delay, and integrate these programs into their format. Stations also use this system to provide unattended recording of programs for smoother integration into their format. This same system provides affiliate alerts for news bulletins and other high priority special event programming.

To assure greater reliability of these signals, ABC instituted a computer driven system (figure 3.) which provides greater flexibility. The importance of this system is enhanced by the high degree of reliability and error checking it has introduced.

The result is a system which extends the benefits of automation to the network affiliate.

SUMMARY

The New ABC Radio Networks Broadcast Center is the culmination of several years of planning and construction. Foremost in this planning were the needs of the local stations as well as the future of ABC Radio. The planning continues as ABC looks at everchanging programming requirements.

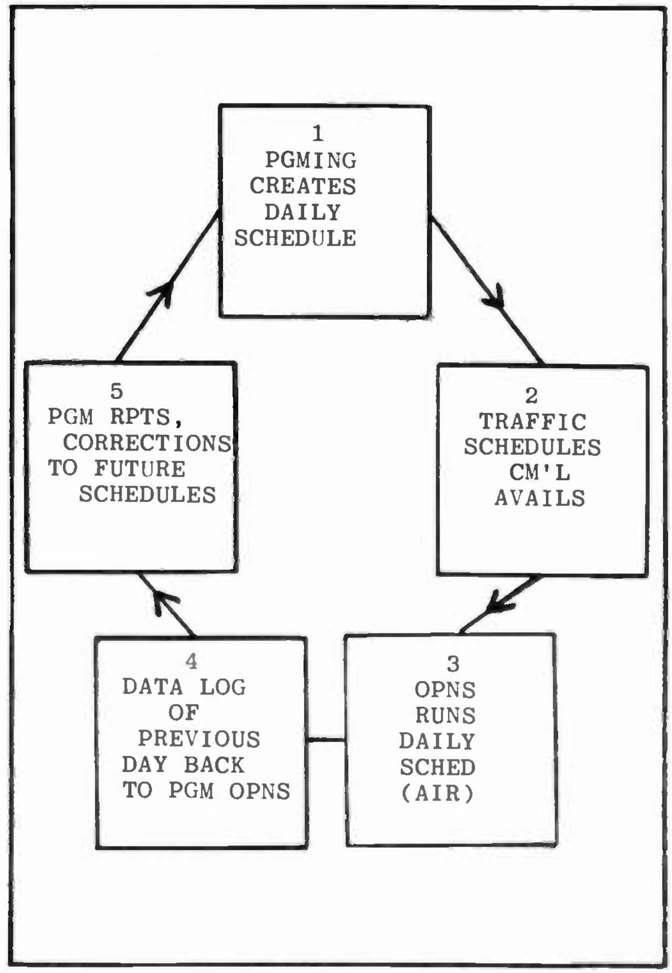


FIGURE 4

UNIQUE ASPECTS OF THE NBC RADIO NETWORKS' 1700 BROADWAY FACILITY

Warren L. Vandeveer, Jr.
Director of Operations and Engineering
NBC Radio Networks
New York, New York

The relocation and construction of a large audio facility such as the NBC Radio Networks is a major undertaking. Time, space, technical and financial constraints impact all areas of the project. In relocating the NBC Radio Networks from Radio City to 1700 Broadway, many innovative applications of technology were used to overcome these project constraints.

INTRODUCTION

In the early 1980's the decision was made to rebuild the NBC Radio Networks' technical facility. Due to the lack of suitable space inside the RCA Building, the Radio City headquarters of the The National Broadcasting Company since 1933, a search began to find a new home in one of the nearby office buildings.

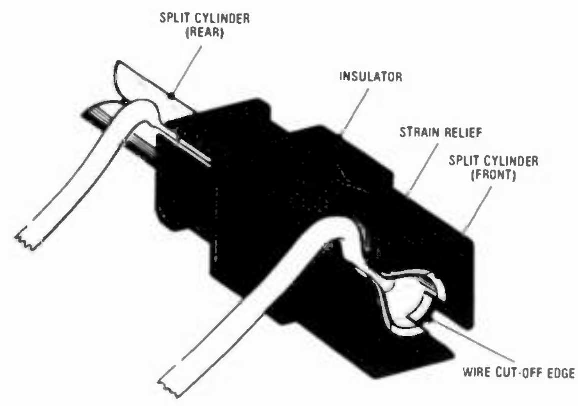
Eventually, two floors of space were secured in the 1700 Broadway Building at 53rd Street and Broadway. One floor was to house the administrative support for the Networks while the other floor was dedicated to technical studios, equipment, newsroom and offices for technical and news management.

Planning began and construction commenced with demolition May 28, 1984. Nine months later, on February 23, 1985, the first newscast originated from our new home on the ninth floor of 1700 Broadway, officially marking our move in. The fast track construction schedule and the "remote" location (a few blocks away) of the facility from NBC at Radio City, created several unique engineering opportunities.

SOLDERLESS CONNECTIONS

In any audio facility, there are many cables and connections to be made interconnecting studios and equipment. In a major radio network facility such as at NBC, there are miles of audio and control cable with thousands of connections. To create order in the midst of all this chaos, we decided to utilize a large wall in the transmission room as the MDF (main distribution frame), a point of interconnect for cables going to and from studios and transmission room equipment. Typical solder "A" blocks or "Christmas Trees" were ruled out due to time and labor constraints--construction time was limited and labor costs would have been prohibitive.

The QCP (Quick Connect Panel) system, developed by ADC Telecommunications of Minneapolis was employed. The system, which was extensively tested and certified for use with 22 gauge, stranded cable (Belden 8451 type) utilizes small, plastic insulated split metal cylinders which mount on a panel. Twenty-two gauge stranded wire is laid across these QCP modules and a special impact wire insertion tool is used to make the final long-life, gas tight connections. No stripping or soldering is required. The cylinders accept up to two wires on either side of the mounting chassis allowing a four wire connection point.



QCP Module (split cylinder and plastic housing) with wire inserted front and rear.

Figure 1

For NBC's requirements, we designed and specified a punch down block consisting of twenty-four rows of six color-coded QCP modules which ADC manufactured. The block was constructed to mount flat on a wall or on brackets four across in 4 rack units of space.

The face of the block is divided into a left and right side each consisting of red (+), black (-) and white (shield) QCP modules with fanning strips along the blocks' edges for wire dressing. Wire on the back of the block connects left and right side like-colored modules, row by row. The rows are numbered and divided into two groups of twelve forming a top and bottom and creating a logical accommodation of our plant standard Belden 9768 twelve pair, individually shielded cable.

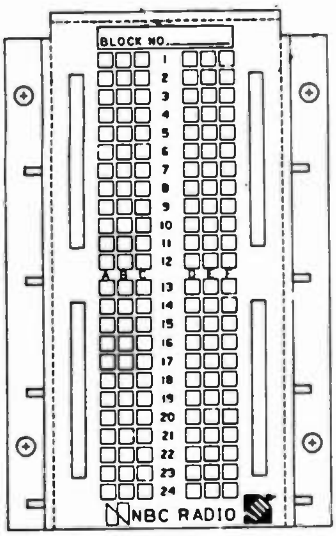


Figure 2-Custom NBC Punch Block

The MDF wall consists of 200 punch blocks in an 8' x 30' area, mounted in columns of 10 blocks. A 3" x 4" Panduit plastic wiring trough and a 1" copper bus bar are installed to the left of the blocks and custom wire rings are fastened to the right. In practice the 9768 cable is run from racks, studios and offices beneath raised flooring, then up the Panduit to a block's left side. Here all the cable's 12 drain wires are attached to the bus bar, but left floating at the cable's far end providing a "star" grounding system. The 12 individual pairs are then dressed and punched down to the block's left side connectors. Obviously the time consuming process of preparing the cable (stripping the outer jacket, separating the pairs, removing the foil shield, and heat shrinking the cable end) is performed but, unlike a solder "A" block, stripping and soldering the individual wires is not required, saving much time.

The block's right side is the connection point for custom manufactured Belden 22 gauge, stranded, unjacketed twisted pair, color-coded black and red. This cross connect wire provides for audio and control connections between individual pairs in the 9768. It is run from one block's right side terminals, looped tightly through the wire rings, routed up the wall to an overhead ladder trough and across to another block's right side terminals. The exclusive use of balanced audio circuits and twisted cross connect wire provide for excellent crosstalk performance. Changes in circuit routing are quickly and easily accommodated by pulling out the old cross connect and installing a new one--the only tool required is an impact punch!

Lug counts for every punch block and wire runs for each cable in our facility were generated with an IBM PC using dBase III. This allows neat, accurate record keeping and makes documentation updating an easy task.

ADC's Pro-Patch Audio series of 1/4" patchbays were specified for use in most of the systems comprising our transmission room's 51 racks. These patchbays provide 48 circuits (an even multiple of our 12 pair cable) and allow our vendors to also benefit from the time-saving QCP installation method. (Vendor feedback on the QCP method is positive; in fact, some vendors are exploring utilizing QCP in their own systems.) Once the factory checked rack systems arrived at 1700 Broadway, prepared cables were punched onto the appropriate terminals and the installation was complete.

Punch blocks were also furnished to equipment vendors for integration into various studio and rack systems. Most vendors removed the block's rear mounted cross connect wires and installed their own internal wiring, reserving the front of the block for fast and easy installation of cable in the field.

A year's experience and thousands of connections have proved the QCP method a reliable means of audio termination.

CABLE SYSTEM

A unique cable distribution system was designed to link our new facility with NBC's headquarters.

Within the Radio City complex, NBC originates and distributes many audio, video and RF feeds. In-house cable television, known as the Jerrold system, provides TV monitoring for 36 channels consisting of local TV stations, NBC network feeds, studio outputs and other programming. The NBC Master Grid is a 160 input by 320 output routing switcher with each input comprised of one video and three audio channels. The Grid provides all of the on-air routing and switching within NBC's facility. For audio monitoring purposes, the ADM system of 150 inputs and 200 outputs is available. Additionally, numerous audio, video and data trunks provide interconnects on an occasional and full-time basis between many of the NBC radio and television facilities within Radio City. Our relocated facility had to be provided with these in-house feeds and facilities which are vital to our Radio Networks' operation.

The major umbilical cord connecting 1700 Broadway and Radio City is a New York Telephone-provided bi-directional coaxial cable system buried beneath the streets and sidewalks of midtown Manhattan. As shown in Figure 3, the forward direction (Radio City to 1700 Broadway) occupies 54-400 MHz while the reverse direction (1700 Broadway to Radio City) extends from 5-30 MHz. NBC Radio-installed Jerrold amplifiers, splitters, combiners, modulators and demodulators located at Radio City and at 1700 Broadway provide the interface with the New York Telephone equipment.

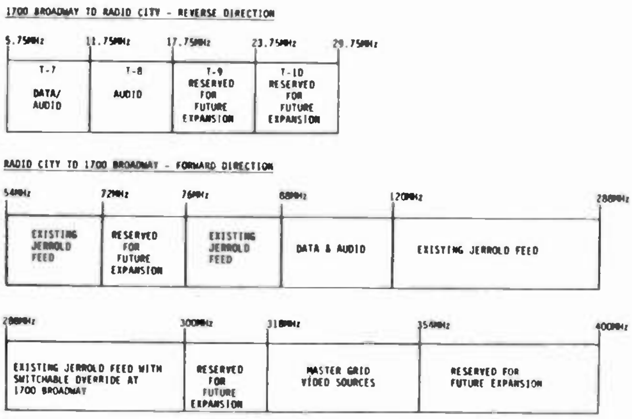


FIGURE 3. FREQUENCY ALLOCATION OF BI-DIRECTIONAL CABLE SYSTEM

An output of the NBC cable TV (Jerrold) system is directly fed into the Radio City headend, along with video modulators converting six Master Grid outputs from video to the allocated RF bands. Bi-directional data links are provided by RF modems. At 1700 Broadway, a wideband cable television distribution system provides televisions on the two NBC occupied floors with the in-house NBC cable offerings.

Implementation of RF audio channels between the two locations initially proved difficult. The standard "cable television" FM modulators which provide acceptable audio for home cable systems were not at all suitable for the on-air quality audio transmission required between the two buildings. After months of searching, we discovered FM RF modulator/ demodulators manufactured by Leaming Industries of Costa Mesa, CA. Leaming was manufacturing and supplying equipment for a new high quality cable audio distribution service which is based on Telefunken's High Com noise reduction system. Slight modifications made these products perfect for our use.

The Leaming frequency agile modulators and demodulators provide audio channels in the 88-120 MHz (forward) and 5-16 MHz (reverse) bands with a frequency response of 20-20,000 Hz $\pm$0.5dB, a signal-to-noise ratio of 75db below +8dBm, and less than 0.5% THD. Each channel occupies only 150 KHz and we currently operate 31 channels in the forward and 26 channels in the reverse direction with ample expansion capability available.

Three modulators or demodulators mount in a single rack unit frame. These frames provide power, and either combine or split the RF for the individual units. Standard cable TV splitter/combiners are then used to route RF to and from the cable system headends.

REMOTE MASTER GRID CONTROL

The Radio Networks are assigned six of the 320 outputs on NBC's Master Grid. Outputs are typically switched using three digit thumbwheels hard wired to the Grid controller and utilizing a variation on decimal coding. This approach requires that a 21 conductor cable be connected to each thumbwheel. The remote location of our new facility made it impossible to operate our Grid outputs in this fashion.

A unidirectional, 9600 baud data link replaced these six multiconductor cables. Three digit thumbwheels coupled via an RS 422 link to an encoder and data transmitter at 1700 Broadway comprised the sending end which connected to a receiver and decoder at Radio City via one of the cable audio channels. This decoder provided the decimal thumbwheel information to the Grid via open collector outputs. The link is invisible to both the thumbwheel operators and the Grid itself, and was implemented by McCurdy Radio using repackaged, microprocessor-based, off the shelf subassemblies and custom software.

COMMERCIAL AUTOMATION SYSTEM

The NBC Radio Network and The Source both provide hourly newscasts which are time zone fed via satellite to our affiliates. A total of six satellite channels are used for this, three for each Network, providing the East Coast, Central/Mountain and Pacific Coast time zones with separate commercial feeds during commercial breaks. We decided to play these commercials from the studio originating the newscast instead of utilizing a central automation system for two reasons: increased reliability and our desire to wait for a plant-wide digital audio storage system to originate not only the commercials but also to record and play virtually all of the audio used at the Networks.

Each of our three on-air news studios is equipped with an automation system. ITC Delta single - and triple-play cart decks provide 13 cartridge slots which are controlled by a custom-designed McCurdy Radio microprocessor-based controller. The 13 cartridge slots provide up to two minutes of commercials per time zone (made up of a maximum of four, 30 second spots) plus a protection cartridge.

At the beginning of a commercial break in the newscast, the control room engineer starts the automation by pressing a button on the audio console. The system then signals the Datatek channel switcher to route the audio from the three banks of automation cartridge machines to the three outgoing audio channels which were previously fed the newscast audio from the console. Simultaneously the appropriate carts are started and the commercial break is underway. Cue tones at the end of thirty second spots cause the automation to roll a second thirty second spot during the one minute break. All three time zones are monitored for silence indicating a malfunction. If this occurs, the automation routes audio from the protection cart to the affected time zone for the duration of the break and signals studio personnel. The automation system's front panel readout counts down the seconds remaining in the break (typically 60.5 seconds in length). When the break is finished, the channel switcher is signaled to again feed the three outgoing channels with console audio. An "automation return" button is provided should it ever become necessary to interrupt the commercial break and return to a feed from the console.

The Datatek channel switcher is equipped with logic cards and automation pre-switchers. These correctly route the proper audio from each time zone's automation output to the correct outgoing channel. In this way, newscasts and commercials could originate for the two Networks simultaneously from any of the three studios. Commercials would be routed to the correct outgoing channels without operator intervention.

THE PAPERLESS NEWSROOM

From the day we moved into our 1700 Broadway facility, wirecopy and typewriters--long the mainstay of any newsroom--have virtually become a thing of the past. We manage this feat by utilizing a news computer system manufactured by Basys. After months of study and field testing by the NBC News Division, the decision was made to install the Basys newsroom computer in all of the NBC News facilities. Fortunately this implementation coincided with our relocation and we were able to integrate the computer system easily into our facility.

The custom designed, human-engineered newsroom desks provide space for the Basys CRT and keyboard. These allow NBC Radio personnel to read the news wires, compose and edit copy, send messages to other users and send text to laser jet printers for creation of hard copies. Terminals in our control rooms allow for log entries and the creation of feature shows. Studio terminals allow talent to use a "teleprompter" mode to read newscasts directly from the computer. Our news and operations/ engineering offices are also equipped with terminals.

Super low capacitance cables provide the RS-232 links which connect the terminals and printers to the central, environmentally controlled communications room. Here a small computer MDF is used to interconnect the equipment with four, 24 port statistical multiplexers. Eight 9600 baud, full duplex data lines (two lines per mux) connect the multiplexers with the news computer at Radio City. Each multiplexer automatically distributes the data traffic between the two data lines, balancing the load on the lines. The news computer system currently uses approximately 70 of the 96 high speed digital paths joining the two locations. The extra paths provide room for expansion and spares in the event of equipment failure.

SUMMARY

Rebuilding the technical facilities of the NBC Radio Networks has been a rewarding experience. Many engineering problems were solved through applications of existing technology. Our rebuild is complete but no broadcast facility is ever finished. New requirements will always send the broadcast engineer in search of unique and innovative solutions.

DESIGNED FOR SUCCESS

Paul W. Donahue
KIIS-FM/AM, Los Angeles, California
Gannett Radio Division

Developments in technology, programming theories, and a sensitivity to the worker's environment now present us with the opportunity to reevaluate some of the traditional methods of studio design and to take advantage of new synergies. This was manifested in the construction of a competitive, cost effective, and format flexible environment which promotes good radio. Presented here is a discussion of methods which were employed to design and construct new broadcast facilities for the Gannett Broadcasting stations KIIS AM and KIIS-FM in Los Angeles, California. Many of the methods adopted at KIIS are broad in concept and can easily be employed when developing other facilities. Our consumer focus during the design phase resulted in the development of better systems than previously attained in similar projects.

We all know how dramatic the changes in electronics have been in the last 10 years. The construction industry and the field of interior design have similarly been through many changes, typified by the emergence of the study of ergonomics, the relationship of the worker to the work environment. Several brainstorming sessions with Reback Design and the Gannett design team were the cornerstone in the success of the KIIS radio facility. An issue which was critical in all phases from design to move-in was the concern for the station personnel, their attitudes, the environment for creativity, and the ease of equipment operation. With the guidance of KIIS' President and General Manager Wally Clark, we were able to fine tune these objectives and to create an atmosphere which nurtures success. This guidance led us to adopt a philosophy with regard to equipment choice and layout: no new, untested technology, or equipment which was cumbersome to operate, was introduced to the facility. This attention to our employees and their environment is an important element in the Gannett Company's corporate culture.

PLANNING AND DESIGN

From the genesis of the KIIS facility design, we sought to eliminate the mindset inherent to the acoustical and architectural experts required in a project of this type. We had previously found that many of the traditional experts recommend a facility which employs overbuilt soundproofing, is inflexible to minor or major format changes, and is unprepared for growth without major reconstruction. Our requirements were met with a studio layout incorporating eight major on-air/production studios and two additional dubbing booths. We researched and implemented alternative methods of wiring a facility which used entry-level technicians and assured flexibility to the future growth of the stations.

Early definition of station goals is crucial to the successful implementation of a new facility. Every detail of design and construction must be carefully planned before construction begins. Design changes are inexpensive when done at this stage but very costly when done during construction. Regular meetings beginning in the planning phase, including station personnel and construction representatives will help to minimize the need for design changes in the field during construction. Operational necessities and requirements of the studio should be included in these meetings. Too often the chief engineer is not actively involved in planning and is left to complete requirements which could have been included at lower cost and completed in a more timely manner when planned at the onset of the project. There is inadequate space here for a complete discussion of group dynamics, but success with group meetings can be assured when one person has final approval of designs and changes. Also, distributing the minutes of each meeting promptly to all involved parties helps to refresh everyones memory and minimizes misunderstanding. The station engineering personnel should develop the same approach to the studio construction and wiring as does the building contractor. Time lines should be developed for ordering, installing, and testing equipment. These approaches will assure a smooth working arrangement with the building contractor and will guarantee timely completion of the project.

ACOUSTICAL CONSIDERATIONS

This stage of design is critical and can be the most costly aspect of a new facility. Many of the acoustical consultants which we interviewed wanted to overdesign the acoustic treatment, which directly translates to higher cost. The typical approach by consultants was to recommend concrete block walls or to recommend the installation of lead sheeting between studio walls to build mass and prevent sound transfer. This approach is certainly a safe one for the consultant, but can needlessly spend resources which can be better utilized elsewhere. Some research into studio design and construction showed that it is difficult to build an inter-studio window with a loss characteristic of greater than around 63 db. Because the studio window is the weak link in the wall system, and our layout demanded extensive visual communications we used this "leakage" criteria for the studio wall design and found that it could be achieved quite easily with multiple layers of drywall on separate double stud walls, which are in turn filled with acoustic insulation. The walls and ceilings are also covered with a pre-manufactured acoustical wall panel for sound absorption. These panels were custom molded into designer-specified shapes and colors. Another factor contributing to the success of this wall treatment involved the holistic approach to the selection of monitor speaker placement. The technology of monitor speakers is advanced and we chose near-field placement of these monitors. The use of near-field monitors has synergistic properties:

1) The speakers are located closer to the operator than the walls, so the walls and the room acoustic treatment do not "color" the monitors easily.

2) Because the monitors are near the operator, the sound pressure level in the room is significantly less than if the monitors were across the room from the operator.

3) The reduced room SPL allows for less restrictive wall treatment and lower construction costs to prevent leakage between studios.

4) Lower monitor power is required to achieve an acceptable SPL.

Our research indicated that the single most important factor in studio design was size. Most radio studios are designed by first determining the equipment needs of the format and then designing a room which is large enough to fit the equipment and personnel. We took a different approach here by first designing each studio with a minimum dimension of 1500 cubic feet. This dimension was discovered by the BBC to be the minimum acceptable area for a studio. This approach allowed for additional design flexibility when designing equipment layouts and reduced the cost of soundproofing between studios. Since windows are placed at least 7 feet from any mics in this size studio, sound reflections from them are minimized and windows can be used successfully in greater number than in a size-restricted studio. Although a 1500 cubic foot studio is only modestly larger than the typical radio studio, we had room to design format-flexibility into the facility. KIIS is a CHR music station with a strong emphasis on personalities. Because successful radio will mirror the trends of a changing marketplace, we must be capable of quickly responding to programming trends which are accurately targeted. We foresee that any variation of our present format or any known format could be implemented in our new facility without any changes in layout.

When we had established the layout of the studios and the design of the walls and windows, we were able to easily define the requirements of the air conditioning and heating system. It was determined early that each studio required a separate feed and independent control over their environment. Since we had already established the soundproofing criteria for the walls and windows and could easily calculate the maximum leakage from the loudest monitor in an adjacent studio, it was easy to determine the maximum allowable noise contributed by the HVAC system. As with wall construction, which was limited by the windows properties, there was no need for the air conditioning to be significantly better than the rest of the studio "system". Our calculations showed that the air conditioning system need only meet the 27db noise criteria. This level has proven to be more than satisfactory for our needs and is completely inaudible.

As with many new facilities, we were given a less than ideal location for a broadcast studio from an acoustical design perspective. Our particular location was in a high rise building in Hollywood with no internal space for studios, high traffic noise from Sunset Blvd, and a high noise level from the building's six high speed elevators. The station on-air personnel all wanted the view of Los Angeles from the studios, so all studios were designed on the exterior walls of the building. This was accomplished by building an interior acoustical wall inside the glass exterior of the building. The studio ceilings were constructed of two layers of 5/8" wallboard on an open grid metal frame which was hung from and isolated from the buildings concrete ceiling by acoustic isolators. The studio floor system uses field removable, concrete-filled computer tiles which were isolated from the building's concrete floor by teflon isolators. This hybrid computer floor system is covered with attractive carpet tiles and gives easy access to the studio wiring for changes.

STUDIO WIRING STANDARDS

Technological developments now allow for some creative approaches to wiring a facility with less skilled workers than previously required. This labor-intensive job can be properly planned to save substantially in labor cost. I believe that most broadcast engineers would agree that active-transformerless equipment is currently preferred, but standards for wiring such equipment without hum and cross-talk problems are not established in our industry. Typically, we tend to overbuild by utilizing unnecessary shielding and grounding techniques which are time consuming and costly. In order to develop the necessary flexibility in our facility without a strong reliance on patch-panels, we sought to develop some simple guidelines which have worked well for us:

1) All equipment must have an active-balance input with an impedence greater than 10k ohms.

2) All equipment must have an active-balanced output capable of driving impedences of less than 1k ohms.

3) A standard level of +8dbm was established for all inter-studio wiring runs in the facilitty. Any level lower than +8dbm was immediately amplified to the correct level to avoid unnecessary shielding and crosstalk. Intra-studio wiring was all done at the standard level of 0dbm.

4) A two-tiered level of star-point grounding was developed and implemented which used the standard U-ground required on all equipment.

5) All inter-studio wiring was done using 25-pair wire cable with a single ground shield. For operational flexibility, all cables terminated on both sides of punch blocks. Wiring between punch blocks was done with movable Scotch-Lock connectors. Substantially more cables were installed than were initially planned for. All wires were numbered and charted.

OPERATIONAL REQUIREMENTS AND BUDGETING

KIIS AM and KIIS-FM employ 72 full and part-time employees to deliver two formats in Los Angeles. Our space requirements were met with an 11000 sq ft facility. The office complex occupies 6000 sq ft and the studio area occupies 5000 sq ft. The studio requirements are met with three on-air studios,two two-track production studios, one eight-track studio, one four-track studio, and a news studio. Excepting the multi-track studios, all studios share similar equipment and layout and can conveniently produce on-air programming for either station. Simplicity and ease of operation were the essential ingredients for the layout and design of these studios. The on-air personalities have enough to do without worrying about technically sophisticated but difficult to operate equipment.

Because construction labor costs are high in Los Angeles, we sought to use off-the-shelf electronic equipment and acoustical items wherever practical. This approach, coupled with the holistic design of the studio soundproofing and environment, permitted us to build studio space which surpasses our expectations at roughly 70% of the cost for similar facilities recently constructed in Los Angeles. The rates quoted for studio construction in Los Angeles, excepting equipment, are between \$165/sq ft and \$190/sq ft. Our cost for completed studios was \$112.00/sq ft. The average cost of electronic equipment in each studio, including new consoles, wiring, and studio furniture, was \$67,000.00 per studio or \$107/sq ft. The office space was constructed for \$27/sq ft and was furnished and decorated for an additional \$50/sq ft. The total cost of the project was \$1.6 million and exceeded our expectations.

THE REDUCTION OF IPM IN AM TRANSMITTERS

Dominic Bordonaro
WAAF/WFTQ Radio
Worcester, Massachusetts

This paper will take a practical, hands-on approach toward the problem of IPM and its effects on AM broadcasting. Not only will it discuss how to recognize IPM and what to do about it, but it will also explain why IPM is an important parameter in mono, as well as stereo, AM broadcasting.

WHY IPM IS IMPORTANT

Before the advent of AM Stereo, few AM broadcast engineers had ever heard of the term IPM, let alone concerned themselves with its effect on their AM transmitters. But as more and more facilities convert to AM Stereo, it is becoming evident that a lot more than amplitude modulation has been coming out of our antennas over the years.

IPM stands for "incidental phase modulation" and can be defined as phase modulation produced by an AM transmitter as a result of its amplitude modulation. In other words, as your AM transmitter goes along its merry way making AM as it should, it is also broadcasting a phase modulated, or PM, version of your program as well Since the only difference between phase modulation and frequency modulation is 6 db per octave, you can think of IPM as a preemphasized FM version of your program coming out of your antenna along with the AM.

In theory, this is of little consequence since, as we all know, FM or PM does not affect the amplitude of a carrier. An envelope detector would ignore all of this IPM, right? That's correct, in theory. But since we're dealing in the real world, let's take a look at what effect IPM has on all of those real world radios out there.

Mono Transmissions

Before we even think about how all of this affects stereo broadcasting, we have to look at what IPM means to the mono broadcaster. As stated above, it means nothing to the mono broadcaster, in theory. An ideal envelope detector would ignore any IPM and reproduce only the AM components of the program. As a matter of fact, that's exactly what happens on your modulation monitor. Modulation monitors are wideband, untuned devices that behave very much like an ideal envelope detector. Phase modulation is totally undetected by a conventional modulation monitor, which is one of the reasons why we never even thought about IPM in the past; we didn't know we had a problem. Unfortunately, there's usually only one mod monitor listening to your station while there are several thousand receivers of lesser quality out there, all more or less subject to the effects of IPM.

Poor Spectrum The first consideration of excessive IPM is the effect on the transmitted spectrum of an AM radio station. When you modulate a perfect AM transmitter with a 1kHz tone, you create two sidebands, one 1kHz above the carrier and one 1kHz below the carrier. When you phase modulate a carrier, you create an infinite number of sidebands at 1kHz intervals above and below the carrier. The number of significant sidebands depends on the magnitude of the modulation. With moderate amounts of IPM, the transmitted spectrum of the radio station can be increased to the point where the legal limits of the channel are exceeded, especially on program material that is excessively preemphasised. Besides being a bad neighbor, this can cause problems with your own listeners as they try to tune in your station with manually tuned radios. Any mistakes in tuning result in a hashy, spitting sound that makes listening to your station a difficult task. Since most people don't take the time to tune their radios exactly, your station tends to sound hashy and spitting.

Slope Detection It's probably been years since you've heard of this one, so let me review: slope detection is a method of recovering audio from an FM or PM wave by using one side, or slope, of a resonant circuit. As the frequency or phase of the wave changes, the output voltage of the detector changes proportionately. and you have demodulation. This same principle is in effect with a mistuned radio on a station with IPM. The slope of the IF passband will demodulate the IPM and will add with the AM envelope and distort it. Although this is most pronounced on a radio that has been mistuned by the consumer, this can happen on any radio as a function of an asymmetrical passband of the IF.

Narrowband Radios IPM, or any phase modulation, creates an infinite number of sidebands. In order for IPM to be undetected by an envelope detector, all of the sidebands must be present at the detector. If the signal passes through a narrow passband IF on its way to the detector, as it does in every radio, then many of the sidebands will be lost. When this incomplete version of phase modulation is presented to an envelope detector, audio is detected. If the passband of the IF is symmetrical, then the detected audio consists mostly of the harmonics of the audio. This is like having a distortion generator built inside of every radio in the field. This is also the main reason why your modulation monitor won't register the added distortion that the radios out there seem to pick up.

Phase Rotation This is a problem that shortwave broadcasters have been dealing with for years. As a radio signal travels through space and bounces off of the ionosphere, the phase relationships between the carrier and modulation sidebands can be disturbed. When this happens, fading of the signal and distortion occur. IPM remains IPM only as long as the phase relationships between the carrier and sidebands remain undisturbed. If the phase relationships change, the IPM becomes AM. When this is added with the AM sidebands that have also been disturbed, intolerable distortion can result, making the station unlistenable in an area where the station may have been listenable had it been free of IPM.

The same thing happens with the AM broadcast band. Phase rotation occurs within the coverage areas of AM stations operating on the high end of the band when close-in skywave comes in on top of the groundwave signal. It can also occur in the nulls of a directional pattern where the phase relationships of the sidebands are changed from the carrier. In fact, the AM band is not an especially phase-stable medium. Transmitting and receiving antennas, tuned circuits, and propagation effects can all serve to turn IPM into an AM component. The main result of this is to decrease the coverage of the affected radio station.

Stereo Transmissions

With all of the reasons for IPM to be avoided by the mono broadcaster. it's suprising there hasn't been more of an awareness of it in the past. Why, then, is there all of a sudden a great interest in IPM? The reason is that IPM has a very definite effect on AM Stereo broadcasting, over and above the reasons already stated.

All 5 of the proposed AM Stereo systems utilize some form of phase or frequency modulation of the carrier in order to transmit stereo information. It is obvious, then, that any undesired phase modulation of the carrier. such as IPM, would have a direct effect on stereo performance. Although the effects of IPM on stereo performance vary from system to system. it is safe to assume that any amount of IPM is undesirable in any of the systems, and that optimum performance is realized when IPM is minimized.

CAUSES OF IPM

As a general rule, since IPM is a direct result of the modulation process, IPM is created in a stage that is being influenced by the modulator. The first place to look is the PA stage. The classic cause of IPM in plate modulated and pulse modulated transmitters is poor neutralization of the final. Since many older 1 Kilowatt transmitters and almost all 5 Kilowatt tube transmitters use triodes in their PAs, this is a good place to look first. Adjusting the neutralization for the lowest IPM is the most accurate way of properly neutralizing an AM transmitter Any other method of neutralization will not result in the lowest amount of IPM.

In most cases, improper neutralization is the culprit. If not, then the next place to look is the driver stage that feeds the PA tube. As the modulation changes the loading of the driver into the grid of the PA, the phase of the driver output may be changing. Many times an adjustment of the PA grid tuning will center the tuning even though the grid meter says otherwise. In any case, when looking for the cause of IPM, remember that the modulating circuits of the transmitter are somehow influencing the phase of the carrier.

CORRECTING IPM

In order to correct IPM in a transmitter. a way is needed to view it so that the effects of different adjustments can be seen. There are several methods for displaying IPM, but there are none so graphic as the display of a spectrum analyzer. For the purpose of this paper, we will use a spectrum analyzer, a tone generator and a distortion analyzer for our test equipment set-up. In this way, the different sideband components can be seen along with the effects of each adjustment.

The first thing that has to be done is to modulate the transmitter with a pure sine wave and make a THD measurement with a distortion analyzer. The purpose of this is to get an idea of what the spectrum analyzer should look like when we hook it up to the transmitter. If the transmitter has an excessive amount of harmonic distortion, we won't be able to tell the difference between the normal distortion sidebands and the IPM sidebands. Figure 1 shows what an ideal transmitter would look like on a spectrum analyzer if it were modulated with a 1kHz tone at 100% modulation. Notice that there are just 3 components; one carrier and two sidebands, just like a textbook. This transmitter would measure 0% distortion, since no harmonic sidebands are present. There is also no IPM present, as IPM would also result in extra sidebands in the spectrum.

If, on the other hand, our ideal transmitter had an IPM problem, it might look like figure 2 on the spectrum analyzer. The distortion analyzer would still read 0%, but the sidebands on the spectrum analyzer would not agree. Since we know that the transmitter is not producing any distortion sidebands, we have to conclude that the sidebands we do see are a direct result of IPM.

So, the idea here is to start with a low harmonic distortion reading on the transmitter so that any IPM sidebands will be immediately recognizable. The most practical way to do this is to modulate the transmitter with a 1kHz tone to a modulation level that is as close to 100% as possible, without going over a 1% THD reading on the distortion analyzer. If you can keep the distortion under 1%, no distortion sideband will be greater than 40db below the 1kHz sidebands. When this is the case, any sidebands that are greater than this figure will be IPM, and they will be easy to spot.

Now that we have a distortion reading of 1% or less, let's hook up the spectrum analyzer and see how the transmitter output looks. Figure 3 is a spectrum analyzer picture of a typical 5 Kilowatt transmitter with a measured THD of .3%, taken before any optimization has been performed. It's worth noting here that this transmitter was carefully neutralized using a more traditional method. You can see that the spectrum in no way agrees with the distortion measurement. All sidebands <u>should</u> be more than 50db below the first order sidebands, but the second order sidebands are only 30db down. These extra sidebands are obviously IPM, invisible to the mod monitor, but present just the same.

We know what the spectrum <u>should</u> look like; let's see if we can make it look that way. The first thing to suspect is the neutralization. On this particular transmitter. an MW-5, the neutralization is adjustable from the front panel. This feature makes it very easy to optimize this adjustment with the transmitter operating. There are several models of transmitters out there that do not have a provision for adjusting the neutralization while the transmitter is on. This makes for a tedious "cut and try" process that can take forever. These same methods, however. can still be applied.

As we turn the neutralization control, we can see the IPM change. Figure 4 shows a dramatic decrease in IPM from figure 3. Notice how much closer the spectrum looks to the distortion reading of .3%. The setting of the neutralization control that produced this picture isn't that far off of the original adjustment. We're just homing in on an exact setting.

We appear to be pretty close. All of the sidebands are at least 50db below the first order sidebands. We seem to be in agreement with our distortion measurement. But, we're still not there yet. Figure 5 is an expanded look at the same spectrum, using a 2db/division resolution. A closer look at the second order and third order sidebands reveal that there is asymmetry around the carrier. We know from AM theory that pure AM creates <u>identical</u> sideband pairs above and below the carrier. Any asymmetry around the carrier can only be explained by one thing - IPM.

A very fine rocking of the neutralization control will reveal a point where the higher order sidebands appear low <u>and</u> symmetrical. This is the point of lowest IPM, seen in figure 6. In this particular transmitter, poor neutralization was the only source of IPM, but it is entirely possible that more than one source exists in a transmitter. If that's the case, then each source will have to be minimized, alternating back and forth until a symmetrical picture emerges that agrees with the distortion measurement. It's worth pointing out here that the PA neutralization will have to be adjusted in this manner each time the PA tube is replaced, since every tube has a different amount of interelectrode capacitance that has to be neutralized.

Usually the only other source of IPM can be found in the RF driver stage that feeds the PA tube grid. Any instability in this stage might cause it to phase modulate as its load, the PA grid, changes with modulation. Here is where you have to get pragmatic. Try adjusting the tuning, the loading, the drive, the neutralization, or anything associated with the stage that can be adjusted. Many times a slight adjustment of a control will reduce IPM significantly. Every transmitter is different, so there are no hard and fast rules here. Just remember to have enough grid current left when you're all done to modulate the positive peaks.

<u>HELPFUL HINTS</u>

A common problem that might crop up when trying to neutralize a transmitter is finding a tube that won't neutralize. Either the neutralizing trimmer cap is at the end of its range or the trimmer doesn't seem to have much effect on the IPM. This can be due to a neutralizing circuit that wasn't designed with enough adjustment range or a tube whose interelectrode capacitance is out of tolerance. This condition seems to show up more often with a rebuilt tube than a new one. I suspect that the reason for this is that after rebuilding, the interelectrode capacitance of the tube is not necessarily the same as it was when it was new. A good policy is to have a few different values of padder capacitors on hand for your transmitter in order to bring your neutralization citcuitry into range with any tube you might encounter.

Another problem that you might run into is a bad load for your transmitter. Although most antenna systems are fairly flat plus or minus 2kHz from the carrier it's still possible that the antenna system is causing an asymmetrical display on the spectrum analyzer. The best policy in this case is to do these proceedures into the station's dummy load instead of the antenna. If that makes a difference, then you know what your next project is. IPM caused by asymmetrical antenna systems is a subject beyond the scope of this paper.

ALTERNATIVE METHODS

Since the average radio station doesn't own a spectrum analyzer, it would seem that the proceedures outlined so far are of little use. Before we dismiss that statement as truth, let me make a point. First of all there is nothing more revealing than looking at your radio station with a spectrum analyzer. Everyone should do it at least once. It's an eye-opening experience. Secondly, you need not own a spectrum analyzer to use one. There are rental companies all over the country that specialize in the rental of electronic equipment to companies who couldn't justify such a purchase. There are perhaps several people in your area who would let you borrow a spectrum analyzer for a night; a college or university, a friend in the radio business or some other electronics industry. The point is that in order for the AM broadcast service to become a quality medium, we all have to start treating the service with a little more respect. That means using the proper tools for the job, instead of just trying to get by If you can possibly do it, get your hands on a spectrum analyzer.

If a spectrum analyzer is totally out of the question, there are some other ways of looking at IPM. One way is to use an oscilloscope. For this method, a sample of your carrier from your transmitter's oscillator is needed. This oscillator sample is connected to the external trigger input on the scope. Then, the RF sample from the transmitter is connected to the vertical input. Adjust the sweep time so that approximately 90 degrees of the RF waveform is visible on the screen, then take a look at the zero axis crossing of the waveform. Any side to side movement of this zero axis crossing represents phase modulation of the carrier. It will appear as a "smear", as opposed to a distinct line, and this smear can be measured in degrees with the oscilloscope. If the sweep time is adjusted so that 90 degrees of the RF waveform covers 9 vertical divisions on the graticule, then each division equals 10 degrees.

The other way of looking at IPM is with a modulation monitor for one of the AM Stereo systems. The AM Stereo modulation monitor for one of the two systems in use has a provision for monitoring L-R information, while the other one can measure incidental phase modulation. Either one can be used to actually hear with your ears the phase modulation of your transmitter. Although IPM is not exactly the same thing as L-R, any information that shows up in the L-R channel during monophonic operation is due to IPM, and a minimization program can be implemented.

A CASE FOR AM STEREO

In this paper, it has been shown that several undesirable effects can be caused by IPM in mono as well as stereo AM transmitters. These effects must be eliminated from the great majority of AM receivers if AM radio is to grow and emerge as a quality broadcasting medium. The only way to do this is to eliminate IPM and other quality bottlenecks from the great majority of AM radio stations. AM Stereo has been the catalyst in this move toward quality, and it remains the single overriding reason for a broadcast facility to improve its performance in these areas. In fact, the greatest benefit to come out of AM Stereo may very well be the improvement that it has on the quality level of AM radio, in general. This applies to the AM receivers as well as the transmitting plants.

In order for this move toward quality to continue, the great majority of AM stations must get behind the AM Stereo movement and improve their facilities so that the entire band can benefit. If AM Stereo operation becomes the rule rather than the exception, not only will the transmission facilities improve, but the need for higher quality AM Stereo receivers will also increase, and that can only serve to benefit the entire AM broadcasting system

Perhaps the largest single deterrent to AM Stereo conversion is not so much the cost, but the indecision of which of the two competing systems to go with. Although I'd like to, I can't make that decision for anyone but myself It's worth pointing out, however, that the issue here is quality. Adding AM Stereo to your transmitter is tantamount to adding "on purpose" phase modulation to your carrier as opposed to incidental phase modulation. Make sure that the phase modulation you choose does not compromise AM receivers in the manner outlined in this paper. The higher quality we hold for AM, the better chance AM has for success in the future.

CONCLUSION

Incidental phase modulation, or IPM, has been with the AM broadcaster for many years, causing problems of which most of us have been unaware. The advent of AM Stereo has brought the issue of IPM to the attention of the industry, and that, in itself, may be part of AM Stereo's greatest contribution - the improvement of the quality of AM. The elimination of harmful amounts of IPM from an AM transmitter is not difficult and many times is easily accomplished by better neutralization of the PA tube. The extra effort required to perform these simple steps is well worth the benefits to both the individual broadcaster and the entire AM broadcasting industry.

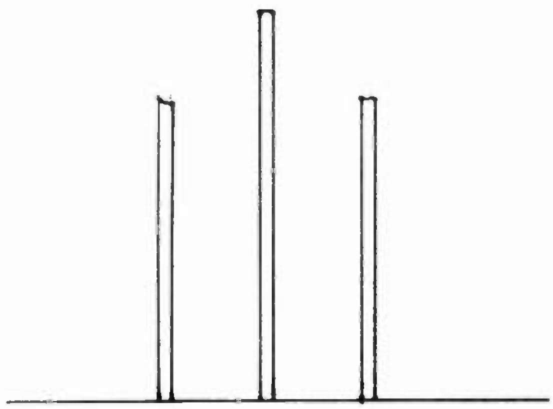


Figure 1 - The spectrum of an ideal transmitter. It has no harmonic sidebands and measures 0% THD.

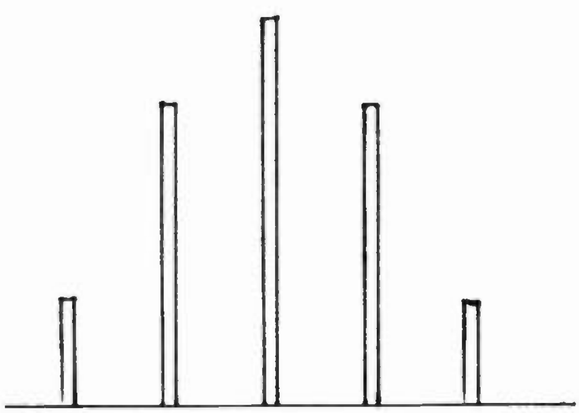


Figure 2 - The spectrum of the same ideal transmitter in figure 1, but with the addition of IPM.

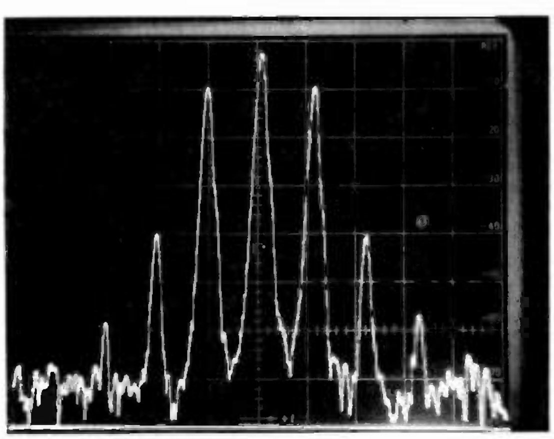


Figure 3 - Although this transmitter measured .3% THD, the second harmonic sidebands are only 30db below the fundamental. The extra sidebands are IPM.

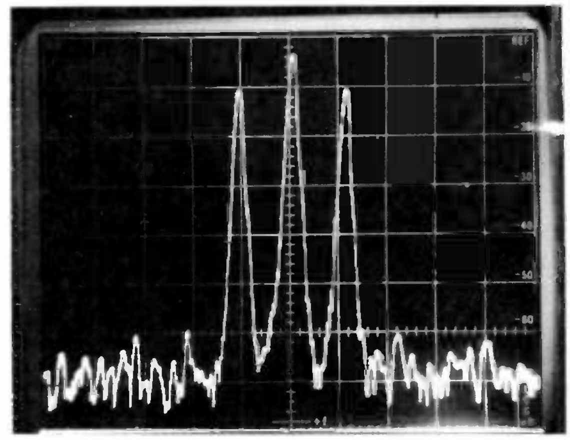


Figure 4 - This is the same transmitter as in figure 3, but after adjusting the neutralization for lowest IPM.

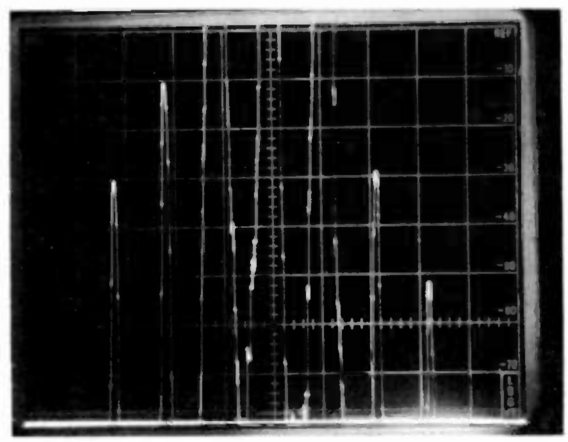


Figure 5 - The spectrum of figure 4 expanded to show the asymmetry of the second and third order sidebands.

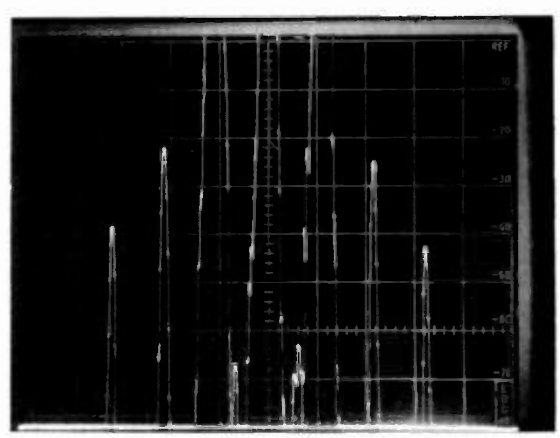


Figure 6 - Fine tuning of the neutralization brings the higher order sidebands into symmetry.

REQUIREMENTS FOR A NEW ENG/EFP TAPE FORMAT

Peter Smith, Director, Equipment and Technical Development Laboratory
National Broadcasting Companies, Inc.
New York, New York

Introduction

In recent months there has been commendable progress in the development of a digital recording standard. As a result, it is likely that 19mm digital video recorders will be introduced in the near future. Initially it is to be expected that because of their relatively high cost, these recorders will be aimed at high-end production where the benefits of digital recording are at their greatest. No doubt, in time, digital recorders will find applications in other areas of our business. However, all the components of a complete digital recording system, especially small sized portable units for ENG/EFP use will probably not be available for several years. In the interim period, there is a need for a high quality news gathering and field production system to complement these high-end digital machines.

Approximately one year ago, a task force of the major users of ENG/EFP equipment within NBC was set up to determine the criteria under which a new format should be selected. The task force includes representatives from NBC Network News, NBC Sports, and Owned and Operated stations and so represents a broad opinion which is somewhat representative of a wide range of users within our industry.

The results of this study is a list of recommendations and requirements which maintains the utility and low cost of existing equipment (U format) while providing desirable additional features to improve operational efficiency and to provide significantly better performance.

New ENG/EFP Format Requirements

The major requirements for a new format or system are listed below. While some simply preserve the features presently available, others require features which cannot be provided by existing equipment.

(1) Significantly Improved Video Performance
Even by today's professional C format standard, and especially in view of the pending introduction of digital recording, the video quality achieved with existing hardware is not good and in the future will look comparatively worse. Added to this, the steady improvement in the picture reproduction of TV receivers will only serve to highlight to our viewers the difference in quality between the news gathering and production formats.

Furthermore when editing takes place in the field before the story is fed back for transmission or when archived material is reused, the final pictures to air may commonly be 4th or 5th generation copies. In consequence, it is important that the improved video quality is maintained through at least 5 generations.

(2) Cassette Based with 60 Minute Capability

For a camera recorder implementation a cassette based system should have at least 15 minute record capability. However, for editing and program production, for the preparation and recording of feeds into the network from remote locations and for archiving of material a 60 minute capability is essential.

(3) Capable of Supporting a Complete ENG/EFP System

The format should allow for the implementation of a complete range of equipment including camera-recorder, field recorder, studio recorder and field edit package. The camera recorder should be small and lightweight without compromising any video or audience performance. The field recorder should be a compact unit which provides full color playback. The studio machine should provide all of the operational features currently available in C format machines including variable speed playback and full editing capability.

Like many other news operations, NBC Network News operation is called upon to cover events around the world. This involves shipping portable editing systems to what are often remote and inaccessible places. A typical systems contains two editing machines and a feed/spare machine together with the usual editing paraphernalia. Presently such a system with U format machines requires eleven cases to transport. A new ENG/EFP format should provide for a specially designed, reliable and easy to transport field edit package to alleviate the present transportation difficulities.

(4) At Least Three Channels of Audio

Last summer, NBC introduced Television programming in stereo. As of February 1986, we air 21 hours a week of stereo programming. We have 58 NBC stations serving 58 percent of television homes. By the end of 1986, more than 75 percent of U.S. televison homes will have NBC stereo TV transmitted locally. While two audio channels may accomodate on-air playback of our final product, for production including field production at least three channels of audio are essential.

(5) Systems Costs Comparable to Existing Equipment

We expect the System cost to be comparable to existing equipment. That is to say that we expect cost savings to occur from the ability to use single person crews, from reduction in transportation costs of a field edit package and from the ability to avoid interformat editing.

What we save in these areas can be applied to initial increased equipment and media costs. However, in common with many broadcasters we do not expect or intend to choose a new ENG format that is going to result in significantly higher operational costs.

(6) Available From More Than One Manufacturer

The system should be available from more than one manufacturer. This helps us in ensuring that there is always incentive for manufacturers to innovate and so make their products better and that there is price competition and some stability of supply.

(7) High Operational Reliability

Finally there is the somewhat obvious need for high operational reliability. Any new format will be thoroughly tested to ensure it meets the demands placed upon our usage of ENG equipment. In general, crews treat equipment with care. However, by the nature of news coverage, tape equipment must be robust, ruggedly constructed and be capable of operation in extreme environmental conditions.

Current Choices in ENG/EFP Formats

In recent years there have been a number of introductions of ENG/EFP equipment which provide alternatives to U format. To date, however, none of the new formats has provided advanced features such as a camera recorder implementation without removing some of the basic utility such as 60 minute recording capability. Furthermore, the improvements in video performance that have been made have concentrated on first generation and the specifications sheet. In reality, at the generations used for air, the video quality improvements are marginal.

Conclusion

A need exists for a high quality news gathering and field production system which meets the various requirements described. We believe that the technology is available to make such a system a reality. Its development can make a significant contribution to the effectiveness of television in providing clear, timely and informative news, sports, and special event coverage for all our viewers.

MAGNETIC MEDIA FOR DTTR

Arthur R. Moore and Michael P. Sharrock
3M
St. Paul, Minnesota

Previously presented at the 20th Annual SMPTE
Television Conference, February 7-8, 1986, in Chicago, Illinois.

A general discussion of the industry trends for magnetic media will be given with comments on new materials. The digital tape television tape recorder (DTTR) requires the use of today's advanced particulate tapes to satisfy the system needs. The DTTR 4:2:2 is designed to use 16 or 13 micron thick, 19mm wide tape packaged in cassettes. The system is capable of making 20 generations of copies, while retaining broadcast quality. Details of the testing will be summarized.

(Previously presented to the 20th Annual SMPTE Television Conference in Chicago, February 7-9, 1986.)

The SMPTE Digital Television Tape Recorder (DTTR) Committee has been in the process of developing an industry consensus for the tape format standard since mid-1983, with the formal work assignment of working group DTTR (V16.64). It is informative to look at the trends in the magnetic video tape industry relative to the requirements of the SMPTE proposed American National Working Standard V16.74 for the DTTR,

The SMPTE Digital Television Tape Recorder (DTTR) Committee has been in the process of developing an industry consensus for the tape format standard since mid-1983, with the formal work assignment of working group DTTR (V16.64). It is informative to look at the trends in the magnetic video tape industry relative to the requirements of the SMPTE proposed American National Working Standard V16.74 for the DTTR, Type D-1. This standard covers the principal tape properties and will become the proposed SMPTE 225 standard.

The magnetic recording industry is constantly changing and growing. It is an industry that has continued to grow by addressing new markets and by improving its technology in a large number of areas. The industry has generally addressed new markets with a large proportion of proven technology in order to minimize the risks. This step-by-step approach is particularly applicable to the various aspects of the magnetic tape for the DTTR.

One of the major issues that was considered is the choice of magnetic material for the tape.

Modern recording tapes utilize a large variety of particulate materials. The first to be commercially significant, gamma ferric oxide (-Fe_2O_3), was used to produce tapes in the late 1940's. This material has become the mainstay of today's audio and computer industries because of its desirable magnetic properties and its great chemical and physical stability. Gamma ferric oxide particles derive their useful magnetic properties (squareness and coercivity) primarily from their needle-like shape; thus, their behavior is very stable with respect to stress and temperature. They also possess great chemical stability. Acicular iron oxide particles are not only important in the their own right, but serve as the precursors for the cobalt-modified oxides and metallic particles. Both of these classes of particulate recording materials can have higher coercivities and are more suited to recording at higher densities, but are more expensive and in some respects less stable than pure iron oxides. The major challenge in producing iron oxides for recording is the control of particle shape, surface quality and size.

The relatively low coercivity values (usually 250-400 Oe) of the iron oxides limit their ability to meet the performance needs of high-density recording. The requirement for higher coercivity was first met in the 1960's with chromium dioxide (CrO_2) particles. Particles of CrO_2 have a high degree of perfection and uniformity of shape that aid in packing and orienting of the coated magnetic media.

Originally, chromium dioxide offered coercivities not very much above those of the iron oxides, and typical particle lengths were in excess of 0.5 um. These properties have been steadily improved to meet the needs of modern, high-density recording, and lengths of less than 0.1 um and coercivities above 1000 Oe have been reported. The most successful particles for application requiring coercivities in excess of 400 Oe are iron oxide to which cobalt has been added. Many of the practical benefits of the original oxides, relating to cost and chemical stability, are retained and coercivities from 400 to well above 1000 Oe are available. Current processes place the cobalt at or near the surface and achieve good stability with respect to temperature and stress. The resulting oxides are termed "surface-doped", "cobalt-adsorbed" or "epitaxial". The particles show uniaxial magnetic properties, each having a single preferred axis of magnetization like the iron oxide particles from which they are made.

It is from these two classes of particles oxides) that the experimental tape samples tested by the SMPTE DTTR committee have been made.

Other particles that could be utilized in the future are being developed. Metal particles are made with either pure iron or an alloy of iron with nickel and/or cobalt. The alloy composition and/or a controlled oxidation of the surface are used to reduce their strong tendency to oxidation. The binder and other components of the coating also play a protective role. Tapes made from these particles can have high coercivities and about twice the retentivity of tapes made from oxide particles.

Perpendicular recording is a future consideration, with barium ferrite as the best candidate for a suitable particulate medium. The potential benefits are a reduction of self-demagnetization and the retention of sharp transitions at high recording densities. Barium ferrite is stable chemically and thermally, and has particle sizes suitable for high-density recording (diameters of 0.1 um or smaller). The addition of cobalt and titanium has provided a means for controlling the coercivity.

Thin-film metallic media made by vapor coating or sputtering are being developed as alternatives to particulate coatings. These are promising with respect to electromagnetic performance, but they have aspects of durability and chemical stability that are still being resolved. They are therefore unsuitable for the basis of a standard at this time.

Of all the materials discussed, cobalt-modified oxides appear to be the only class that combines high coercivity, chemical stability and availability on a global basis at this time. The utilization of the various particulate materials is shown in Figure 1 along with their commercialization history.

The SMPTE committee, after much deliberation and experimentation, has based the DTTR format on advanced metal oxide particles. This 850-Oe class of materials is the upper edge of the advanced oxide media being developed for today's applications and is shown in Figure 2 with the typical coercivities used in various other recording systems as a function of the system introduction date. As recording materials have evolved, they have been used together with advances in electronics and head technology to generate various video formats. The tape program density (min/ft^2) of media is plotted vs. system introduction date in Figure 3. The SMPTE DTTR Standard should be available in the 1986 to 1987 time frame and will achieve 0.28 min/ft^2. The program density is a little higher than that for the one-inch type C or B analog recorder. The tape is packaged in a cassette and will be either 16 um or 13 um thick; hence the tape caliper is very similar to that of consumer video tape (Figure 4). (Typical type C tape is 26 um thick.) The width of the DTTR tape is 19 mm and is very close to that of the U-matic tapes, as shown in Figure 5. The mechanical handling of a 13-um tape that is 19 mm wide will require very gentle and yet positive tape handling systems. The track width in the DTTR system is 1.6 mils (40 um), which is a little narrower than that in the 2-hr VHS or Beta systems and about one-half of that in the U-matic system (Figure 6). The head-to-tape-velocity is considerably higher than in VHS or Beta and will be between that of a one-inch analog system (1000 ips) and that of the quadruplex system (1500 ips). The resulting minimum wavelength is shown in Figure 7 and is shorter than that in the VHS-Beta systems but longer than that in the 8-mm system. This wavelength is appropriate for the advanced oxide tape technology that is available.

The density trends of the recording industry can be summarized by looking at a plot of the linear, track and areal densities in Figure 8. The DTTR format track density is about midway between the extremes used in the VHS-Beta formats. This is a relatively aggressive track density, considering that a high degree of interchange is required. The linear density is slightly above that of the VHS-Beta systems but well within reach of the advanced oxide tapes.

The SMPTE working group on the DTTR System has received input from media suppliers and arrived at the DTTR D-1 tape specifications summarized in Figure 9.

Developmental tapes have been submitted to the SMPTE for testing by the major DTTR manufacturers. Testing on prototype recorders has proven the ability of the tapes to give adequate electromagnetic performance with acceptable error rates.

Three 13-um tapes were tested with 800 to 940 Oe coercivities and Br's of 1200 to 1300 G. The tapes recorded optimally at 0.9-um wavelength with 0.65 to 0.68 Ampere-Turn, giving 44 to 48 dB (rms/rms) ratios of output to amplifier noise (300-kHz bandwidth). The modulation noise 1 MHz from the carrier was down 36 to 41.7 dB (rms/rms). The error rate for one of these samples was approximately 0.7 bytes per 10^5 bytes.

Up to six 16-um tapes were tested with 740 to 940 Oe coercivities and Br's of 1150 to 1300 G The tapes recorded optimally at 0.9-um wavelength with 0.57 to 0.74 Ampere-Turn, giving 37 to 48 dB (rms/rms) ratios of output to amplifier noise (300-kHz bandwidth). The error rate was from 0.1 to 3.6 bytes per 10^5 bytes.

The error-rate plots in Figure 10 show the DTTR System requirements and the average data for the 13-um and 16-um tapes tested. The 16-um tapes are slightly better than the 13-um tapes in error rates on the early developmental samples. The data for a good 13-um tape are shown in Figure 11.

Initial runability data from the major manufacturers indicate that in repeated testing for 500 replays, the 16-um tapes experience no serious problems in threading, multiple pass and rewind/fast forward (@ 12 m/sec tape speed). The 13-um tapes showed behavior very similar to that of the 16-um tapes, except that slight damage occurred during threading on some early prototype recorders. A signal decay of 1 to 2 dB after 500 replays was experienced on some of the tape samples.

The activities of the SMPTE have shown that it is feasible to make oxide particulate tape to meet the DTTR requirements. As the DTTR recorders become available, the additional requirements of interchange will be determined and the long-term durability in field situations can be assessed.

DEMYSTIFYING TV MTS SPECIFICATIONS

James R. (Rick) Carpenter, Manager of Audio Engineering
Broadcast Electronics, Inc.
Quincy, Illinois

ABSTRACT

The adoption of the Zenith/dbx system for Multichannel Television Sound (MTS) in December 1983 paved the way for the commercial transmission of stereo audio and second language programming in the U.S. The MTS nomenclature is a mixture of borrowed FM and some new MTS specific terminology. This paper will explore the broadcast equipment specifications that have the most significant impact on MTS system performance and will give brief explanations of the new MTS terminology.

The received performance of the TV MTS signal is influenced by every link in the transmission chain from original program source to the viewers living room. Figure 1 shows a typical origination to end user block diagram. Every block in this diagram, including the audio source equipment itself, has the potential to significantly degrade the performance of the received TV audio. Since the broadcaster has no control over consumer equipment performance, but should note that receiver performance is rapidly improving, emphasis will be on the following equipment performance topics:

THE AUDIO CHAIN
STEREO GENERATOR
COMPOSITE STL
AURAL EXCITER

THE AUDIO CHAIN

The audio chain includes all the equipment (DA's, mixers, switchers, processors, discrete STL, etc), wiring, and connections between the audio source and the TV MTS generator. The most important specifications for equipment in the audio chain are frequency response, signal-to-noise ratio, distortion, separation, headroom and channel-to-channel tracking.

Frequency Response

Frequency response is actually the deviation from a constant amplitude across a particular span of frequencies. Researchers have found that under some conditions variations as small as ±.2 dB can be discerned, especially in the ears' critical 100Hz to 10,000Hz range. Since the ear is less sensitive to response errors at the extremes, an audio system specification of ±.5 dB 50Hz to 15,000Hz and ±.25 dB 100Hz to 10,000Hz is adequate to deliver excellent audio. A total system specification of ±1 dB 50Hz to 15,000Hz including the stereo encoder and RF chain should be a system performance target. Fortunately, most solid-state mixers, distribution amps, etc. have frequency response specifications much better than those given above. Unfortunately, much of the source material (VTR, Network, etc.) will not be quite that good unless noise reduction or digital encoding becomes commonplace.

Signal-to-Noise Ratio (SNR)

Signal-to-noise ratio (SNR) is the amplitude difference in dB between a "standard level" audio signal and the systems residual noise and hum. The SNR of any equipment in the audio chain should be greater than 65 dB (unweighted). This will ensure that the source SNR or the transmitter FM SNR will be the limiting factor in the system noise contribution. The performance target for the entire system should be greater than 58 dB.

Total Harmonic Distortion (THD)

Total Harmonic Distortion (THD) is the creation by a nonlinear device of spurious signals harmonically related to the audio waveform. Research has shown that although THD levels greater than 1% are easily detectable during sinewave testing, people will tolerate somewhat higher levels of THD on musical material. There is at least one audio "enhancer" that adds even harmonic distortion to programming to give a "richer" sound. THD in any part of the audio chain should be less than .25% from 50Hz to 15,000Hz and the whole audio chain should be less than .5% THD from 50Hz to 15,000Hz.

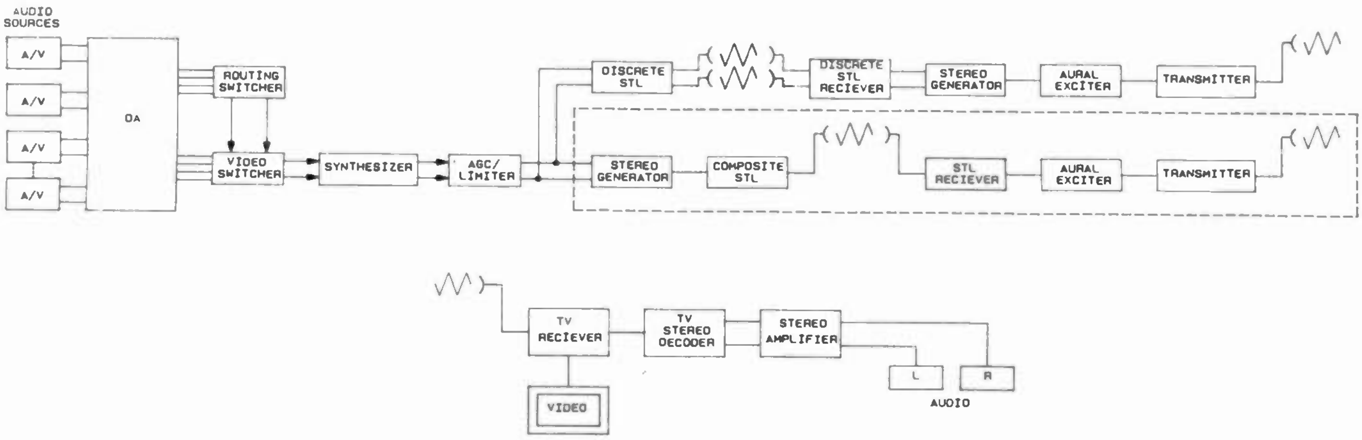


FIGURE 1. TYPICAL TV MTS BLOCK DIAGRAM

A performance target for the entire system (RF included) should be 1% THD from 50Hz to 15,000Hz.

Although harmonics of frequencies greater than 7,500Hz will be attenuated by the 15,000Hz low-pass filters in the TV MTS generator, presence of these harmonics in the audio stages before the generator may raise the level of IMD products in the audio signal. The THD test is sensitive to the SNR of the device under test. If the device has a SNR of 60 dB, the distortion analyzer best distortion reading will be greater than .1% (60dB = .001 = .1%). An audio spectrum analyzer will allow true THD readings because it will disregard the broadband noise floor of the tested device.

Intermodulation Distortion (IMD)

Intermodulation distortion (IMD) is the creation by a non-linear device of spurious signals not harmonically related to the audio waveform. These distortion components are sum and difference (beat notes) mixing products that research has shown are more objectionable to listeners than even harmonic distortion products. The SMPTE IMD (60Hz/7000Hz mixed 4:1 amplitude ratio) should be less than .25% for each part of the audio chain and less than .5% for the whole audio chain. The IMD measurement is not greatly affected by the noise floor of the tested device. A performance target for the entire system (including RF) should be 1% IMD.

Separation

Separation is a specialized definition for signal crosstalk between the left and right channels of a stereo system. The minimum amount of stereo separation needed to define a stable stereo image has been found to be greater than 17 dB at the listeners position. Stereo separation is very likely to be badly degraded at every link in the transmission chain, requiring much better than the nominal 17 dB to be necessary for the audio chain. A separation requirement of greater than 50 dB from 50Hz to 15,000Hz should be minimum for the each piece of equipment in the audio chain. The whole audio system should have separation greater than 40 dB from 400Hz to 15,000HZ, 35 dB from 50Hz to 400Hz. A performance target for the entire system (including RF) should be 30 dB from 100Hz to 12,000Hz, 20 dB at 50Hz and 15,000Hz.

Headroom

Headroom is the difference (in dB) between the normal operating level and the maximum output level of the device being tested. In equipment monitored by VU type meters the equipment should have 15 db of headroom above "Ø VU" or normal operating level to allow for musical peaks that the averaging meter ballistics ignore. When the audio system operates without enough headroom, the time average of the program distortion becomes high enough to be audible.

Channel-to-Channel Amplitude and Phase Tracking

Channel to channel amplitude and phase tracking is the match between the amplitude versus frequency and phase versus frequency responses of the stereo channels (L,R). Poor channel-to-channel tracking will result in a wandering or off-center stereo image and monaural summing errors that can be very obvious and distracting to viewers. The most obvious error is completely out of phase condition (L=-R) which gives no mono signal (L+R=0). The amplitude and phase match of the L and R channels should be good enough that with both channels driven with the same amplitude signal, but one channel inverted (L=-R) and summed electrically the residual should be 40 dB below the equivalent L+R level from 50Hz to 15,000 Hz. The chart in Figure 2 gives the amplitude and phase requirements to achieve various crosstalk performances.

STEREO GENERATORS

In order to discuss TV stereo generator specifications, it is necessary to briefly review the BTSC system standards. The TV Stereo system is a modification of the standard FM Stereo system. The main differences are:

1. 25,000Hz main channel (L+R) deviation.
2. 50,000Hz subchannel (L-R) deviation 2x (6 dB) greater than the main channel FM is 75,000Hz deviation for main or subchannel.
3. Noise reduction in the subchannel (L-R).
4. Pilot frequency equal to fH (15,734Hz).

Compatibility with existing monophonic receivers was the reason behind point 1 above. The reason for points 2 and 3 above is that without noise reduction, the received TV Stereo SNR would be less than 50 dB in outlying areas. With the dbx compandor in the stereo subchannel, and the 6 dB increase in level, the L and R SNR should be dependent only on the main channel SNR, which has been better than 63 dB in system tests. The use of fH as the pilot should result in less buzz beat interference.

Figure 3 shows the FM versus TV Stereo baseband spectrum. Figure 4 shows the aural carrier modulation standards for the TV Stereo system. Figure 5 is a block diagram of a typical TV Stereo generator.

Some of the specifications for TV Stereo generators are no different than those for other audio equipment, except for the fact that they cannot be verified without use of a decoder and the decoder contribution to performance must be recognized.

There are at least two operation modes for TV Stereo generators; the normal (noise reduction in), operational mode and a test mode called "75us equivalent mode".

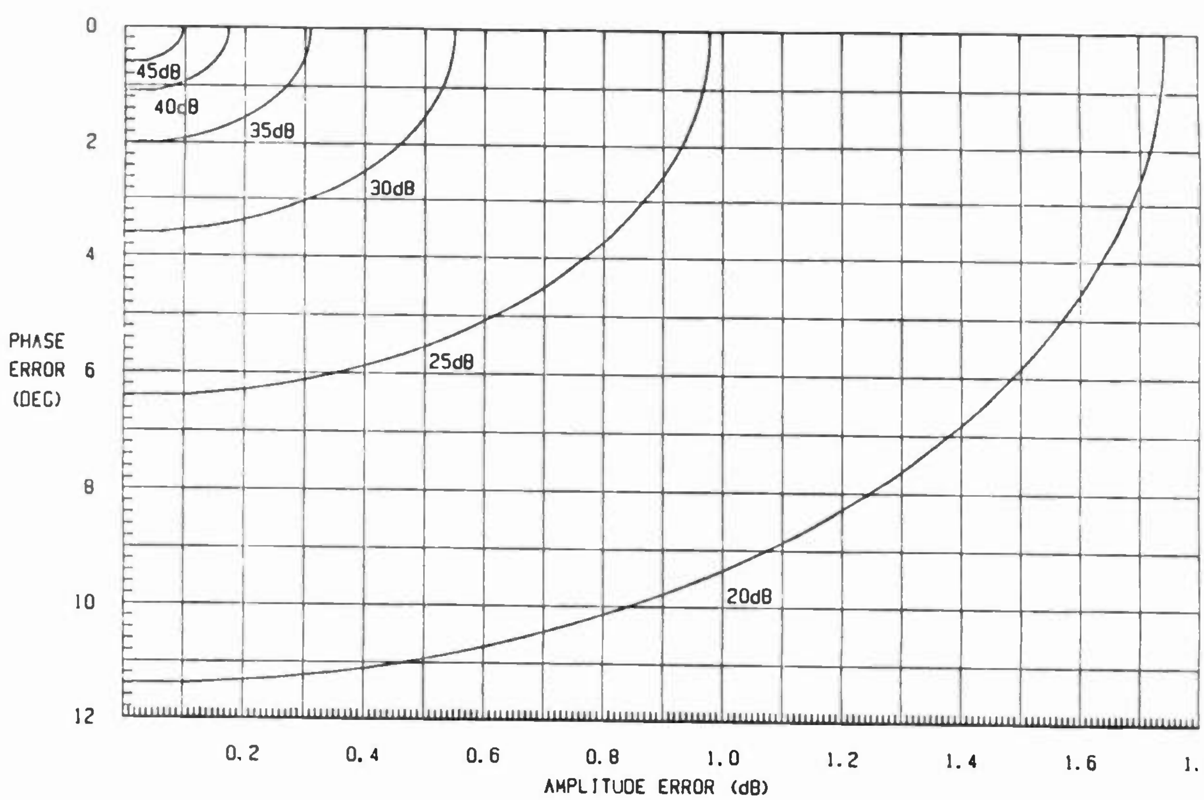


FIGURE 2. CROSSTALK AS A FUNCTION OF AMPLITUDE AND PHASE

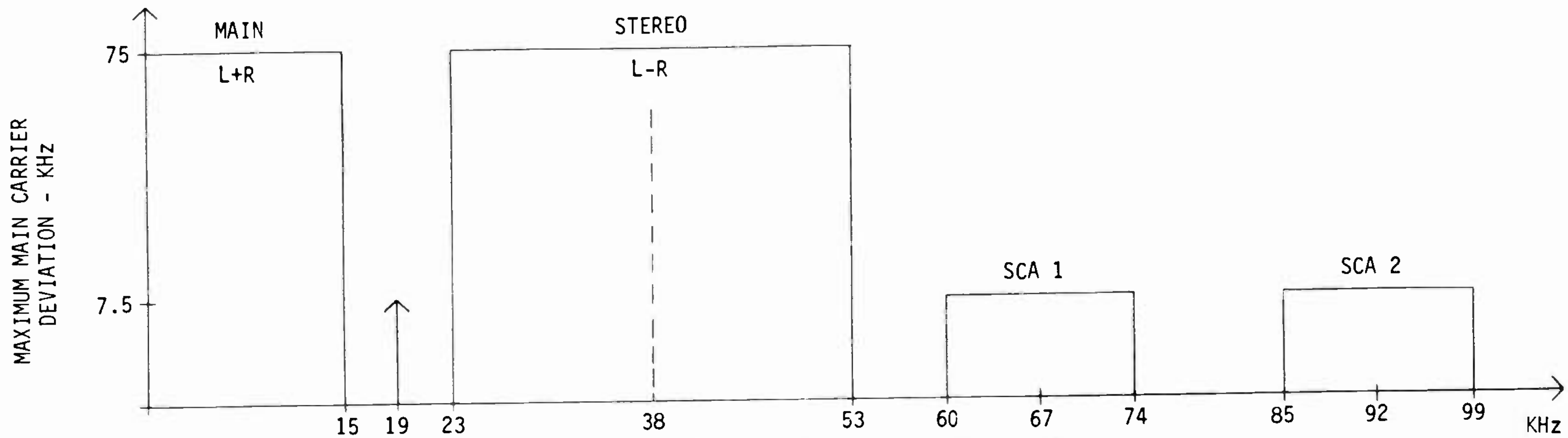


FIGURE 3A. BASE BAND FREQUENCY ALLOCATIONS FOR FM

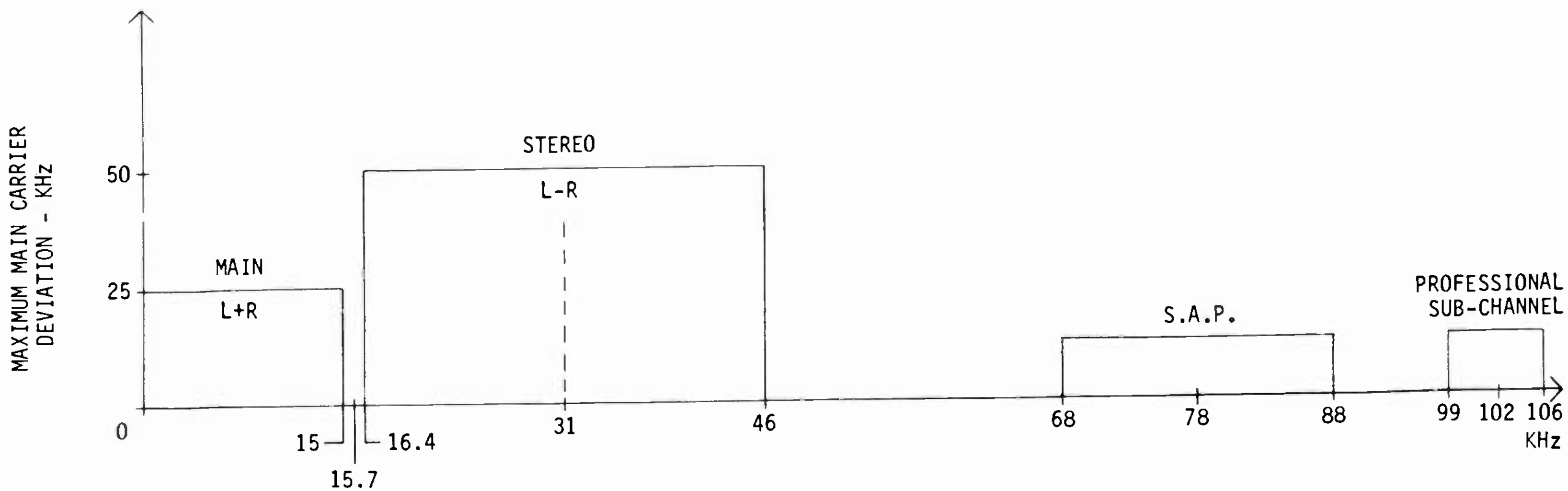


FIGURE 3B. BASE BAND FREQUENCY ALLOCATIONS OF BTSC TV STEREO SYSTEM; f_H (15,734.26 Hz)

Service or Signal	Modulating Signal	Modulating Frequency Range kHz	Audio Processing or Pre-Emphasis	Subcarrier Frequency *	Subcarrier Modulation Type	Subcarrier Deviation kHz	Aural Carrier Peak Deviation kHz
Monophonic	L + R	.05 - 15	75 μs				25 †
Pilot				f_H			5
Stereophonic	L - R	.05 - 15	BTSC Compression	$2f_H$	AM-DSB SC		50 †
Second Program		.05 - 10	BTSC Compression	$5f_H$	FM	10	15
Professional Channel	Voice or Data	.3 - 3.4 0 - 1.5	150 μs 0	$6\frac{1}{2}f_H$	FM FSK	3	3
						TOTAL	73

* f_H = 15.734 kHz

† Sum does not exceed 50 kHz

FIGURE 4. AURAL CARRIER MODULATION STANDARD

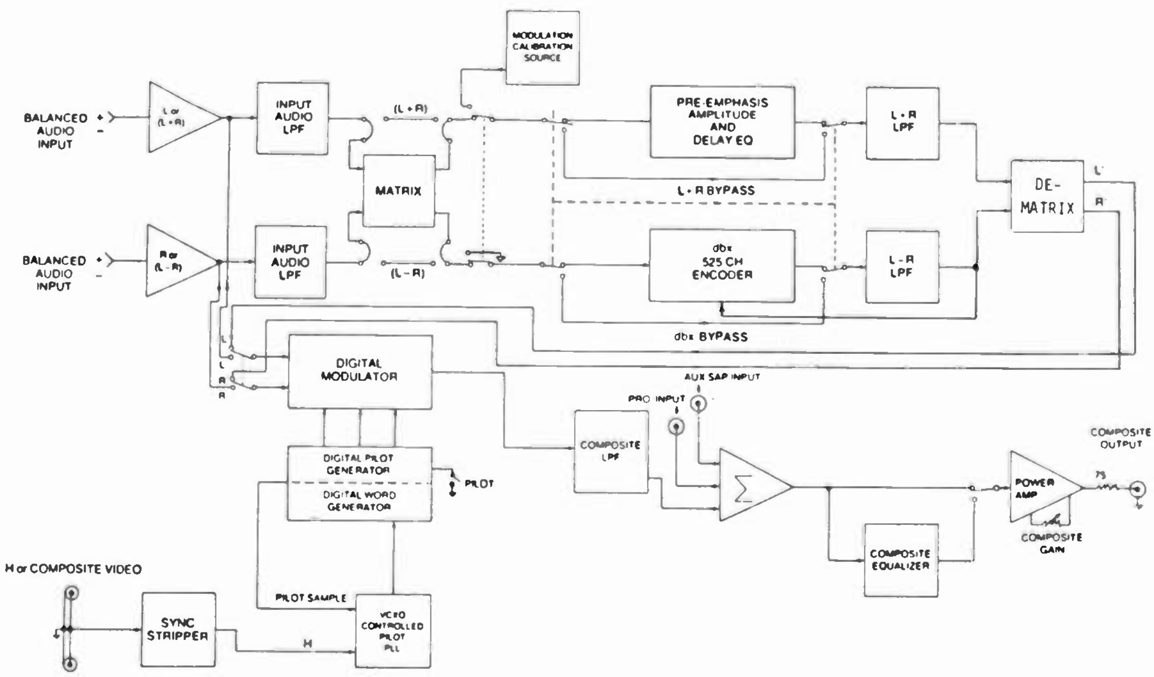


FIGURE 5. TV MTS GENERATOR BLOCK DIAGRAM

In the 75us equivalent mode, the dbx noise reduction system in L-R is replaced with a 75us pre-emphasis network identical to that in L+R. This step was taken to allow noise, distortion and separation measurements to be made without the level dependent degradation caused by the noise reduction. There is a disagreement about inclusion of the difficult subchannel filters in the 75us equivalent mode. Performance tests made without the subchannel filters in 75us equivalent mode provide better frequency response and separation measurements than those with filters in the system.

Specifications reviewed for TV Stereo generators include audio filtering, frequency response, separation, crosstalk, spurious suppression and deviation calibration.

The Subchannel Filters

The subchannel filters serve to limit the dbx control line bandwidth and to control the out of band energy created by the noise reduction card. When there is no audio input to the dbx circuitry, the spectral compressor gain is at maximum, creating a high level parabolic noise spectrum which needs to be bandlimited to audio frequencies to prevent spectrum spillover. Since the pilot is separated from the subchannel by only 734Hz, the filter slope needs to be very sharp to provide pilot protection with flat response to 15000Hz.

Any out of band information on the dbx control line (such as fH) after the subchannel filter will cause the dbx circuitry to mis-encode, causing degradation of received separation and frequency response when decoded. In order to ensure stereo separation greater than 40 dB, the subchannel filters need to be matched within .08 dB amplitude difference and 1 degree phase difference. For good overall frequency response the filters response should be better than ±.2 dB 50Hz to 15,000Hz.

The Stereo generator frequency response should be better than ±1 dB 50Hz to 15,000HZ (with noise reduction) and ±.5 dB without noise reduction, to help meet the total system response goals.

Separation

The separation specification of a stereo generator can be measured in three ways. The generator should be better than the OST-60 numbers given below.

Baseband (FM) generator
(no audio filters included):
    50 dB minimum 50Hz to 15,000Hz.

Noise reduction bypassed
(all audio filters included):
    40 dB minimum 50Hz to 14,000Hz.

Full system BTSC mode
(all filters and noise reduction included):
    30 dB minimum 100Hz to 8,000Hz decreasing to 30 dB at 14,000Hz, 26 dB minimum at 50Hz.

Linear Crosstalk

Linear Crosstalk is leakage from L+R to L-R or L-R to L+R caused by amplitude and phase matching of L and R channels which will result in a wandering or off-center stereo image and monaural summing errors that can be very obvious and distracting to viewers. The Stereo generator linear crosstalk should be better than 40 dB below 100% with all filters in circuit.

Non-linear Crosstalk

Non-linear crosstalk is leakage from L+R to L-R or L-R to L+R caused by distortion products in L+R or L-R. The distortion products generated in the L-R channel cause interference in the SAP or PRO spectrum. The generator specification should be better than 70 dB below 100%.

Spurious Suppression

Spurs are caused by nonlinearities in the AM-DSB modulation of L-R. These unwanted distortion products can cause noise and whistles in the SAP and PRO channels, especially since the SAP is 10.5 dB below L-R and the PRO is 20 dB below L-R. The generator spurious suppression should be greater than 75 dB below 100% L-R.

Deviation Calibration

Unlike non-companded FM stereo, the BTSC system requires precise adjustment of aural deviation calibration for optimum received stereo separation and frequency response. Like some tape noise reduction systems, the encoder to decoder levels must be carefully matched for good system performance. For example, an aural deviation error of 1 dB will degrade separation from "perfect" to less than 20 dB (Figure 6). The stereo generator should incorporate a deviation calibration system that allows the aural deviation to be quickly and easily set and checked with an accuracy of better than 1%.

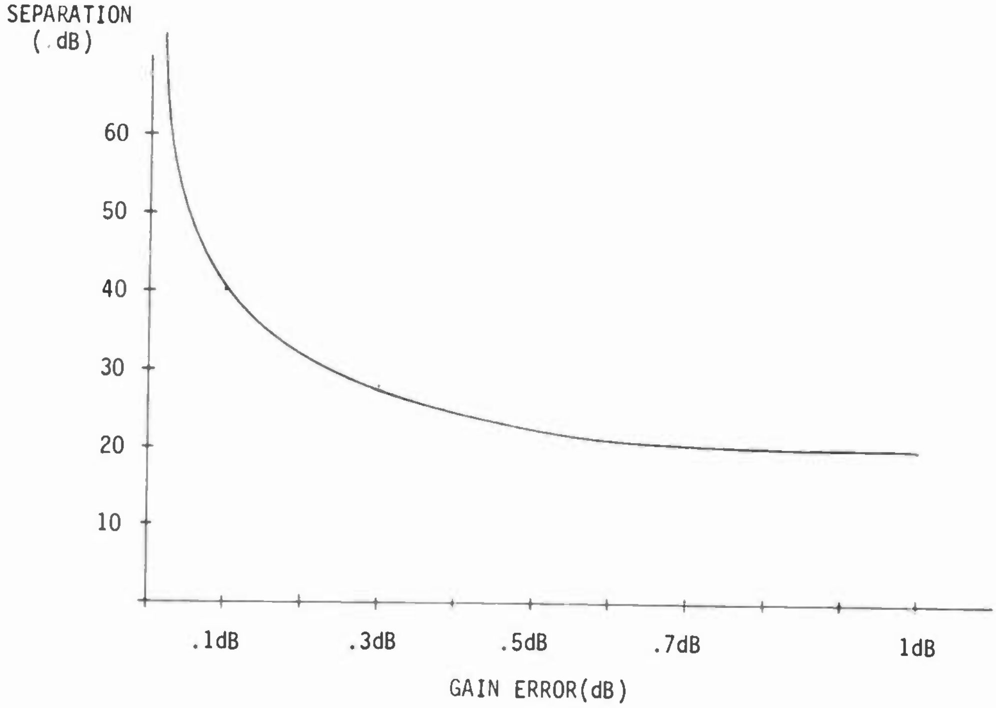


FIGURE 6. STEREO SEPARATION VS COMPOSITE GAIN ERROR

COMPOSITE STL

Frequency Response

In order to maintain a system separation greater than 40 dB, the composite amplitude response must be within ±.17 dB and the composite phase response must be less than ±1 degree from linear phase over the band from 50Hz to 47,000Hz. If a SAP or PRO is to be added, the composite amplitude and phase response must be flat (±1 dB, ±10 degrees) to 120,000Hz to prevent crosstalk.

SNR

The FM signal to noise ratio of the STL should be better than 65 dB unweighted with 75us de-emphasis.

Distortion

The aural composite STL should have distortion better than .1%. Any distortion of the baseband signal caused by the STL will have secondary effects of the stereo, SAP and PRO crosstalk, which is quite noticeable at the receiver with rather small amounts of distortion added to the baseband.

Amplitude Stability

The encoded TV Stereo composite signal is highly sensitive to gain variations in the composite path. As shown in Figure 6, a gain error of less than 10% (1dB) will reduce the system separation to less than 20 dB. This is assuming that the separation was perfect before the gain error was introduced. For good separation the composite path should have a maximum gain drift of ±.2 dB over time and temperature. The best composite link is properly terminated coaxial cable.

AURAL EXCITER

Frequency Response

In order to maintain a system separation greater than 40 dB, the composite amplitude response must be within ±.08 dB and the composite phase response must be less than ±1 degree from linear phase over the band from 50Hz to 47,000Hz and over an aural carrier deviation of 50,000Hz. If a SAP or PRO is to be added, the composite amplitude and phase response must be flat (±1 dB, ±10 degrees) to 120,000Hz to prevent crosstalk.

SNR

The FM signal to noise ratio of the aural exciter should be better than 65 dB unweighted with 75us de-emphasis.

Distortion

The aural FM modulator should have distortion better than .1%. Any distortion of the baseband signal caused by the modulated oscillator will have secondary effects of the stereo, SAP and PRO crosstalk, which is quite noticeable at the receiver with rather small amounts of distortion added to the baseband. For example, an increase of baseband harmonic distortion from .05% to 1.0% will increase crosstalk into the SAP as much as 26 dB.

Amplitude Stability

The encoded TV Stereo composite signal is highly sensitive to gain variations in the composite path. As shown in Figure 6, a gain error of less than 10% (1dB) will reduce the system separation to less than 20 dB. This is assuming that the separation was perfect before the gain error was introduced. For good separation the aural exciter should have a maximum gain drift of ±.2 dB over time and temperature.

The explanations provided above provide a starting point for understanding the complex and difficult process of delivering quality TV Stereo sound.

REFERENCES

1. Buecklein, R., "The Audibility of Frequency Response Irregularities", (Journal of the Audio Engineering Society) pp. 126-131 (Vol. 29 #3-1981 March).

2. Plenge, G.H., Jakubowski, H., and Schoene, P., "Which Bandwidth is Necessary for Optimal Sound Transmission?", presented at the 62nd Convention of the Audio Engineering Society, Brussels, 1979 March 13-16.

3. Snow, W.B., "Audible Frequency Ranges of Music, Speech and Noise", (Journal Acoustical Society of America) pp. 155-166 (Vol. 3 - 1931).

4. Eilers, C., "The Zenith Multichannel TV Sound System," Proceedings of 38th NAB Engineering Conference, 1984.

5. Federal Communications Commission, "Multichannel Television Sound Transmission and Audio Processing Requirements for the BTSC System," OST Bulletin No. 60.

6. Electronic Industries Association, "Multichannel Television Sound - BTSC System Recommended Practices," EIA Television Systems Bulletin No. 5, July 1985.

7. Mendenhall, G., "Testing Television Transmission Systems for Multichannel Sound Compatibility," proceedings of 39th NAB Engineering Conference, 1985.

MAINTAINING MONO COMPATIBILITY WITH STEREO TV SOUND

Randy Hoffner, Staff Engineer-Technical Development
National Broadcasting Company, Inc.
New York, New York

Television broadcasting of high-quality stereophonic sound at the local station and network level places stringent demands upon production, videotape, and distribution equipment and personnel. I will examine how these three areas may contribute to the success or failure of the stereo broadcasting effort; and how the NBC Television Network overcame obstacles to stereo television network distribution.

One of the most critical tasks facing anyone involved in the production, recording, distribution, or broadcasting of stereo sound for television is that of maintaining a compatible and accurate monophonic signal. At this point in stereo television's development, it is obvious that mono receivers constitute the bulk of sets in use, a condition that will prevail for quite some time. We are now in the third decade of stereo FM broadcasting, and there are still a great many mono FM radios in use. It is safe to say that there will always be some mono television receivers in the field, and therefore consideration of the monophonic audio signal will always be important in television broadcasting.

Degradation of the mono signal may occur at any point in the television production, distribution, and broadcasting process from the microphones used to capture the sound initially to the transmitter itself.

In a situation where the stereo soundtrack of a television program was simulcast on an FM radio station, separate mono and stereo tracks could be employed, and the mix optimized for either stereo or mono without a pressing need to pay attention to compatibility. However, with BTSC stereo the mono signal transmitted is necessarily the sum of the left and right stereo channels, and this is the root of potential mono compatiblity problems. The summation of left and right stereo channels is not necessarily an accurate mono signal unless special precautions are taken.

MICROPHONES

The preservation of mono compatibility starts with the placement of stereo microphones. Assuming that a stereo microphone technique is being used, as opposed to creating a stereo effect by the process of pan-potting monophonic signals, the placement of stereo microphone pairs may be done in either a spaced or a coincident manner.

Spaced placement involves placing two or more microphones at a distance from one another, the distance varying from a few inches to many feet. This separation produces microphone outputs with differences in both amplitude and phase, because the physical distance between microphones permits sound from the same source to arrive at each microphone at a different time. These phase differences can cause serious mono compatibility problems. Consider the hypothetical setup of Figure 1(a), in which two microphones are spaced such that a sound source is one meter (D_1) from the left microphone and two meters (D_2) from the right microphone. A sound leaving the source will arrive at the right microphone $(D_2-D_1)/c$ seconds later than it arrives at the left microphone, where c is the speed of sound in air (344 m/sec). Plugging in the values yields 1/344 or about 3 milliseconds difference in arrival time. At certain frequencies this delay will result in outputs which are totally in-phase and thereby fully reinforce each other while at other frequencies the outputs will be totally out-of-phase and thereby cancel each other. The lowest frequency at which cancellation will occur is that frequency at which D_2-D_1 equals one-half wavelength: $f= 0.5c\ (D_2-D_1) = 172$ Hertz. Signal reinforcements will take place at integral multiples: 2f, 3f, 4f, etc., while cancellations will take place at:

$$\frac{f}{2}, \frac{3f}{2}, \frac{5f}{2}, \text{etc.}$$

The frequency interval between successive peaks and dips is a constant 172 Hertz. The peak-to-dip ratio depends upon the relative amplitude of the two signals, being greatest (9.5 dB) when these amplitudes are equal. When plotted on a logarithmic frequency basis, as in figure 1 (b), the dips and peaks cluster together with rising frequency, producing a very dense pattern of peaks and dips in the higher frequency region. Because this plot resembles the teeth of a comb, this phenomemon is called comb-filtering. Comb-filtering occurs anytime a signal is recombined with itself through a delayed path. Thus comb-filtering will occur in any spaced multi-miking arrangement, and even with only one microphone if reflections as well as direct sounds are permitted to reach it. The comb-filtering effect with spaced stereo microphones will result in a point sound source only sounding natural in mono if it is very near one microphone or midway between the two.

Coincident (or X-Y) microphone technique involves the placement of two stereo microphones so that they are clustered together and thereby occupy virtually the same physical space. An example of a coincident technique is the Blumlein technique shown in Figure 2. The coincident technique not only provides a very accurate stereo image when reproduced, but it also eliminates time-of-arrival differences between the two microphones ensuring an accurate mono sum signal free of comb-filtering effects. The stereo effect is produced solely by amplitude differences between the two microphones.

A variation on the coincident technique is the middle-side or M-S technique shown in Figure 3. The M-S setup is a cardioid microphone (M) pointed at the center of the sound field, and a figure-8 microphone (S), oriented at right angles to the M-mike's lobe direction. The M-Mike provides the mono signal, while the S-mike provides difference information which is added to and subtracted from the M-signal to yield the left and right channels. This is a sum-and-difference technique, and produces perfect mono compatibility because the mono signal is produced only by the M-microphone. An interesting feature of the M-S technique is that the width of the stereo image may be adjusted by varying the amount of S-signal introduced to the dematrix device.

A major virtue of any coincident miking technique is the complete mono compatibility of the summed left and right signals that results from the absence of time-of-arrival differences between the microphones.

VIDEOTAPE

The next point in the television production and transmission process where mono compatibility may be impaired is the videotape area. A very large percentage of both network and local television programming is ultimately stored on and replayed from videotape, which inherently harbors potential for compromise of the mono sum signal. Stereo not only requires two audio channels, it requires that these channels be identical in their electrical characteristics as well. To preserve the integrity of both the stereo and the mono sum signals frequency response, phasing, and group delay characteristics for the two audio channels must be matched. Differences in frequency and phase response, such as unmatched equalization settings between channels, will cause errors in the mono sum signal stemming from improper balance of left and right channel components resulting from differing frequency response in each channel, and mono sum cancellations produced by interchannel group delay differences. Record and playback equalization networks consist of adjustable capacitive and/or inductive circuits, and adjustment of reactance necessarily changes the group delay characteristics of the circuit. If the left and right channels are adjusted differently from each other, the result will be differences in phase shift at certain frequencies, as well as differences in amplitude response.

Interchannel amplitude and phase errors may be present across the entire audio spectrum or they may be frequency-selective, but in either case the mono sum signal will suffer. The main point to be made here is that scrupulous attention must be paid to proper setup and maintenance of the audio section of a videotape machine used for stereo recording or playback to assure that amplitude, frequency, and phase response of both audio channels are both properly and identically adjusted.

The alignment of the audio head is another potential problem area for mono compatiblity. Figure 4 illustrates the effect head azimuth has on the mono sum. In (a) the pole pieces of a playback head are perpindicular to the audio tracks they are playing, which is the desired situation. The correlated waveforms being played back will reinforce each other when the channels are summed. In (b) we see a head whose azimuth is tilted with respect to the correlated waveforms to be played back. The waveforms are relatively low in frequency, and the top channel leads the bottom channel by a small portion of a cycle. This condition will result in a summed signal of lower amplitude than would be obtained if the azimuth were correct, but at this frequency the loss is not so serious because the phase difference between channels is only a few degrees. In (c) waveforms of a higher frequency are played using a head more tilted from the perpindicular. In this case the top waveform will be leading the bottom waveform by almost 180 degrees. The result is that when one waveform is at a peak, the other is at a trough, and they will almost entirely cancel each other, resulting in their virtual disappearance from the mono sum signal.
Figure 5 is a plot of mono sum power loss with varying degrees of phase shift between stereo channels. It may be seen that phase errors of over 50 degrees produce significant (more than one dB) mono sum cancellation.

The audio head azimuth problem is a significant one for videotape machines because many machines in use today have audio heads that are either difficult or impossible to adjust in azimuth. Increasing attention is being afforded this problem by manufacturers of videotape machines, particularly one-inch machines, in light of the rapidly expanding use of these machines for stereo audio.

DISTRIBUTION

When the NBC Television Network began planning to broadcast stereo sound, it was recognized that certain programs would be transmitted in stereo, while the balance of programming would be in mono. This situation would continue for quite some time, with progressively more stereo programming being added. But for a long time to come, there would be a mix of mono and stereo programs, mono and stereo commercials, and a general hodge-podge of mono and stereo elements, in no particular order. Therefore, complete compatibility must exist between mono and stereo, requiring no switching or other intervention at the affiliate site to accomodate the type of audio being transmitted. The mono affiliate must receive a continuous mono signal at the proper level, whether that signal originates as a monophonic program or is the sum of the left and right channels of a stereo program. The most practical situation for a stereo affiliate is to continuously receive two channels of audio regardless of whether they are identical (mono) or contain differences in amplitude and phase (stereo). This permits the stereo affiliate to continuously feed two channels of audio into the station's stereo generator, without worrying about whether what is coming in is stereo or mono.

If we have a nominal stereo signal, the content of the left and right channels may range from absolute non-correlation between signals in the two channels (fortunately for the mono sum, we will infrequently encounter this in practice), to complete correlation between left and right channels (mono).

The typical stereo television audio signal will fall somewhere between these two extremes, and will in fact generally contain a significant amount of correlation, resulting in a pleasing mono sum.

If there is a polarity reversal between left and right channels along the way, the result will be a 180 degree phase error between the two channels. This will produce virtually complete cancellation of any mono material, and thus its disappearance from the mono sum.

The decision was made to distribute discrete left and right channel stereo throughout the Network system. This leads to the requirement that two-channel audio be delivered to the affiliate at all times, either stereo or two-channel mono. The stereo affiliate may then pass these two channels to the station stereo generator, without regard to whether stereo or mono audio is being sent. The mono affiliate is required to sum the left and right channels before feeding the audio to the mono transmitter. In this way, the mono signal transmitted by the mono affiliate, and the mono signal transmitted by the stereo affiliate, will contain a proper 1:1 mix of left and right channels in the case of stereo programming, and the closest approximation to level parity between stereo and mono programming will be achieved. As previously stated, nominal stereo programming may range from absolute non-correlation between left and right channels, to complete correlation between channels. Referring to Figure 6, assuming equal-amplitude left and right channel signals, for a signal with 100% correlation between left and right channels (mono) summing the two channels produces an output voltage double, or 6dB higher than that of either input channel. For a situation where there is no correlation between channels the sum level is 3 dB higher than that of either input channel. This makes a worst-case difference of 3 dB between stereo audio and mono audio. Fortunately, in television a situation is seldom encountered where there is not some correlation between channels, and in fact there is usually considerable correlation. In practice, the difference in sum level between mono and stereo material usually falls somewhere between 0 and 2 dB, an amount which is not bothersome to the affiliate or to the viewer.

Figure 7 illustrates how a stereo and a mono program are distributed to the NBC Television Network. For a stereo program, the left and right channels are passed from the source through Audio 1 and Audio 2 of the master grid (NBC's in-plant audio and video distribution system) through the channel release package in Switching Central to the Skypath (TM) Satellite uplink. At the affiliate site, the program is downlinked and demodulated to left and right channels. For a mono program, the audio is passed through Audio 1 of the master grid to Switching Central where it is split to feed Skypath (TM) with equal-level, in-phase mono on both audio channels. This is similarly downlinked at the affiliate site and demodulated to two channels. If the affiliate is transmitting in stereo, the left and right channels are sent through the affiliate's audio system to the stereo generator. If the affiliate is operating in mono, the two channels must be summed before being routed through the affiliate's audio system to the mono transmitter. Figure 8 is an illustration of a channel summing scheme used at the affiliate station which provides the affiliate with both stereo and mono sum audio. This system ensures full compatibility between mono and stereo audio for both stereo and mono transmission.

Of course, attention must be paid in the distribution system to amplitude and phase errors between channels just as in the videotape area. However, the errors are easier to control in electronic than in tape systems.

Although the conversion of a television network from monophonic to stereophonic broadcasting involves fairly straightforward technical concepts, operationally the implementation is not so simple. A random mixture of monophonic and stereophonic program elements has to be delivered to mono and stereo affiliates and in all cases the sum of the left and right channels has to be of high quality. This challenges each and every link in the long audio chain from origin to receiver.

Figure 1a. Spaced Pair with Path Length Difference

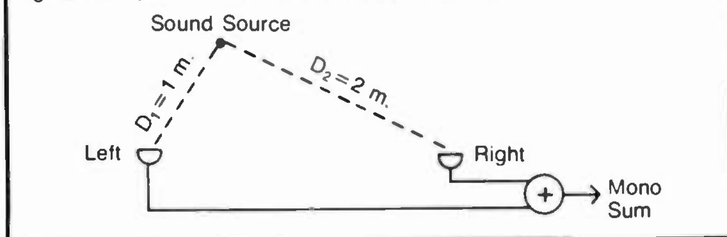


Figure 1b. Comb-Filtering Effect Produced by 1a

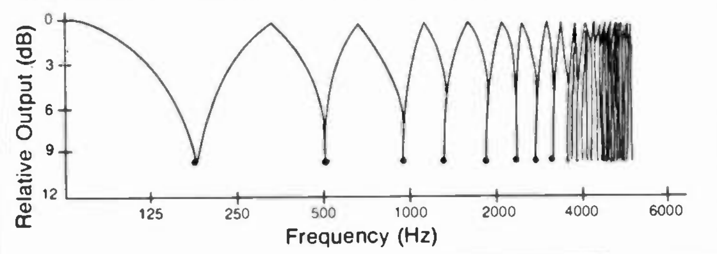


Figure 2. Blumlein Microphone Pair

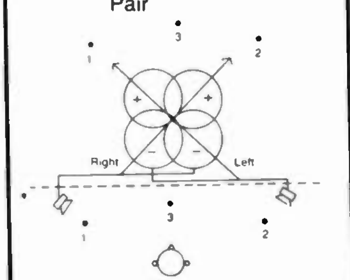


Figure 3. M-S Pair

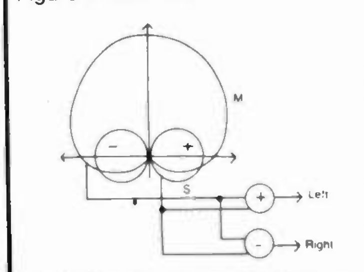
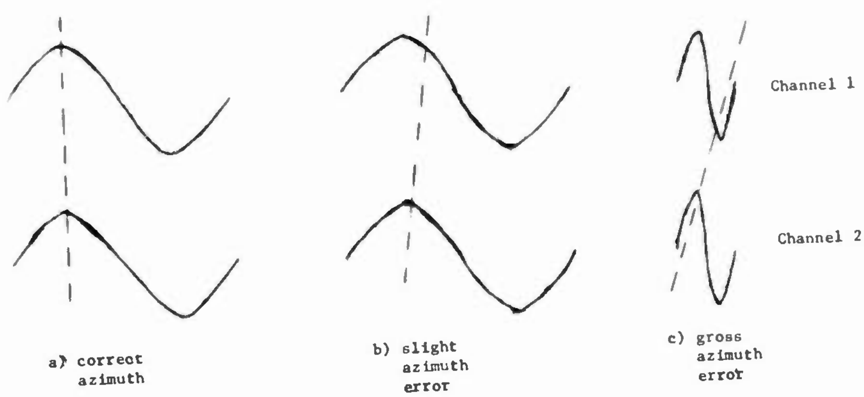


Figure 4



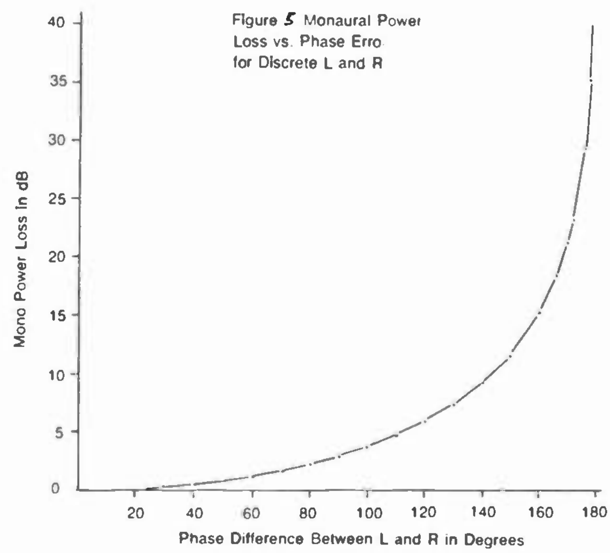
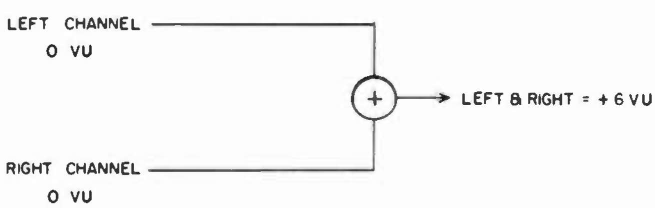
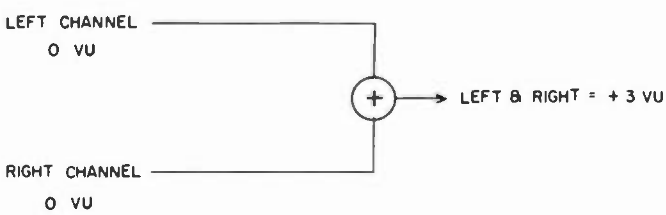


FIGURE 6



(A) TOTAL CORRELATION BETWEEN LEFT & RIGHT CHANNELS (MONO)



(B) NO CORRELATION BETWEEN LEFT & RIGHT CHANNELS

Figure 7

NBC New York Stereo Implementation

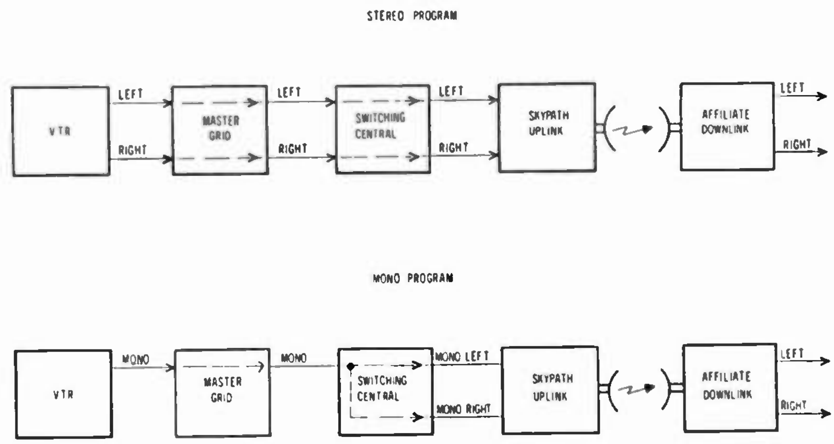
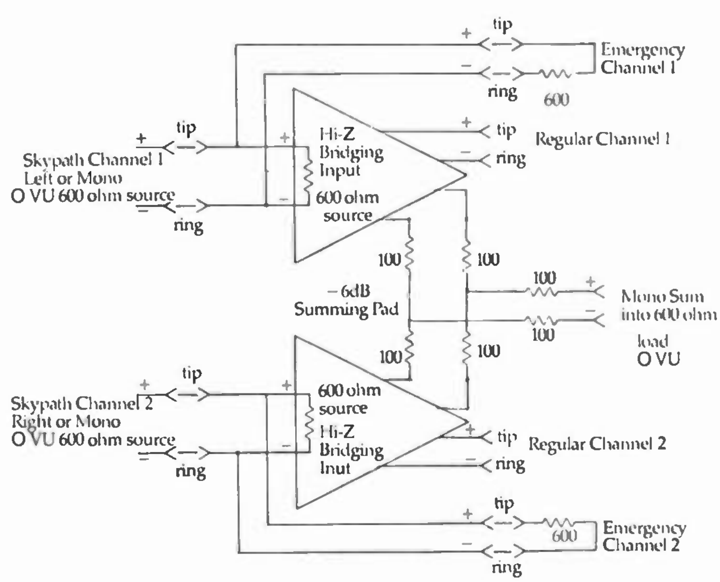


Figure 8

NBC STEREO
Affiliate Implementation



ADVANCED ACOUSTIC DESIGN OF STEREO BROADCAST AND RECORDING FACILITIES

Peter D'Antonio and John H. Konnert
RPG Diffusor Systems, Inc.
Largo, Maryland

ABSTRACT

The RPG is a new computer-designed reflection-phase grating, based on mathematical number-theory sequences, which provides optimum broad-bandwidth wide-angle sound diffusion, without introducing absorption. In addition to eliminating common acoustical problems such as flutter and slap echo, resonances and frequency coloration, the RPG improves "dead" sounding rooms by psychoacoustically creating the "open" impression and natural ambiance of a large room in a physically small space. The RPG is a new fundamental acoustical design ingredient which was formerly unavailable, consequently, it is finding widespread application. In this article we describe the advanced acoustical designs of broadcast and recording facilities utilizing this innovative technology and the concept of a reflection-free zone.

INTRODUCTION

The introduction of stereo TV, stereo AM radio, digital recording, compact discs, recent advances in 3D stereo imaging and emphasis on quality audio-for-video in general, has placed new importance on the acoustic design of recording and broadcast facilities. In this paper we will discuss advanced acoustical designs for three environments in the broadcast audio chain- the reference monitoring or control room, the recording studio, and the announce or voiceover booth. In each of these designs we will describe the role of reflection phase grating diffusors (RPG^{tm}). The RPG represents a new class of acoustical room treatment, formerly missing from architectural acoustics design, which provides broad-bandwidth wide-angle diffusion. Together with absorptive and reflective surfaces almost any critical listening or performing environment can be effectively created.

The acoustical analog of the diffraction grating, which has played an important part in the optical sciences for over 100 years, was not used in architectural acoustics until the discovery[1] and development[2-18] of the RPG, within the past decade. The one-dimensional RPG consists of a periodic grouping of an array of wells of equal width, but different depths, separated by thin dividers. The diffraction directions for each frequency are determined by the dimension of the repeat unit and the intensity in any direction is determined by the depth sequence within a period. The depths are based on mathematical number-theory sequences which provide optimum phase variation, and result in the desirable property that the Fourier transform of the exponentiated sequence values has constant magnitude in the

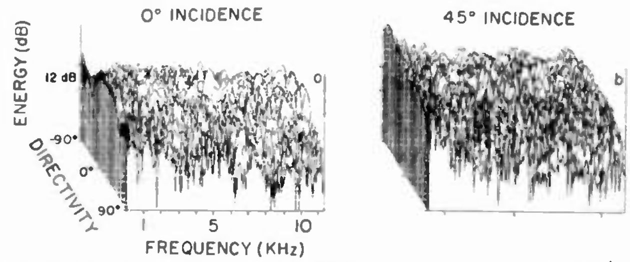


Figure 1. Left-The frequency response of a QRD^{tm} as a function of scattering angle (directivity) for 0^o incidence. Right-45^o incidence. The speaker-microphone and microphone-diffusor distance was 15'.

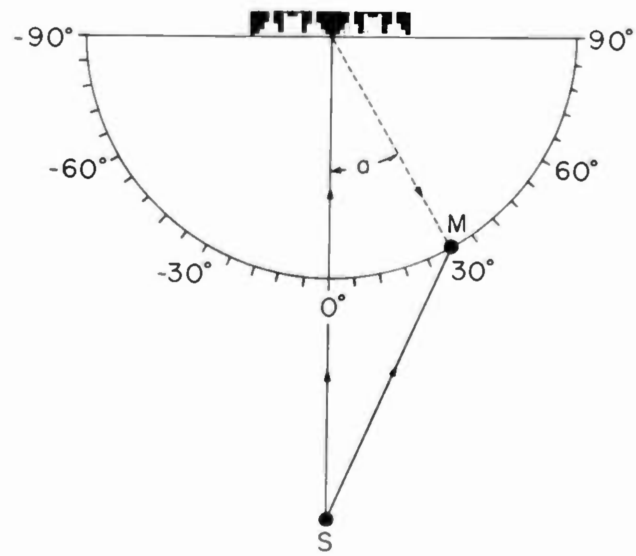


Figure 2. Scattering geometry for measuring the polar energy response of a QRD^{tm} diffusive surface for 0^o incidence, using a boundary measurement based on TDS. a is the scattering angle, S and M are the source and microphone positions, respectively.

diffraction directions. This insures that the RPG behaves like an ideal diffusor in that the surface irregularities provide excellent time distribution of the backscattered sound and uniform wide-angle coverage over a broad designable frequency bandwidth.

D'Antonio and Konnert[13] measured the time, frequency and directivity response of sound diffusing surfaces using a new boundary measurement technique based on time-delay spectrometry (TDS). Figure 1 illustrates the directivity-energy-frequency response at 0^o and 45^o incidence for an RPG based on a quadratic-residue depth sequence (QRD[tm]). The geometry used in the experimental measurements can be seen in Figure 2. In Figure 3 the octave-averaged polar response at 0^o and 45^o, obtained from frequency slices in the 3D curves of Figure 1, are shown. Figures 1 and 3 illustrate the uniform spatial distribution of the backscattered energy over 5 musical octaves! Using the 2 KHz polar pattern and the energy-time curve (ETC) obtained using TDS, we can compare the temporal and spatial characteristics of an absorptive, reflective and diffusive surface (Figure 4). The RPG represents an essential acoustical building block which was formerly unavailable. Consequently, it is having a profound influence on architectural acoustics and is finding widespread application in all critical listening and performing environments including: the audio/video recording/broadcast industry, performing arts facilities, churches and religious broadcasting, educational institutions, audio/video and teleconferencing facilities, entertainment venues, and home use. A few broadcast installations include: NBC (Bill Cosby Show, Saturday Night Live and Burbank Studios), WFMT production room and live broadcast studio, WBGO live broadcast studio, KMJQ, WLLT, WNKS, WJHU, WTIC-TV, Word of Faith World Outreach Center, Jimmy Swaggart Ministries.

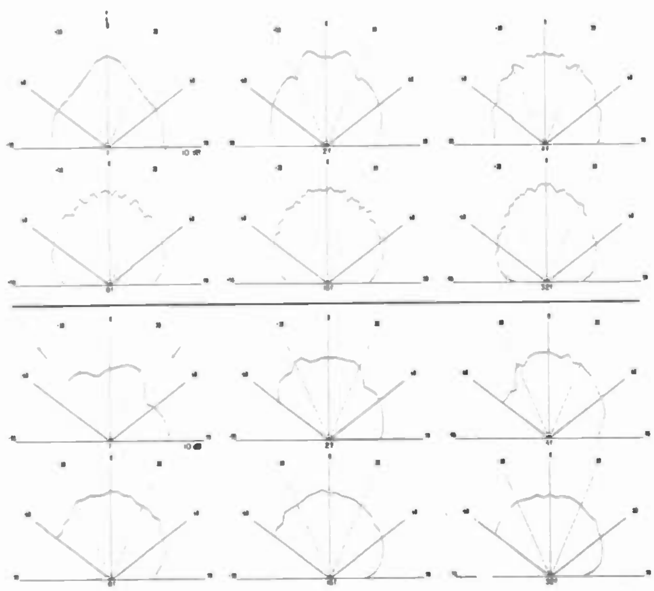


Figure 3. Top- Octave-averaged polar response for 0^o incidence. Bottom- 45^o incidence. Arrows indicate the incident and specular reflection directions.

RECORDING CONTROL ROOM

The objective of music production in a recording control room is to either faithfully reproduce the frequency balance and spatial textures of a recording environment or to create in post-processing a realistic or artificial sonic image with a prescribed spectral distribution and simulated spatial cues using effects processing. In either case, the control or reference monitoring room, as the name implies, must be neutral so that perceived sounds are not convoluted with the acoustical ideosyncracies of the control room.

Our research has focused on effective ways to optimize both LEDE[tm 19] and conventional designs, by implementing a reflection-free zone (RFZ[tm]) over a wide area surrounding the mix position and creating a dense diffuse sound field having significant lateral components in the room, using RPG diffusors. The RFZ is achieved by splaying, massive speaker boundary surfaces, which can contain distributed absorption, thereby minimizing boundary reflections at the mix position. The RFZ permits the accurate binaural perception of pre-encoded spatial textures over a wide area, minimizes speaker-boundary interference frequency coloration, caused by very early reflections, and allows the formation of an initial time delay gap (ITD) before the onset of indirect reflected energy. The diffuse sound field is created using RPG diffusors on the rear and side walls. The creation of an ITD with the RFZ allows the indirect energy reflection pattern to be sequenced at any arrival time desired, and directionalized with significant lateral components derived by RPG orientation. Efficient coupling between

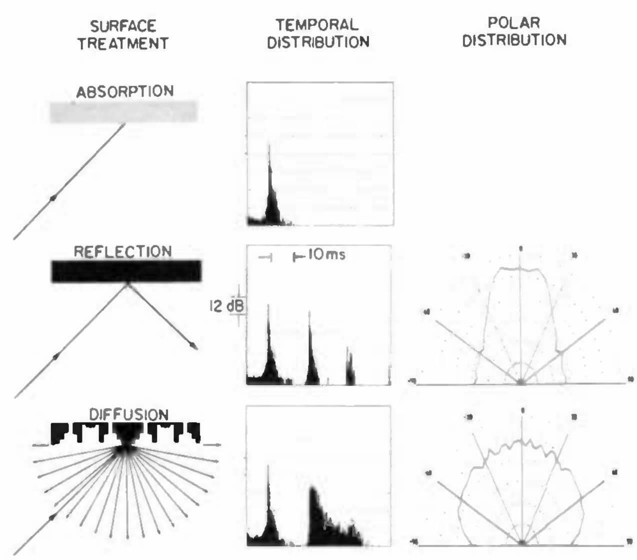


Figure 4. Comparison of temporal and spatial diffusing properties of an absorptive, reflective and diffusive surface. The scattered energy from an absorptive surface is negligible and no polar distribution is indicated. The reflective surface directs scattered energy principally in the specular direction, with minimal time spread. Whereas, the diffusive surface provides appreciable time and angular distribution of the backscattered sound.

specular surfaces on the walls, floor and ceiling and diffusive surfaces is critical in providing a uniformly dense reflection pattern throughout the ETC. Low frequency modal response is optimized through the use of a new low frequency diffusion system (LFD tm) and/or low-frequency absorption.

The RFZ/RPG design approach has evolved from TDS measurements[19], theoretical calculations[7,10], and psychoacoustical observations over the past twenty years[1, 20-25]. This research has provided many clues about the mechanism which the auditory system uses to binaurally perceive music in a room. Paramount among these observations is the affect of very early reflections (less than 10 ms) on frequency coloration and the perception of stereo images. Figure 5 was taken from Barron[20] with a threshold modification for a stereo source by Marshall and Hyde[21]. Barron found that reflections which are too early and/or too strong with respect to the direct sound can cause false localization and coloration. Observations by Rodgers[22] suggested that early reflections confuse the auditory system and result in image shifting, because they cause comb filter patterns which are very similar to the interference resulting from coherent reflections from the folds of the outer ear (pinna transforms). Don Davis measured these comb filter patterns using TDS and this research formed the basis of the LEDE design philosophy[19]. The Listening Environment Diagnostic Recording (LEDR tm) developed at Northwestern University, is an excellent method for evaluating the ability of an acoustic environment to reproduce pre-encoded spatial paths. The tape contains three digitally encoded spatial paths- an "up", an "over" and an "in". Early reflections, speaker mis-alignment and lack of diffusion systematically corrupt stereo images.

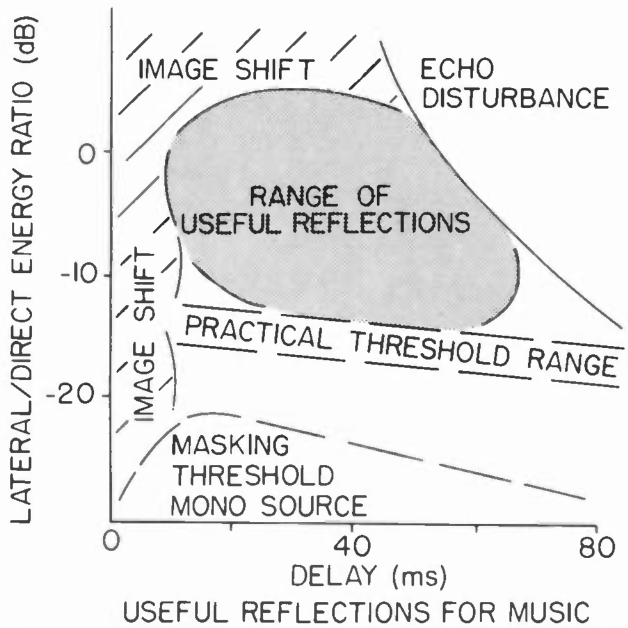


Figure 5. Illustration re-drawn from Barron[20] showing the affect of reflections on the perception of music. The practical threshold was added by Marshall and Hyde[21] for a stereo source.

Beranek[23] pointed out the importance of an ITD gap before the onset of the indirect reflected energy in a room, to the perceived size of an enclosure. Barron[20] also observed an intensity and temporal range in which reflections are useful. Therefore, by controlling very early reflections in small rooms, an initial time delay can be introduced to sequence the arrival time of the indirect reflected energy to fall within this useful reflection zone, and increase the apparent size of the room.

Reflection Free Zone-RFZ

The RFZ is principally responsible for minimizing frequency coloration and preserving pre-encoded stereo images. A very useful diffraction theory developed by Kirchhoff[7,10,24] can be used to model the frequency coloration caused by scattering from boundary surfaces. Kirchhoff included the inclination factor missing from the Fresnel near-field formulations. The Kirchhoff theory can be descriptively factored into three variables which affect the amplitude of the scattered energy- the reflection function, which is 1 for a reflective surface and complex for a diffusive or absorptive surface with a phase change; the inclination factor, which is a maximum for normal incidence and scattering; and the interference term, which is a maximum in the specular direction (angle of incidence equals angle of reflection). The reflection function is minimized by making the surface absorptive or diffusive, the inclination factor is minimized at oblique incidence and observation angles, and the

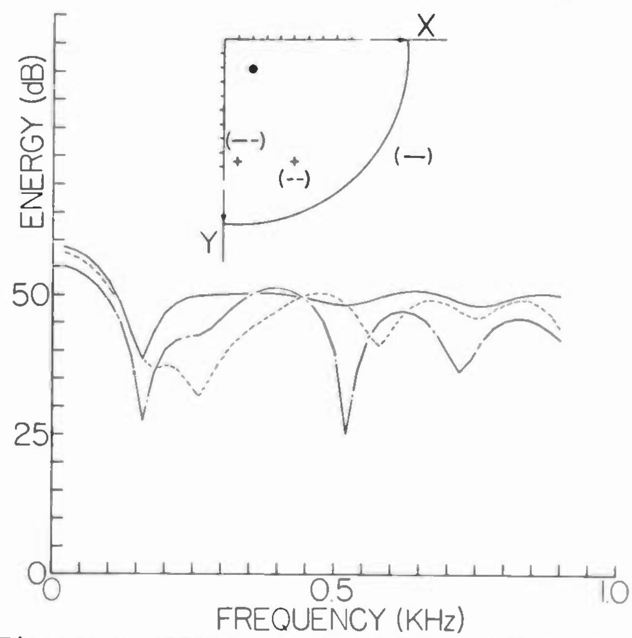


Figure 6. SBIR calculated using Kirchhoff diffraction theory at three observation points with respect to a source (dot) located at x=y=z=2 feet from the orthogonal trihedral corner. The long-short dashed line represents the response obseved at (1.0, 8.66, 6.0) and the dashed line represents the (5.0, 8.66, 6.0) position. The solid curve represents the far field calculation which is an average over all possible observation positions in an octant.

interference term is a minimum in non-specular directions.

Thus, reducing all three terms minimizes the interference between the direct and reflected sound. The Kirchhoff equation is easily programmed[7,10] to provide the speaker-boundary interference (SBIR) for a particular source location, observation position, size and orientation of the reflecting boundary. Such a calculation is shown in Figure 6. Theoretically, as a point source approaches the trihedral corner, the first interference notch approaches infinity. In reality, we must deal with speaker enclosures and multiple woofer designs. It seems prudent to flush-mount the woofer as close as is physically possible to the trihedral corner formed by the splayed ceiling and side walls. This causes the first interference notch, which is the most difficult to control, to be raised into a frequency range where decreasing the reflection function, inclination factor and interference term are optimally effective.

Stereo imagery is sensitive to frequency domaine notches in the 1-18 KHz range because these notches mimic the pinna and torso transfer functions caused by coherent reflections from the outer ear and upper body. This frequency range can easily be controlled by either an absorptive, reflective or absorptive/reflective RFZ. If speaker boundaries cannot be angled away form the mix position, then absorption is a natural choice. The absorption can be strategically placed to minimize offending very early reflections. If one can reconfigure the speaker boundaries, then the RFZ is that much more effective. Very early reflections below 1 ms can arise from reflections off the face of the speaker cabinet, console reflections, and reflections from near-field monitors. To minimize these problems absorption can be placed on and around the face of the speakers. Consoles can be tilted and fitted with absorptive/reflective hoods. The speaker height can also be adjusted to minimize this reflection. The console reflection is one of the principal disadvantages of near field monitoring. In addition to reflections, speaker time misalignment can also contribute to corruption of stereo images.

In Figure 7 we show a plan view of a typical control room utilizing the RFZ, RPG and low frequency diffusor (LFD[tm]), which will be discussed later. The normals (long-short dash) to the face of the monitors intersect behind the mix position. The RFZ is depicted by a symmetrical six-sided shaded area surrounding the console (rectangle), mix position (cross) and producer area behind the mix position. The dashed lines defining the RFZ indicate limiting reflections from the side boundaries. The upper left dotted line represents the limiting reflection of the right speaker from the glass window. Reflections from the right speaker off the left speaker baffle do not affect the RFZ. Limiting reflections from the right speaker off the left wall segment opposite the console are represented as the dashed line to the left of the mix position. The limiting reflection of the right speaker from the left wall segment behind the console is represented by the shortest dashed line to the left and behind the mix position. Since the RFZ is symmetrical, limiting reflections from the left speaker off the right boundaries are similarly represented.

In Figure 8 we show a control room elevation. The speaker baffle can be inclined such that the axis of the high frequency driver is oriented a foot or so behind the mix position, with an angle of elevation of approximately 13°. The ceiling reflection is minimized by utilizing a rigid, massive RFZ baffle sloping forward from the top of the speaker to the gradually rising ceiling. There are two design variables involved in

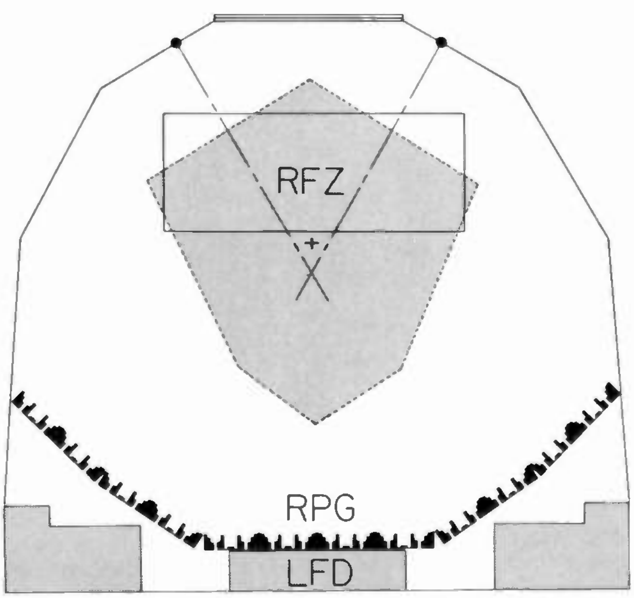


Figure 7. Plan view of an RFZ/RPG control room with LFD. Limiting reflections from surface boundaries form a symmetrical six-sided RFZ.

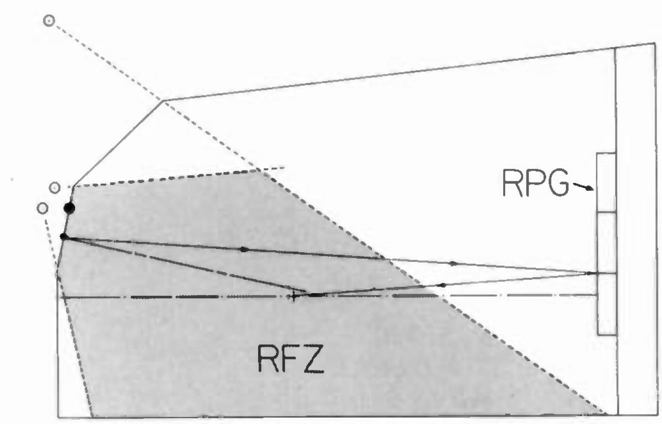


Figure 8. Elevation for an RFZ/RPG control room showing virtual sources (open circles) of woofer (large dot) from front wall, RFZ baffle and ceiling, which affect limiting RFZ reflections (dashed lines). Direction (solid line) of incident sound from the tweeter (small dot) and reflected sound from an RPG cluster is shown along with tweeter orientation (long-short dash).

controlling ceiling reflections, the angle of declination of the RFZ baffle and the height of the ceiling. These two parameters are optimized to provide the desired RFZ. The nearly horizontal RFZ baffle limiting reflection is only a function of the angle of declination, whereas the ceiling limiting reflection (running diagonally) is a function of the angle of declination and the ceiling height. A useful acoustical trouble-shooting technique is to methodically cover the speaker boundary surfaces with mirrors. If the reflection of either speaker is visible, when viewed seated at the mix position, then that surface will generate a specular reflection and should be addressed.

Reflection Phase Grating Diffusors-RPG

Once we have configured the front of the control room so that the predominent energy at all positions across the mixing console is the direct sound, we next turn our attention to creating a diffuse sound field using RPG diffusors on the rear and side walls. The RPGs reintroduce the energy passing the mix position after an ITD temporally and spatially diffused. By varying the depth of the room the early energy reflection pattern can be sequenced at any arrival time desired and directionalized by orienting the diffusors. The primary function of RPG diffusion is to: 1) provide a uniform high density of closely spaced reflections at the mix position, without any density gradients or discontinuities, 2) provide a dense pattern of uniformly distributed irregularly-spaced frequency notches. The RPG insures that any inadvertent reflection combinations with slight time differences, which could result in broadband frequency anomalies, are minimized, 3) uniformly backscatter a broad frequency bandwidth over a wide angle, and 4) reduce the backscattered energy to minimize interference with the direct sound, frequency coloration and image shifting.

Several researches, most notably Haas[25], have described the ability of the auditory system to temporally fuse similar sounds within a time window (approximately 20 ms for program material) which depends on the nature of the source. It is this temporal fusion which allows us to blend the direct sound, early reflections and reverberation into one louder and fuller event. Barron[20], Schroeder[1], Marshall[21] and others have observed that in addition to amplitude and temporal distribution, the directionality of early reflections is an important parameter affecting the binaural perception of music. Diffuse lateral reflections lead to greater binaural dissimilarity, an increased spatial impression and therefore, higher listener preference. Consequently, we want to immerse the listener in a dense diffuse sound field, with significant lateral components, which produces a stereophonic experience and a sense of envelopment.

The rear of the room consists of reflective and diffusive surfaces. The reflective surfaces are positioned such that they do not reflect direct sound to the mix postion, but rather, reflect direct sound to the diffusive surfaces. If the side walls and ceiling behind the mix position specularly feed the rear diffusors, the auditory system will perceive the first room reflections from the diffusive surfaces. Effective rooms can be designed with the rear wall approximately 8-12 feet behind the mix position, mimicing the initial time delay and "open" ambiance of a much larger room. The backscattered energy is distributed into a hemidisc which is as thick as the height of the diffusive cluster. This hemidisc can be conveniently directed at the mix position

Figure 9. Rear view of the control room at Tele-Image, Dallas, TX showing the upper and lower RPG clusters. Acoustical consultant Russell Berger, Joiner-Rose Group.

Figure 10. Rear view of the control room at Master Sound Astoria in the Kaufmann Astoria Film Studios, Astoria, New York, showing rear and side RPG clusters. Acoustical consultant Charles Billelo Associates.

by either moving the source or the RPGs. Providing enough space is available, any bandwidth can be obtained by appropriate RPG design parameters. We have been using a five musical octave range for the most advanced room designs with much success. Psychoacoustical observations suggest that smaller bandwidths are also effective.

The earliest indirect sound to arrive at the mix position in the design shown in Figure 7 is from an RPG on the same side as the source. The latest arriving indirect sound from the side walls is from an RPG opposite the source. Each diffuse reflection is spread approximately 2-4 ms and the temporal spread between diffusors on each side of the rear wall is approximately 5 ms. Reflections from the specular side walls and ceiling act as delayed sources and further increase the reflection density at the mix position.

The optimum vertical position of the laterally diffusing RPG cluster (lower two tiers) on the rear wall is one which specularly directs the center of the diffuse scattered hemidisk back to the mix position. This ray is indicated with a solid line in Figure 8. The upper tier of diffusors in Figure 8 are vertically diffusing, with wells running horizontally, and their height is not critical. A very simple installation proceedure is to use a mirror to properly orient the center of the RPG cluster. While seated at the mix position facing the diffusors, an assistant adjusts the height and/or tilt of the mirror until a reflection of the high frequency driver is visible. This assures proper orientation of the diffuse energy. A view of an RPG diffused rear wall section can be seen in Figures 9 and 10. An ETC of a typical RFZ/RPG control room is shown in Figure 11, with 6 temporal regions identified. The factors affecting these regions are listed: 1) The direct sound is

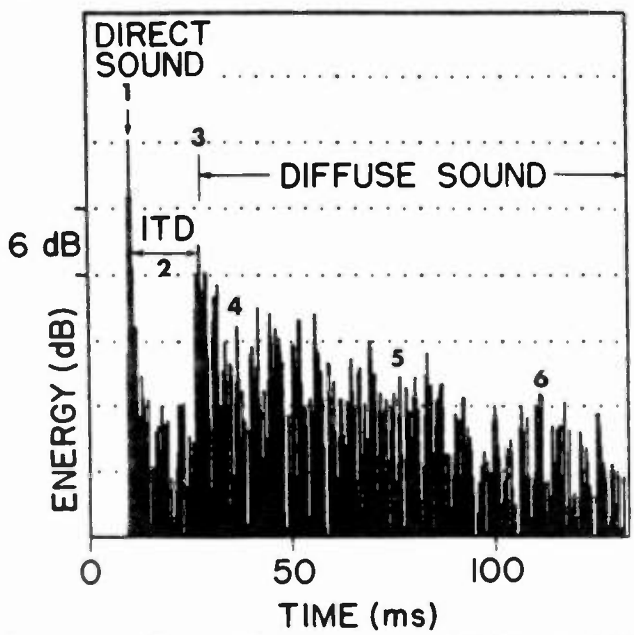


Figure 11. ETC of an 8000 sq. ft. RFZ/RPG control room identifying six temporal regions explained in the text. The ITD is approximately 17 ms.

affected by the quality of the reproduction system and speaker time-alignment, 2) the ITD is affected by very early reflections from console and boundaries and can be minimized by an effective RFZ, 3) the initial indirect energy we hear after the direct sound is determined by the surface treatment on the side and rear walls. The RPG insures that this reflected energy arrives as a diffuse packet of energy rising abruptly after the ITD, 4) the density of reflections in this temporal range depend on the efficiency of coupling between specular side walls/ceiling and diffusive surface, 5) these reflections are multiple order interactions between specular and diffusive surfaces, 6) the limiting reflections forming the decay characteristics of the room depend on the amount of absorption used in the formation of the RFZ on the speaker boundary surfaces and in the rest of the room.

Optimizing Low-frequency Response

A very effective evaluation of the decay characteristics of rooms is provided by a TDS 3D time-energy-frequency measurement, shown in Figure 12. The 31 frequency response measurements were made 5.5 ms apart at a sweep rate of 200.92 Hz/sec and a bandwidth of 10 Hz (time resolution of 50 ms and frequency resolution of 20 Hz). Note the ringing modes at 42 Hz and 63 Hz. A room with a tight sounding bass will exhibit a uniform decay of all modal frequencies. To provide good low end room response one can utilize optimized room dimensional ratios, low frequency Helmholtz or diaphramatic absorption and/or LFDs. The LFD, shown schematically in Figure 7, is a new approach to low frequency modal modification and reduction of low frequency anomalies (as in Figure 6) caused by the interference between direct and delayed reflected sound. LFDs have been installed in Chicago Trax and Jericho Recording Studio, Chicago, IL and Welk Music Group, Nashville, TN with good results. The LFDs require an overall width close to a modal

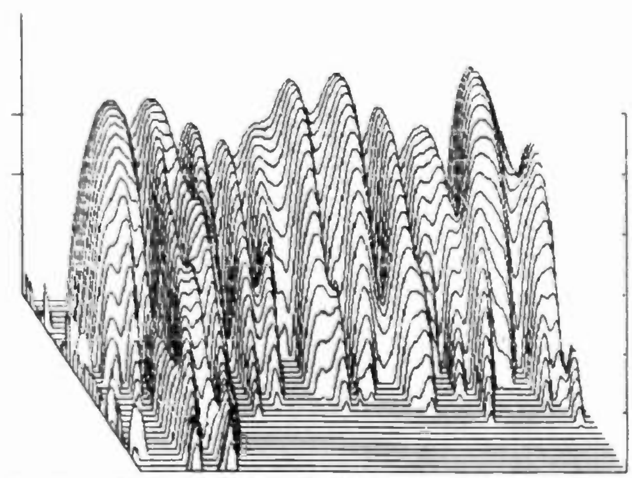


Figure 12. 3D time-energy-frequency measurement illustrating two ringing modes at 42 Hz and 63 Hz. Vertical energy axis is 6 dB/div, horizontal frequency axis runs left-right from 0 Hz to 351.2 Hz and time axis runs from 9.4 ms (back) to 180 ms (front). An optimum decay characteristic would be a dense modal pattern which decays uniformly.

wavelength and employ wide (approximately 2-3') and deep wells (approximately 2-4') whose depths are based on quadratic-residue, primitive-root or Zeck logarithm number-theory sequences[1]. Depending on available space, LFDs can be designed to affect the decay characteristics and density of the axial resonant modes for wavelengths comperable to the dimensions of the room.

Combo Production Rooms

In some instances the recording control room additionally serves as a production room, with several "live" microphones, essentially combining the control room and the studio. RFZ/RPG control rooms work well for this purpose because the diffuse sound field minimizes acoustic feedback caused by focused specular reflections. In Figure 13-left a very strong specular reflection which could cause electro-acoustic problems is uniformly diffused into the sound field by application of an RPG over the offending surface, Figure 13-right. Care should be taken to minimize any reflections from the console, auxillary desks or racks and near-field speakers at the mix position and open microphone locations. This can easily be evaluated by examinimg the ETC using TDS.

Combo rooms are often used in a "talk-show" format which involves several "open" mics. Potential interference arising from table, wall and ceiling specular reflections can be minimized by appropriate microphone technique and RPG surfaces. In contrast to absorptive treatment which will also reduce specular reflections, the RPG does not produce the adverse acoustical side-effect of a "dead" room, all too common in broadcast environments. In fact, the RPG will provide a pleasing ambiance to the participants while reducing reflected energy coloration and acoustic feedback problems.

A particularly effective production desk arrangement is to position a "low-boy" rack behind the mix position, Figure 9, containing signal processing. This desk top can be used as a production desk and a synthesizer station. If the RFZ is made appropriately large to encompass this location, it can also be used to critically monitor the program. An additional benefit of the RPG diffusors is that the diffuse indirect reflected energy allows effective use of the

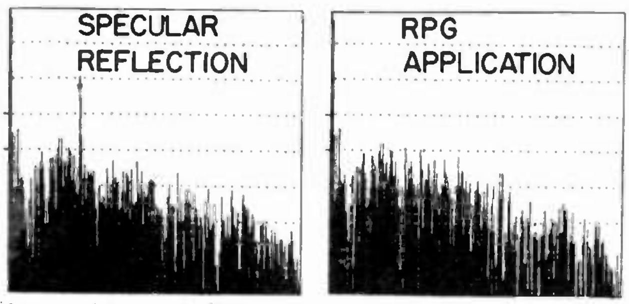


Figure 13. Left-ETC of a room with an intense specular reflection. Right-Treatment of offending surface with RPG diffusors uniformly distributes the energy into the sound field without destroying the natural ambiance.

entire rear area of the control room.

Practical Advantages of an RFZ/RPG Control Room

1. This approach allows great mobility across the entire width of the console providing a very wide "sweet spot". Thus engineer and producer are not elbowing for position at the console and can hear essentially the same program mix at different seating positions.
2. The presence of diffuse energy allows monitoring at much lower levels. In designs where the rear is essentially an acoustic "black hole" to minimize interference, the monitor level must be raised to appreciable levels so that the mixer senses a feeling of envelopment. The RPG provides this spatial impression even at low levels. Traditional control room designs can easily be optimized by establishing an RFZ and placing RPGs in front of a portion of the rear bass absorbers to provide diffuse energy. The bass absorbers will be only minimally affected because of the ability of long wavelengths to diffract around and/or transmit through the diffusors.
3. These rooms allow the accurate perception of stereo images, evaluation of frequency balance, signal processing and reverberation in post-production. They simultaneously provide good definition and spatiousness.
4. Provide a musical product that is transferable to other listening environments.
5. Exhibit uniform modal decay characteristics.

RECORDING STUDIO

In a recording studio the decay time, level of indirect reflected energy, spectral balance and all spatial percepts of sound space, i.e. directionality, distance, definition, spatiousness, and spatial texture are created by the acoustical environment. The arrival time, temporal distribution, density, and directionality of the early energy and direct/early energy

Figure 14. RPG "T-bar" suspended ceiling at BlueJay Recording Studios, Carlisle, MA, integrates diffusion, absorption and lighting.

ratio are crucial for determining the desired recorded ambiance and spatial characteristics. The fundamental importance of a significant uniformly dense and diffuse early lateral sound field in creating a high spatial impression and a heightened sense of ensemble for performing musicians has been firmly established. Diffusion in studios has traditionally been provided by mono- and polychylindrical columns, irregular geometrical shapes, reflective surfaces with distributed absorption, etc. While these surfaces provide useful scattering, they cannot provide the spatial and temporal diffusion characteristic of an RPG surface, over a broad range of frequencies.

The acoustics of the recording studio can be tailored to provide the necessary early reflections and dense diffuse sound field, with a uniform decay time over the audio spectrum. This provides a spacious sound with the sweetening of a concert hall which can effectively be used for recording and/or live broadcast of jazz, orchestral or symphonic performances. Many of the design principles used to optimize performing arts facilities[10,18] can be utilized in the design of effective recording studios. It is very important that the recording environment provide ensemble reflections for performing musicians to enable them to hear other performers and themselves, so that they can develop a sense of pitch through acoustic feedback. The RPG is an ideal ensemble reflector because it provides an optimum temporal pattern of reflections and uniform scattering over a wide-angle, for any desired frequency range. In addition, the diffuse energy can be directed by orienting the diffusors. Appropriate placement of the diffusors so that reflected energy arrives within a temporal window centered at approximately 20 ms (Figure 5), with significant lateral components, is relatively straightforward. This can be accomplished using RPG clusters with vertical wells, running longitudinally along lower walls, or raised and tilted so that they are suspended between the ceiling and side walls. A very effective integrated lighting and suspended "T-bar" RPG ceiling treatment can be seen in Blue Jay Recording Studios, Carlisle, MA in Figure 14. The RPG can also be used to correct common acoustical problems by diffusing high-level confusing slap echos (greater than 100 ms), flutter echos and resonances, which disrupt the uniformity of the indirect energy, without introducing absorption. In situations where the performers are in a room with a low ceiling or close to a boundary surface, the RPG can be used to make these surfaces psychoacoustically "disappear". This occurs because the sound is uniformly scattered in all directions and no one direction is favored.

In addition to enhancing the general ambiance of a large room, the RPG can be used to create variable acoustics in localized areas of the room for specific recording applications. Localized diffusion can be achieved by use of the RPG in a movable partition or "gobo", which can be used to section a drum kit, provide ensemble reflections for a small group of acoustic instruments or vocalist. An arrangement which is particularly effective is to use a figure "8" pattern and position the microphone between the sound source and the RPG cluster. With appropriate microphone techniques the diffuse early reflections can be used to "thicken" acoustic and amplified sounds and make the use of digital reverberation in post-processing more natural sounding and effective. The distance between the mic and the diffusor can establish the size of the imaginary room being creating. By varying this distance and the amount of diffusion many different acoustical environments can be simulated. Customarily absorption has been used to reduce the acoustic disadvantages of mobile studios. The RPG offers a complementary surface treatment which provides a natural ambiance or "open" impression in this restricted space.

VOICEOVER BOOTH

The announce booth is an important part of commercial broadcast. Voiceovers are usually done in a very restricted space. These impoverished acoustical environments translate, unfortunately,

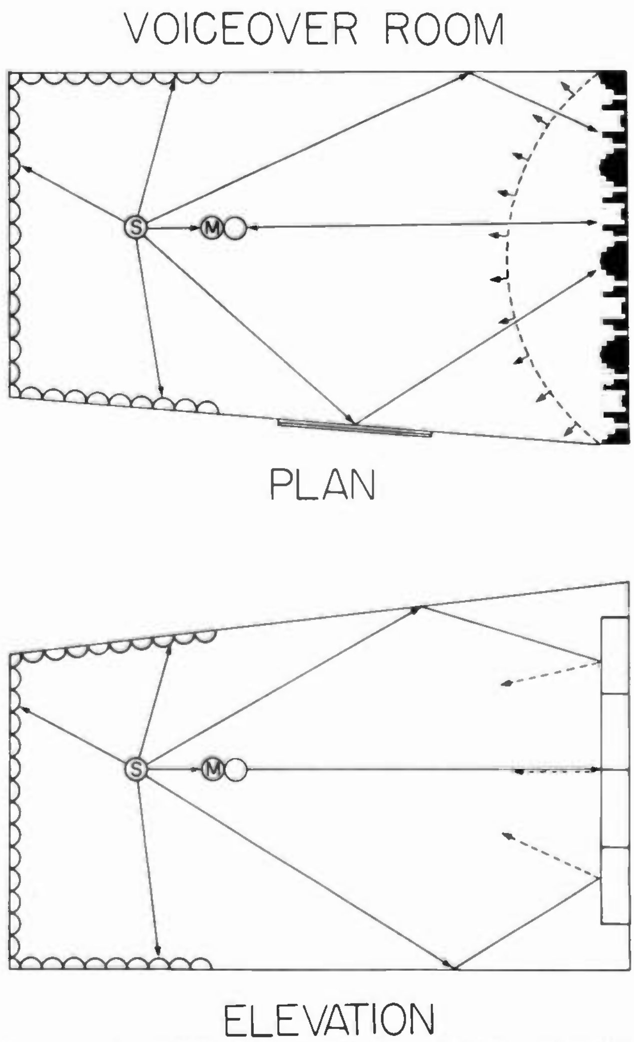


Figure 15. Plan and elevation for a voiceover booth design which increases the apparent size of the room and enhances announcements.

into dull recordings which lack ambiance. To overcome this, signal processing and artificial reverberation are used to try to produce crisp, sonorous announcements which cut through on the air. The problem with small rooms is that the ITD is very short, there is very little diffuse energy and modal effects cause position dependent intensity variations (hot spots and voids). By utilizing the RFZ/RPG approach, we can now improve the acoustics of small rooms by psychoacoustically creating the impression of a larger room in a physically small space. In Figure 15 we show a plan and elevation of a voiceover booth which has been optimized. The RFZ is created using absorption (semi-circles) behind and to the sides of the figure "8" microphone (M), to minimize early reflections which provide the auditory system with clues as to the size of the room. The sound (solid lines) from the source (S) then travels to the farthest wall, which is treated with RPGs, where it is diffused spatially and temporally (dashed lines) and returns back to the microphone. The ceiling and side walls should be splayed slightly, 1" per foot to minimize flutter echos, and reflect the sound to and from the RPG surface, thus increasing the density of diffuse energy. Many geometries can be made to work, if the criteria of an RFZ and a sequenced diffuse sound are established. If the room does not conform to this rectangular shape and is smaller and square, then a more spatious impression may be created by using a diffusive suspended "T-bar" suspended ceiling. Modal modification can be accomplished by low frequency absorption using damped membranes and/or LFDs.

Another significant frequency coloration effect in broadcast is comb filter interference in the frequency domaine, caused by the combination of direct and reflected sound from a table top. Comb filtering consists of periodic frequency notches on a linear frequency scale and causes a "hollow" sound lacking body. When the levels of the two signals are identical, the nulls in the comb filter are essentially infinite. As the level of the reflected energy decreases, the resulting interference is decreased. Use of a boundary microphone[11], a figure "8" polar pattern and an absorptive or acoustically transparent table top can be used to minimize this interference. When the figure "8" response pattern of a microphone is oriented horizontally the minimum sensitivity occurs in a plane perpendicular to the table top. Therefore, offending table reflections and paper rustling sounds are diminished. The other important advantage of the figure "8" pattern is that in a room which has an RFZ and RPGs, the sensitivity lobe opposite the direct sound can be used to pick up the delayed diffuse energy which provides sonority and a natural "open" ambiance. Absorptive table tops are easily provided and acoustically transparent designs can be fabricated by cutting a hole in that expensive new rosewood table, you just convinced management you couldn't live without, and attaching mesh screen to provide support for papers. Tables should be avoided when standing announcements can be accomodated.

REFERENCES

[1] M.R. Schroeder, Number Theory in Science and Communication, with Applications in Cryptography, Physics, Digital Information and Self-Similarity, Springer, Berlin, 1986.

[2] P. D'Antonio and J.H. Konnert, "The Reflection Phase Grating Diffusor: Design Theory and Application", J. Audio Eng. Soc., Vol 32, No. 4, pp. 228-238 (April 1984).

[3] Synergetic Audio Concepts Newsletter, Vol. 11, No. 2, pp. 14-17 (Winter 1984).

[4] Synergetic Audio Concepts Tech Topics, Vol. 11, No. 7 (Spring 1984).

[5] P. D'Antonio, J.H. Konnert and F. Becker, "The RPG Reflection Phase Grating Diffusor: Experimental Measurements", 76th AES Convention, New York (October 1984), Preprint No. 2158.

[6] P. D'Antonio and J.H. Konnert, "The RPG Reflection Phase Grating Acoustical Diffusor: Applications", 76th AES Convention, New York (October 1984), Preprint No. 2156.

[7] P. D'Antonio and J.H. Konnert, "The RFZ/RPG Approach To Control Room Monitoring", 76th AES Convention, New York (October 1984), Preprint No. 2157.

[8] Synergetic Audio Concepts Tech Topics, Vol. 12, No. 1 (Fall 1984).

[9] R. Todrank, "Incorporating Reflection Phase Grating Diffusors on the Rear Wall to Enhance Spatial Imaging and Stereo Ambiance", Recording Engineer/Producer, Vol. 15, No. 6, pp. 122-125 (December 1984).

[10] P. D'Antonio and J.H. Konnert, "The Role of Reflection Phase Grating Diffusors in Critical Listening and Performing Environments", 78th AES Convention, Anaheim (May 1985), Preprint No. 2255.

[11]* C. Bilello and P. D'Antonio, Sound & Communication, Vol. 31, No. 9, pp. 14-18 (September 1985).

[12] P. D'Antonio, "The Reflection Phase Grating Acoustical Diffusor: Diffuse It or Lose It", db Magazine, Vol. 19. No. 5, pp. 46-49 (September/October 1985).

[13] P. D'Antonio and J.H. Konnert, "The Acoustical Properties of Sound Diffusing Surfaces: The Time, Frequency and Directivity Energy Response", Invited Paper B-6, 79th AES New York (October 1985), Preprint 2295.

[14] P. D'Antonio, "The RPG Diffusor", Pro Sound News, Innovations in Sound, Vol. 7, No. 10, pp. 51, 61 (October 1985).

[15] W. Baldwin, Forbes Magazine, pp. 152-153 (October 1985).

[16] P. D'Antonio and J.H. Konnert, "Recording Control Room Design Incorporating a Reflection Free Zone and Reflection Phase Grating Acoustical Diffusors", Invited Paper D2, 110th Meeting: Acoustical Society of America, J. Acoust. Soc. Am. Suppl. 1, Vol. 78, p. S9 (November 1985).

[17] I. Peterson, "Acoustic Residues", Science News, Vol. 129, No. 1, pp. 12-13 (1986).

[18] P. D'Antonio and John H. Konnert, "The Reflection Phase Grating Acoustical Diffusor: Application in Critical Listening and Performing Environments", Invited paper 12th International Congress on Acoustics, Room Acoustics: Recent Developments session, Toronto (July 1986).

[19] D. Davis and C. Davis, "The LEDE Concept for the Control of Acoustic and Psychoacoustic Parameters in Recording Control Rooms", J. Audio Eng. Soc., Vol. 28, No. 9, pp. 585-595 (1980).
[20] M.F.R. Barron, "The Effects of Early Reflections on Subjective Acoustic Quality in Concert Halls", Ph.D. Thesis, University of Southampton (1974).
[21] J.R. Hyde and A.H. Marshall, "Requirements for Successful Concert Hall Design: Need For Lateral and Ensemble Reflections", IEEE International Conference on Acoustics, Speech, and Signal Processing, Paper A2.4, (April 1980)
[22] C.A.P. Rodgers, "Pinna Transformations and Sound Reproduction", J. Audio Eng. Soc., Vol. 29, pp. 226-234 (1981).
[23] L.L. Beranek, Music Acoustics and Architecture, Wiley, New York (1961).
[24] M. Born and E. Wolf, Principles of Optics, Sixth Edition, Pergamon Press, Great Britain (1984).
[25] H. Haas, "The Influence of a Single Echo on the Audibility of Speech", J. Audio Eng. Soc., Vol. 20, pp. 145-159 (March 1972).

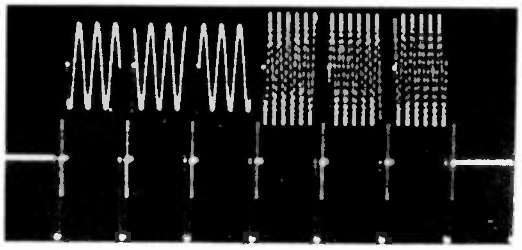
tm RPG, QRD, RFZ and LFD are trademarks of RPG Diffusor Systems, Inc.; LEDE is a trademark of Synergetic Audio Concepts and LEDR is a trademark of Northwestern University.

VIMCAS (VERTICAL INTERVAL MULTI-CHANNEL AUDIO SYSTEM)

Basil F. Pinzone
Pinzone Communications
Newbury, Ohio

Robert Broad
I.R.T. Electronics Pty. Ltd.
Sydney, Australia

The ability to add high quality audio channels to existing and new video mediums is uniquely and simply implemented with the use of VIMCAS. The VERTICAL INTERVAL MULTI-CHANNEL AUDIO SYSTEM presented here addresses the need for adding superior quality multi-channel audio while economically utilizing the VBI (Vertical Blanking Interval). The system is based on the use of both digital and analog techniques to obtain maximum bandwidth with minimum line usage. Typical applications include VTR, satellite, microwave, and over-the-air.



DESIGN CRITERIA

An effective VIMCAS system needed to address a number of design criteria centered around the following industry requirements:

CART MACHINES-CONVERSION TO STEREO:

The RCA TCR-100 and AMPEX ACR-25 have seen a lot of years and, of course, there are several replacement systems available today. However, a majority of stations have committed to 2-3 more years of quad cart for various reasons. According to a recent PINZONE survey, 244 (88%) of 277 respondents planned to keep their quad cart machine for a minimum of 2 years and 195 (70%) planned to keep them for a minimum of 3-5 years. The same survey revealed 493 (56%) of 876 respondents planned to have basic stereo transmission capability by early 1987.

A truly high quality stereo conversion system that requires no machine modification and no mechanical limitations would be considered ideal.

SATELLITE TRANSMISSION:

The ever-increasing desire to add stereo, SAP (secondary audio programming), multi-language, and auxiliary audio and data has been slowly eroding the overall quality of the satellite transponder's primary purpose, the main channel. Each new subcarrier requires main channel power reduction to compensate for subcarrier insertion and increased pre-detection bandwidth, thereby increasing noise bandwidth. The ultimate result is reduced C/N and S/N. With the addition of intermod, the end-product becomes subject to a delicate and precarious balance.

The ability to economically use the vertical interval of the main channel for primary multi-channel audio is greatly desired. This would improve the overall system performance as well as improv e audio fidelity.

MICROWAVE LINKS:

The application needs of satellite transmission apply equally here. In addition, there are many links that don't have the capability to add additional subcarriers. A system which can make economical use of the VBI for the additional audio can greatly enhance the usefulness of existing microwave systems.

ENG NEWSFEEDS:

Often, ENG vans find themselves operating in an area that is less than desirable for feeds back to the station. In marginal signal environments it is usually the audio subcarrier that is first to go. A system that would permit audio to travel with the main channel video would permit reliable feeds from those marginal areas that seem to exist exactly where you don't want them to.

ENG FOLDBACK OVER-THE-AIR:

ENG vans that can receive directives from the 'city-desk' in the entire viewing area can 'stand-by' in regions not before possible. A foldback system that can utilize the station's full power can do much to expand the ENG van's effective area.

MULTI-LINGUAL APPLICATIONS:

The ability to provide program material in several languages is in greater demand today. A system which permits source encoding and passthrough on existing studio equipment would make this practical. The system employed would have to economically use the VBI so that several languages could be encoded.

NET/SYNDICATION STEREO PASSTHROUGH:

A transparent VBI encoding system could be employed to provide network and syndication programming to stations with stereo exciters but haven't yet converted their studios to stereo. Network and syndicated program material could be encoded and passed through the entire system beginning with the satellite feed, through the station's video routing system, over the microwave, and to the transmitter for decoding and stereo broadcast.

The same would apply to syndicated programming on tape. The encoded tape would output the video into the normal video routing system to the transmitter for decoding and broadcast.

STEREO COMMERCIALS:

As in stereo programming passthrough noted above, commercials can be encoded at the agency for ultimate decoding at the transmitter for broadcast. The station would not necessarily have to be converted to stereo at its studio as a pre-requisite to broadcasting stereo commercials.

CRITERIA SUMMARY

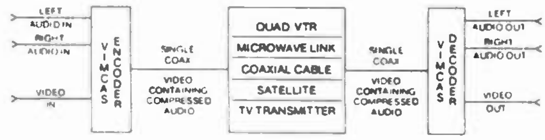
The system ultimately desired would need to be a superior fidelity system that uses space in the vertical interval economically. Since the system may be used in tape applications, consideration to skipping lines used for headswitch is needed as well as the desire to select lines around or about any VITS/VIRS/CAPTIONING signal. Line selection should be user selectable and NOT require consecutive placement. To permit precise sampling in the VBI, the encoding system should use the video signal to provide all of the synchronizing information.

THE VIMCAS SYSTEM CONCEPT

The VIMCAS system enables a number of audio channels to be integrated into the vertical interval. The use of three lines per field gives a high quality sound channel with a bandwidth of 14 KHz. A stereo pair would require six lines. The VIMCAS system could employ anywhere from one to four channels in the VBI or up to eighty channels in the full field.

The system is based on the use of both digital and analogue techniques to obtain maximum bandwidth with minimum line usage. The lines used may be selected in the field by the user.

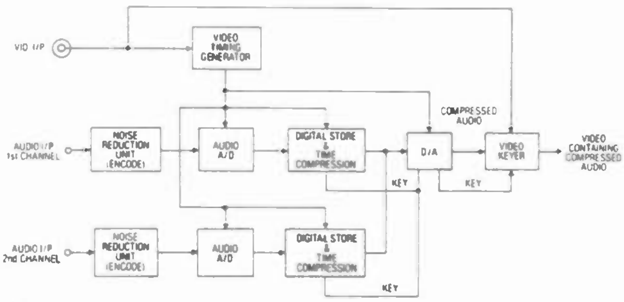
System performance and stability has been achieved by using the video signal to provide all the synchronizing information for the encoding and decoding of the audio signal. This method of synchronization has a number of advantages in that it is not affected by delay or other circuit irregularities in the transmission path. It allows precise sampling of the audio thereby eliminating problems associated with reconstituting the audio signal.



This simplified block diagram shows how VIMCAS can accept multiple audio channels and relay them during the video vertical interval.

VIMCAS ENCODER:

The audio signal is first passed through a noise reduction circuit which dynamically compresses the input signal. The signal is then band limited and converted into digital form by an Analog to Digital (A/D) converter. The 2H sampling rate is derived from the video signal via a timing generator.



ENCODER

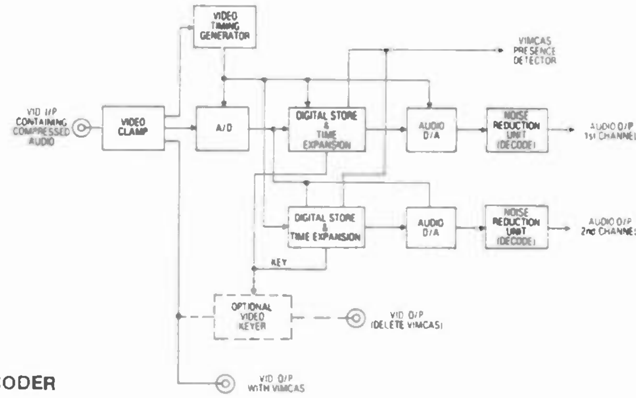
The digital signal from the A/D converter is then passed into a digital store under control of the video timing generator. When the nominated line, on which the audio is to be impressed, arrives, the digitized audio is passed into a Digital to Analog (D/A) converter at high speed thereby time compressing that portion of the audio onto the selected line. This is repeated for the number of lines required to achieve the required bandwidth - e.g. 3 lines for a 14 kHz channel or six lines for two stereo channels.

Additional audio channels can be added, depending on the lines available in the vertical interval.

A technique of "compressed audio overlap" is used which eliminates transient settling time, thus reducing system distortion/noise to a minimum.

The compressed audio is keyed into the video by a keyer which is controlled by signals generated in the timing logic.

The signal at the output of the encoder is standard video at standard level with compressed audio in the vertical interval. The peak to peak excursions of compressed audio are contained between the blanking level and peak white level.



DECODER

VIMCAS DECODER:

The video signal containing the time compressed audio is first processed by a blanking level clamp amplifier thus setting a reference to prevent average picture level (APL) changes from altering the reference level for decoding. The signal then passes into a high speed A/D converter which is continuously operating at a precise sampling rate locked to the color subcarrier derived from the video signal. The digitized samples of time compressed audio are now available for storage in digital memory, however, due to redundancy added in the encoder, not all of the samples are required. The samples most likely to be distorted due to transient discontinuities are those at the start of the line and these are disregarded. The stored information representing the audio signal is then converted to analog using a D/A converter operating at the same precise rate as the D/A in the encoder.

Additional audio channels are provided by increasing the number of digital stores, D/A converters and noise reduction decoders.

SPECIFICATIONS:	VIMCAS (1) E-D	VIMCAS Typ via VTR
Frequency Response at +8dBm - 40Hz-14kHz	0 dB +1 dB -2 dB	0 dB +1 dB -2 dB
Distortion (2) at +16dBm - 400Hz	< 0.2%	2%
Noise (3) ref +16dBm input	-85dB	-75dB
Differential Phasing (4) CH1 to Ch2 - 40Hz to 14kHz	3 deg ∙3	3 deg ∙3
Crosstalk - CHl to Ch2	-80dB	-80dB
Audio Delay Encoder in to Decoder out	40mS	—
Vertical Interval Usage	3 lines/field/channel	
TV system	625 line, 50 field, PAL 525 line, 60 field, NTSC	

APPLICATION NOTES:

1.) The VIMCAS system permits you to add extra channels to your VTR's without modifying existing equipment.

2.) The VIMCAS system allows simultaneous audio and video switching by a standard video switcher.

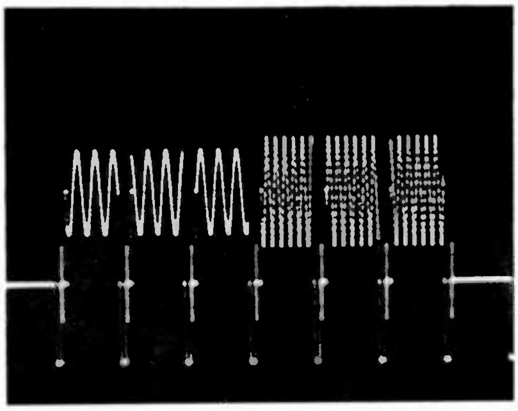
3.) VIMCAS provides the capability to transmit additional audio channels by satellite, microwave, and cable without the expense of additional power or bandwidth.

4.) Once audio is VIMCAS encoded, it stays with the video through normal video channel routing and handling. It is always decodable at the end of the video chain provided that portion of the VBI used stays intact.

5.) VIMCAS economically uses the VBI to allow use of stereo/multi-channel audio, stereo commercial passthrough, stereo program passthrough, multilanguage, ENG feeds, ENG foldback, background music, and data. The system is easily used in in-house, videotape, satellite, and microwave applications.

SUMMARY

In review, the VIMCAS approach addresses the needs of the industry in a very unique fashion. With true high fidelity audio and use of only 3 lines per channel, VIMCAS can be an effective solution to the ever increasing demands of today's marketplace.



NEW TRENDS IN WEATHER GRAPHICS, WEATHER DATA AND DELIVERY SYSTEMS

Dr. Joel N. Myers, President
Accu-Weather, Inc.
State College, Pennsylvania

Spectacular new developments in the presentation of weather information and forecasts have occurred since 1980. They are continuing and can be expected to continue through the foreseeable future.

Hand in hand with new developments in presentation, have been new developments in the supply of available weather data. This has given television weathercasters vastly increased resources upon which to base their presentations. These new developments include the satellite delivery of graphics and weather database products, new plainpaper FAX machines, and the withdrawal of AT&T from the land line delivery of weather data.

The weathercasters' maps and charts are like the reporter's film clip or interview. The weathercaster's report requires accurate weather "sources." And, unique to the weather show, is the presentation of a prediction about future weather events, something the news department undertakes in its field only on special occasions such as at election time.

In the corridors of the NAB exhibit floor, between the Accu-Weather booth, the ColorGraphics display, satellites shown by ESD, and a printer at the WSI booth putting out yards of paper, one could be left dazzled. The array of products, delivery methods and the task of evaluating the value of each for the bottom line can be overwhelming.

To help put all of these products and developments into perspective, I want to focus on three main areas. One is weather graphics, which includes satellite and radar images. The second is weather databases, such as WSI and Accu-Data™. And, the third is satellite delivery of graphics and data, including the new breakthrough in plainpaper NAFAX and DIFAX facimile machines.

The best way to evaluate existing products and services, and new ones as they appear, is to relate them to the qualities that make a weather presentation successful and highly rated. Eliminating the effects of the weather personality who is an undeniable plus, the qualities that lead to higher ratings are appearance and quality of graphics, the content and completeness of the weather database, and the accuracy of forecasting. Of course, all things being equal, cost must also be considered.

1. Graphics. The look and appearance of graphics is a function of the quality of the image which a station's graphics unit is capable of displaying and the quality of the graphics service being subscribed to. Some stations produce some of their own graphics while subscribing to an outside source for satellite and radar images and weather data, which may or may not be navigated onto their own map backgrounds. Other stations subscribe to an outside graphics service for most, if not all, of their images.

To produce weather images day in and day out requires artistically talented individuals on staff who are familiar with both the weather and the graphics unit. It requires that management dedicate the personnel and the equipment to the weather show day, evenings, nights and weekends.

To enhance the versatility of the station's options with both equipment and personnel, a ready-for-air graphics service can be used on a subscription basis. The graphics service allows the station to acquire some or all of the ready-for-air images it may want without tying up personnel and equipment to any significant extent. Also, it provides a professional look consistently. Of course, some images, like satellites, cannot be created in-house.

Ready-for-air graphics services vary. All of them -- Accu-Weather, ESD, Kavouras[1], and WSI -- have satellite images and radar plots. But, in the area of actual weather graphics -- weather maps, charts, temperature band maps, displays, and features -- they vary considerably. Some have only limited computer-generated offerings which are "stiff" looking. Others are created by professional artists using state-of-the-art graphics units units, and provide research tested looks as well as station specified custom graphics. These professional and customized graphics are what we pioneered at Accu-Weather.

These graphics services, which include satellite images, radars, temeprature band maps and dozens of graphics, are available by telephone dial-up and, in some cases, by satellite delivery.

[1] The Kavourus service is primarily limited to owners of Kavourus graphics hardware units.

Some stations are considering satellite delivery because of the long connect-time on the telephone, experienced when using some graphics services. On a modern system though, connect time per image should not exceed 1-1/2 to 2-1/2 minutes, with satellite images slightly longer. This short telephone delivery time is not operational with all vendors though, so care is advised.

Satellite delivery of graphics, up until this point, has only been beneficial for high volume users; that is, stations that need in excess of three or four hundred graphics per month. This is because the costs of putting in a dish, and then monthly transmission cost for satellite delivery, were quite high. When amortized over a number of graphics, it only made sense economically for satellite delivery of graphics when a station was able to subscribe to at least three or four hundred images per month. And some systems require a front end unit in order to get the graphics from the dish into the ColorGraphics receiver, and the front end unit can cost up to $13,000.

With the new Equatorial/SISCORP arrangement that is being represented by Accu-Weather, it becomes economical for a TV station to receive satellite delivery of graphics even if the station only wants to commit to as little as 150 graphics per month. This results from new two foot dish micro Earth stations and the latest computer technology.

2. Data. Special content for a weather show can come from wire service or network feeds when dramatic weather events are in the news, but on a day-in day-out basis a good weather presenter needs access to extensive weather data resources. The resources need to be extensive because of the variable nature of the weather and the need to secure certain types of information one day and other information the next.

NAFAX and DIFAX circuits and National Weather Service lines historically provided some of this information. Weather data cicuits and weather data bases provide the rest.

Also, this year, efforts at replacing NAFAX and DIFAX by private weather services have begun. Most aim at duplicating the NAFAX or DIFAX chart service with a different printer or delivery, aiming to deliver the same basic service. These changes are being fueled by increasing costs imposed by the government, especially by the fact that AT&T is phasing itself out of the data delivery business and by the fact that the National Weather Service has picked the Equatorial satellite system to deliver the NAFAX and DIFAX signal, as well as their other data circuits. These developments are leading to a major escalation of rates.

Where many stations have paid only $50 to only a few hundred dollars a month for a data line to connect up to NAFAX or a National Weather Service data circuit, in the next six months you may see bills for this data escalate to, in some cases, $500 to $1000 a month. This means that every television station will need to evaluate its means of acquiring data. If a station now has three or four different sources of data, such as NAFAX, Weather Wire, and the FAA line, it could see its line costs escalate from a total of $400 a month to perhaps as high as $2000 a month. On the other hand, if that station makes the appropriate change to satellite delivery, it could bring its costs back down to $400 a month, and perhaps wind up with even more valuable information. This is because some of the services, such as the SISCORP/Accu-Weather arrangement, have value-added data and information.

For example, a plainpaper printer can replace the traditional Alden facsimile, and the savings, by not having to use specially treated paper and by not having to rent or lease a complex Alden machine, can wind up giving a station more and better quality data at less money than it is paying now. So, we are entering a period of significant change when stations who do nothing will face strongly escalating costs. Where some stations have already made the jump early to a large satellite dish, they may now find it advantageous to switch to a small dish representing the new Equatorial technology. Extensive data need not mean expensive data, if the right choices are made.

Another option and new development in this area of databases is the Advanced Map Plotting System™ (AMPS™). It uses state-of-the-art computer technology to provide the user with the same kind of charts available on NAFAX and DIFAX, but at less cost, with greater timeliness and clarity, and with full user selectivity. Additionally, AMPS™ provides many products not available elsewhere.

The weather database was made necessary by the fact that there are 10,000 different kinds of weather data, summaries, synopses, forecasts and all kinds of weather information that come in from all over the world. Just in the United States, various weather informational products are generated by the National Weather Service, the Federal Aviation Administration, the Army, the Air Force, the Navy, and the Satellite Center and radar installations. Within the National Weather Service alone there are many different branches: the Hurricane Center, the Severe Storms Forecast Center, dozens of forecast offices around the country, nearly 1000 weather observing stations, each generating dozens of reports.

Each one of these 10,000 kinds of information then also contains many individual reports from individual reporting stations. For example, just one of the 10,000 is surface weather observations; yet surface observations come in every hour from about 1000 weather reporting stations around the country. Each weather report from each one of those thousand weather stations contains about 25 different kinds of information such as temperature, humidity, sky condition and barometric pressure, and each is encoded. The weather database takes all these large volumes of weather information, decodes it, reconfigures it, and makes it available to the meteorologist just what he needs in the format that is most useful to him and on a timely basis.

In addition, weather databases have been integrated into graphics equipment to navigate and display the latest pertinent information, such as temperatures and radar echoes. There are basically three weather databases: WSI, which has been in business for about six years, Kavouras and Accu-Data™. The Kavouras system is mainly restricted to Kavouras graphics units, whereas WSI and Accu-Data™ interface with most of the popular graphics systems including ColorGraphics, Vidifont, Chyron, etc.

The main differences between the databases are response time and cost. A weather database, depending on usage, can vary from a few thousand dollars a year to as much as fifty thousand dollars a year. Consequently, response time and cost should be looked at very carefully.

3. Satellite Delivery. As I mentioned earlier, major changes are going on in the area of satellite delivery. Perhaps the greatest new development is the fact that AT&T is getting out of the delivery business, forcing all television stations and meteorologists who want weather data to get it by satellite. Another new development is the patented spread-spectrum technology that Equatorial has, which allows highly accurate data and graphics transmissions with a small two foot dish. Some data companies only have the channel space available to deliver one or a few products by this Equatorial dish. As near as I can tell, these include Alden and WSI, whereas other satellite delivery companies can deliver as many as ten products on the Equatorial dish. One of these products which represents a major cost savings potential for stations is the WeatherMate 350, which is a plainpaper FAX machine that will take the NAFAX and DIFAX charts by satellite and, just to give you an idea of the costs, could be as low as $400 a month total for the rental of the machine and the satellite delivery. Typical current costs for receiving this information range from $400 to $1500 per month. This means that, for the first time, a station that has not been able to afford DIFAX can now subscribe to DIFAX for less than the cost it may be paying now for NAFAX alone.

4. Forecasts. The final key ingredient for a weather presentation is the forecast. Everyone wants to know what tomorrow's weather will be. This is also the most difficult ingredient to produce. Forecasting weather is both an art and a science. Forecasting-briefing services for television are available to support station personnel through a team approach, or to provide full broadcast services. Even a station with its own meteorologist may benefit by securing the services of a private weather forecasting service.

These services work with station personnel to produce accurate, tailored forecasts designed to fit the station concepts, personalities and audience preferences. Coupled with a strong local on-air personality and/or a promotable weather trademark, audience response can be tremendous.

Accuracy is, of course, the critical element of any weather forecast. Graphics, data, accurate forecasts and communication skills -- these are the cornerstones of the weather presentation. Some stations are fortunate enough to have expert meteorological, artistic and communication talent in-house to work on some or all of these tasks. Others have varying strengths. All can usually benefit from outside help in the graphics, database, forecast or communication end.

Selection of a weather service should be undertaken carefully. Some services are one dimensional, providing perhaps only satellite and radar images. Others are multi-dimensional, providing several different services, perhaps data and some graphics.

Lastly, there are one or two totally comprehensive services which provide all needed weather presentation elements -- graphics, data, forecasts, and communication skills.

A station should be able to select, in menu fashion, only those elements needed or desired. The comprehensive weather service company can be more flexible and cost efficient and provide for growth in a station's concepts over time. Dealing with a single supplier is also usually more convenient for station personnel.

Keeping the above perspectives in mind should greatly enable station management to evaluate the needs and future directions in weather presentation. And perhaps, more importantly, with the proper choices, a station can improve ratings while actually reducing weather costs.

KEEPING THE VIDEO CART MACHINE ON THE AIR AND OTHER MAINTENANCE PROCEDURES

Roy H. Trumbull-Assistant Chief Engineer
KRON-TV - San Francisco, California

The video cart machine is the one piece of equipment in a TV station whose failure can be directly measured in lost revenue dollars. It therefore assumes a high maintenance priority.

Potential Betacart problems are discussed as are troubles and fixes for the TCR100.

The role of the computer in a modern maintenance program is examined.

Keeping two cart machines on-the-air has given me a sense of humility and a feeling not unlike that experienced by Don Quixote when he saw his first windmill. We are changing to new cart machines this year and I must admit to mixed feelings. As the Russian saying goes: "Better the devil you know that the devil you don't know."

For the past four years we haven't trusted our cart machine enough to put it on the air during prime time. The prospect of losing one spot is bad enough but in an ACR25 or TCR100 a mechanical jam can cost you three out of four carts. In the top ten markets, in prime time, that can be a piece of change. Like many stations we've gone to a dub reel and one night that caught up with us when a capstan motor failed and there was no backup reel. During the recent Super Bowl we had two reels for everything.

As I write this we are installing a Betacart which, with 4 transports, will have better odds going for it. I think it'll be an improvement but I don't think it's the final answer. When engineers get together the ideal machine is always the laser disk. We're going to see a lot of action in the development of disk systems over the next five years. For the present, the answer is going to be multiple transport 1/2 inch format systems.

I don't know if it'll be a problem with the Beta format but we found the full wrap in the U-Matic 800s to be particularly hard to align. Our Dave Johnson developed a 3 page long procedure, that takes about a day and a half to do, which must be done whenever a time code or audio head is replaced in order to maintain track to track audio balance. I don't see anything materially different in the 1/2 inch BETA format. The simplicity of the M format tape path makes a lot more sense to me but I don't think it'll take a significant piece of the market until MII portable equipment is available.

Some stations developed 'cartitus' to the extent that they've installed walls full of transports. They don't want to ever again use a complex loading mechanism. I certainly can't fault that attitude. After all, in the Betacart there is one complex loading mechanism loading another in each individual BVW-11.

The stations I've talked to have averaged two to three failures of the elevator mechanism in the first year of operation. They all recommend having a spare elevator assembly on hand if you have just one Betacart.

But in all fairness, when asked to compare their operation now versus with their former cart machines they all report much lower discrepancy counts and greater operator confidence in the equipment.

One of the major tape manufacturers appears to be having binder problems with their carts. There is a loss of RF at the cue point and a contamination of the slip ring assembly with oxide. I don't want to name names because they are aware of the problem and are moving to correct it.

In major markets touch typing by union

technicians comes rather dear. Sony is wed to the 3.5 inch drive and MSDOS which is a combination only normally available on an HP computer. Walking into a computer store and asking about a conversion for a PC is like trying to make conversation with the three Chinese monkeys. I stayed up one night and forced myself to read an entire issue of BYTE and sure enough there is a company called Manzana that will add a 3.5 inch drive to a PC and one of their dealer's will write software to convert traffic files into Betacart files.

We'll be using the Grass Valley interface to load cart events from an M200 automation system into the Betacart but as a backup we'll have the days carts available on disk too.

The next step will be to wed a PC to the barcode printer so that the user portion of the label can be used for the agency master reel and cut number. I don't expect to get that done soon but when I do I'll sell it to you. Being able to load the days record order into the barcode system will save 4 man-hours of senseless retyping of information that already exists as a data file.

So much for BETA; since fate dealt me a pair of TCR100s to keep going these last 7 years, that's what I'll concentrate on for the remainder of my talk.

I have Pinzone diagnostic boxes tied into both machines to keep track of the state of all sensors. The TCR is loaded with switches and optical sensors. Pinzone makes a computer option that tracks load and unload cycle times to sense potential troubles and give an early warning. If I was keeping the machines a little longer I'd buy it.

We've had a lot of trouble with switches developing resistance and failing and with optical sensors going intermittent. Our machines are from the 9000 shop order series and came with the half park sensors that stop the sliders from retracting all the way after a load. The sensors were always failing and the last time we had Bill Bowen visit for a rebuild we had all that taken out to make the transports more reliable.

The other sensor that get's changed every time the machine goes weird is the supply reel tach sensor. If it's intermittent you can have a rather violent thread cycle in which the arms activate and release at a rapid rate. This is also the sensor to check when carts rewind and tear the tape right off the takeup reel. When you look at the amplified output of the sensor before it's shaped, it should not collapse in amplitude during high speed rewind. That's the criteria for setting the engagement of the sensor to the tach wheel.

The sensors are made by Sensor Technology in Chatsworth, CA. and may be bought from them directly. The model is STCT DA 200P per RCA reference number 20-10-1422.

A common problem with the reel brakes is that the cotter pin that connects the brake to the actuator breaks. We've gone for days with a paper clip in place of the cotter pin. James Weldon at WTVD came up with the simple answer of putting a #6 washer on the shaft before installing the cotter pin and that's greatly reduced breakage.

The floating damper arms in the tape path make use of an aluminum adjustment screw to set tension. There's a nut for that purpose but the screw is subject to excessive vibration and the screw threads literally get filed right off the screw. The metal filings contaminate the record amps causing blotches in the picture and terrible diff gain and phase. We regularly go through the electronics with an air blast. But we've greatly cut down on the filings by using an elastic stop nut on the other side of the screw to keep it from vibrating.

The reel servo contains a board known as the TKP Torque set board. By using the tach sensors it computes an initial torque when you're at some point other than the start of the tape. This is useful if you regularly edit on the TCR but if you don't then it's a good board to pull and put on the shelf. The board acts as a D to A board and stores a DC value. Sometimes it stores the wrong value and as a result the machine will never lock up. We've pulled ours and have installed jumpers to kill the warning tally.

One critical design flaw in the TCR was the 5 volt power bus which has a hard time delivering 5 volts to the top drawer without delivering way over 5 volts along the way in one of the other nests. Our Alan Eng split off the top drawer and we added another power supply and now the voltage is nice and solid. Before, not only was it low but it was loaded with spikes.

For years everyone argued about when and how to clean the capstan surface to avoid having it become sticky. We finally just stopped cleaning it altogether and our capstan failures have dropped.

Two years ago we routined out all of the sample and hold capacitors and replaced them with poly propylene capacitors which have exceptionally low dialectric absorption.

We had some head clogging going on and suspected a blockage in the vacuum system. One tip you may find useful is that with no tapes loaded the guide vacuum should read 35 pounds. If you press reset the pressure should drop to 22 pounds if there are no blockages.

These are just a few of over 320 tips I've collected on the care and feeding of the TCR. Years ago I formed an informal user's group to collect and computerize trouble reports and fixes. I've had reports from as far away as France and Australia. We've put all of our maintenance records onto the station's mainframe. Each record has up to six keywords which are used to generate an index of the records.

The advantage to such a database is that the overall available information base is much broader plus you have access to the experiences of techs who may be on vacation or others who left two years ago. You paid for all that knowledge so why shouldn't it be available when you need it?

I can't imagine doing maintenance today without using computers although that was certainly the case 5 years ago. We keep track of trouble reports, parts inventory, and do facilities planning and word processing. Computers increase productivity. Hewlett Packard's been taking that message on the road for years and it's true. We've five PC class computers plus access to the mainframe. We've just added a CAD system.

For me the bottom line on the maintenance of cart machines is that it's essential to make friends and share information. We have always lent parts to the other station in town with a TCR and will do the same for Betacart stations. People have called me from all over the country with TCR questions and before we made the Betacart decision I made plenty of phone calls. Nowadays they give this activity a fancy name; they call it networking.

All I know is that a company thinks twice about how they deal with a customer who regularly talks with six to a dozen other customers. It sure must give the salesmen some dark thoughts but in the end the resulting improved product benefits everyone.

ENGINEERING MANAGEMENT OF RADIO & TV TOWER STRUCTURES

R. D. Upsahl, T. Tschanz, M. J. Batt, S. D. Hansen
Skilling Ward Rogers Barkshire, Inc.
Seattle, Washington

ABSTRACT

This paper presents new approaches for assisting station management and engineering staffs to extend the service life and develop full utilization of their radio and television towers. Many towers, in service since the 1940's, are in need of a thorough field inspection and load rating.

Typical findings from completed tower evaluations include overly flexible towers with overstressed portions, slack guy lines and loose bracing, lack of adequate cross bracing for horizontal girths, missing and under torqued bolts, corrosion, and improper antenna and wave guide mountings.

An engineering management program for radio and television towers is outlined which describes tower evaluation, including field inspection, dynamic measurement and load rating; upgrading or repair, when required; and a preventative maintenance program. Also discussed is the impact of new transmission equipment additions to existing towers.

INTRODUCTION

The tower structure is an important component in the delivery of a communication company's service to market. Towers usually support many antennas which transmits signals not only to station listeners and viewers but to private or public agencies receivers. The tower's important service is sometimes taken for granted by all but the station's engineering staff.

A tower represents a sizeable economic investment. The cost in lost income and the effort planning and design, required to perform and deal with environmental concerns, permitting and public involvement that would be required for an untimely tower replacement could be equal or greater than the tower's construction cost. The process would also require a significant amount of time. Prudent communication companies have emergency programs to remain on-the-air during the period of time their tower might be out of service. Maintenance of a station's broadcast tower structure is obviously an important and high priority concern.

A review of tower design and conventional code analysis methods shows variations between actual wind loads and member forces and stresses associated with the different design codes governing tower design. New analysis procedures are described for determining design wind speed loads and member forces in dynamically responsive tower structures based on recent findings from wind tunnel research. Comparisons of safety factors from these analysis procedures show the differences in conventional code analysis and computed values using rigorous dynamic analysis for certain portions of example towers. Typical findings from completed tower evaluations are discussed.

SWRB is a structural and civil engineering firm located in Seattle with a staff of over 100. Our capabilities in structural design of very tall buildings has proven very useful to tower owners. Many of the buildings we have designed, such as the 110-story twin tower New York World Trade Center and 76-story Columbia Center in Seattle have similar design requirements to towers. Particularly, the firm specializes in wind engineering for tall buildings which has proven very applicable to dynamically responsive tower structures.

While working with members of the broadcasting community in the Pacific Northwest and Alaska, SWRB has developed an understanding of the concerns of tower owners, a knowledge of tower design codes and standards. SWRB personnel have had the opportunity to evaluate over ten existing free-standing and guyed towers in light of new analysis technology. Based on this experience, we feel the following engineering management program is extremely useful in assisting tower owners to extend existing tower service life, to develop full utilization of their facilities and to make an informed assessment of their towers' ability to withstand environmental conditions.

ENGINEERING MANAGEMENT PROGRAM

The engineering management program consists of the following:

- Tower Evaluation
  - field inspection
  - measurement of dynamic properties
  - load rating

- Upgrading Facilities or Repair
- Preventative Maintenance Program
- New Equipment Additions

Tower Evaluation

The initial step of the engineering management program is the tower evaluation procedure. This procedure establishes the current condition and structural adequacy of the existing tower. The evaluation is divided into three activities: field inspection, measurement of dynamic properties and load rating. The first two activities are completed in the field on the tower, while load rating consists of an office analysis.

All three activities are documented and presented to the owner in a report. This report describes the tower condition as it exists, the actual structural adequacy of the tower and each structural system member and connection, and makes recommendations for bringing the tower up to specification if this is indicated.

The Field Inspection of a tower may be completed in varying levels of detail. It consists, at least, of a top to bottom visual inspection and a measurement of the tower dynamic properties. It should be conducted by a structural engineer familiar with tower structural systems. A qualified inspector can then assess the need for additional inspection following his initial reconnaissance.

The Inspector that a tower owner hires should be more than a quality control inspector, who is more often concerned with only paint or corrosion protection. The inspector should be a structural engineer with background not only in inspection, but in analysis and design of similiar structural systems. A tower inspector must also have the proper skills, attitude, motivation and the physical climbing ability to collect the necessary information. Only then can a proper tower evaluation be completed and long range considerations be formulated by the owner.

The duties of the inspector include proper planning and preparation. Existing drawings are acquired and studied, if available. Methods for recording information in a logical fashion are established in advance. A permanent record of the inspection is made as it is accomplished with the use of field notes, photographs and video taping of the important findings. Photographs offer sharper resolution than video tape, but video supplies valuable audio comments.

The inspector must employ safe work habits and practices at all times. The proper equipment and tools must be available and utilized. An important consideration is working with an assistant who can provide safety lines when needed and can record information. When physical climbing is not possible in certain areas of the tower, a spider staging is a good alternative method for inspecting joints and members.

Proper clothing is important. It should be lightweight, but warm. The wind blows harder and the temperature drops the higher you climb. The climbing gear used should be good quality. A climbing belt is a must and a chest harness is recommended if there is the possible need for hanging from a member to inspect from below or outside. Safety lines provide assurance that if your primary line fails you've got a back up, just as redundancy is important in structures. Sometimes special tools are required such as torque wrenches, dynamometers, communications equipment and accelerometers.

Careful planning is critically important to an efficient and effective inspection procedure. The ascent of a tower can take some time, especially if carrying equipment. You can't return for forgotten items. The inspector must be knowledgeable about structures and be able to safely reach each member and connection. The structural system cannot be inspected from the ladder. The physical demand on the inspector limits the amount of time spent on each inspection trip.

Tower Inspection Procedures have been developed for free-standing and guyed steel towers. The inspector can utilize the historical information such as plans and specifications, shop drawings, and previous inspections to assist in the verification of "as built" configuration. Member size and length, bolt size, cable characteristics and material properties must also be verified. The material properties are checked whenever possible. A low stressed member can be removed (and replaced with a new member) and its mechanical and chemical properties, such as ultimate strength and weld-ability determined in the laboratory.

Procedures and items to look for in the inspection of towers:

- Utilize a systematic and thorough approach to inspect the foundation, structural members, connections and corrosion protection (paint).
- Look for deterioration at all joints and members including missing or corroding bolts.
- Look for corrosion of guy cables. Corrosion reduces the load capacity of the cable. Continued corrosion can cause individual strand failure, leading to reduced cable section and ultimate guy failure. Loss of one guy means collapse of the tower.
- All welds should be inspected. Ultrasonic testing is recommended in full-penetration butt welds to check for any cracks that may have developed over time.
- Check vertical members for straightness and corrosion. Look for stress concentrations as evidenced by flaking paint on the inside leg where a tower transitions from one framing system to another.

- o Check horizontal members for straightness and fasteners.
- o Check angle bracing and tension rod bracing. Note member straightness or bowed appearance, which may indicate insufficient compression capability for member length or tension members taking compression.
- o Member misalignments sometimes may be the result of a serious problem and should be studied to determine cause.

A continuing scheduled inspection procedure as part of a preventative maintenance program following an initial thorough field inspection will help increase the life of the tower. A log of reports should be established.

Tower Diagnostics is another important aspect of the field work which involves the determination of the towers dynamic characteristics. The stiffness of a tower is probably the single most important factor that an owner should be concerned about. In the case of a tower structure responding to wind loads, the less flexible the tower, the more desirable. Loose bracing and/or slack guy wires can be characteristics of overly flexible towers.

A measure of tower stiffness is determined by obtaining the tower's period of vibration as it is deflected by applied loads. The period of vibration is the time in seconds for the tower to deflect from vertical, recover and swing past vertical, and return or cycle back to vertical again. For a free-standing tower with a typical height of 500-feet, a period of two seconds is good, while a period of five seconds is not good. A tower with a longer period of vibration builds greater stresses in certain members than if it had a shorter period of vibration as it sways back and forth in the wind.

The period of vibration for a tower can be both calculated by knowing the structural system configuration and member properties or measured in the field. Measurement of the tower's actual period of vibration is preferable to calculation which assumes a "perfect" structural system. The comparison of these two values can yield very useful information regarding the actual dynamic performance of the tower. One way to field measure the period is to observe the movement of the tower during a strong wind storm by videotaping the movement.

Another way that we have found to determine the period that is reliable, accurate and provides other useful information is the accelerometer method. In this method the accelerometer is placed at various levels of the tower and the signal is transmitted to recording and plotted instruments at ground level. Accelerometers are mounted in triplets to record all directional and torsional periods.

The printout allows an accurate determination the primary periods along with damping properties. This information allows us to quickly determine if:

- o A tower is too flexible
- o Loose guy wires are causing a lack of stiffness in guyed towers
- o Bracing is loose or inadequate in the guyed or free-standing tower

The Load Rating of the tower is accomplished by office analysis utilizing information acquired in the field. Analysis utilizes the "as built" characteristics of the tower's structural system, its current condition and actual or measured period of vibration. The tower's structural system geometry and member properties is modeled on the computer. The weak links (or limiting members) of the overall structural system are thus identified. The capacity these members should carry is determined to enable the overall system to meet the required capacity of the design loads.

Upgrading Facilities or Repair

An upgrading or repair program should be initiated to correct deficiencies identified in the field inspection or load rating analysis, such as corrosion or structural problems. General corrosion problems requiring touch up or complete rehabilitation of the protective coating system can be accomplished by many painting contractors, particularly bridge painters.

Structural repairs requiring replacement of members or connections, or extensive retrofitting activities requires the use of special tower contractors. A limited number of qualified contractors are available; perhaps a handful are available on the West Coast. As a consequence, we have had little success with attempting to openly bid retrofitting work. Owners generally negotiate with a select group of contractors who are invited to submit proposals. Request for proposals must be carefully scheduled because often the contractors are very busy and won't respond.

The report documenting the tower evaluation process including field inspection, dynamic monitoring and load rating will list deficiencies, if any, and make recommendations for needed action. Routine problems such as painting, member or connection repair, replacing bolts and antenna mounting adjustments can be corrected by contractors without further engineering effort other than construction surveillance or inspection if desired by the owner.

When overstressed conditions are found, a further engineering effort is required to design needed improvements and prepare contract documents. Upon discovery of an overstressed condition in a tower, thorough analysis of the condition should be completed and alternative methods of correction developed. A cost effectiveness evaluation of the various alternatives is completed to allow the owner and engineer to establish a plan of action and priorites. Contract documents are prepared and a contractor selected to complete the retrofitting work.

The majority of deficiencies discovered during our tower evaluations which require correction fall into the following two basic categories:

Needed Maintenance and Repairs

- Nuts and bolts with corrosion
- Nuts and bolts missing from connections
- Connection plates with corrosion
- Corrosion in hidden and hard to paint areas
- Cracked insulators
- Corroded guys and connections
- Loose bracing and guys
- Bowed members

Structural Inadequacy of Tower at Design Wind Speed

The most significant condition found on some towers evaluated to date is an overstressed condition existing in the top portion of the tower. The conventional static design analysis utilized in most existing and new towers, as explained later, produced designs lacking stiffness and strength in the top portions. These overly flexible towers have long periods of vibration with attendant higher stress in the structural members than was allowed for in the original design because dynamics were not considered.

Towers with these overstressed conditions exhibit flexibility for several reasons including the use of high strength steel in the design, or utilization of a wider spaced bracing system in the top portion of the tower. Both these reasons allow a tower to meet static load conditions but lack stiffness which allows high dynamic loads.

A number of key alternatives are available to solve this compressive buckling overstressed condition, including:

- Add material to structural members to increase capacity and/or reduce stresses
- Stiffen the tower to reduce the period of vibration and reduce the dynamic loads and member forces and stresses
- Combinations of the above

The first two alternatives above are very interrelated. Increasing structural member cross sectional area by adding material will accommodate higher member forces and reduce stresses while also increasing stiffness. Sometimes adding bracing increases stiffness even more and effectively reduces dynamic loads.

Our designs usually involve an optimization process of adding cross sectional area to key structural members and stiffening the structural system by adding bracing. Other methods of stiffening are tightening existing bracing and connections. In guyed towers, recalculating guy forces and retensioning cables may also increase stiffness.

Different combinations of methods are analyzed by the computer model for design efficiency. The model takes into consideration aerodynamics of the addition materials and icing as it reanalyzes tower stiffness and dynamic stresses. Construction cost of each method is also determined to obtain the most efficient and least cost alternative.

Tower structure cost is a function of materials, fabrication, erection, protective coating and mobilization and general conditions. Tower costs are relatively sensitive to labor. Thus, simple solutions utilizing fewer, easily fabricated and erected material additions or changes are usually the most cost effective. Our experience has shown the cost of strengthening the top portion of towers can vary from five to fifteen percent (5 - 15%) of the existing tower value.

Retrofit programs have successfully returned existing towers to full capability in meeting their design capacity. These same programs can also develop additional capacity to meet the requirements for additional transmission equipment. Analysis, as a side benefit, yields information on the best location for these facilities relative to strength and minimum antenna displacements.

Other alternatives worth mentioning which can increase stiffness are: adding guys, widening the distance across the faces of the tower, adding tuned mass dampers and spreading the tower legs. These would be effective, but may not be practical, too costly or space limiting.

Replacement of antennas with lighter weight antennas is also expensive, but is very effective in reducing dynamic stresses in the upper portions of towers. In one case, reduction in antenna weight of 2.6 tons resulted in a sixty to eighty percent (60 - 80%) reduction in dynamic stresses in the upper portion of a guyed tower.

Preventative Maintenance Program

Tower maintenance involves the work necessary to keep the tower structural system and the mounting systems for the additional specialized equipment such as antennas and cables operational. The general term "maintenance" can be divided into corrective maintenance, which involves repair after breakdown and preventative maintenance, which constitutes the efforts and precautions taken to prevent breakdown.

A carefully considered and implemented preventative maintenance program will serve an owner well. The program should consist of an initial tower evaluation including field inspection, measurement of dynamic characteristics and load rating; plus completion of repairs or upgrading, if necessary. This should be followed by execution of a regularly scheduled inspection and maintenance program. This program is recommended for both existing towers and new towers. New towers designed by conventional static code analysis should also have their dynamic properties measured and be load rated. Once the tower has received its initial inspection, then the suggestions included in Figure 1 - below can be implemented.

TOWER INSPECTION AND MAINTENANCE

Yearly	Y	After Storms	A
Monthly	M	Manufacturer's	S
Daily	D		

Item	Period	Item	Period
Structure		**Foundations**	
Alignment	Y A	Base Details	Y
Paint	Y A	Guy Anchors	Y
Corrosion	Y	Insulators	Y
Members	Y A		
Connections	Y A	**Operational**	
Vibration	Y	Safety Devices	D
		Ladders	D
Guys		Elevators	M S
Tensions	Y A	Antenna Mountings	Y A
Strands	Y A		
Corrosion	Y	Conduits & Waveguides	Y A
Sockets	Y A		
Pins	Y	Lighting & Fixtures	D A S
Insulators	Y		

FIGURE 1

Items listed in the figure should be inspected as suggested and maintained in good condition. Protective coatings should be inspected yearly and after major storms. A complete cleaning and painting of the tower should be scheduled every seven to ten years. Guy lines should be considered for replacement if corroded or where tensioning records show a decrease in tension per manufacturers recommendations.

Once the tower evaluation program is completed and the tower is on a regularly scheduled preventative maintenance program, an owner should have an excellent understanding of the structural adequacy of the facility and confidence in obtaining full utilization of the facility during its expected service life.

New Equipment Additions

A continuing demand exists for installation of new equipment on towers. Many times, permitting agencies are reluctant to allow mounting of additional equipment on existing towers without further analysis. Once a tower is load rated and a computer model exists, an analysis can easily be provided showing additional capacity should it exist.

When making new equipment additions to towers, reduction in tower member loads and stresses may be realized by using light weight equipment. Owners and manufactures should be advised of these advantages. Reduction in weight of main TV antennas would allow substantial reduction of stresses in existing towers and more economical designs of new towers.

TOWER ANALYSIS PRACTICES

This section reviews conventional and advanced tower design and analysis practices. Most towers have been designed utilizing a conventional static analysis governed by various design codes. The design codes historically have approximated wind pressures and characteristics for analysis. Only recently have these codes recognized the importance of the variability of wind and dynamic behavior of structures. Recent advances in wind technology, and the dynamic behavior of structures, together with advanced computer analysis has allowed analysis of towers as they really work. Comparisons of these two analysis methods and findings are discussed.

Conventional Static Analysis by Design Code

In tower design, the structural engineer designs a structural system capable of resisting the vertical gravity loads (dead loads) of the structure, such as structure weight, equipment, antennas, ice, etc. and lateral loads (live loads) such as wind and seismic loads. In the case of a tower structure, the wind induced loads are much greater than self weight or seismic loads and therefore control in the design. The design procedure is simple. The designer enters the design code and obtains a design wind pressure for a particular geographic location and applies it against the exposed frame of the structure. The cantilever moments and shears are then determined for the free-standing tower. For the guyed tower, the multiple or continuous span moments and shears are computed. A structure is then designed to resist these forces.

The accuracy with which loads are known, play an important role in the analysis and design of tower structures. Some loads, such as gravity loads, can be very accurately determined, while other loads, such as the wind, are not well known. Wind induced loads do not have a constant value which can be entered into a static structural analysis. The variability of the load placed upon a tower structure by the wind is defined by its turbulent properties and probability of strength and occurrence. Additionally, variable wind loads cause tower structures to exhibit dynamic behavior, which introduces additional bending load due to swaying motion which complicates analysis further.

In the past, the technology had not developed a complete understanding of how the wind acted upon a structure, nor had designers the means to accomplish the ultimately required sophisticated analysis. As a result, designers, industry and public agencies charged with tower construction responsibilities incorporated into the design codes what was thought at the time to be the most prudent approach to determining wind induced loads. In part, this amounted to a standardized method for approximating wind pressure envelopes on structures which hopefully developed a design value greater than an actual value for the design wind speed. Suggested design wind pressures for geographic areas of the United States were mapped. Dynamic effects if recognized by a code were usually handled by a globally applied load increase. Thus when a tower experienced its design wind speed, designers had hopefully allowed for a wind load on a member at least as great as was actually imposed.

Code authorities and industry continue to monitor tower failures and the success of the system overall. Historically, the factors used to determine wind loads have increased with each new addition of the various design codes. The latest editions, although allowing conventional analysis, now recognize the importance of dynamic behavior and recommend a more rigorous approach to analysis, especially in the case of towers.

Design Codes

These design codes are often utilized for the structural design of towers depending on jurisdiction and when the tower was designed:

- o Electronic Industries Association (EIA)[1]
- o Uniform building Code (UBC)[2]
- o American National Standards Institute (ANSI)[3]

All three codes approach the definition of wind pressure acting on a structure in a similar manner. All codes provide a formula composed of factors which are combined to obtain a pressure (pounds per square foot) for a particular wind design speed. The designer chooses factor values from provided tables and computes the design pressure. The codes differ somewhat in the number of factors used and in the detail provided for each factor. The pressure is then multiplied by the exposed area of structure to determine a lateral force usable in determining the bending moment and shears acting upon the tower structure.

Electronics Industries Association (EIA) Code
"Section 2.1.3 Wind Loading - Wind loads shall be defined as the maximum forces and torques produced by a specified unit horizontal wind pressure acting on the towers, antenna assemblies, reflectors, guys and other appurtenances attached thereto. In all cases, the specified ice coating shall be included as part of the projected area."

The EIA code provides a table of wind pressures which considers geographic location by zone and height of tower structure. This pressure value is further modified by shape of structural member and type of structure: latticed (most towers) or closed face (buildings). The EIA code also state that "wind loads shall be considered basic design loads with no increase in the basic allowable unit stress."

The Uniform Building (UBC) Code, 1982 edition, Section 2311.(1) states:

"**Wind Design Sec. 2311.(1) General:** Every building or structure and every portion thereof shall be designed and constructed to resist the wind effects determined in accordance with the requirements of this section. Wind shall be assumed to come from any horizontal direction. No reduction in wind pressure shall be taken for the shielding effect of adjacent structures.

Structures sensitive to dynamic effects, such as buildings with a height-width ratio greater than five, structures sensitive to wind-excited oscillations, such as vortex shedding or icing, and buildings over 400 feet in height, shall be, and any structure may be, designed in accordance with approved national standards."

The UBC provides a formula for determining design wind pressures. The design wind pressure is determined by multiplying together values for a combined height, exposure and gust factor coefficient; a pressure coefficient for the structure or portion of structure under consideration; the wind stagnation pressure at a standard height of 30-feet for a particular basic wind speed (taken as a 50-year wind speed from a map showing geographic location in the U.S.); and an importance factor.

Flexible radio and television towers certainly fit the UBC definition of structures sensitive to dynamic effects. The approved "national standard" referred to above is the American National Standards Institute (ANSI) code.

The American National Standards Institute (ANSI) Code states that two procedures may be used for determination of wind induced loads, as outlined in Section 6.4 of the code:

"6.4 Calculation of Wind Loads

Sec. 6.4.1 General: The design wind loads for buildings and other structures as a whole or for individual components and cladding thereof shall be determined using one of the following procedures:

(1) Analytical procedure in accordance with 6.4.2.

(2) Wind-tunnel procedure in accordance with 6.4.3"

The analytical procedure determines a pressure that is expected to act on a structure. The procedure recognizes the differences of dynamically responsive structures and utilizes separate formula for determining pressures. The gust response factors, pressure coefficients and force coefficients of this standard are based on a mean wind speed corresponding to the fastest-mile wind speed for a particular geographic location. The design wind speed (50-year frequency is converted to a pressure acting at a particular height. The gust response factor accounts for the additional loading effects due to wind turbulence and dynamic amplifications for flexible structures, but does not include allowances for aerodynamic effects such as crosswind deflections, vortex shedding or flutter. Charts are only provided for uniform mass, vertical faced type structures. The ANSI procedure still provides the designer a pressure for a static tower analysis but utilizes factors which bump up the static design pressures to compensate for dynamic effects. The ANSI procedure remains a static quasi-dynamic procedure.

Section 6.4 and Appendix A6.6 of the ANSI code provide a procedure for buildings but section 6.4.2 cautions that other structures require judgement on the part of the designer:

"**6.4.2.2 Limitations of Analytical Procedure.** The provisions given under 6.4.2 apply to the majority of buildings and other structures but the designer is cautioned that judgment is required for those buildings and structures having unusual geometric shapes, response characteristics, or site locations for which channeling effects or buffeting in the wake of upwind obstructions may warrant special consideration. For such situations, the designer should refer to recognized literature for documentation pertaining to wind-load effects or use the wind-tunnel procedure of 6.4.3"

All three codes share similarities in procedure, that of providing a pressure applied against exposed surfaces useful in a static analysis. The UBC and ANSI codes also recognize the importance of dynamically responsive structures and allow for a more rigorous approach for analysis.

Wind Speed and Exceedence Frequencies

Wind speed or wind pressure criteria for tower design in the United States is well documented and is available in all three codes. The Electronic Industries Association (EIA) shows a U.S. map of EIA Basic Wind Loading Zones. The map defines, geographically, three basic zones: A, B and C. Table information defines minimum horizontal wind pressure in pounds per square foot for height ranges 0 to 300 feet, 300 to 650 feet and 650 feet and above. In all cases EIA allows two-thirds of these pressures for round members. Pressures vary from 30 to 85 pounds per square foot by height and geographic location.

The American National Standards Institute (ANSI) show a basic wind speed map for the U.S. This map outlines the basic wind speeds and special wind regions for the 48 states. The basic wind speed is shown as at least 70 miles per hour with some contours as high as 110 miles per hour. Special wind regions are also defined. The Uniform Building Code (UBC) usually adopts the ANSI Code for wind speed contours. However, the 1985 UBC has shown some increases in wind speed for various locations.

Wind speed data and wind speed probability or exceedence frequencies are compiled from decades of records by the National Weather Service (NWS) at over 129 locations in the U.S. Most large airports have a NWS office. Wind information published for these locations includes various wind speed rates by definition, wind speed probability of occurance, and directional probability and magnitude.

One of three wind speed measurements appears as the statistical wind speed. The "fastest mile" is the highest recorded average speed at which a mile of wind passed the station. The "fastest minute wind" is the highest recorded velocity sustained for one minute. The "peak gust" is the highest recorded instantaneous wind speed. The "fastest mile" and "fastest minute wind" average out to approximately the same value, and "peak gust" values are about 1.3 times the "fastest minute wind." Previous studies for extreme wind analysis and structure design have established the annual "fastest minute wind" as the most appropriate design value. Newspapers usually report gust speed during storm periods. Design wind speeds are sustained values and would normally be less dramatic when reported during a storm.

When determining a design wind speed, the engineer as directed by the design code acknowledges a risk factor. This risk factor is defined by the probability or acceptability that a wind storm exceeding the design wind speed could occur during the scheduled lifetime of the structure. Most codes require this to be at least the 50-year wind storm or event.

Unfortunately, the 50-year wind storm is commonly thought of as a wind speed exceeded once every 50-years, and further, not likely to even occur for 50 years. Statisically, however, a 50-year event is defined as the wind speed which has a two percent probability each year of being exceeded. This basically establishes the level of risk acceptible that a wind speed exceeding the design wind speed has a two percent (2%) chance of occuring during each year of the scheduled lifetime of the structure, this year, next year, every year.

In Seattle, for a return period of 10 years, the estimated maximum sustained wind speed (not gust speed) is about 55 miles per hour (MPH). That means a ten percent (10%) chance exists that a 55-MPH mean wind speed storm will be exceeded in any year. The 50-year (two percent chance) wind speed is about 70-MPH, and the 100-year (one percent chance) wind speed is about 75-MPH. The Seattle Building Code requires a design wind speed of 80-MPH. The highest sustained wind speed measured in Seattle was 66-MPH in 1981, although higher gust speeds occur occasionally, of course.

Statistical data is also available for the combined occurence of ice and wind. The ice coating of a tower adds both weight to the tower and increases member area exposed to the wind. Ice and wind have combined to bring down numerous guyed towers.

Current Wind Engineering Technology

Wind tunnel research, since the 1960's has provided considerable knowledge into the fundamental mechanisms of wind characteristics and wind loading effects. Design of such structures as the 110-story twin tower New York World Trade Center by our firm, the 1800-foot high free-standing CN Tower in Toronto, and other tall structures has assisted in the development of wind engineering technology. It is well known that structure loads, specifically loads in structural members induced by wind, depends primarily on a.) the probabilities that certain wind speeds are reached, b.) the turbulent properties of the wind, and c.) the dynamic properties of structure.

Turbulent Wind Characteristics include wind speed, direction, turbulence and correlation, local effects and special conditions. Most design codes recognize the variation in wind speed both relative to probability of exceedence (discussed earlier) and also with height above ground level. The static velocity profile of wind (velocity relative to the distance from the ground) is not uniform, but increases approximately with a parabolic relationship from ground level up to 1000 to 2000 feet. This elevation is also called the wind gradient. Velocity up to the gradient level is dependent on surface conditions. Trees and houses slow the velocity down such that it approaches zero at gound level. However, up to some height, the velocity increases and approaches its uniform maximum value, not-changing above that level.

The wind is also directional. In Seattle for example, the probability of high winds is far greater from the southwest than from other directions. Most codes disregard directional effects, which is best handled by wind tunnel tests.

The turbulence of wind dominates the response of flexible stuctures such as radio and television towers. These big wind eddies may be thought of as wind impulses randomly thrown at the structure. Wind impulses can load the tower at different levels, at regular or irregular time intervals, with varying energy causing the tower to sway around. Any combination of these parameters is possible, and certain turbulent patterns will affect a structure more severely than others. These patterns depend on a structure's drag coefficient and surface shape. Fortunately these impulses are not very well correlated, when a big one hits a part of the structure, it is likely to be hit by smaller ones at the same time some distance away. This correlation is taken into account as well as the turbulence in dynamic analysis.

The local effects such as geographic location, topography and upstream exposure can be very important. A ten percent (10%) sloping hill can increase wind speed by twenty percent (20%) as it passes over, resulting in fifty percent (50%) higher loads on a structure placed on top of the hill. Tops of hills make better locations for windmills than towers based soley upon this parameter.

Special cases such as hurricanes and tornadoes may also be important, although a radio and television tower could not be economically designed to withstand a tornado.

The Dynamic Properties of Structures which control its dynamic behavior in the wind include its mode shapes, period of vibration, stiffness, mass and its distribution, structural damping and aerodynamics. Flexible structures such as radio and television towers are heavily influenced by the wind.

A tower has a natural mode of vibration in every direction. The individual mode shape functions are geometric descriptions of a structure's natural response to external stimulations. They are affected by the design, the masses and their distribution, and the properties of the members within the structure. The fundamental mode is the shape the tower assumes as it sways back and forth, with the horizontal deflection measured from the vertical axis and varying proceeding up the tower. The greatest deflection is at the top for the first (fundamental) mode. Higher modes may have the maximum displacement at other elevations. An infinite number of higher mode shapes exists, variable with different geometry or mass distribution. The period of vibration is the time, usually in seconds, for the tower to move once back and forth through a point. Each mode has an associated period of vibration.

Building designers must be very careful in controlling building sway or drift. Unihabited towers, however, sway more and act differently than buildings but are often designed with the same code or by industry codes which do not take into account the differences.

A delicate relationship exists between a structures mass and its stiffness. The stiffness describes how high a force is needed to move a structure a given amount. High stiffness in a structure is desirable but expensive if achieved with large amounts of material. Heavy mass is also less easily moved around by the wind. However, one would expect that as the mass of a structure increases, the period of vibration would also increase, leading to less desireable higher stresses in resisting members. One must increase mass somewhat to increase stiffness, as stiffness depends primarily on the sizes and geometric spacing of the member-elements. Large masses are therefore acceptable, provided they are accompanied by adequate stiffness. Note that just adding dead weight, such as antennas, acts detrimentally because it lengthens the period and does not add stiffness. Modern structures use less and less materials for reason of economy. Stiffness must be achieved through ingenious framing systems.

Structural damping is the ability of the structure to resist dynamic motion and return to a static, stationary state. During an ongoing dynamic event, the system's damping ability limits it from becoming in a continuously increasing state of excitation. With zero damping, the structure would sway more and more with each cycle from energy added by the wind. Thus, the same amount of energy must be removed from the system, as added, to prevent destruction of the system. Radio and television towers have very little damping, perhaps one half of one percent (½%) of critical. Unfortunately this is a very low value which makes them dynamically sensitive.

Aerodynamics represent the remaining property of the turbulent wind. Fortunately, towers do not normally exhibit serious problems such as the famous Tacoma Narrows Bridge, a suspension bridge which destroyed itself in the wind. However, it must be assessed if vortex shedding could occur where the structure has large movements in the cross wind direction. Other aerodynamic properties such as drag coefficients for members are defined by their shape and angle to the wind.

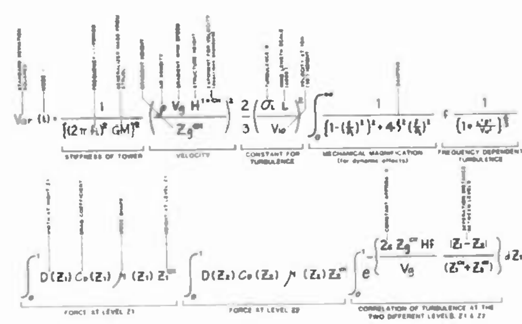
Many of the basics of wind engineering were learned in wind tunnel tests which is the best method currently available for structure evaluation. Unfortunately, these tests are complex and relatively expensive for a structure which costs less than, say, $10 million. In a wind tunnel test all the surrounding terrain, buildings or neighboring towers would be modeled.

Advanced Computer Analysis allows towers to be analyzed the way they really work. Our method spends more effort to accurately determine wind induced loads through consideration of the characteristics of turbulent wind and the dynamic properties of tower structures, than do conventional design code governed static analyses. Once structure loads are defined, finite element analysis of the tower structural system determines member forces and stress values. This method can be used to analyze and load rate existing towers as well as design new towers.

Our analysis procedure for flexible tower structures considers the tower being subjected to two parts of wind load: static loads due to a leaning away from the wind a roughly steady amount, and dynamic loads due to a fluctuating about the static position due to turbulence in the wind. Once determined these two load parts can be combined to obtain the various total wind loading cases. Many load cases exists because the various dynamic mode shapes of the structure are produced by wind loads.

The static wind load analysis determines the average leaning position of the tower for the average wind speed encountered during a design wind speed storm, usually the 50-year event. Drag coefficients of structural members exposed to the wind used in determining the wind loads at each level of the tower are obtained from charts produced by the International Association for Shell and Spatial Structures[4]. These coefficients probably will be universally adopted some day by design codes for lattice structures. The dynamic components or displacements of the tower then move around this mean position.

The dynamic wind loads are determined by our WIND program by calculation of dynamic displacements occurring at each level of the tower through integration techniques. These techniques consider the basic components of the structure's mass, period of vibration, damping, turbulence and correlation. The basic formula used in this procedure is shown in Figure 2.



EQUATION TO DETERMINE DYNAMIC DISPLACEMENTS

FIGURE 2

The original research and concepts of dynamic response in structures utilized in our analysis were developed by A.G. Davenport5 On-going wind tunnel research by Davenport, Director of the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario and others on individual parameters has made them more accurately defined. ANSI recognizes the procedure in Appendix A6 by providing simplified charts, applicable to buildings. Our procedure follows the same intent, except in a much more detailed way suitable to towers.

Once the static and dynamic wind loads are determined this information is input to our in-house mainframe computer which utilizes our enhanced version of STRUDL (Structural Design Language) to model the entire structural system of the tower. Tower computer models often contain over 3000 members. STRUDL's finite element analysis procedures determines forces and stresses for all the many load cases in each structural member of the tower.

Non-linear behavior such as observed in guyed towers requires several iterations of this procedure. Conventional static analysis of guyed towers treats the system as a multiple supported beam. The guys are considered as fixed supports where they connect to the tower. Our analysis recognizes guy connections or supports as exerting variable levels of load. When the tower moves away from the wind, force in the front guys increase but at a variable rate depending on guy inclination and size. Force in the back guy decreases in a similar manner. The force in the guy is a function of wind load and distance displaced, much like a spring. In fact, our analysis treats these supports as a spring. Analysis of non-linear systems require many iterations by computer, more of a tuning process. Guyed towers still need much research to be fully understood.

Findings From Advanced Analysis

Figure 3 graphically shows the comparison of leg stress resulting from a load rating analysis of free-standing generic towers of like geometry but designed utilizing wind pressures (same design wind speed) defined by each of the codes shown. The leg described is the compression leg. This is the most critical leg of a three-legged free-standing tower. It is located on the side away from the direction of the wind and is most vulnerable to buckling. The horizontal axis represents the level of stress computed by means of our rigorous analysis in this leg at each vertical elevation of the tower (vertical

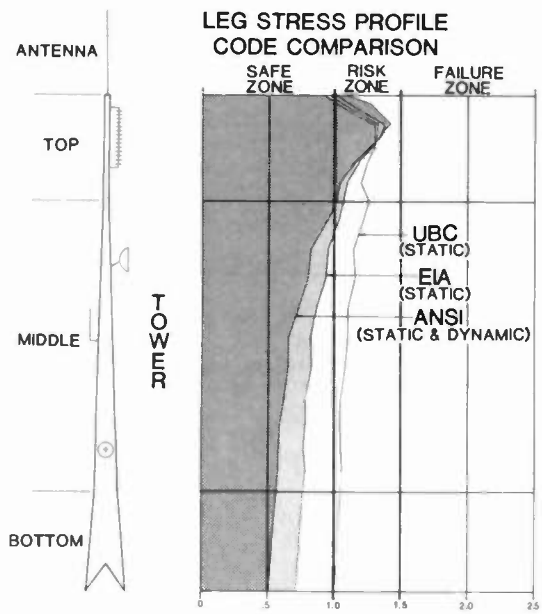


FIGURE 3

axis) utilizing the loads and resulting characteristics of the tower as would be designed by means of each code. The leg stress (horizontal axis) is represented by a ratio of the computed load in the tower leg divided by the allowable load. Thus a factor of 1.0 on the horizontal axis represents one hundred percent (100%) of allowable stress in the leg and 0.5 represents fifty percent (50%) of allowable leg stress. The horizontal axis is also divided into zones of risk (safe zone, risk zone and failure zone.)

The profile shown is what we believe to be the actual stress occuring in the leg at each elevation. The conventional static analysis and individual code standards which defined each of the generic towers predicted that the leg stress at each elevation would be at 1.0 or one hundred percent (100%) of allowable. The actual stress (computed by our method) shows that the example UBC designed tower is actually overstressed throughout its entire height. The ANSI and EIA codes generally produce towers understressed in the bottom portion of the tower, while all codes produce towers overstressed in the top portion of the tower.

This condition of overstress has been determined to exist in many tower we have evaluated to date. We further have observed in several towers paint entirely flaked off leg members following fairly severe wind storm in the portion of calculated overstress. This is an indication of physical distress in the system. Towers displaying this condition have been strengthened.

Again, observing Figure 3, the goal when designing a new tower or retrofiting an existing tower would be to a.) determine the actual wind loads with a high degree of accuracy based upon a particular wind design speed, and b.) then design a new tower structure or strengthen an existing tower such that the allowable leg stresses (and horizontal and diagonal member stress) achieved exactly one hundred percent (100%) of allowable stress at every elevation in the tower. This profile would be represented as a vertical line at 1.0 on the figure.

Figure 4 graphically demonstrates the differences in leg stress (static and dynamic effects) for the same free-standing generic towers based on different wind design speeds. Note that for an 80-MPH design wind speed as used in Seattle, the leg stresses are in the risk zone, while for 50-MPH wind speeds stresses are only fifty percent (50%) of allowable. Many tower owners often state "... but my tower has stood up for so many years...". In the Seattle area, this is because we have not seen the wind design speed. Our highest sustained wind speed date has been 66-MPH, which occured recently.

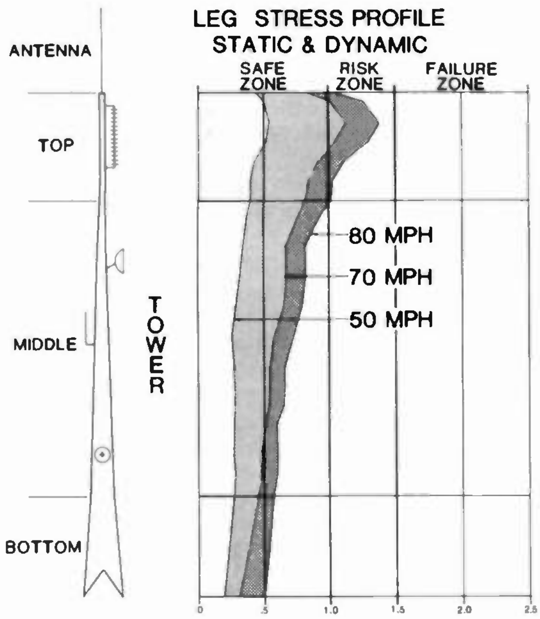


FIGURE 4

Static and dynamic stresses increase rapidly with increasing wind speeds, the static stresses by the square of the velocity (i.e. a doubling of the wind increases the stress four fold), and the dynamic stress by an even higher factor, such as the velocity to the 2.5 power. Static stresses would typically be high due to large exposed areas at high tower elevations. Dynamic stresses depend, in addition, on the natural period of vibration, the damping of the structure, and the amplitude of the mode shape. In fact, an increase of only ten percent (10%) in period length increases dynamic stresses by twenty percent (20%). The period depends upon structural stiffness and mass which are not considered at all in the conventional analysis.

Figure 5 graphically describes similar findings in a generic guyed tower. Guyed towers display non-linear behavior which makes their understanding and evaluation much more complex than free-standing towers. The figure compares total load in the back tower leg determined by the conventional analysis procedure of static linear design, to our static dynamic non-linear design approach. The back leg is most vulnerable to compression buckling. The conventional approach determines a wind pressure which is applied to the tower structure. The total load in the back leg is determined by combining the dead load with the static wind load. In our procedure, a wind pressure is also applied to the tower. The total load in the back leg is determined by combining the dead load, plus the static wind load, plus the dynamic wind load.

Note in our procedure the differences between the load curves for static wind load because of the variability in guy forces which are treated as springs. The most important comparison is that of total load determined between the two procedures. Our procedure defines a much greater load in the top portion of the tower than does the conventional procedure. We have experienced several guyed towers with overstress conditions in the upper portions. These have been strengthened.

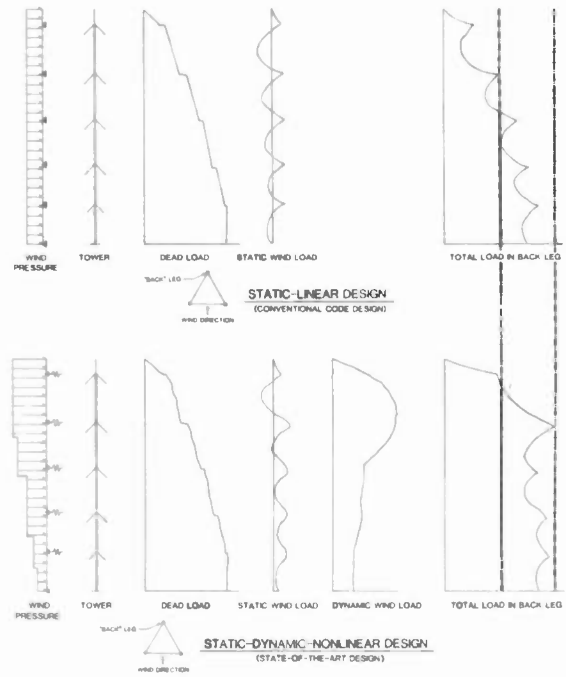


FIGURE 5

CONCLUSIONS

A structural engineering review of radio and television towers shows that most towers can benefit from an engineering management program. This includes field inspections, dynamic measurements, advanced stress analysis, upgrading and repair and maintenance. The procedures are described in detail in the paper, including more accurate procedures to determine stresses, taking into account the wind turbulence and dynamic behavior. By use of examples it is shown that procedures used in the past result in towers whose safety is compromised by weak links. As described in the text, upgrades are possible.

ACKNOWLEDGEMENTS

The Authors would like to acknowledge the contributions of a number of individuals to the preparation of this paper. These include management and engineering staff from radio and television broadcasting companies in the Pacific Northwest and SWRB members, Mr. Al Jones for preparing the graphics and Ms. Catherine Branstetter for the typing of the manuscript.

REFERENCES

1. Structural Standards for Steel Antenna Towers and Antenna Supporting Structures EIA Standard RS-222-C, Electronic Industries Association, Washington, D.C., 1976.

2. Uniform Building Code, 1982 Edition, International Conference of Building Officials, Whittier, California, 1982.

3. American National Standard Minimum Design Loads for Buildings and Other Structures, ANSI A58.1-1982, American National Standards Institute, Inc., New York, New York, 1982.

4. Recommendations for Guyed Masts, The Working Group on Guyed Masts of The International Association of Shell and Spatial Structures, Madrid, Spain, 1981.

5. A. G. Davenport, The Response of Slender Line-Like Structures to a Gusty Wind, Journal of the Structural Division ASCE, December, 1963.

NEW TECHNIQUES IN CONTROLLING AND DOCUMENTING ICE BUILD-UP ON TALL TOWERS

Karl Renwanz, Vice President, Engineering & Operations
WNEV-TV
Boston, Massachusetts

The problem of tower icing has long faced the broadcaster for both self-supporting and guyed towers. Many tower owners have experienced the collapse of a giant metal structure under the tremendous stress of ice build-up. As if this fear wasn't enough, in recent years civilization has moved closer to broadcast towers causing concern for personal injury and liability problems. Cities and towns across the country have approved residential and business construction permits under the shadow of many tall towers only to find out later that significant ice damage can result from winter and spring storms. The fact that the tower was constructed first does not take away the broadcasters liability in this situation and consequently broadcasters must seek solutions to this additional liability.

At WNEV-TV, Boston, we utilize a self-supporting 1067 foot structure in Newton, Massachusetts. Our tower spans 114 feet at the base and even at the 800 foot level, the tower is still 18 feet wide. With an estimated 120,000 square feet of steel surface many potential solutions to ice build-up must be ruled out simply due to the sheer mass of the structure.

After suffering through a couple of intense ice storms in the Spring of 1984, WNEV-TV undertook the task of aggressively seeking a solution to the ice buildup on our Newton tower. Contacts were made with numerous individuals and organizations who had done previous work in the field of ice research including NAB which had a committee researching tower ice problems for more than a decade. We found little or nothing in the way of solutions, only more questions. After numerous contacts, it became obvious that the leading research group was the United States Army Cold Regions Research Laboratory (CRREL), a group of more than 300 scientists and engineers located in Lebanon, New Hampshire whose research deals with cold weather phenomenon. Representatives of CRREL were very excited about our interest in seeking a solution to the tower icing problem and admitted that there was no known practical solution to their knowledge.

While CRREL did have certain policy restrictions on their involvement with a privately held company researching ice build-up, they did commit data analysis and software support to our effort so the data would be more meaningful and perhaps help CRREL in further research as well. We jointly designed an elaborate monitoring system which included five cameras and three meteorological measurement stations on our tower. We employed the services of a prestigious civil engineering firm, Simpson Gumpertz & Heger of Arlington, Massachusetts, to assist in this project.

The most important element of our project is the research and data gathering that must take place so that we can scientifically determine what causes ice to form on our tower as well as what conditions cause the ice to dislodge from the various metal formations. With scientific data gathering as our basic goal, we mounted 3 solid state meteorological test probes at levels of 400 feet, 690 feet, and 850 feet to monitor wind speed, direction, humidity, temperature and barametric pressure. The data is sent through fiber optic cables to our transmitter building on the ground for recording and constant monitoring. Ice detectors were mounted at the same levels along side the meteorological probes to detect ice formation. The meteorological data is recorded on a Techtran magnetic cassette tape recorder and averages are printed on a Digilink chart recorder every half hour, 24 hours a day unless three ice detections occur in a single half hour period which then causes the meteorological data to be recorded every 15 minutes until 1 half hour period occurs with no ice detection. Data sampling occurs every three seconds but the Digilink averages the samples. The Techtran tape is sent to CRREL for further analysis. CRREL takes the tape and reads the information into their Prime computer main frame. Daily averages and totals are plotted on Hewlett Packard plotting machines for each level of our tower under test. Trends will be correlated with concurrent meteorological data at Logan Airport and frequency estimates based on past data from Logan Airport can then be made to determine how many times over the past 30 years serious icing conditions have existed. From this, one can project the number of future occurrences expected in upcoming years.

A number of specific questions will be addressed throughout our testing:

1. Specific tower levels and structural members more likely to collect ice

2. Physical characteristics of the ice formations

    a. Thickness

    b. Color (density)

    c. Shape and orientation

3. Affects of protective coatings

4. Ice-metal separation

    a. Causes (wind, solar)

    b. Sites more likely than others

5. Physical characteristics of ice falls

    a. Size, shape

    b. Projectory, fall zones

6. Meteorological conditions that cause icing and ice fall

7. Correlate with concurrent Logan Airport meteorological data

8. Develop frequency estimates based on Logan Airport data

In an attempt to supplement the meteorological data, we mounted 5 cameras in strategic locations for the purpose of monitoring ice formation and ice fall. Three locations were the same as those previously mentioned for the meteorological test equipment, with a fourth being a camera on the ground looking up at the tower and a fifth camera set back 200 yards to monitor any ice departures from the tower structure. All five black and white cameras are fed to time lapse video recorders so that any ice movement will be recorded. We chose Panasonic Model 1850 cameras which are capable of operating at .1 foot candles as well as under heavy RF conditions, such as exist on a broadcast tower. We have added supplemental lighting to assist on dark, non-overcast nights. The Model 1850 camera is very responsive to "invisible", infrared light. Pan, tilt, zoom, and focus controls are operated remotely from our transmitter control room on the ground so we can closely analyze various members of the tower in an icing situation.

We view the data gathering aspect of our tower icing work as a long-range project which may take several years to come up with finite answers to the age old problem of tower icing. Meanwhile, we are exploring numerous options in search of potential solutions to thia problem by conducting experiments that have a reasonable probability of success. One such test utilizes a super hydrophobic coating called Vellox 140. Super hydrophobic means it is something much more than just repellant, water resistant, or just hydrophobic. The literature claims that the unique chemical and physical structure of the surface is so highly repellant to water that droplets are held away from the surface at such a distance that a visible layer of air can be seen at the interface between the water and surface. This air layer appears as a silvery sheen when the droplets are viewed at certain angles and thus allows the droplets to roll freely and rapidly off the surface.

Our research found approximately 1 dozen users of this product with about 50% of them considering their application a success. The main problem we uncovered in our research was the critical application process which must be adhered to. Rather than coat our entire tower with this two-coat process, we chose three horizontal bands in the same areas as the meteorological and video equipment so we could have precise conditions monitored in the Velloxed area. The bands varied in height from 30 to 50 feet. The base coat is applied as a heavy brush coat primer and can be tinted somewhat to assist in maintaining FAA colors. Steel temperature, humidity, and wind speed must be taken into consideration when the application is made. An electrostatic application has been developed which minimizes waste and allows the material to wrap around nuts and bolts much better in flange areas of the tower.

The topcoat is a solution of low viscosity and particle concentrations are very low. Hence repeated overspray of the area is essential in order to build a satisfactory depth of the coating and to achieve good bonding. Typically, an average of 7 or 8 top coats are required. The base coat steel temperature requirement is approximately 45 degrees while the top coat can be applied in much lower temperatures. The topcoat is applied at an approximate 55 degree angle, requiring seven applications to coat a circular metal member. Too many applications of top coat can leave unbonded particles that cling to the surface and reduce the hydrophobicity. When water droplets hit the surface, although repelled, they tend to be coated by loose particles and adhere to the tower. This has something to do with molecular attraction. Using a soft cloth or brush one can brush off the areas that are oversprayed which will allow only the particles to stick and therefore increase the hydrophobicity.

We experienced some of this "over-spraying" phenomenon which makes the tower appear to be only partially hydrophobic. Brushing lightly over the area seems to improve the hydrophobicity.

Some experiments have shown that Vellox slowly wears off when pounded by the rain. Wide ranges of life expectancy estimates abound with current Vellox users. Many believe the life of this super-hydrophobic coating to be only a few years, at which time the effectiveness diminishes to the point of requiring recoating. Vellox coated towers tend to be a bit slippery according to some tower crews. This factor needs further analysis with regard to safety.

The cost of Vellox coating a broadcast tower is somewhat expensive. Many variables enter the picture. Your tower paint must be in good condition to allow proper bonding of the Vellox base coat. If not, a complete paint job may be in order prior to beginning the Vellox procedure. Vellox itself is costly per gallon. Base coat costs $84.00 per gallon in quantity while topcoat costs $66.00 per gallon. The rule of thumb has been $.90 per square foot for exterior applications. In addition, when tower crews work on the structure, the Vellox gets abraided away and loses its effectiveness.

We attempted another experiment using low frequency, high magnitude vibration. The object of applied vibration is either to prevent ice buildup by shedding water from the tower before it freezes, or to fracture the ice bond of successive accretions causing them to fall from the structure in harmless increments.

The behavior of the prototype vibrator is similar to that of an unbalanced car tire. The applied force of the eccentric rotating weight increases with rpm. At 1800 rpm, the machine generates 800 pounds of force applied 30 times a second.

Cold room tests show that the vibrator can remove up to about 80% of a 3/4" ice cover from an 8 foot span of 10 X 2.6" (c 10 by 15.3 pounds per foot) channel iron in a single 20 second cycle from start to full speed and back to stop. Most of the deicing occurs during resonance vibration when beam displacements are about 5/8". Ice removal is facilitated by thicker, more continuous ice accretions. The vibrator's effectiveness in removing ice would probably be increased by a surface coating which promoted continuous accretion but reduced the bond strength of ice to the test surface.

Mounted on the crown block of our tower at 860 feet, the prototype propagated observable vibrations through about 60 feet of the structure. However, vibrational magnitudes on the order of those which removed ice in cold room tests did not propagate that far. The massiveness of the tower probably accounts for this though modification of the prototype might significantly improve performance.

Currently, the United States Army Cold Regions Research Laboratory is funding further development and testing of the vibrational ice control system in application to guyed transmission towers. Development is aimed at construction of a second generation prototype incorporating remote adjustability of eccentricity and frequency. Testing will be carried out on an artificially iced 60 foot Rohn-type 25 or 45 guyed tower.

Credit on this project should be given to Robert Donaldson, a student at Thayer School of Engineering at Dartmouth College.

Preliminary research and development of one possible model by Dr. Stephen Ackley of Cold Regions Research Laboratory on passive ice control by wind actuated ice deterrents showed it probably would not be acceptable due to wind forces alone not being enough to prevent ice build-up.

Based on a 1957 experiment by Chief Engineer, Paul Hurd of WHDH, Boston, we are moving ahead on installing plastic coated wire mesh, wrapped around joints to contain snow and ice, preventing it from falling off while it melts. One test showed the wire in good condition twenty years later. Tower loading characteristics should not significantly alter after this installation.

Presently, the only system proven effective in controlling icing is electrothermal heaters. This approach is infeasible, both economically and practically. Electrothermal deicers are generally fine, high resistance filaments wrapped around or taped to structural members. The exposure of these filaments and their light gauge make them highly susceptible to mechanical damage and failure due to the impact of falling ice. Additionally, considerable tower work occurs throughout the year due to an extensive microwave network associated with our tower. Thus, considerable maintenance would be required.

Tests done in Finland using electrothermal deicers showed that for a 100 meter guyed tower, 300 kw of power are required continuously for an eight hour cycle. Based on six cents per kilowatt hour, it would cost nearly $15,000 per 24 hour day to operate the electrothermal deicers. Add to this the cost of purchasing and installing the deicers and you can see why this is not feasible.

When building a new tower or evaluting your present situation, insurance premiums must become an important consideration. The rates for tower facilities have risen dramatically in the past three years and projections show no less of a rise in years to come. Owning a circular plot of land with a radius at least the height of the tower structure is a sure method of reducing your liability and public nuisance complaints. Insurance carriers will likely adjust rates in your favor as a result.

Short of this, you should probably consider constructing a building that encapsulates your tower with office space for rent, which of course, would have a rotating restaurant just under your antenna so you can offset the cost of insurance premiums. Then, you would be left with a relatively simple problem: making sure your various emmissions do not exceed the State's non-ionizing radiation level set for the general public.

SPOT: AN AUTOMATED STATION BREAK COMPOSITION AND PLAYBACK SYSTEM

G. Beverlin, R. Murch and R. Ilowite
WPIX-TV, New York and Dubner Computer Systems

Commercial television stations earn revenue and establish their identity during station breaks. Properly airing the commercials, promos and other short events which make up these breaks is very important to broadcasters. WPIX-TV, New York and Dubner Computer Systems have developed SPOT, an automated way to meet this need while extending the useful life of a station's existing equipment.

SPOT controls the station's existing videocart machines along with new 1/2" VTRs and support equipment to continuously prerecord station breaks about two hours before air. In this way videocart machine problems and most operator errors are moved off-line where they can be corrected before reaching air.

Background

As the source for their breaks, most TV stations use one of the two videocart machines developed about fifteen years ago. These machines represent a large financial investment and the systems which support them extend into nearly every aspect of station operation. Unfortunately, all too often videocart machines are also the source of embarassment and lost revenue as cart jams, mechanical problems and operator errors hurt the air product.

But, the complexity of aging videocart machines, coupled with the demands placed upon them, make it very hard to insure the near 100 percent reliability we require of On-air equipment. And, there is a trend toward multiple 5 and 10 second events within single breaks, a situation cart machines cannot easily handle. For these reasons and others many broadcasters are now showing a heightened interest in the next generation of MERPS (Multiple Event Record Play System) machines.

But which of the new machines should we choose? For many, the choice is unclear. None of the several machines shown at recent trade shows have a track record in the field and most of them have a mechanical threading mechanism which could jam like the present gear. Also, there look to be developments in the wings which could quickly obsolete the new machines now available. For example, one manufacturer is talking about a digital cart machine soon and several companies are working on videodisc systems that might obsolete tape altogether. So, to improve On-air reliability now and perhaps to buy time until the choice for the next generation machine is more clear, many stations have decided to air their breaks from a spot reel.

Spot reels have been around for some time. Making them is usually a manual process involving the transfer of whole station breaks from videocart machines or agency reels on to longer tapes (often 1"). It is these tapes which are then cued and played at air time. Broadcasters justify the additional effort and expense of spot reel production on the dependability of the longer format. The station looks better since any videocart machine problems which arise during the transfer can be corrected before they affect air.

Unfortunately, spot reels have their own problems. From the time a tape is made, until it airs, the program log should not be changed. This can be a serious limitation since manual systems often compile as much as 24 hours ahead. Also, spot reel production requires dedicated facilities and staff with yet one more set of coordination difficulties, operator errors and machine interchange problems. For these reasons, airing station breaks from a conventional spot reel ends up being a mixed blessing at best.

SPOT: An Automated Spot Reel System

At WPIX-TV, we hoped to gain the improved reliability of a spot reel without the problems of purely manual composition and playback. We worked with Dubner Computer Systems to develop a system called SPOT.

SPOT is a machine control system. At its center is a computer which accepts instructions from an operator and controls videocart machines, 1/2" VTRs and support equipment to execute those instructions. The system is shown in Figures 1 and 2.

Many of the errors which plague manual systems occur during loading, shuffling and cueing playback tapes so this process was made automatic in SPOT. The tapes in SPOT's 1/2" record/play decks are never removed except for periodic maintenance. The computer uses timecode to keep track of tape name and location for each recorded break. It automatically cues the appropriate tape for air as requested by the operator or the house automation. With three record/play VTRs one deck is available for On-Air use, one is ready to air and the last deck can be used to compose clusters to be aired later. Since SPOT has no thread/unthread cycles and since no operator intervention is required between break composition and playback, reliability is very high.

Working With SPOT

Once each day the program log is loaded into SPOT from an automation system or from a floppy disk provided by Traffic. Manual log entry and log editing are also possible.

Work begins when the operator selects the first station break on the log to be composed and then loads a videocart machine with the needed carts. SPOT then controls the videocart machine and one of the 1/2" record/play decks to transfer the break to cassette. During this process SPOT checks for VTR warnings and also compares the videocart machine's off-tape ID information against the program log. Problems are immediately brought to the operator's attention so they can be corrected.

SPOT continuously monitors the status of the videocart machine. It prerolls the 1/2" record VTR and waits whenever required. In this way very short commercials and bumpers are automatically accommodated with no breakup or discontinuity On-Air. As an additional benefit, this logic allows the system to operate even with a videocart machine that has only one working transport.

Figure 1: SPOT

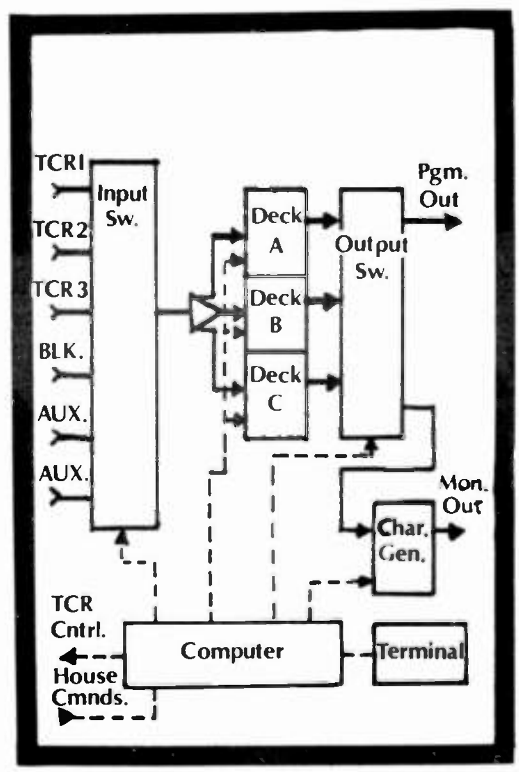


Figure 2: Block Diagram

As each station break is transferred, SPOT requires the operator to verify the quality of the recording. Enough time is provided to completely screen each break at normal play speed immediately after the transfer. During this verification SPOT can re-edit any substandard elements as required without remaking the entire break. After the break is transferred and its quality verified it becomes part of the queue waiting for On-Air playback. SPOT then determines the next break to be transferred and calculates whether it will fit on the current record tape. The needed carts are loaded into the video-cart machine and the process repeats.

Meanwhile, playback can begin. As instructed by the operator, SPOT will cue any prerecorded station break for Air, generate a slate which describes the break and await the play command. When this command is received, SPOT plays the break and then automatically cues to the next one recorded.

Running SPOT becomes like managing a pipeline. The operator puts breaks into the line while On-Air systems and the SPOT computer pull them out. SPOT automatically keeps track of the breaks and the tapes which contain them. Further, SPOT knows which VTR contains each tape and automatically transfers these machines from record service to play and back without operator intervention.

Human Interface

SPOT is easy to use and it automatically detects common operator errors like misreading the log or loading the wrong carts. At the same time operators must stay in charge to deal with unexpected log changes and technical problems. For these reasons, SPOT uses a computer assisted (vs. computer controlled) approach in its interaction with people.

Our design assumes the operator is a competent, concerned person. Accordingly, elaborate menus and "help" screens are used sparingly. Instead, the operator is given status information about what SPOT is doing and what it expects of the operator and the external equipment to proceed. Similarly, SPOT will alert an operator who attempts a potentially hazardous operation (eg: one which would effect On-Air playback) but will allow the operator to override the caution as needed. SPOT's status screen is shown in figure 3.

Computer

We selected one of the new "supermicros" as the nucleus of SPOT. This computer contains two Motorola 68000 processors, 1 Megabyte of RAM, a hard disk drive and an 8" floppy disk drive. This computer provided the processing speed we required. The hard disk is used for initial program loading and as a back-up should there be a power failure. The floppy drive can also be used to load the program should the hard disk fail. All VTR and switcher control is accomplished using the serial ports on this computer. Currently, the house automation is interfaced through a parallel port.

SPOT also uses a small microprocessor based interface to control the videocart machine. This interface accepts RS-422 communication from SPOT's main computer and converts it into the parallel control and status needs of the videocart machine.

Software

SPOT was programmed almost entirely in C, a language which compiles efficiently for this computer, with small portions written in 68000 assembler language. Since SPOT runs in real time a delay of only milleseconds can cause a lost frame of video. For this reason SPOT was designed to run without an operating system. This gives us complete control over processing time and the advantage of having all the computer's memory to ourselves.

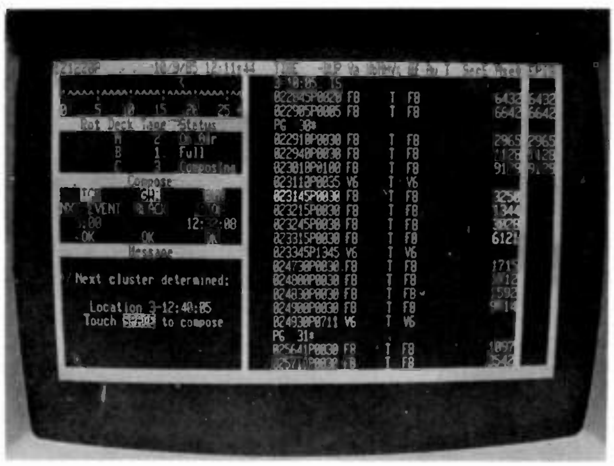


Figure 3: Status Screen

Developing SPOT proved to be an evolutionary process. We anticipated this and rather than trying to produce a specification that accounted for every detail, we agreed instead on the general concepts about what was to be done. During the development, we tried to maintain constant communication about the nature of the operator's interaction with the system and how SPOT would handle unusual or error conditions.

We often brought our plans to the engineers who would actually be working with the system, showing them what had been done and soliciting their criticisms and advice. Indeed, many of the best system features were sparked by questions that began: "Yeah, but what do you do if...?" By taking this interactive approach, and by programming with the expectation that operational details might change several times, we avoided painting ourselves into any corners. A happy side effect of this process was a growth in morale among the engineers and operators who were understandably apprenhensive about the intrusion of a computer system into their work environment.

Results

SPOT has been on line at WPIX-TV since July of 1985. It is responsible for a dramatic improvement in the reliability of our On-Air product. The videocart machine problems which used to account for most of the entries on our Discrepancy Reports have now all but vanished. Operator acceptance remains high. We recommend this approach to other broadcasters waiting to see what new tools the future brings.

"PAG-lok"—NEW CAMERA/BATTERY INTERFACE SYSTEM WITH ACCOMPANYING UNIVERSAL CHARGER

Bebe F. McClain
President
PAG America, Limited

Clive Hawkins
PAG Ltd.
Asheville, North Carolina

Although battery systems may appear to be a mundane subject devoid of technical excitement, they are used by virtually everyone in the broadcast business and have been the source of untold problems since the advent of ENG. Advances in this area will greatly benefit every person who uses cameras outside the studio environment.

"PAG-lok" is an entirely new camera/battery interface system adaptable to various types of batteries and battery holders. Little new design has appeared in this area since ENG was established. This new system overcomes the shortcomings of older systems and is more applicable to todays requirements for a more sturdy, lower cost system.

In addition, PAG America will be offering a low cost microprocessor controlled compact fast charger with "PAG-lok" fittings to charge "PAG-lok" batteries and any other NiCad ENG battery or belt of any manufacture in the 12-14volt/2-12Ah range.

Since the advent of small video cameras, users have tried various types of self-contained power packs to operate their cameras outside the studio environment. DC power systems from related industries have been used as well as new systems devised in the infancy of ENG. None have proven to be totally satisfactory and batteries remain a major problem to users from operational, maintenance, and cost viewpoints. All portable cameras require batteries and all users have been plagued, at one time or another, with DC power headaches. After surveying the existing systems, PAG Ltd. has developed a new battery system to eliminate these problems and meet the ENG needs of today.

Because battery belts were used for film cameras, it was a natural transition to adapt them for early ENG use. Unfortunately the ENG camera operator, unlike the film camera person, became tethered by 2 cables, one to the battery belt and one to the VTR. It soon became apparent that an on-board camera battery was needed.

Some such systems were proposed and eagerly adopted. And, since those early days, few other systems have been proposed, or existing ones been improved. Years have passed, over a decade, and while ENG cameras have radically changed, the on-board battery systems have not.

Having been approached by many users to investigate the area of on-board camera/battery mounting systems, PAG Ltd. of London, accepted the challenge to develop an entirely new system to meet the users' needs of the 1980's. This meant totally discarding present systems and starting anew.

PAG Ltd., founded in 1968 to develop and market batteries and chargers for the film industry, was well suited to undertake such a project. They have their own design, manufacturing, and sheet metal facilities and now supply batteries and chargers not only to the video world, but also to the military world. PAG Ltd. has been assessed and registered as complying with the stringent performance and safety requirements of the Defense Standard 05-21.

When approached by American ENG users, namely TV networks and group owned stations, to investigate the areas of a new mounting system, including batteries and a small safe universal type charger, PAG Ltd., began intensive market research concerning user requirements. This work has been done in conjunction with PAG America, Limited, which was founded in 1984 to serve the U.S. market.

Discussions were held about existing systems and many improvements were requested. The new "PAG-lok" system resulted and represents a complete evolutionary step in camera/battery interface systems.

Let us review the findings of that market research to examine the areas that needed improvement.

MECHANICAL IMPROVEMENTS

1. Locking System

   Many on-board batteries have utilized separate mechanical locking and electrical connection systems. These involve pendant cables. Users have traditionally preferred systems with no pendant cables since these cables are subject to stress. Also, the mechanical system, often a wedge, are subject to damage, and if turned upside down, could disengage the battery.

Other types of battery mounts offer combined electrical and mechanical systems, but the ones in common use, reportedly, often inadvertently become unlocked. The result is that the battery either loses electrical connection and does not power the camera, or falls off completely causing loss of power, loss of the battery itself, and possible injury to people or surroundings.

When a cameraperson is leaning out of a helicopter, or over a railing of a stadium, a falling battery can cause severe damage. Happenings such as these were recounted.

It was obvious that the release mechanism of the lock needed to be "out of harms way" and it was further suggested that it be obvious to the operator, by a quick glance, that the lock was definitely engaged.

The new "PAG-lok" mount, smaller than those on the market, has its release mechanism centered at the top of the camera battery bracket which is located below the top surface of the camera. By having the release positioned here, and not to the side, the chance of an unsuspecting disengaging blow is greatly lessened.

The locking system itself consists of four grooved claws. The two claws at the top are used to position the battery on the camera bracket and the two claws on the lower portion are mechanically locked in place when a spring boss is engaged. This type system, when compared to the "key hole" and "wedge" systems in use, is much less subject to unintentional dislocation.

2. One-Handed Operation

Although some commonly used mounting systems are purported to offer one-handed operation, they, in practice, do not. Camera operators have indicated that true one-handed operation is essential to changing batteries in rushed, cramped environments.

To effectively change batteries, the camera operator needs to hold the camera with one hand and change the battery with the other hand. Or, the VTR operator, while holding his own gear in one hand, must change the camera battery with his free hand. Either of these is possible with "PAG-lok". A middle finger depresses the release while the outside fingers grip the battery and easily remove it upward.

Installing the fresh battery is equally as easy since no lock needs to be moved and the two large top claws, find their "home" position quickly. With other mounting systems, the electrical connection must first be carefully seated to avoid damage to pins before the mechanical mating is achieved.

"PAG-lok's" sequence of mounting is one of its most outstanding features. Mechanical contact is made BEFORE electrical contact. Not only does this afford fast connection but it eliminates all possible stress on the electrical contacts. Broken pins can render a battery inoperable, require maintenance time, and incur cost.

ELECTRICAL IMPROVEMENTS

1. New Type Contacts

The whole concept of employing banana pins or pendant cables appeared to be worrisome to users. Pins can break and over long usage become stripped resulting in only point contact. Pendant cables can become disconnected or can be pulled loose from connectors.

To eliminate this, PAG selected military type, self-cleaning contacts that offer extremely low resistance that does not degrade after years of use. Our tests indicate that the connector resistance maintains lower resistance figures than banana pins, for example, even though they have similar figures when new. One reason is that physical wear and tear on banana pins is very marked after even short periods, which creates "hot spots" of high resistance early in the working life.

The self-cleaning aspect is indeed a major advantage. As the flanges of the contacts depress, they wipe clean the surface of the mating contacts on the battery half.

2. Additional Ports & Select Switches

You will note that there are six contact ports on the "PAG-lok" system. PAG chargers, being microprocessor controlled, need no special sensors, and thus require only two contacts. But, to accommodate those formats on the market that require three contacts, "PAG-lok" has made provisions for this by incorporating three ports for housing three contacts.

And, because some cameras are subject to RF interference, a fourth port is used to provide a grounding contact between the battery and the camera in order to eliminate RFI.

Research is underway at PAG that will hopefully lead to a battery system that will allow the user to instantaneously know the capacity of his battery. Perhaps there could even be a gas gauge type indicator in his viewfinder to indicate this.

In order to accomplish this, more access will be needed into the battery than is provided with present two or three contact systems. Thus, two additional ports (a fifth and sixth port) are incorporated into the system and are reserved as a means for future interrogation.

To allow the user to select other power sources, there is a 3-way power switch on the bottom of the "PAG-lok" camera bracket.

Center-off - (no battery power, or use with AC supply),
Side 1 - battery on,
Side 2 - external DC (belt, VCR battery).

SAFETY ADVANTAGES

The "PAG-lok" has no direct access from the electrical contacts to the inner battery. The great safety concern when using or charging a battery is explosion. Damaged, or improperly charged cells can produce hydrogen gas. If gas forms inside the battery and escapes through a point where an electrical spark can occur, and not through the sides, this could be dangerous. Other systems have direct access into the battery where the electrical connection is made. If gas were to flow out here, and a spark were made by improper connection to a charger or by other acts of the user, one can imagine the results.

Also, by "PAG-lok" having no direct access into the battery, it is made water resistant. If water were to enter the battery it could cause corrosion and provide for unsafe operation.

Another safety advantage is, as mentioned, the secure locking device that reduces the possibility of the battery falling off and causing injury.

FLEXIBILITY

Other types of overall improvements suggested by users concerned having a system that was flexible enough to accommodate more than one type of battery. The "PAG-lok" system incorporates a family of products. They are:

- on-board batteries in 4Ah capacities of either 13.2 volts or 14.4 volts. Also, these two batteries are offered with regular GE cells for fast/slow charging, or with the new XP-60 GE super cells designed for longer running time when fast charged. This significantly longer running time has been observed by all who have tested "PAG-lok" and has been cited as one of its most outstanding features. The primary objective stated by camera operators appears to be a reliable system that offers increased operational time. "PAG-lok" batteries were designed around this criteria.

- a special holder that accommodates any BP-90 type battery.

- a special holder that accommodates any NP-1 type battery.

- a small fast charger that accepts any 2-12Ah NiCad battery, 12-14 volts, of any manufacture.

The "PAG-lok" family of products are targeted to be priced more economically than the prevalent systems on the market. And, the "PAG-lok" system, when proven to be acceptable, will be licensed at a reasonable one time fee, to those who can meet the licensing requirements.

Some commonly used systems are patented and are available to other manufacturers at high yearly fees or on a high fee per unit manufactured which can greatly increase the overall cost making them uneconomical to manufacturers.

It is PAG's intent to create a true world standard. This will only be accomplished when camera manufacturers mold into the cameras a universal battery connector, as they now do with the video out connector, such as the BNC. To be successful, the system needs to be readily available to both camera and battery manufacturers. This standardization should reduce the cost of batteries to the user who will not have to buy different battery brackets for each camera. There will be true interchangeability.

All the above improvements will contribute to an overall reduction in maintenance of battery systems and a reduction in the amount of equipment that must be maintained. Maintenance time and down time are of utmost concern to all stations and production houses. The entire "PAG-lok" system was designed to withstand high resistance against fracture, cracking, and/or chipping upon impact so that the total system on a camera can be dropped from a height of six feet onto a hard surface, landing at any angle, with no malformation. It is a sturdy system that will withstand severe "g" forces encountered in a field environment.

A major part of any battery system is the charging system to be used. PAG's universal type chargers, incorporating microprocessors are in use throughout the world. The new "PAG-lok" mini-charger is an addition to this family.

Whereas most other battery manufacturers have chosen to make batteries that can only be charged on their systems, and vice versa, PAG has taken the approach of designing chargers that fast and slow charge NiCad ENG batteries of any manufacture. "PAG-lok" batteries can be charged using the PAG SPEEDCHARGE 6000/SEQUENCER 6000 charging systems and the PAG MASTERCHARGER systems now in use.

The SPEEDCHARGE 6000 accepts any NiCad 10-15V/2-12Ah battery for fast or slow charging and for revitalization. It is also a power supply. By adding the SEQUENCER 6000, any 8 NiCad batteries in the specified range can be sequentially fast charged. All types of NiCads of different manufacture can be mixed for charging on this system.

The single unit MASTERCHARGER accommodates any 4 such batteries for fast or slow charging, plus acts as a power supply. Also, both systems detect faulty batteries.

This year, PAG has developed a small, low cost single channel fast charger as part of the "PAG-lok" family. It uses the advanced microcomputer system of the other PAG chargers and accepts the same wide range of NiCad batteries. This unique PAG system allows for safe fast charging by the incorporation of a microcomputer chip that uses 10 algorithms to give consistent good charge that is precisely terminated at the right time. Most other charging systems do not incorporate microcomputer chips and are designed to measure or be controlled by one parameter. PAG has long investigated charging systems and found that these simple approaches are deficient in one or more respects. A few of these systems are:

Timed Charging. This type system, designed for fully discharged batteries, does not work well if fully charged batteries are applied. Overcharging and loss of capacity can result since charge is given for a specified time irrespective of the state of charge of the battery connected.

Dump/Time Charging. Here the battery is fully discharged and then charged. This takes time, wastes energy can reduce life and aggravate imbalance in cells.

Voltage Sensing. This system would work if an electronic signal could indicate when a battery is fully charged. But, it can't. Also, voltage levels of a battery vary with temperature, age and internal design of cells and current levels. So, this too is unacceptable.

Temperature Sensing. This simplistic way requires a sensor to be placed in the battery and a special sensing circuit to be placed in the charger, thereby limiting the charger to only charging those batteries with a corresponding sensor. Unfortunately, this locks the user into this one system.

The thermal sensor in the battery is usually designed to cut-off charging when the temperature rises due to overcharging. Of all the simple fast charge cut-off methods in use, this is probably the most common. Because it is simple, it suffers from major drawbacks. Tests have shown that:

1) No cut-off signal is generated until the cells have undergone considerable overcharging. Therefore, the battery is routinely overcharged, resulting in a shortening of its life.

2) If a battery is warm from use or from exposure to the sun, it can cut off early, having accepted only a partial charge.

3) If the battery is at a low temperature, this overcharging period is extended and hydrogen gas may be vented from the cells. Whenever there is hydrogen gas there is a consequent risk of explosion.

4) If a battery is already fully charged, it can receive a substantial overcharge before it heats up sufficiently to cause cut-off.

PAG s years of research into battery charging has shown that these and other existing systems of fast charging termination are not totally satisfactory.

They found that a highly trained operator, using a voltmeter and an ammeter could manually adjust the current to safely fast charge a wide variety of batteries using measurements that would then be taken into consideration with his experience, knowledge of the different voltages, capacities, cell characteristics, etc., of the various batteries. This would be an impractical method.

But, a microcomputer could be used to supervise and monitor this, plus other aspects that a person could not. That is exactly what PAG systems use. The battery itself acts as its own overcharge sensor while the charger delivers controlled power and the microprocessor monitors the results.

The PAG fast charge system has four segments. The initial precharge segment detects faulty batteries and interrogates the batery before main charging occurs. A controlled current of 4 amps is given and interrupted 16 times per minute for durations of 20m seconds. The battery voltage is read every 4m seconds and the readings are analyzed. No single algorithm can be used to judge if overcharging is occurring, but 10 algorithms in combination can.

During the main charge segment, these algorithms are constantly checked and results are stored. As a fail safe, there is also a time cut off. When full charge is indicated, the balancing segment begins to equalize the charge in all the cells. A series of long current pulses then brings all cells into a full charge state.

Finally, the program enters the trickle charge segment which applies occasional short pulses of current to compensate for any self-discharge of the battery.

An obvious advantage of this charging system is that it will safely handle hot or cold batteries. Unlike commonly used systems that lock out the possibility of charging except within a specific temperature range, the PAG chargers will deliver whatever charge the battery can safely accept. Even a small amount of delivered charge is much more acceptable than the "no go" situation offered by others.

The new small charger proposed for use with the "PAG-lok" system embodies a facility for fast connection of "PAG-lok" batteries. In addition, there is a BP-90 socket to accommodate this widely used BP-90 type of battery. A whole series of adaptors will be available for charging most batteries in common use, including NP-1 batteries, batteries using quick locking systems, and batteries and belts using 4-pin XLR connectors.

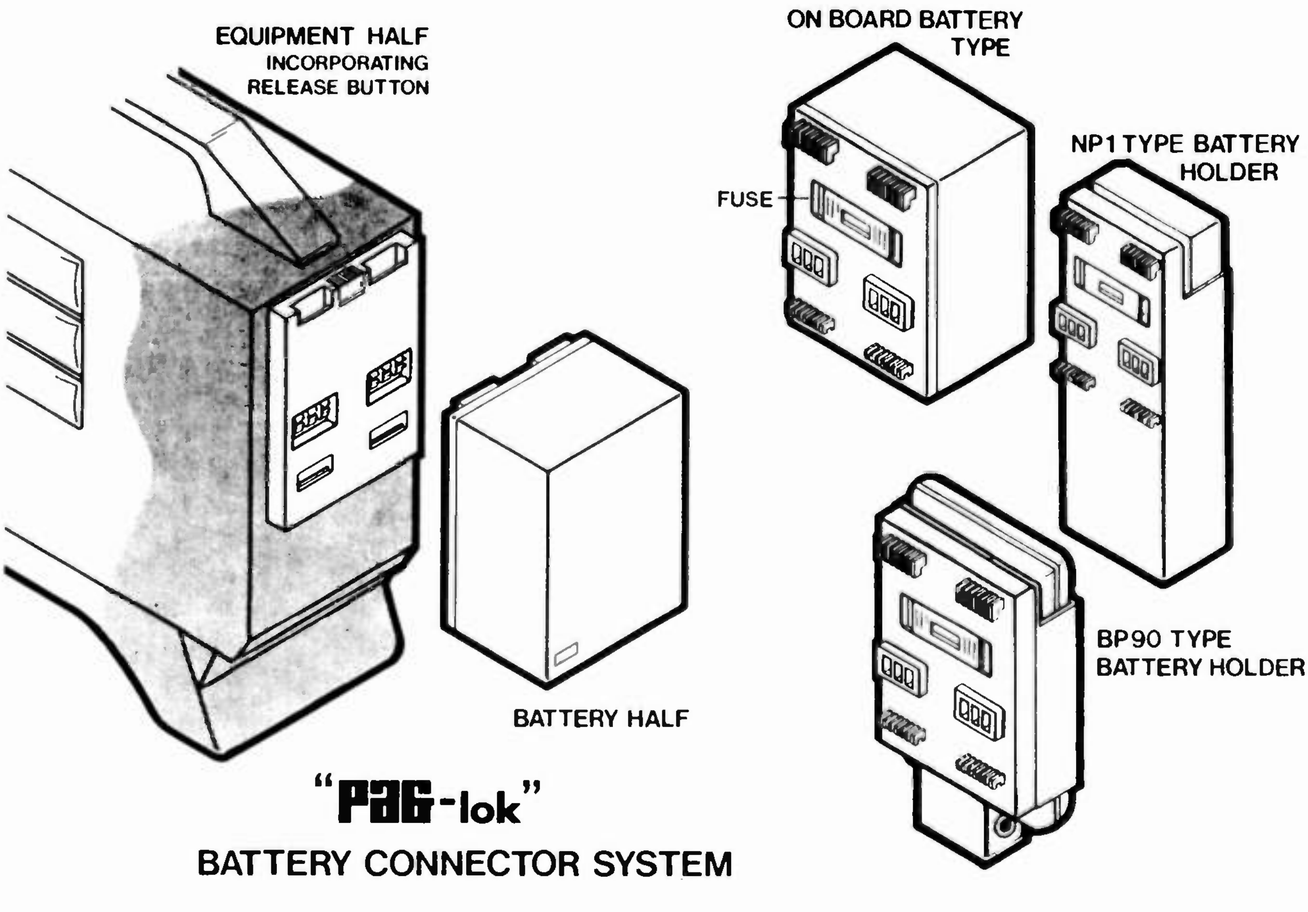
To summarize, the new "PAG-lok" camera/battery mounting system with accompanying batteries and chargers is considered to be a quantum leap in battery system design that is superior in:

- Mechanical design
- Electrical design
- Safety
- Flexibility
- Cost
- Availability
- Low maintenance
- Charging method

The "PAG-lok" system was carefully thought out, taking into consideration all the user requirements and eliminating the shortcomings of existing systems.

PAG thanks all those network, station, production house and camera manufacturing personnel who have given the valuable input needed to devise the "PAG-lok" system.

(A video demonstration of the system will be given at end of the presentation.)



"PAG-lok"
BATTERY CONNECTOR SYSTEM

THE U.S. PROPOSAL TO THE CCIR FOR A HIGH DEFINITION TELEVISION WORLDWIDE STUDIO ORIGINATION STANDARD

L.J. Thorpe and H. Tanimura
Sony Broadcast Products Company
Teaneck, New Jersey

Abstract:

In 1985 the 1125/60 HDTV proposal was officially adopted by the U.S. as our recommendation to CCIR for a worldwide studio origination standard. This paper reviews this HDTV system from the viewpoint of the extensive research upon which it is based and the sound technical parameters underlying this new TV signal format. The broad application of this high performance TV system to Business & Industry, Motion Picture special effects, Broadcasting are discussed.

1.0 INTRODUCTION:

We can commence with a short examination of two current opposing and commonly expressed assumptions:

(a) HDTV is a technical fad and it will pass away

(b) HDTV IS going to happen

Anyone standing back and soberly reviewing the pell mell explosion of electronic technology of the past 50 years, if they be also at all sensitive to mankinds' voracious hunger for information - would be foolhardy indeed to assume that a dramatic improvement in electronic imaging is simply going to go away. Whatever the technical and/or political background of the viewer - there are very few who are not visibly impressed with the superb television pictures on view at this NAB's HDTV exhibit. The world is **NOT** going to walk away from such quality.

So, we're going to start **THIS** talk on the firm basis of assumption (b) - HDTV IS surely going to happen. Having made such a bold assumption we are, of course, promptly confronted by some inevitable follow-up questions:

- **WHAT is HDTV?**
- **WHERE did it come from?**
- **WHY did the US adopt the 1125/60 HDTV system?**
- **IS the 1125/60 a good system - and if so - WHY?**
- **WHAT IS the role of the various committees?**
- **WHAT ARE the advantages of a single world standard**

and finally

- **DOES HDTV conflict with the emerging digital 525 TV era?**
- **WHO will use HDTV?**
- **WHAT does it mean to the USA Broadcaster?**

Its very appropriate to set the stage by pointing out, at the outset, that BROADCASTING has **NOT** been the primary driving force behind HDTV. Broadcasting considerations are only **ONE** - albeit an important one - aspect of a much bigger overall HDTV scenario.

2.0 BACKGROUND:

Let us return to the beginning - our first question:

WHAT IS HDTV?

The story opened in the late 1960's - in Japan. The Japanese Broadcasting Corporation NHK undertook an in depth, long term, examination of what might constitute a totally new "viewing experience" - using the electronic medium of television. (1) A research team, led by the now renowned Dr. Fujio of the NHK Technical Research Labs, began a search for the technical parameters that would define a TV system of radically improved capability. (2) This TV system was envisaged to attain a quality level sufficiently adequate to address the legion needs of a future sophisticated **"information society"**. It would thus embrace:

- **Industrial applications**
- **Motion Picture Production**
- **Broadcasting - future applications and services**
- **High quality information capture, storage and retrieval**
- **Education, Medical, cultural apppl ications**
- **Community viewing, Electronic theatres**

The term "New Viewing Experience" is worthy of elaboration - from the standpoint of a human viewer. As targetted by the NHK research group this new experience would comprise:

Substantially higher quality visual image
and
High quality multi-channel sound.

The separate qualities to realize a higher performance TV image would, in turn, be an ensemble of:

- **Larger Picture**
- **Wider Picture**
- **Increased horiz and vertical resolution**
- **Considerably enhanced color rendition and resolution**
- **Elimination of current TV "artifacts"**

Now **THE** quest really began: how to establish just **HOW** large an image; just **HOW** wide; **how** much more resolution (both Luminance **AND** color) was required to adequately satisfy our eye-brain system? What **ARE** all of the current artifacts of TV - and to what level must they be reduced?

By the mid 1970's NHK had developed prototype television equipment to conduct their investigations. The term **High Definition Television** was also introduced - soon to be dubbed **HDTV:** In the mid 1970's they published the basic technical parameters of a new TV system which matched the conclusions they had forged from a voluminous amount of psychophysical data:

1125 LINES
60 FIELDS
2:1 INTERLACE
5:3 ASPECT RATIO
COMPONENT VIDEO OPERATION

The larger picture called for a suggested optimum viewing distance of 3 times picture height. The picture included a more than **two-field** increase in Horizontal and Vertical resolution over present-day TV - with a more than **ten-fold** increase in color resolution. Together with the wider picture - this produced an aggregate **five-fold** increase in real picture information as presented to the viewer. (3)(4)

3.0 INTERNATIONAL COMMITTEES ON HDTV:

In 1982 the CCIR formed Study Group 11/6 and charged them with studying the possibility of achieving a single worldwide HDTV standard:

- **STUDIO ORIGINATION**
  and
- **INTERNATIONAL PROGRAM EXCHANGE**

At a historic meeting in Algiers in 1983 all of the world's major Broadcasting unions adopted a significant resolution that encouraged coordinated study of HDTV systems.

A singularly important opportunity was thus presented to the world community to achieve what had never before been realized - **one universal TV standard for production.**

In Feb 1985 at a historic meeting during the SMPTE Winter Conference in San Francisco the SMPTE Working Group on High Definition Electronic Production thrashed out a final concensus which read:

The SMPTE WGHDEP would prefer a progressive scan standard for production. However, in the interest of achieving a worldwide standard, this committee will accept a family of standards that include both 1125 line 60HZ 2:1 interlaced, and a progressive scan member, and will continue to work towards the evaluation of preferred specifications for the progressive system.

The SMPTE Working Group had wisely recognized that the 1125/60/2:1 system offerred a very sound basis for a superior new TV system - which could be realized using today's available technology. As technology progresses in the future the 1125/60 is open to a continuing evolution - ultimately to a progressive scan version which might be needed - for certain applications.

The SMPTE also recommended a widening of the aspect ratio from 5:3 to 5.33:3 to better accomodate the HDTV system to a range of currently exployed film image formats. The selection of 5.33:3 also had the nicety:

$$5.33:3 = 16/9 = 4^2/3^2$$

In April 1985 the ATSC formalized the USA choice of an HDTV system - whose basic scanning parameters were:

1125 LINES
60 FIELDS
2:1 INTERLACE
16/9 ASPECT RATIO
1035 ACTIVE LINES

4.0 THE 1125/60 SYSTEM - WHY IS IT SO GOOD?:

The collective parameters which contribute to any scanning TV system are contained within the well known expression which relates the **minimum bandwidth** required to reproduce all of the information within a given TV standard - to the **scanning parameters** themselves:

$$F_{min} = \frac{1}{2} \; K \; A \; N^2 \; f_F \; \frac{(1 + 1/K_h)}{(1 + 1/K_v)}$$

where

I = Interlace ratio
K = Kell Factor - generally assumed to have approx value of 0.7
A = Aspect Ratio
N = Total number of scanning lines in single interlaced frame
f_F = Frame repetition rate
K_h = Horizontal retrace ratio
K_v = Vertical retrace ratio

This basic relationship allows us to examine the effect of individual scanning parameters of a TV system.

4.1 BANDWIDTH CONSIDERATIONS:

The first thing quite apparent from this expression is the tremendous dependance of bandwidth on the Line Number - this being a square power law. Its worthwhile beginning our examination of HDTV from the viewpoint of its bandwidth requirements. If, for example, we substitute values for the US proposed 1125/60 system we find:

$$F_{min} = 1 \; x0.7x1.77x1125^2x30\frac{(1+0.13)}{(1+0.06)}$$

$$= 25 \text{ MHZ}$$

which states that a **MINIMUM** bandwidth of **25 MHZ** is required to properly reproduce this TV standard. What does this bandwidth mean in terms of the resolution capabilities of this HDTV system?

4.2 RESOLUTION CONSIDERATIONS:

Horiz Resolution in Lines picture height

$$= \frac{2 \; T_A}{A} . f_b$$

T_A = Active picture period

A = Aspect ratio

f_b = Bandwidth

So, for example, in our present **525 NTSC** system with its 4.3 MHZ bandwith, we realise:

Horiz Resolution

$$= \frac{2 \times 52.6 \times 10^{-6} \times 4.2 \times 10^6}{1.33}$$

$$= 332 \text{ TVL/ph}$$

Vertical resolution is determined by the number of active TV lines, which for the 525 NTSC system is given by

Vertical resolution is determined by the number of active TV lines, which for the 525 NTSC system is given by

$$525 - (2 \times 21)$$
$$= 483 \text{ TVL}$$

In practise this is modified by the Kell and Interlace factors - generally assumed to have a value of approx 0.7. Therefore **effective vertical resolution** for 525 NTSC is:

$$483 \times 0.7$$
$$= \mathbf{338\ TVL/ph}$$

If we apply this approach to the new HDTV system, we get

For the 1125/60 HDTV system:

$$\text{Horizontal Resolution} = \frac{2\ TA}{A} \cdot f_b$$

$$= \frac{2 \times 25.86 \times 25}{1.77}$$

$$= \mathbf{730\ TVL/ph}$$

Again, the vertical resolution is given by the number of active lines - which in this case has been defined to be 1035. Again, the Kell and Interlace Factors come into play reducing the effective vertical definition to :

$$1035 \times 0.7 = \mathbf{725\ TVL}$$

So comparing the new **HDTV system** with our present **525 NTSC** we have:

	525 NTSC	1125 HDTV
HORIZ RESOLUTION (TVL/ph)	**332**	**730**
VERT RESOLUTION TVL	**338**	**725**

which more than meets the established criteria of at least doubling both horizontal and vertical resolution.

4.3 INTERLACE/PROGRESSIVE SCAN CONSIDERATIONS:

During the many deliberations on HDTV throughout 1983/84 various potential weaknesses of the 1125/60 approach were postulated and alternative approaches were offered as palliatives. Prominent among these discussions were issues relating to frame rate and motion portrayal; impact of interlace scanning on motion and on aliasing artifacts; the impact of the interlace scanning on digital processing techniques.

Of the various alternate systems proposed, that of RCA/NBC probably drew the most interest - in that it rested squarely on the premise that a superior new TV system should **avoid** all of the historic limitations of interlace - and be based instead upon a **progressive** scanning system. To simply take the 1125/60 system and make it progressive scanning would, unfortunately, dramatically elevate the bandwidth according to:

$$F_{min} = 1/2 \times 0.7 \times 1.77 \times 1125^2\ 60\ \frac{(1.13)}{(1.06)}$$
$$= \mathbf{50\ MHZ}$$

Few disputed that this would represent a magnificent HDTV signal - but because of the enormous bandwidth its practical implementation would await radically new technologies in some future era.

RCA/NBC accordingly proposed a new system - carefully structured to **UTILIZE APPROX THE SAME BANDWIDTH AS THE 1125/60 SYSTEM** - but trading off Line Number for the elevated frame rate of **progressive** scanning. They suggested a 750 line system - which produced:

$$F_{min} = 1/2 \times 0.7 \times 1.77 \times 750^2 \times 60 \times 1.1$$
$$= \mathbf{23\ MHZ}$$

A prototype such system was assembled and demonstrated, side by side with the 1125/60 interlaced system, at the SMPTE Winter Conference in Feb 1985. With both HDTV cameras viewing the same scene, and directly feeding their respective monitors, it was generally conceded that the two systems produced **subjective** results that were very close. But the inherent strength of the 1125/60 system clearly emerged when the two systems were subjected to tests that embraced the broader aspects of real world applications. Notable among these were the **transfer of the HDTV original to 35mm film.**

A prototype such system was assembled and demonstrated, side by side with the 1125/60 interlaced system, at the SMPTE Winter Conference in Feb 1985. With both HDTV cameras viewing the same scene, and directly feeding their respective monitors, it was generally conceded that the two systems produced **subjective** results that were very close. But the inherent strength of the 1125/60 system clearly emerged when the two systems were subjected to tests that embraced the broader aspects of real world applications. Notable among these were the **transfer of the HDTV original to 35mm film.**

This transfer is a highly complex process involving the Tandem connection of many elements of a **total** system. The MTF's of these elements cascade. The inherent information - the actual number of horizontal and vertical "samples" - of the originating picture source becomes crucial to the survival of the signal through this complex transformation. Practical transfers on a high quality laser film recorder were conducted on both the 1125 and the 750 line systems. An essential part of this transfer processing is the use of digital frame stores to produce a **progressive scan** TV frame (in non real-time) that realizes the full potential of the 125/60 system. The demonstrated results **clearly** showed the superiority of the 1125 line system - its 33% more vertical samples were of major consequence in the final film.

4.5 HDTV VIDEO COMPONENT CONSIDERATIONS:

The original NHK Proposal had recommended a set of primaries which were composed of a Luminance signal Y and two separate color difference components C_W and C_N.

The bandwidths proposed by NHK were as follows:

$Y = 20$ MHZ

$C_W = 7.5$ MHZ

$C_N = 5.5$ MHZ

and were chosen (based on physchophysical support for compromises that were believed to be very satisfactory) to produce primaries that were manageable for **TRANSMISSION** - in terms of bandwidth.

In the USA, however, the ATSC focussed on the first step - namely, a choice of video components that would form the basis for the **highest quality HDTV studio origination.** Key to some of the choices made was the recognition that it is very important to facilitate the process of conversion of 1125/60 to the current 525/60 and 625/50 systems based on **CCIR Recommendation 601.** ATSC Is therefore currently engaged in formulating a US position on HDTV **digital coding.** The first key premise that was established was that the Horizontal Resolution be twice that of the 4:2:2 code specified in CCIR-601 - NOT twice that of conventional 525 NTSC.

In the 4:2:2 code the Luminance video signal has 720 active samples per line.

Hence for HDTV the number of active samples should become:

$$720 \times \frac{5.33}{4} \times 2$$

$$= 1920 \text{ active samples}$$

The 4:2:2 code in CCIR Recommendation 601 refers to the digital sampling pattern and the resolution characteristics of the studio standard for the video components of Luminance and two color difference frequencies. A primary sampling frequency of $\frac{13.5}{4}$ MHZ has been chosen in CCIR-601. This produces (for CCIR-601) the following sampling frequencies:

$$Y = \frac{13.5}{4} \times 4 = 13.5 \text{ MHZ}$$

$$R\text{-}Y = \frac{13.5}{4} \times 2 = 6.75 \text{ MHZ}$$

$$B\text{-}Y = \frac{13.5}{4} \times 2 = 6.75 \text{ MHZ}$$

It is very desirable for conversion to preserve simple clocking relationships between HDTV and the 4:2:2 digital codes. The ATSC is examining a variety of possible digital codes for HDTV. At this time of writing a tentative code of **22:11:11** is under close examination. This code produces for the 1125/60 system the following:

$$Y = \frac{13.5}{4} \times 22 = 74.25 \text{ MHZ}$$

$$R-Y = \frac{13.5}{4} \times 11 = 37.625 \text{ MHZ}$$

$$R-Y = \frac{13.5}{4} \times 11 = 37.625 \text{ MHZ}$$

If we assume the same order filters in the D/A converters as REC-601 then the bandwidths of the analog HDTV video components will be:

$$Y = \frac{74.25}{2.45} = 30 \text{ MHZ}$$

$$R-Y = \frac{37.625}{2.45} = 15 \text{ MHZ}$$

$$B-Y = \frac{37.625}{2.45} = 15 \text{ MHZ}$$

This would produce a horizontal luminance resolution of:

$$= 2 \frac{TA}{A} . f_b$$

$$= \frac{2 \times 25.86}{1.77} \times 30$$

$$= 876 \text{ TVL/ph}$$

which is a performance beyond that we had originally assumed. So, the current US HDTV standard is a very high performing system - an origination system capable of many applications.

5.0 WHAT ARE THE ADVANTAGES OF A SINGLE WORLDWIDE HDTV STANDARD?

We've spoken about the wide-ranging committee work and the enormous effort currently being directed to seek a single world standard for HDTV Studio Origination and International Program Exchange. Its quite appropriate therefore for you, the Broadcaster, to ask what all the fuss is about. What **ARE** the advantages of our gaining this single standard?

The advantages are **VERY** significant to **all** of us - and they are summarized as follows:

5.1 **It offers program software producers an important new alternative to 35mm film.** The latter is a universal world standard. All of the advantages of that would pertain also to this new electronic HDTV alternative. This choice inherently offers a major new universal programming flexibility for the future.

5.2 A single worldwide standard offers a uniform **TECHNICAL** quality to the international marketplace.

5.3 Program software producers, worldwide, will **compete on an equal footing.**

5.4 Equipment manufacturers will compete in a **single world market** - direct competition and improved economies of scale will have immediate fiscal benefit to the end-user.

5.5 **Basic R&D for 1125/60 is complete.** By its universal adoption manufacturers do not have to start from scratch. All Broadcasting entities in all countries have equal access to the relevant technologies - which are guaranteed to be licensed to all under reasonable terms and conditions.

5.6 A single studio origination standard will stand poised to meet the flourishing emergence of new DISTRIBUTION media such as video disc, VCR, fiber optic and in the future by cable and DBS-utilizing suitable conversion means.

6.0 DOES HDTV CONFLICT WITH THE EMERGING COMPONENT 525 DIGITAL STUDIO?:

Enormous Strides have taken place in the development of digital technology during the past decade. The fact that this burgeoning technology essentially paralleled the emergence of HDTV has led to the inevitable query as to the relative dynamics of these two **seemingly** independent movements.

From the cooperative efforts of the SMPTE in the USA and the EBU in Europe there emerged the coordinated definition of an all-component studio standard employing digital video signals. This work was formally ratified by the CCIR Plenany Assembly of 1982 as the now famous **recommendation CCIR-601.** This standard anticipated, in very timely standard anticipated, in very timely fashion, the future digital equipment developments. Indeed, that pivotal item of equipment so central to the digital studio - the **component DVTR** - became the subject a subsequent intense international effort which only, just in recent months, came to fruition with a new worldwide agreement on a **tape format** entirely consistent with the CCIR-601 guidelines.

Has all of this long effort been diluted in any way with the virtually simultaneous advent of HDTV? Does this superior new HD TV system preempt the dawn of the 4:2:2 digital era, which to many represents the technical pinnacle of compability for the studio origination of 525 and 625 TV?

The answer is **NO** - not at all. In fact, the wisdom of our industry's best international engineering talent faced up to these somewhat disparate movements - and carefully ensured a future synergism between the two.

Unlike NTSC, both the HDTV and the Enhanced 525 systems are, by definition, **component** video based systems. ATSC has therefore taken the approach of structuring the 1125/60 signal to be a "superset" of the 525 CCIR-601 component standard - from the viewpoint of:

COMPONENT VIDEO SET
COMPONENT BANDWIDTHS
DIGITAL CODING
CHOICE OF SAMPLING FREQUENCIES

The goal of the ATSC is to firmly establish as direct a correlation between these two signals to ensure simple conversion from HDTV to Enhanced 525 (and from there to 525 NTSC).

So, just as 35mm film will remain a major program origination source for 525 NTSC, or for ENHANCED 525 Component systems - so too, will the component HDTV electronic master be an alternative future program origination source. The steps to ensure direct, sound technical translation between the two have wisely been taken by ATSC.

7.0 <u>WHO WILL USE HDTV</u>?

It was stated at the outset that HDTV was always considered as a broad based, highest quality, universal TV system capable of addressing all of the needs of a future "information society". It perhaps simplifies things if the potential HDTV user world were separated into:

- **HI-TECH CLOSED CIRCUIT APPLICATIONS WITHIN BUSINESS AND INDUSTRY**
- **MOTION PICTURE PRODUCTION AND DISTRIBUTION**
- **BROADCASTING**

The first of these is where the **near-term** market activity will surely lie. There are a vast and diverse array of needs within Business and Industry for high quality electronic imaging. To name but a few:

Flight Simulators

Training Simulators

Teleconferencing - capable of handling documents

Printing/Publishing

Point of Purchase

Medical

Educational, cultural, community viewing etc

In the domain of **Motion Picture Production** SONY has been continually active for more than two years. We have never envisaged HDTV as **replacing** film. Nevertheless the Hollywood community itself has identified some key areas where HDTV techniques will serve as an invaluable adjunct to their primary film production. Blue Screen compositing of foreground and background images is such a needed application. Today, using film/optical techniques in the traditional manner is a highly time consuming and costly enterprise - often producing results that are less than satisfactory. HDTV offers the distinct advantage of being able to realise a great deal of this in **real-time** - thus introducing an important new flexibility for optimizing the final composite itself from the standpoint of color matching the foreground and background images, dealing with shadows etc.

This past year has seen a continuing series of important experiments between SONY and the Ultimatte Corporation (who produced a powerful 1125/60 version of their well know Ultimatte system) along these lines. The HDTV experimental composites have, each time been transferred by us to 35mm film. These films have been circulated among the Motion Picture community - and been greeted with wide acclaim. This work continues.

in an era where our deeper understanding of television is flowering in all the major TV labs of the world. HDTV will therefore grow very vigorously indeed. HDTV pictures indisputably capture the attention and acclaim of the viewer - both technical and lay. Just walk around the HDTV exhibit at this NAB.

Given all of that, there is little doubt that HDTV warrants close examination by the **US Broadcaster.** It **WILL** figure in the world of Broadcasting. Whether that is in five years, or fifteen years,is a moot point.

The solid foundations of a studio origination standard are now essentially in place. The next task facing us all is to grapple with the distribution and transmission means necessary to transport this high quality TV signal. Just as the NHK devoted a long decade to perfect the 1125/60 system, so too, the Broadcaster should carefully and painstakingly examine the implications of handling this undoubtedly formidable signal over the airwaves.

This challenge has recently been picked up by the MST and NAB who are, at this time, laying plans for a series of tests on terrestial broadcasting of future advanced TV system - **including HDTV.** This is a significant first step.

REFERENCES:

1. T. FUJIO

   STUDY OF HIGH-DEFINITION TV SYSTEM IN THE FUTURE IEEE TRANS., BC-24,1978

2. T. FUJIO, J. SHIDA, T. KOMOTO AND T. NISHISAWA

   HIGH-DEFINITION TV SYSTEM - SIGNAL STANDARD AND TRANSMISSION SMPTE J. VOL.89 NO.8.1980

3. K. HAYASHI

   RESEARCH AND DEVELOPMENT ON HIGH-DEFINITION TELEVISION IN JAPAN SMPTE J. VOL.89 NO.8.1980

4. T. FUJIO

   HIGH DEFINITION TELEVISION NHK TECHNICAL MONOGRAPH JUNE 1982

COMPATIBLE TERRESTRIAL HDTV TRANSMISSION

William E. Glenn, Ph.D., Director
New York Institute of Technology
Dania, Florida

ABSTRACT

A description is given of the improvements that can be made in NTSC, enhanced TV and HDTV transmission systems. A quantitative comparison of the performance of these systems after including these improvements will be given. An approach for implementing compatible terrestrial HDTV transmission, which can be received either by standard NTSC receivers or 1125-line HDTV receivers, will be described. This transmission uses a standard NTSC channel plus a half-channel transmission of detail which need not be adjacent in frequency or location.

INTRODUCTION

Currently, there is considerable interest in developing new and improved television systems. The Advanced Television Standards Committee (ATSC) has three subcommittees devoted to studying and recommending the development of new production and distribution standards. It is obvious that there will be major changes in the way we view television in the next decade. What does this mean to the terrestrial broadcaster?

Before discussing transmission standards, let us first discuss the proposed system improvements as viewed by the three ATSC subcommittees. There are many proposed system improvements. However, the most discussed improvement in all subcommittees is an increase in resolution.

The term "resolution" is somewhat misleading. TV lines per picture height cannot be translated into resolution on the retina of the viewer without knowing the viewing distance. When viewing normal program material (not test charts) viewers are very good at maximizing the total amount of information they can derive from the image within their field of view. Approximately 50% of the neurons in the visual cortex are devoted to processing information from the central 1 degree of viewing angle.[1] A viewer will therefore "back up" when viewing an image to increase the proportion of the image that is within this 1 degree field. Eventually, the information in this area is lost, when the limiting resolution of the display exceeds the limiting resolution of the eye. The optimum occurs where the limiting resolution of the display is about 22 cycles per degree of visual angle, as viewed by the observer. At this point, the contrast sensitivity of the visual system is about 30% of peak sensitivity. This occurs at about seven screen heights for 525-line television and at about 3-½ screen heights for HDTV and 35mm projected motion-picture film. It is no surprise that seven screen heights is about the most common viewing distance for the typical television viewer, and that 3-½ screen heights is the viewing distance of the center of most movie theaters, and is the distance recommended by NHK for viewing of the 1125-line HDTV system.

HDTV should really be termed "wide-screen television". The HDTV viewer sees the same resolution on the retina with five times the solid angle for the field of view, as when viewing an equivalent 525-line display. We ought not to ask, "Can the viewer see the difference if you increase the resolution on a given size display?", but rather, "Given the same resolution on the retina, can the viewer see the difference if the image is five times the area?" I think the answer is obvious.

Based on this analysis, let us compare the proposed systems considered by the ATSC subcommittees.

Improved NTSC

The charter of this subcommittee, under the chairmanship of Kerns Powers, is to suggest ways in which to improve image quality within NTSC broadcast standards. We should obviously try to produce as good an image as possible within existing standards before making a standards change. The following is a partial list of improvements that can be made:

1. Remove cross-color and cross-luminance artifacts. These result from using the same frequency spectrum to transmit luminance and chrominance. These can be eliminated by using the 15-cycle interlace of the color carrier to allow separation at this frame rate for color and detail luminance.[2] It can also be done by "combing" the spectrum at the transmitter to eliminate the overlap.[3]

2. Use progressive scan in the camera and scan convert to NTSC.[4] Camera tubes have better vertical resolution if they are progressively scanned.

3. Use progressive scan in the display at 1050 (or 1125) lines, scan converted and processed

from an NTSC signal.[5,6] This results in a less visible line structure. If a frame store and motion adaptive processing is used, it can also remove interline flicker and give a slight improvement in vertical resolution.

4. Use diagonal sampling with pre and post-filtering.[5,7,8] The visual system has better resolution in the cardinal directions than on the diagonal (this is referred to as the "oblique effect"). Diagonal sampling improves vertical and horizontal resolution at the expense of diagonal resolution. Pre and post-filtering removes aliasing and "zig-zag" lines resulting from sampling.

5. Modify the camera gamma to approximate a logarithmic function and the display gamma to more closely approximate an antilogarithmic function.[9] This makes noise less visible. With the appropriate camera matrix, it also makes luminance and chrominance independent of each other resulting in greater apparent sharpness in saturated colors.

6. Derive luminance from R, G, B signals with independently weighted response curves (based on psychophysical data).[9] High spatial frequency chrominance information produces a luminance sensation in a real scene. The apparent sharpness of saturated colors can be improved without an increase in system bandwidth by using high frequency pre-emphasis to red and high frequency attenuation to blue when deriving Y from R, G, B signals.

7. Use temporal enhancement to improve the apparent sharpness of moving objects.[10] The same problems exist in time due to sampling as in space. Temporal filtering, which may also be combined with temporal oversampling in the camera and display, can result in moving objects appearing sharper and having fewer motion artifacts.

If all of these improvements are made, we should have better resolution, neither cross-color nor cross-luminance, no interline flicker, better apparent S/N ratio and better apparent sharpness in moving objects and in saturated colors. The total apparent increase in resolution would be about 1.3 vertically and 1.5 horizontally, giving a total increase in viewing area of about a factor of two, at the same resolution on the viewer's retina.

Enhanced TV

The charter of the Enhanced TV Subcommittee, chaired by Dan Wells, is to consider way to develop an improved 525-line transmission system which does involve a change in transmission standards. This subcommittee has concentrated on analog component transmission by satellite. The bandwidth has generally been increased to seven or eight megahertz.

Analog component transmission of color signals produces a more favorable signal-to-noise ratio for chrominance when FM subcarriers are used, as in satellite transmission or tape recorders. By sending luminance and chrominance as separate signals without frequency overlap (as in NTSC), cross luminance or cross color artifacts are avoided. These improvements are, however, at the expense of bandwidth. The remaining improvements listed above can also be incorporated into MAC transmission.

High Definition Television (HDTV)

The charter of the HDTV Subcommittee, chaired by Ren McMann, is to develop a high definition standard with about twice the vertical and horizontal resolution of NTSC transmission. This also requires a standards change. This subcommittee has concentrated on the 1125-line, 3x5 aspect ratio format proposed by NHK. There has been some discussion of transmission systems that do not use bandwidth reduction[11] or systems that do not display in this format.[6] However, to date, there have been two proposed transmission systems using bandwidth compression for display in this format. These are the NHK MUSE[12] system and the NYIT compatible HDTV transmission system.[13,14] They both take about the same transmission bandwidth (7 to 9 megahertz), and both require a frame store in the receiver. They both should produce about the same image quality.

Most of the improvements discussed in improved NTSC systems can also be incorporated in improved versions of HDTV. For example, progressive scanning of both the camera and display can be used without a change of the recording (production) format or transmission format (which would normally be interlaced).

System Comparison

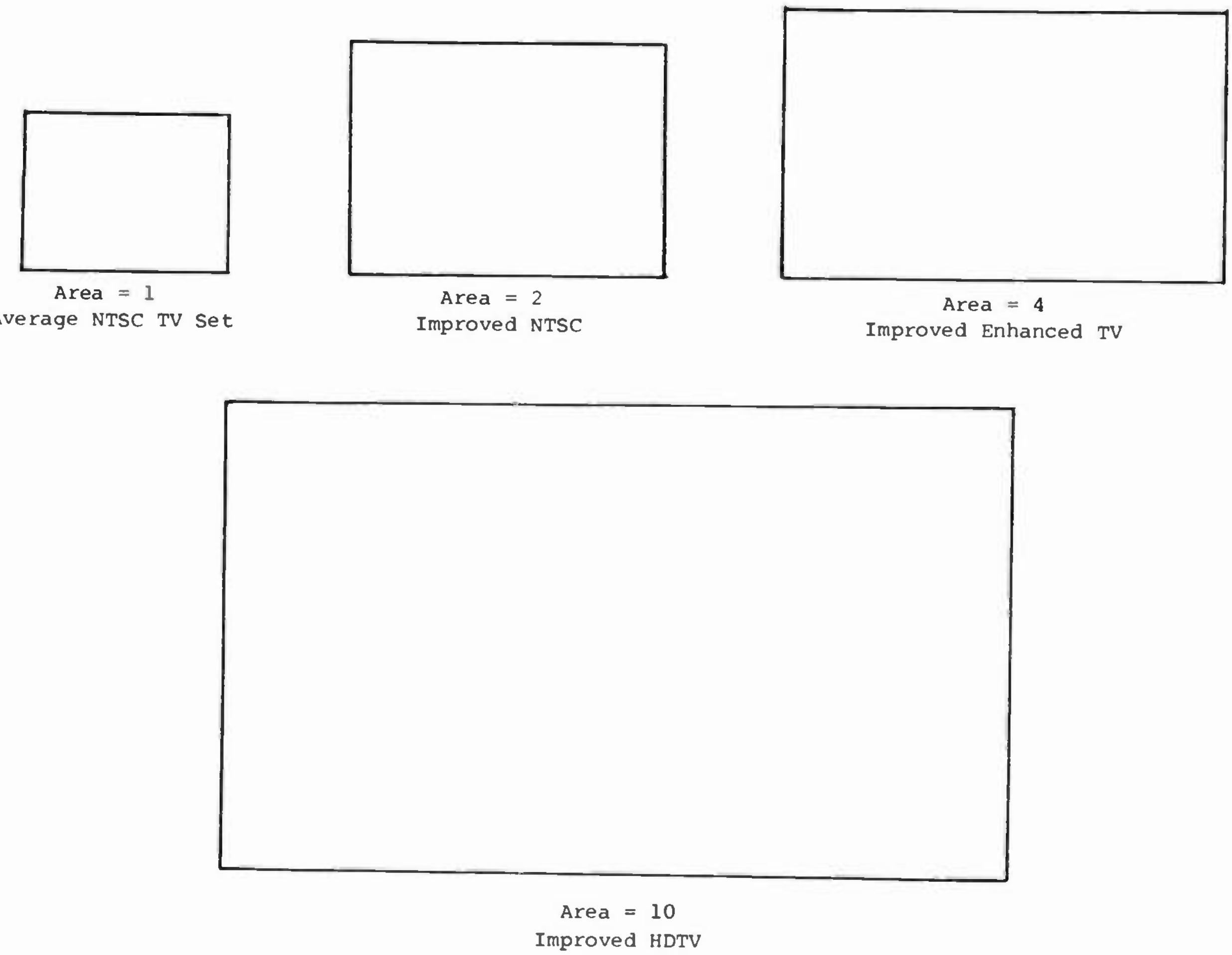
In order to make a fair comparison between improved NTSC, enhanced, and HDTV systems, I will assume that all systems have the improvements listed above in the improved NTSC discussion. It is true that HDTV will probably not use many of these improvements when first introduced. However, they can be introduced in HDTV early in its development without a change in recording or transmission format.

Let us now compare the benefit derived from improved NTSC, enhanced TV or HDTV transmissions. The HDTV format uses bandwidth reduction to the same bandwidth as the enhanced system at the expense of a frame store in the receiver. If we now assume the same resolution on the viewer's retina, the displayed images will have relative sizes as shown in Figure 1. A standard, unimproved, 525-line NTSC receiver with a screen area of 1 is used as reference.

Transmission Standards

We should certainly improve NTSC as much as possible. These improvements should then be incorporated into both enhanced and HDTV system designs. HDTV systems obtain a considerable increase in field of view at the same resolution on the viewer's retina. This is at the expense of a frame store

FIGURE 1



Relative sizes of images displayed with the same resolution on the viewer's retina.

in the receiver. At the projected cost of frame stores, this benefit is well worth the investment.

Both enhanced and HDTV distribution systems may develop that require a change in transmission standards. However, since they both require about the same bandwidth, we may be faced with a choice between them. In such a choice the 1125-line, 3x5 aspect ratio display format will probably win. This is partly for the technical reasons described above, and partly based on the huge investments of NHK, Sony, Ikagami and others in developing this industry. This effort is very reminiscent of the efforts of RCA, CBS, G.E. and others in the days of the NTSC color development.

HDTV can be distributed in NYIT or MUSE format by disc, cassette, satellite and cable. Where does this leave the terrestrial broadcaster? As presently configured, MUSE format would require allocation of two adjacent channels for terrestrial transmission. The NYIT format is designed to build on existing NTSC transmissions. An additional detail signal is transmitted to allow HDTV receivers to reconstruct 1125-line images from the combination of the NTSC and the detail transmissions. We expect that the detail transmission will require about half-channel bandwidth. It need not be adjacent in frequency and does not need to have its antenna co-located with the NTSC transmitter. Detail transmission could be in the UHF spectrum. The detail transmitter could be time-shared between two stations. Alternatively, channels that are not now used because of possible adjacent channel or co-channel interference could be used with a single lower bandwidth detail transmission. This transmission would have less visible structure and synch signals, and could use a suppressed carrier.

It is unlikely that we could develop a viable terrestrial HDTV broadcast system by re-allocating the broadcast spectrum into adjacent two-channel blocks for incompatible transmission. The format NYIT has been developing has the advantage of compatibility. It would leave the base NTSC transmission where it presently is in the spectrum. Another portion of any available channel is required for display of this signal by 1125-line receivers.

This compatible transmission should allow the continuation of a viable terrestrial broadcast industry with minimum turmoil as HDTV penetrates the television market.

REFERENCES

1. Kandel, E.R. & Schwartz, J.H. (Eds.), Principles of Neural Science. New York: Elsevier North-Holland (1981).

2. Glenn, W.E., Glenn, K.G., Marcinka, J., Dhein, R., Abrahams, I.C. 'Reduced bandwidth requirements for compatible high definition television transmission.' Proceedings of the 38th Annual Broadcast Engineering Conference, National Association of Broadcasters, Washington, D.C. (1984) pp. 297-305.

3. Faroudja, Y.C., SMPTE (Los Angeles Convention - 1985).

4. Glenn, W.E., Glenn, K.G., Bastian, C. "Imaging system design based on psychophysical data." Proceedings of Society for Information Display, pp. 294-297 (1984).

5. Prodan, R. (Philips Labs Demonstration).

6. Jackson, R.N., Annegarn, M.J.J.C. 'Compatible systems for high-quality television.' SMPTE Journal, 92 (1983) pp. 719-723.

7. Wendland, B. 'Extended definition television with high picture quality,' SMPTE Journal 92, pp. 1028-1035.

8. Wendland, B., and Schroeder, H. 'On picture quality of some signal processing techniques,' SMPTE Journal, 93. pp. 915-922 (1984).

9. Glenn, W.E. & Glenn, K.G. 'HDTV Colorimetry,' HDTV Colloquium, Vol 1, Ottawa, Canada: Government of Canada, 2.1, pp. 1-19 (1985)

10. Glenn, W.E. & Glenn, K.G. 'Discrimination of sharpness in a televised moving image,' Proceedings of Society for Information Display 26 (1) pp. 71-78 (1985).

11. Goldberg, A.A., McMann, R.H. 'A compatible HDTV system,' NAB Conference Proceedings - 38th (1984).

12. Sugimoto, M. 'A single channel HDTV broadcast system,' NHK Technical Report presented to HDTV Subcommittee, SMPTE Conference, Montreal, Quebec (1984).

13. Glenn, W.E., Glenn, K.G., Dhein, R.L., Abrahams, I.C. 'Compatible transmission of high definition television using bandwidth reduction,' Proceedings of 37th Annual Broadcast Engineering Conference, National Association of Broadcasters, Washington, D.C. pp. 341-349 (1983).

14. Glenn, W.E., Glenn, K.G., Marcinka, J., Dhein, R., Abrahams, I.C. 'Reduced bandwidth requirements for compatible high definition television transmission,' Proceedings of 38th Annual Broadcast Engineering Conference, National Association of Broadcasters, Washington, D.C. pp. 297-305 (1984).

ADVANCED TELEVISION TERRESTRIAL BROADCAST DEMONSTRATION PROJECT

A Cooperative Project of
The National Association of Broadcasters and
The Association of Maximum Service Telecasters
E.B. Crutchfield
Project Director
Washington, District of Columbia

INTRODUCTION

Delivery of improved or higher definition television is possible by a relatively conventional, terrestrial system of broadcasting, using existing spectrum. Preliminary work indicates that such a system could be developed around our existing broadcast system, taking advantage of the vast resources of engineering, programming and management expertise of television broadcasters of today.

Terrestrial broadcasting of a significantly higher definition television has seldom been discussed. It has been assumed that this next major step in the improvement of television will be limited to special satellite or cable channels or a new generation of video disc or tape players.

OBJECTIVE

The objective of this project is to demonstrate to the broadcast industry, its regulators and the public that significant advances in the technical improvement of television have reached the point where they may be delivered, on an experimental basis, via terrestrial broadcast methods. There are several systems currently under active development, some compatible, some incompatible with our NTSC standard. Most, however, require more than the 6 MHz bandwidth currently allocated to television channels.

This demonstration is very important for two reasons.

1. For many broadcasters, advanced television systems are still laboratory curiosities. Our members need to know more about these systems, particularly their potential use by broadcasters and by competing media.

2. It is essential that Congress and the FCC be persuaded not to preclude, through changes in UHF spectrum allocations, the broadcast delivery of advanced television. This is an urgent matter since the FCC is currently considering a major proposal to allow Land Mobile services to share parts of the UHF television spectrum.

The National Association of Broadcasters (NAB) and the Association of Maximum Service Telecasters (MST) are preparing a series of demonstration broadcasts in the Washington, DC area and possibly other cities. The first system to be demonstrated will probably be the 1125 line, MUSE system, developed by NHK (Japan Broadcasting). NHK has already conducted a broadcast test of this system in Japan, and has agreed to loan equipment to us and provide engineering support. In addition, we have offers of equipment from manufacturers developing high definition cameras, recorders and other production equipment. Several transmitter manufacturers have offered to modify and loan us a transmitter to be used in this project.

Tentative plans are to place the transmitter at a site offered by a local broadcaster in the Tenley Circle area of northwest Washington. Depending on the number of decoders available, receivers will be located at key sites in the downtown area. Ideally, these would include Congress, the FCC, NAB and MST. Programming would include locally-produced material, live and on tape, as well as film material and programs produced by the various networks and equipment manufacturers working with HDTV.

ADVANCED TELEVISION SYSTEMS

There is a wide range of improved television systems. Scientists and engineers in the U.S., Japan and Europe are studying or actually testing various approaches. At one end of the technological spectrum are improvements to the existing NTSC (or PAL or SECAM) standard. These apply to one or more phases of the imaging, encoding, processing and display systems and are generally compatible with existing equipment.

Because of compatibility these improvements may be tested with existing broadcast facilities. No special test setup or authorization is required. Furthermore, much of the work being done is in the area of receiver improvement and appears on the market in the form of the latest model receiver.

Current television standards have inherent limitations in the encoding processes and in bandwidths. While these standards still have significant potential for improvement, the next big step in improvement of picture quality is expected to come in the form of a system incorporating some of the following departures:

- increased number of scanning lines (possibly double or more),
- progressive scanning,
- wider aspect ratio,
- higher frame rate,
- component encoding and wider bandwidths for all channels,
- digital transmission.

Probably the most important factor, from the point of view of the broadcaster, is the increase in bandwidth of the final output signal. It now appears that making a major improvement in picture quality means, inescapably, transmitting more information per unit time, which means more bandwidth. The HDTV system proposed to CCIR by the U.S. and Japan as a world production standard uses 1125 lines, an aspect ratio of 16:9 and produces a signal of almost 30 MHz.

The increased bandwidth of these proposed systems does not necessarily preclude terrestrial broadcast delivery of some form of improved or high definition television. Several systems currently being developed may permit this without dismantling our existing system of terrestrial broadcasting. This NAB-MST project is intended to demonstrate these possibilities so that broadcasters can anticipate and participate in the next major step in television improvement.

PROJECT PLANS

One of the biggest limitations on this project is availability of equipment. Many of the systems currently under development are not yet out of the laboratory. Where operating systems exist there is only one or a few prototype or developmental models, and these are in considerable demand by the engineers, for further development, and by others for demonstration purposes.

Initially, the demonstration broadcasts are planned for the Washington, DC-area. Depending on the availability of receiving equipment, receiving sites will be set up in regulatory offices, Congress and public locations. The transmitter will be located at broadcasting facilities of WDVM, a member of NAB and MST, which has offered space and has a tower with a direct line-of-sight to most locations in the downtown area. This proposed location is shown in Fig. 1.

With transmission paths of 10 km or less it may be possible, depending on the nature of the signal, particularly bandwidth, to provide sufficient signal with a transmitter power in the range of 100 to 1,000 watts.

There is also interest in the technical prospects for carrying a broadcast HDTV signal over cable. The proposed transmitter location shown is within line-of-site of at least one major CATV headend.

The MUSE System

The first system demonstration planned for the Advanced Television Terrestrial Broadcast project is the MUSE system, developed by the Japanese public broadcasting network, NHK. MUSE, which stands for Multiple Sub-Nyquist Sampling Encoding, was originally developed for satellite distribution of the proposed HDTV standard. An HDTV picture can be reconstructed from a signal of only about 8 MHz, including stereo sound. This is not very much greater than the 6 MHz bandwidth of a standard U.S. television broadcast channel.

An important, non-technical advantage of MUSE is that it is a working system. It has been tested by NHK in both satellite and terrestrial broadcast applications. In their tests, however, NHK used frequency modulation, while we expect to use amplitude modulation to save channel width. Subject to FCC authorization for experimental operation, we plan to operate a modified transmitter in the UHF band.

Other Systems

Several other systems are in developmental stages which should permit demonstrating them in the near future. Variations of multiplexed analog component (MAC) systems may be available soon. The MAC systems are, like MUSE, originally planned for satellite use, and some are actually being used at present.

Another new system which may be available soon is one which uses two television channels which are not necessarily contiguous. This approach involves transmitting a standard NTSC signal on one channel with additional picture information being transmitted on the second channel. Conventional receivers will work with the first channel while high definition receivers will combine the two channels to produce a high definition picture.

PROGRAMMING

Programming will cover a wide range of material: drama, light entertainment, sports, news and documentary. Another reason for beginning this project with the MUSE system is because it is designed to work with the proposed HDTV production standard and there appears to be much program material recorded in this format. NHK and CBS are the primary sources but other companies have produced programs in this format.

The availability of a film-to-HDTV scanner from Rank Cintel offers the opportunity to transfer a wide range of program material originally produced on 35 mm film.

It is important that programming for this project be attractive and interesting. Many of the people whose present actions will influence the future of terrestrial broadcasting and advanced television development are non-technical and cannot be expected to spend much time looking at color bars, resolution charts or ducks floating on a lake.

CONCLUSION

It is too early to predict when advanced television systems will appear on the market or in what form. From the amount of research and development currently being done however, we can tell that one or more systems are likely to appear in the near future. The purpose of this project is to help the broadcast industry evaluate the progress of advanced television systems and determine its role in the development and adoption of a system for broadcast use.

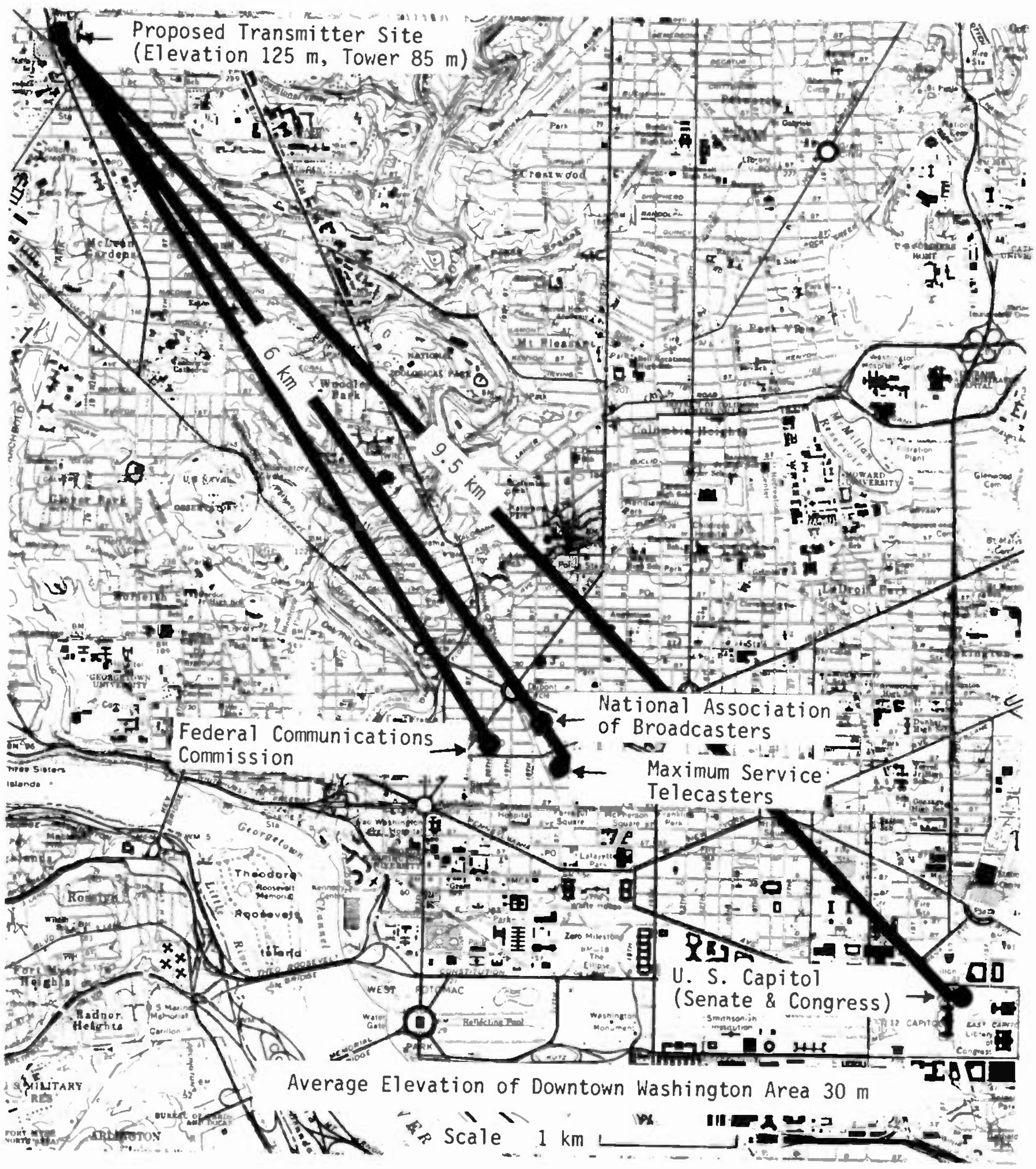


Fig. 1 Proposed Transmitter and Receiving Sites

COMPARING VARIOUS PROPOSALS FOR AUDIO FOR HIGH DEFINITION TELEVISION SYSTEMS

George H. Plenge
Institut für Rundfunktechnik, München

ABSTRACT

3 suggestions for HDTV sound systems are currently under consideration by the CCIR. These suggestions differ from each other in number of channels transmission modus and design philosophy.

One of the three suggestions originates from our institution, in which now basic experiments for auditory localisation with concurrent visual perception are conducted.

Results of these experiments and the consequences for sound systems in HDTV will be reported upon. A critical comparison of the three proposals submited to CCIR will follow.

Nowadays the usual television standards provide - insofar as stereophonic transmission is included - a transmission method which is closely associated with that employed in FM-radio. The signals L and R are matrixed in different methods (L + R, L - R; L + R, R); but the following is common to all methods :

- analog sound transmission
- 2 sound information elements
- phantom sound sources for the presentation of direction.

Errors in localization are only of minor significance because

- only a small viewing angle is used in presentation of small picture (TV screen normally not more than 70 cm diagonally)
- this viewing angle is further restricted because of the required viewing distance to about 14^{o} with a recommended viewing distance of 5 x picture height
- the acoustically conveyed position of "OFF" sources can not be controlled by sight; errors are only recognized if, eg. an "OFF" source comes into the picture and discrepancies between the location, which up until then was only perceived acoustically, and the suddenly visible location occur during the changeover.

The system suggested for the near future, such as C-MAC or D-MAC, resp. the system D-2-MAC-P inaugurated this year in Europe for DBS, use a digital sound transmission. Sound channels with varying frequency range, error protection, as well as definition in various combinations, are usable. The multiplicity of the available sound channels - eg. with C-MAC - serve, however, only to make it possible to be able to transmit the television sound in various languages.

For stereophonic recording and transmitting there is no change from methods used until now - including the locating errors mentioned above. However, the general quality is improved by the change to a digital technique.

The use of large screen projectors for the now usual standards or for the MAC-standards leads to perceptible and bothersome errors in the acoustical presentation of location of sound sources, especially then if several people view this large screen pitcture.

The enormous costs of an HDTV system only make sense if a large screen is used. The viewing angle will change from 14^{o} (normal distance 5 x height, 3/4 format) to at least 33^{o} (distance 3 x height, 3/5 format).

In the meantime three different proposals to overcome these problems have been made and published in at least three CCIR publications from

United States /1/
FRG /2/
Japan /3/.

These proposals partly differ and partly coincide in their objectives.

All three proposals attempt to improve the presentation of directions. The Japanese proposal attempts as well to achieve more "realism" in the sound reproduction.

The main features of thesse three contributions may be characterized by the following three excerpts of the CCIR New Report to Study Programme AG/10 : Sound Systems for HDTV and EDTV.

U.S. proposal describes a triphonic sound system incorporating an audio matrix hierarchy which provides for third discrete audio channel, pefereably for the transmission and reproduction of center-front dialogue programme. With a center channel loudspeaker located in proximity with the video monitor, a stable source of center sound is achieved, in contrast to the highly unstable phantom center sounds achieved by widely-spaced left and right loudspeakers. This triphonic system, which is applicable to both conventional and high definition television service, provides an additional benefit of permitting non-ciritical placement of the two conventional stereo loudspeakers in a quasi-sourround sound mode.

The FRG proposal assumes a vierwers distant to the screen of 3 x height so that a viewing angle of at least 33° results. These will cause head movements of the spectator (listener) and - if more than one person takes part -sitting side by side naturally.
This is contradictory to reception of stable phantom sources normally used in stereophony. To overcome this problem so called substituting sound sources can be applied, to convey correct localization of directions.

Within the limits given by just noticeable differences in localization, ca. 13 loudspeakers would be necessary to cover the wider angle of 33°. This is valid only for listening without viewing and under special subjective test conditions.

In normal situations - especially listening with simultaneous viewing to concomitant pictures - the noticeable differences are expected to be much larger so that 5 substituting sound sources resp. loudspeakers are sufficient.

This system will make use of 5 separated sound channels which must be available as well for recording, storing, transmission and reproduction.

Compatibility with existing monophonic or stereophonic systems can be achieved by simple matrixing networks.

Japan proposal would be desirable to make use of four sound signals in order to reproduce a better sensation of reality.

Reproduction of a sound field used two or three sound signals gives an inferior sensation of reality in the arrangement of two or three loudspeakers located infront of a viewer. Judging from past experience, the situation cannot be improved in other three loudspeaker arrangements, for example, three loudspeaker arrangements in which a viewer faces the left and right loudspeaker with a wider angle of from 90 to 120 degrees.

On the other hand, the use of more than four sound signals could be expected to increase difficulties in the economical and technical feasibility of the system, although it would provide superior sensation of reality.

Therefore, the sound-signal system for HDTV would be the desirable choice from standpoint of realizing a better sensation of reality.

It would be desirable to adopt loudspeaker arrangements which include three loudspeakers set in front of viewers, one under the center of the screen and others to the left and right, in order to maintain a better coincidence of the direction of the sound image and that of the video image on the screen for viewers on either side of the central axis perpendicular to the screen.

Comparison of the proposals as regards "realism" : Only the Japanese proposal anticipates in principle special channels and loudspeakers for spatial information (ambiente); the presentation of "OFF" sound is not provided via these loudspeakers.

The three proposals differ considerably as regards presentation of direction :

The Japanese proposal plans to have 3 loudspeakers in front of the listeners for the reproduction of direction (fig. 1 and 2).

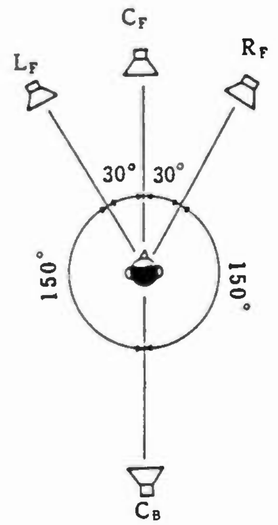
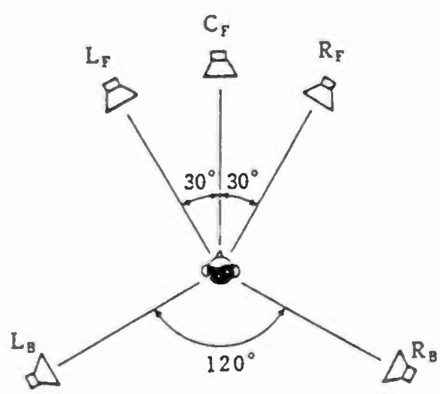


FIG. 1

4CH④ 3−1(A)



4CH⑤ 3−1(B)

FIG. 2

As a result of listening tests conducted with the reproduction of an orchestra via two loudspeakers and a singer via a middle loudspeaker it has been determined that this is a satisfactory solution for the presentation of the **important** sources, which are represented on the screen (singer) - as well as for a listener sitting out of axis (fig. 3).

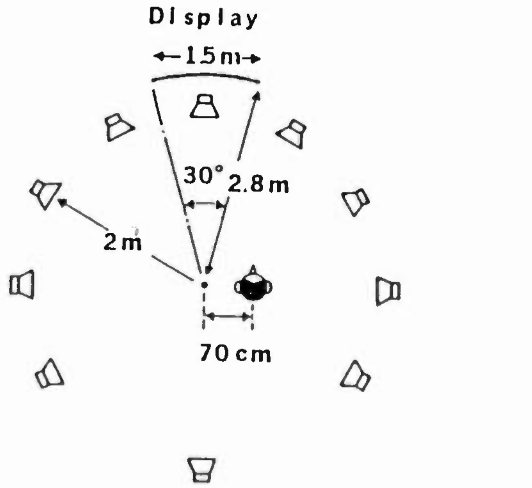


FIG. 3

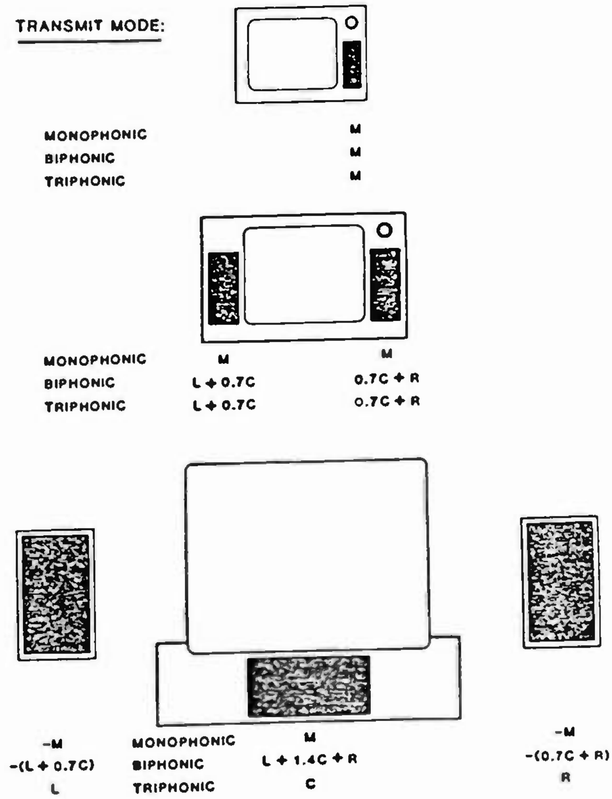
Sound sources represented between very left (or right) end centre of the screen did not occur.

The sound image of the orchestral sections was spread over the front loudspeakers. The audience reaction in the hall and reverberation sounds are provided by the side loudspeakers.

The U.S. proposal takes into consideration initially the existing situation with relatively small screens. It serves initally to improve the current situation (fig. 4). In addition it should also be applicable to large screens (HDTV).

Consequently - the compatibility with existing systems is a prerequisite - the reproduction of the middle channel is achieved by matrixing (fig. 4). Only the sound sources, which are considered particularly important, are reproduced over the middle channel : "... in which **important dialogue** is usually assigned to a **discrete center** channel feeding a center-screen loudspeaker. While the method requires slightly more complex mixing and recording facilities, it is direct in its approach and provides satisfactory reproduction of important signals. Although the addition of a new loudspeaker interposed between the left and right loudspeakers provides the opportunity to pan additional virtual images at the near left and near right locations, for non-dialogue effects it appears quite satisfactory to simply pan from left to right, especially for rapidly moving or non-discrete effects" /4/.

This differing treatment of the sound sources may be correct for existing systems. It is questionable whether this method is adequate for a large screen such as will be used for HDTV.



Reception mode hierarchy

FIG. 4

Even the presentation of a dialog with 2 people standing beside each other is unsatisfactory because both of them are acoustically reproduced at one location. If one speaker is further to one side then he can only be represented over the middle channel - that is, falsely -; or over the normal "pan-potting", which would correct for a listener on the loudspeaker axis but false for all other listeners.

The FRG proposla is concentrated on the situation of HDTV with a large screen. It is assumed that sufficient capacity exists in a HDTV system for storing and transmitting a large number ($\geq$ 5) of sound channels of high quality.

The principle of substituting sound sources (fig. 5) guarantees that, regardless of their position, all listeners also localize acoustically sound sources where they are presented on the screen. "OFF" sources also can be localised better - and for all listeners at approximately the same place. The presentation of many sound sources - eg. an orchestra - can also be better accomplished by the use of an "intensity stereophonic system" expanded to 5 (or more) channels.

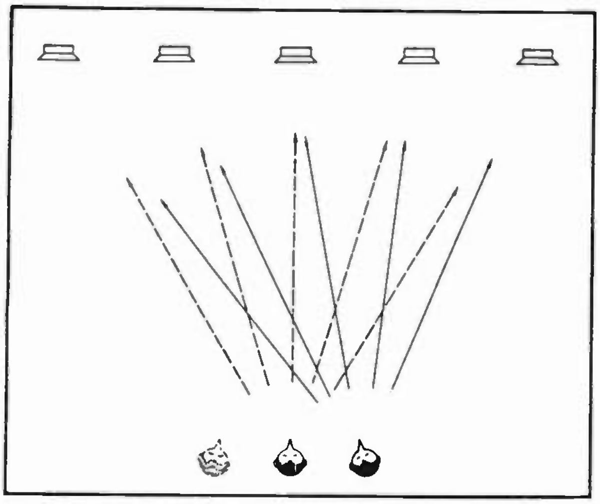


FIG. 5 Perceived sound incident directions substituting sound sources

The larger number of channels which has to be taken into consideration in the control desk during recording is surely a disadvantage. This, however only means a greater technical expanse - the "handling" of such a control desk will hardly differ from that of customary panels.

The variances in the perceived direction of phantom sound sources for listeners out of axis have been determined by listening tests conducted in the IRT in Munich. They take into consideration the simplest case in which only 3 people are sitting next to each other.

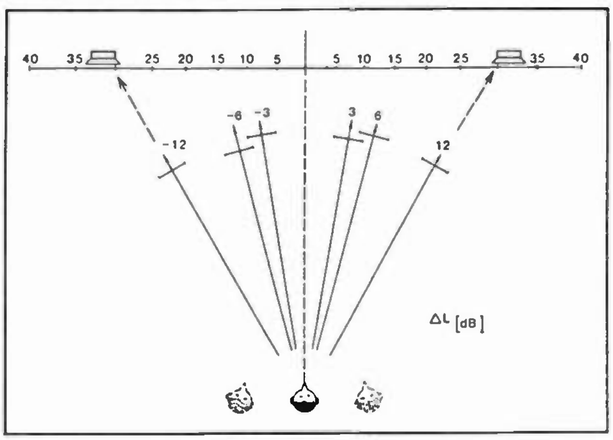


FIG. 6 Perceived sound incident direction Phantom source, level diff. Regular position of the listener

The figures 6 - 9 show the results of listening experiments for the perceived direction of phantom sources produced either by level differences or time differences.

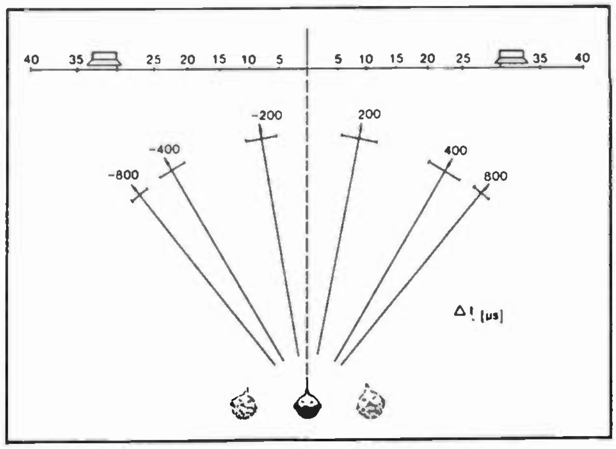


FIG. 7 Perceived sound incident direction Phantom source, time diff. Regular position of the listener

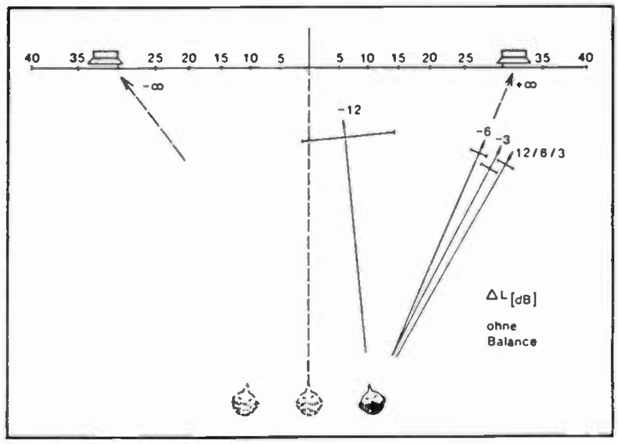


FIG. 8 Perceived sound incident direction Phantom source, level diff. shifted position of the listener, unbalanced

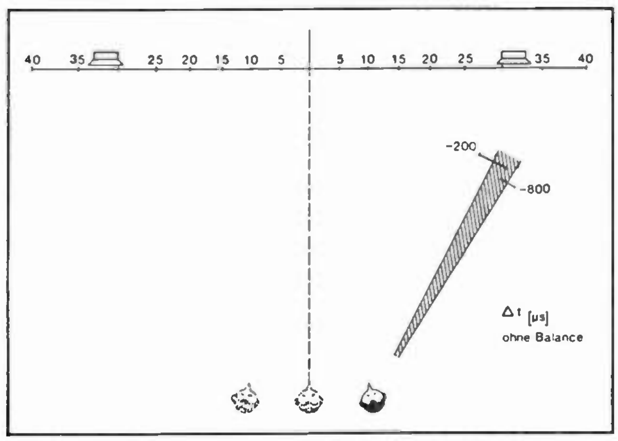


FIG. 9 Perceived sound incident direction Phantom source, time diff. shifted position of the listener, unbalanced

Especially fig. 9 (time differences) shows severe degradations of phantom source localization. These are due to the fact that the displacement of the listener will cause time differences in the order of 2 ms and more, the inherent signal time differences amounting to a maximum of 0.8 ms. A combination of both leads to ambiguous interpretations of the resulting time differences by the listening sense.

In a system with, for instance, 5 channels or 5 substituting sound sources, we have to expect no localization errors for the 5 directions conveyed by the 5 loudspeakers and only small deviations for directions between two of these speakers represented by phantom sources produced by these two loudspeakers (fig. 5).

In the FRG proposal it is assumed that only 5 directions have to be reproduced in order to present an angle of 33°. The maximum error is then 4.2° (fig. 10).

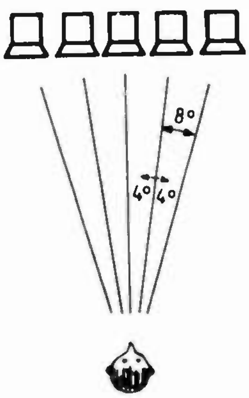


FIG. 10

A sufficient dominance of the viewing event over the listening event is assumed. The results available up until now pertaining to this problem are in part contradictory and in part there are considerable quantitative differences. Thus Urbantschitsch /5/, Witkin, Wapner and Leventhal /6/ - as well as Jackson /7/ and others - found tolerated variances between viewing and listening events between 17° and 38°; more recent tests such as from Canon /8/ or Lehringer /9/ variances in the range 3° - 8°. All of the authors - except Lehringer - found an enlargement of the tolerance against listening event deviation with simultaneous viewing event; Lehringer attributes his results to his special test situation - rigid raster for the picture presentation. Tests have now begun in the IRT which should clarify these circumstances as pertains to the special situation HDTV.

Thereby it is also to be investigated whether variances result when a close relationship between the acoustical signal and the optical signal exists or not.

The following extreme cases are investigated :

relationship	listening event	viewing event
no	pink noise gaussian envelope	white flash gaussian envelope
very close	speaker	speaker

A further objective of the study is to clarify the question of whether the method of substituting sound sources is also applicable when rapidly moving sound sources are reproduced. Furthermore, it is unclear whether by closing the eyes an "after effect of the dominance of vision against hearing" arises and how long this might be the case.

Overall we expect, according to initial results, that a maximum discrepancey between viewing and listening event of approximately 4° is allowable; a careful verification with many varying sound sources, scene enactments and viewer positions is required for a proposal of standards. As well, the question of how to get more realism according to the Japanese proposal should be taken into account. This may lead to a greater number of loudspeakers and/or an appropriate alteration of the loudspeaker arrangement. It would seem to us to be necessary to have these studies - according to study program AQ 10 - conducted by several institutes and that the results thereof be compared to one another carefully.

/1/ Draft Contribution to Report 795 - Triphonic sound in television. USA. CCIR Doc. 10/219-E; June 1985.

/2/ Sound design and sound transmission in a future HDTV system. FRG. CCIR Doc. 10/252-E; August 1985.

/3/ Draft new Report - Sound systems for HDTV. Japan. CCIR Doc. 10/272-E; October 1985.

/4/ Torick, E. L. : Triphonic sound system. UK Patent Application (6B 2130056 A); 1984.

/5/ Urbantschitsch, V. : Zur Lehre von den Schallempfindungen. Pflügers Arch. 24 (1889), 574.

/6/ Witkin, H. A., Wapner, S. und Leventhal, T. : Sound localization with conflicting visual and auditory cues. J. Exp. Psychol. 43 (1951), 58.

/7/ Jackson, C. V. : Visual factors in auditory localization. Quart. J. Exp. Psychol. 5 (1953), 52.

/8/ Canon, L. K. : Intermodality inconsistency of input and directed attention as determinants of the nature of adaption. J. Exp. Psychol. 84 (1970), 141.

/9/ Lehringer, F. J. : Über die Beeinflussung der Hörereignisrichtung durch das Sehereignis bei der Personendarstellung in Telekonferenzen. Heinrich-Hertz-Institut Berlin, GmbH.

NEW TECHNIQUES FOR VOICE/DATA SERVICES IN SATELLITE NEWS GATHERING OPERATIONS

Sidney M. Skjei
GTE Spacenet Corporation
McLean, Virginia

INTRODUCTION

Transportable Ku-band earth stations are increasingly being used for Satellite News Gathering (SNG) purposes. Since terrestrial telephone connections to these SNG truck or "flyaway" earth stations are often precluded by temporal or geographical factors, considerable interest exists in providing two-way satellite voice and data communications capabilities for SNG operations.

In response to this need, several new techniques and new applications of old techniques have been employed for SNG voice/data services:

- Single channel per carrier (SCPC) voice and interrupt feedback (IFB) circuits using companded Frequency Modulation (FM) analog modulation or 32 kilobits per second (Kbps) digital modulation.
- Analog or digital multiple channel per carrier (MCPC) techniques providing several (e.g., five) voice and data circuits to/from an SNG unit.
- Band-edge SCPC or MCPC carriers accessing a satellite transponder also occupied by one or two video feeds.
- Foreign exchange (FX) telephone signalling to permit direct dial capability to SNG units through a shared master earth station.
- Use of video subcarrriers or blanking intervals for voice/ data channels from SNG units.

The purpose of this paper is to discuss alternatives for SNG voice/data services and facilitate selection of the appropriate set of techniques to meet a particular SNG unit's needs. Clearly, one solution is not likely to be optimum for all applications, as a major network's SNG operational requirements may be considerably different from those of a small, unaffiliated broadcaster serving a rural community.

SNG VOICE/DATA DECISIONS

As the SNG unit is designed to transmit a fairly complex signal (television video plus audio) to its home station, adding one or a few voice/data channels would seem fairly easy. Indeed, providing voice/data services to SNG units is not difficult; but a large number of alternatives for providing these services must be considered even if there are relatively few system design choices to make concerning the video transmission.

For example, the SNG unit can communicate directly to its home station via satellite, or the call can be relayed from a central or master earth station through the terrestrial telephone network.

The number of voice/data circuits to be provided to the unit must be determined; should multiple circuits be desired, they could be provided either by several SCPC circuits, or multiplexed together into one MCPC signal.

With regard to selecting a method of transponder access, a completely different set of alternatives exists. The voice/data circuit can be: (1) transmitted into a satellite transponder which is different from the video transponder, (2) added to the video signal either in a blanking interval or as a subcarrier, (3) transmitted into the same transponder as the video, but on the band-edge (frequency extremity) of the transponder, or (4) a combination of these methods.

It must be decided whether to use the same high power amplifier (HPA) as the video feed, or alternatively, to add a smaller HPA for the voice and data service only.

Conventional analog frequency modulated (FM) transmission can be utilized, or one of a growing number of digital transmission techniques can be implemented.

Before specifically discussing these various alternatives, however, it may be useful to review a few basics of transponder access and HPA operation, particularly as regards generation of intermodulation interference, in order to establish a basis for several important considerations that will follow. (The reader who is familiar with intermodulation products generated by nonlinear devices may wish to skip the next section.)

INTERMODULATION INTERFERENCE

When more than one signal is amplified by an earth station HPA or satellite transponder which is operating "linearly" (i.e., an increase in input signal power results in a proportional increase in output signal power), each signal is amplified separately without generating noteworthy additional interference. In traveling wave tube amplifiers (TWTAs) used for satellite communications, this "linear" operation generally means operating the amplifier at approximately 10% to 25% of maximum power output.

Naturally, this inefficiency is undesirable from a cost and performance standpoint, but when higher operating levels are used, the amplifier is no longer linear and does not provide a proportional increase in output power for an increase in input power. This is evident from Figure 1, which represents the input/output power characteristics of a typical TWTA used in truck or flyaway SNG earth station HPAs[1], or in the satellite transponder itself. Operating a TWTA near the top portion of this transfer curve is termed "nonlinear" operation and results in generation of interference within the amplifier called "intermodulation products" whenever more than one signal is amplified simultaneously.

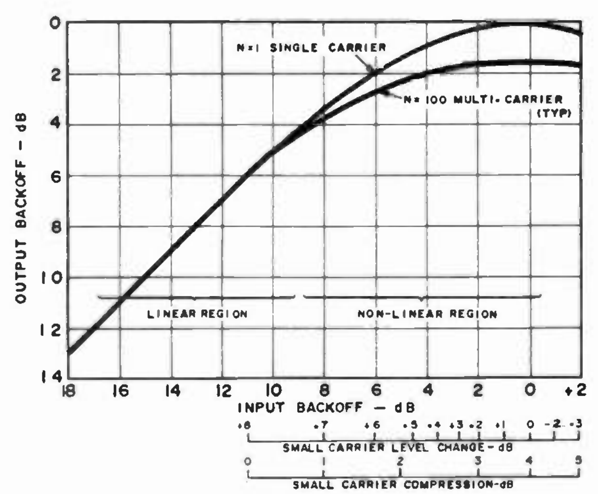


Figure I TYPICAL TWT TRANSFER CHARACTERISTICS

Intermodulation products can be generated in other uplink transmitting equipment such as Intermediate Power Amplifiers (IPAs) and up converters if they are operated in their nonlinear region. Furthermore, intermodulation products can be generated by any device which operates nonlinearly (e.g., solid state power amplifiers), not just TWTAs.

The frequencies at which nonlinear devices generate intermodulation products are generally predictable. For example, if two unmodulated carriers are transmitted at frequencies f_1 and f_2, then intermodulation products will occur at frequencies $|nf_1 - mf_2|$, where n and m are integers and where $n-m = \pm 1$. Generally, third order intermods (n, m equal one or two) are of primary concern in assessing intermod interference.

Since TWTAs used as earth station HPAs are wideband (500 MHz), there is fairly high probability that any significant intermodulation products generated in uplink equipment will be transmitted to the satellite. The satellite transponder itself has a more restricted bandwidth (less than 80 MHz); consequently, intermodulation products generated in the transponder have a greater likelihood of being filtered out and not transmitted back to the earth station.

The amplitude of the intermodulation products (or "intermods") can also be predicted. Figure 2 presents the results of a software simulation performed to determine worst case relative intermod power generated when one large signal and one small signal (for example, unmodulated video and voice/data carriers) are amplified by the same TWTA[2]. The amplifier used as a model is a spacecraft TWTA, but the results are representative of all TWTAs, including those in SNG unit HPAs.

From Figure 2, looking at point "A" and considering only unmodulated carriers, it can be determined that for 1 dB HPA output backoff and with voice/data carrier output power 20 dB below the power of the video carrier, the ratio of video power to intermod power is approximately 26 dB. This means the intermod power is only 6 dB below the voice/data carrier power.

Having established this common ground regarding the generation of intermodulation interference, the relative merits of alternatives for providing duplex voice/data services to SNG units can be explored.

NETWORK CONSIDERATIONS: DEDICATED OR SHARED MASTER EARTH STATION

A fundamental SNG network design consideration regards networking alternatives. As shown in Figure 3a, a dedicated master earth station can be implemented in or near the SNG unit's home station; alternatively, the master

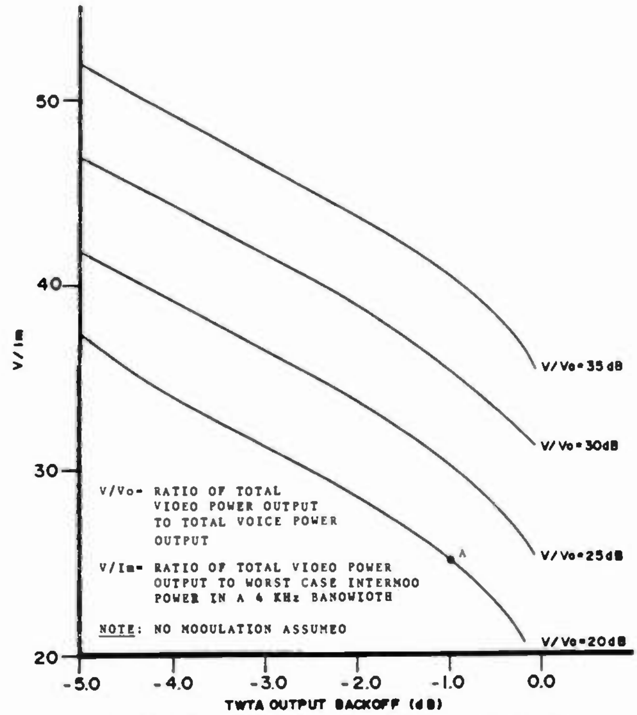


Figure 2 VIDEO CARRIER TO INTERMODULATION INTERFERANCE AS A FUNCTION OF TWTA BACKOFF

station can be shared among several broadcast stations, as shown in Figure 3b.

The dedicated station offers the advantage of complete control of all SNG communications assets, as well as the operational convenience of having the link between the master earth station and the home station be no more than a short length of cable.

The shared master station, on the other hand, must be accessed through the terrestrial telephone network, resulting in telephone line charges. However, the shared master station generally offers the advantage of reduced equipment and operational costs, potential reductions in space segment costs due to use of larger antennas, as well as economical access to a large pool of expert earth station maintenance technicians, operators, and engineers. A shared master earth station can often be manned 24 hours for relatively little additional cost to the broadcast stations sharing the facility. Further, implementation of a shared master station often eliminates the need for costly satellite transmitting equipment at the home station, such as voice modulators, multiplexers, echo cancellers, upconverters, and HPAs, not to mention reduced antenna and antenna feed costs.

SCPC OR MCPC ACCESS

The number of voice/data circuits (a circuit as discussed here consists of one or two one-way channels constituting a complete connection) required by the SCPC unit is another primary consideration to be addressed. In addition to the basic two-way voice circuit used by the SNG unit to coordinate activities with the home station, SNG units generally require a one-way IFB circuit from the home station for cuing and on-the-air feedback. SNG units have in some cases been provided additional channels, such as:

- an "on-call" or common user coordination circuit used to establish initial coordination with the master control station and/or satellite carrier (i.e., polarization adjustment, power levels, and frequency assignment).
- a data circuit from the master control station to control the unit's transmission equipment (e.g., power level), provide script text, etc.
- a data circuit from the unit to the home station or the master control station providing equipment status, draft script text, etc.
- a voice circuit for the unit's news director
- a voice circuit for the unit's engineering/technical director

It is important to determine whether these circuits are required prior to video transmission, during video transmission, or continuously, as this determination will influence selection of the transponder access method, discussed later in this paper.

SCPC Access

If the number of the circuits required is small, an SCPC approach may be the optimum way of meeting the SNG unit's communications requirements. For example, if the unit only requires a common user circuit on initial unit setup, followed by a voice coordination circuit and IFB circuit prior to, during, and after video transmission, then the SCPC approach may meet all requirements with minimum complexity and cost. Figure 4 shows an equipment configuration for such an SCPC system[3].

In SCPC satellite access, every channel has a separate satellite access. Thus, for the example cited, three accesses are required for the coordination circuit and the IFB circuit (one channel from the truck and two channels from the master station). The SCPC method provides considerable operational flexibility in that each voice/data circuit can be assigned to a different SNG unit, or multiple circuits can be assigned to one unit.

The SCPC method requires less earth and space segment power per channel than MCPC multiplexing methods because it is not necessary to support the overhead of unused frequency (for analog multiplex channels) or bit rate (for digital multiplex channels) required for multiplexing. However, if equipment complexity is increased by the addition of an efficient multiplexing technique, the overhead and additional power requirements can be reduced significantly.

MCPC Access

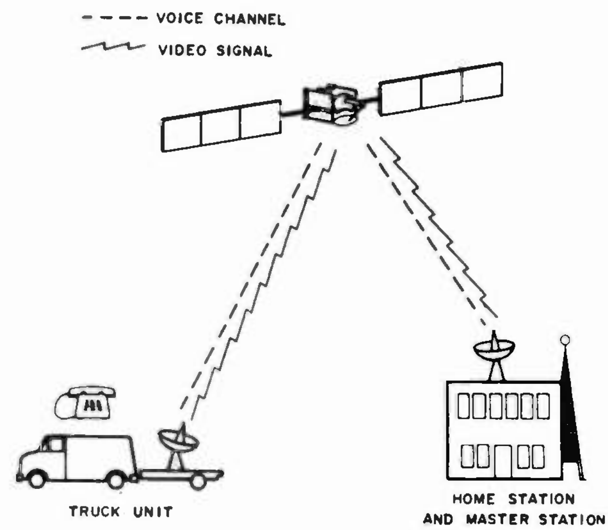
If the SNG unit requires other circuits (e.g., a directors circuit, engineers circuit and one or two data circuits) in addition to those cited in the previous example, the MCPC alternative becomes quite attractive. In the multiplex method, all channels intended for a particular destination are combined together and then transmitted as one signal. This combination or multiplexing can take place on a frequency or time basis, with frequency commonly used for analog transmission and time commonly used for digital transmission. Figure 5 shows an equipment configuration for multiplexed transmission.

The multiplex method also facilitates combining the voice and data channels with the video signal (for example, as a subcarrier). Utilizing multiplexing equipment, one subcarrier could be used to transmit five channels to the master station, instead of using five separate subcarriers.

Revisiting the earlier discussion of intermodulation interference, both advantages and disadvantages of the MCPC method are evident. On the plus side, the several channels multiplexed together before amplification through a nonlinear device now behave as one signal and not as several individual signals which would interact with each other to create intermodulation products. This eliminates voice channel to voice channel intermods which would occur if multiple SCPC channels shared an SNG unit HPA with a video signal. Further, should it prove desirable (see Annex) to utilize a separate, smaller HPA for voice/data service only, the MCPC method will permit use of a smaller HPA than would multiple SCPC channels.

On the other hand, the MCPC signal will form intermodulation products with a video signal with which it is nonlinearly amplified, and as observable from Figure 2, the worst case MCPC-video intermods will now be more powerful than the worst case SCPC-video intermods because the MCPC signal is now closer in power to the video signal (decreased V/Vo ratio).

As a result, the SNG unit owner must ensure that he does not exceed intermodulation limits imposed by the satellite carrier. INTELSAT, for example, limits transmitted intermodulation products to 10 dBW/4 kHz[4]. Utilizing video signal dispersal and increasing HPA size (thus increasing HPA backoff) can control this



a. DEDICATED MASTER EARTH STATION CO-LOCATED WITH HOME STATION

Figure 3 SNG NETWORK ALTERNATIVES

potential problem. The Annex to this paper contains a sample calculation of intermodulation interference when a common HPA is used for video and voice/data applications, and shows how HPA backoff and energy dispersal techniques can be used to reduce this interference.

BAND-EDGE, VIDEO ASSOCIATED OR SEPARATE TRANSPONDER ACCESS

Perhaps one of the most striking differences in the various methods of providing voice service to SNG units concerns the method by which voice channels access the satellite transponder itself. Three main methods exist, but combinations and variations on these methods are also evident. Furthermore, more than one method may be used during various phases of SNG operations. For example, band-edge access may be used prior to transmitting the video/audio feed, followed by a combination of band-edge (to the SNG unit) and video-associated subcarrier (from the SNG unit) during the feed.

Band-Edge Access

In the band-edge access technique, one or more voice/data channels are placed at the edge (frequency extremity) of a transponder which normally carries one or two[5] video transmissions, usually with the transponder operating at or near "saturation" (100% of usable power). This technique may be financially attractive to those who buy or rent whole transponders, because it offers voice/data circuits at no additional space segment cost above what would have been required for the video feed(s) only. The voice/data channels take up perhaps one hundredth of the transponder power, so the power reduction to the video is hardly measurable.

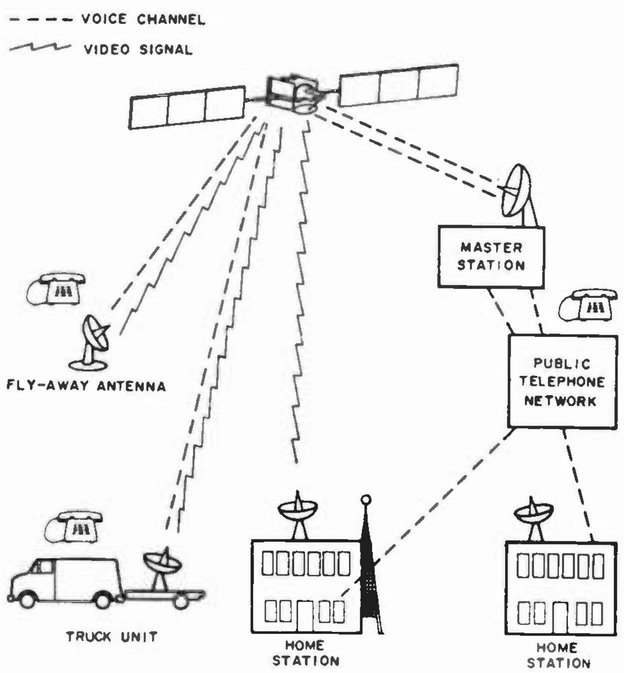


Figure 3 b. SHARED MASTER EARTH STATION

Another advantage of this type of access is that it minimizes up and down converter costs for networks which can be contained within one transponder, since both the voice/data circuits and the video feed(s) use the same transponder.

Most of the potential difficulties associated with the band-edge access technique are due to the fact that the transponder carrying the voice/data signals, and normally the earth station HPA providing the combined uplink signal, are operating nonlinearly in order to provide maximum carrier-to-noise ratio to the video feed. As previously discussed, sharing the same nonlinear HPA results in intermodulation interference (Figure 2) which is normally not filtered at the HPA output. Because the same saturated transponder in the satellite is used for both video and voice, small signal suppression occurs and the earth station HPA must transmit the voice/data signal at up to four times more power (6 dB) than would be required if the voice were in a separate transponder. This small signal suppression, which is similar to "capture effect" in an FM receiver, arises whenever a large (video) and a small (voice/data) signal both access a highly nonlinear transponder. The result is a lower video/voice ratio (V/Vo) shown in Figure 2, thus increasing the worst case intermodulation interference generated in the HPA.

Further, because of the small signal suppression effects, the voice/data signal is very sensitive to change in power levels of the one or two video signals sharing the transponder. As can be noted from Figure 1, a ± 2 dB change in the video power results in a -3 and +2 (respectively) change in the voice/data power. The net result of this effect is that a transponder carrying both video SNG feeds and voice/data band-edge signals must be carefully and continuously monitored and user power controlled to ensure that assigned power levels are properly maintained.

Finally, the band-edge method is susceptible to adjacent channel interference from the adjacent satellite transponder and/or earth stations accessing that transponder. Wideband digital modulation signals such as TDMA are now common and can cause in interference into the band-edge areas of adjacent transponders. This problem could, however, be eliminated if frequencies at the highest and lowest extremity of the 500 MHz satellite band are chosen to carry the band-edge voice/data signal.

Video Associated Access

Voice/data signals from the SNG unit to its home station can be combined or multiplexed with the video feed prior to transmission, which has the considerable advantage that intermodulation interference from the SNG unit's HPA is eliminated. Since only one consolidated video and voice/data signal is amplified, no intermodulation interference is generated in the HPA. Consequently, this access method would seem particularly attractive to SNG units limited in their HPA and antenna size--such as flyaway SNG units, and can preclude the need for additional HPA backoff due to satellite carrier imposed intermodulation limits.

Two methods presently exist for combining the voice/data link with the video feed: adding the voice/data as a separate subcarrier, and combining the voice/data in a time multiplexed fashion with the video signal--such as during a blanking interval. The subcarrier method represents an extension of a common audio multiplexing technique and has seen extensive implementation. The time multiplexing method has not been extensively implemented, perhaps due to its complexity, although techniques such as "sound in sync" have been available for several years.

One major disadvantage of both these methods is that two way voice/data services are only available when the video feed is being transmitted. Consequently, this method is rarely implemented as the sole means of access, but rather is combined with another access method (such as band-edge) which is used when video is not being transmitted by the SNG unit. Such a combination of techniques should work reasonably well in a network enjoying close monitoring and control, but could lead to difficulties in a network not continuously scrutinized. Further, in an application in which SNG units can direct-dial calls without human operator intervention, the direct dial capability would likely be lost when switching to the video associated channel.

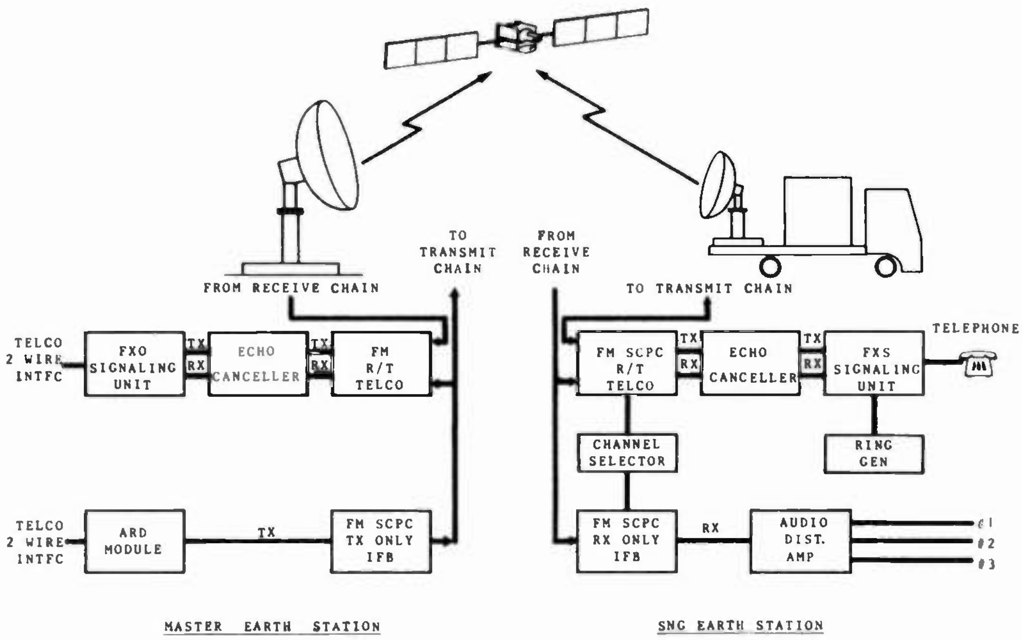


Figure 4 SCPC SNG COMMUNICATION SYSTEM

It should also be noted that this method can be used for only one direction of the two way voice circuit (as the master or home station does not generally transmit a video signal). Consequently, another transponder access method (band edge or separate transponder) must be used for the voice link to the SNG unit.

Separate Transponder Access

In this access method, voice/data signals are placed in a satellite transponder separate from the video transponder. This transponder is operated sufficiently close to its linear (backed-off) region to significantly reduce intermodulation interference and eliminate voice/data signal variations due to power level changes in other carriers sharing the same transponder.

Since this separate voice/data transponder is independent from the video transponder, SNG unit generated intermod interference can be avoided by separating the two transponders in frequency (or polarization) sufficient to use an independent but smaller (see Annex for example) power amplifier for the voice/data links. This amplifier can be coupled to the antenna via a low loss diplexer filter combiner, and as noted in the example, can reduce the size of the main HPA required by the SNG unit.

Another advantage of the separate transponder access method is that it facilitates automatic, stable, and interruption-free direct-dial telephone operation (no human intervention). Once the circuits are established, they remain in place as long as desired and do not have to be moved to another access method.

In addition to these advantages to networks of any size, there are several advantages to networks of moderate to large size or networks requiring more than one transponder during periods of peak video activity. These advantages include a virtually unlimited number of voice/data channels which are available all the time, ease of monitoring voice/data traffic due to centralization, and ready exchange of information among SNG units utilizing different transponders for their video feeds. The master control station configuration for this access method is readily and economically expandable to any number of voice/video channels by adding additional baseband equipment.

ANALOG OR DIGITAL MODULATION

The question of utilizing analog or digital communication methods for voice/data services is not unique to the SNG and broadcasting industry. This same question is being addressed in many other segments of the terrestrial and satellite communications industries.

Analog Modulation

Analog communication techniques, such as companded FM, have been used for many years and are generally well understood by operations and maintenance technicians. The technology is quite mature, resulting in relatively low equipment costs. FM is a robust (fault tolerant), proven transmission method which seems well suited to many voice communication applications in which the analog channel contains telephone signalling information (such as dual tone multiple frequency-DTMF-signalling used on the terrestrial network).

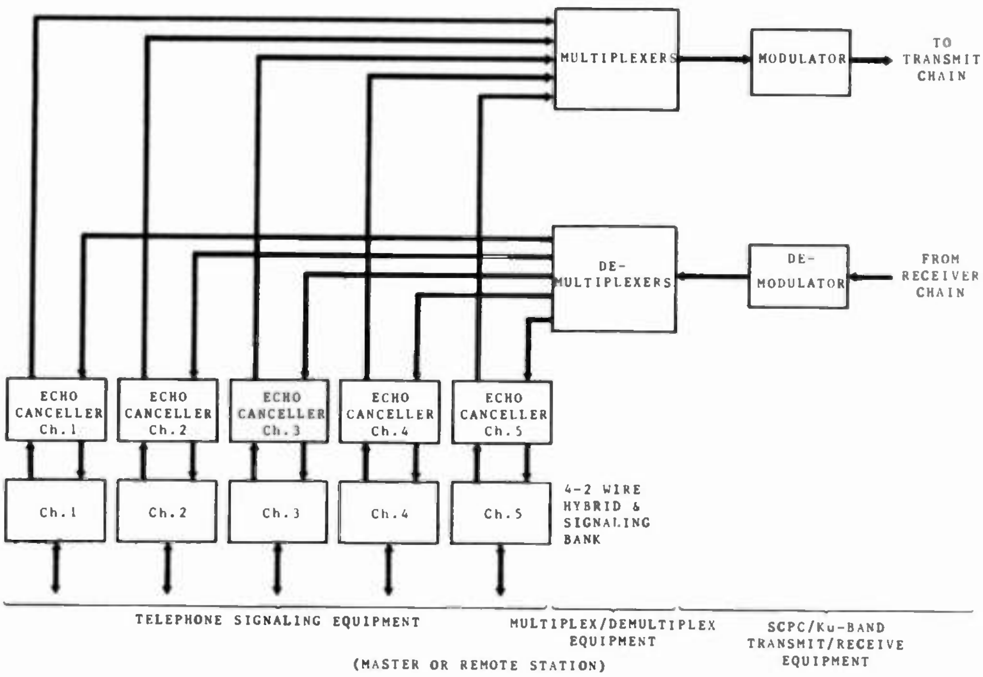


Figure 5 MULTIPLEXED SNG COMMUNICATION SYSTEM

Digital Modulation

Digital modulation techniques were initially developed for long distance terrestrial telephone networks in which analog signals would suffer an increase in background noise proportional to the distance traveled. The main advantage of the digital signal is that it can be retransmitted and repeated many times, while still in digital form, without adding more noise. This main advantage is, of course, lost for an SNG circuit that is converted from analog to digital at the SNG unit, transmitted directly via satellite to the master station, and then reconverted to analog either to obtain the signalling information in the analog channel, or to interface with an analog telephone network.

However, digital modulation has many important advantages which should be considered in choosing voice service for an SNG network. One advantage is that digital modulation provides a better means of sending data directly from the SNG unit back to the home station. Were analog methods to be used for any part of this connection, data quality would generally deteriorate compared to that obtainable with direct, end-to-end digital transmission. As a result, digital modulation would seem a good choice for applications where the digital format can be maintained from the SNG unit to the home station, regardless of the number of intervening connections or satellite hops.

Another advantage is that digital transmission offers the potential opportunity to trade off equipment complexity against space segment costs. By implementing an advanced low data rate (e.g., 32 kilobits per second) digital modulation technique with soft decision forward error correction coding, the potential exists to reduce the amount of space segment power used for a voice or data channel. Further, for MCPC applications, digital multiplex techniques with very low overheads are reportedly available.

Digital modulation also offers the advantage of being readily amenable to encryption, and may require fewer adjustments and alignments than analog equipment, once installed and operating. Additionally, digital modulation equipment continues to decrease in price as technology and techniques continue to improve.

SUMMARY AND CONCLUSIONS

Several alternative techniques currently available for providing voice and data services to SNG units have been discussed. No one method or technique is considered to be universally applicable to all situations. The number of SNG units in a network, the unit HPA and antenna size, owner sensitivity to ground equipment versus space segment costs, maintenance facilities, and frequency of SNG operations are but a few of the factors which will influence the selection of the particular technique(s) to be implemented. In any event, it is clear that a sufficiently wide range of alternatives exist today to meet an SNG unit's requirements for duplex voice and data services.

ACKNOWLEDGEMENT

The author would like to thank Katherine Talberth, Ronald Hall, Cathy Beard, and Amy Pletcher for their assistance and support in developing this paper.

REFERENCES

1. J.M. Hooper, F.C. McCormick, "Video Plus," Satellite Communication Symposium '82, Scientific Atlanta, pp. 3A-2, 8.

2. Talberth, K., Private Communications, 1986.

3. Flynn, B., "Design Considerations for News Express: The Florida News Network's Mobile Ku-Band Satellite Service," Proceedings of the 39th Annual Broadcast Engineering Conference, National Association of Broadcasters, 1985.

4. Standard C Performance Characteristics of Earth Stations in the Intelsat V System, BG-28-73 (Rev. 1), INTELSAT, 1982, pp. 29.

5. Conover, R.A., "The CONUS Dual Video SNG System," Proceedings of the 39th Annual Broadcast Engineering Conference, National Association of Broadcasters, 1985.

ANNEX

WORST CASE INTERMODULATION INTERFERENCE AND HPA SIZE

An example utilizing Figure 2 helps to illustrate how intermodulation interference can be reduced by using energy dispersal and HPA backoff. Of course, each TWTA HPA will exhibit slightly different transfer characteristics, and Figure 2 should only be used as a general guideline. SNG units with intermediate power amplifiers, (IPAs) can have much worse intermods if these IPAs are not operated in their linear region. To determine exact intermodulation characteristics, tests should be conducted on the specific uplink transmit configuration.

For purposes of this example, assume an SNG unit with a 2.4 meter diameter transmit antenna having 49 dB transmit gain. Further assume that the unit requires 73 dBW effective isotropic radiated power (EIRP) for its video feed and 48 dBW EIRP for its voice/video carrier.

The ratio of total output video power to total output voice power, or V/Vo in Figure 2, is then 73-48 or 25 dB.

If the satellite carrier of choice has the same intermod limit cited previously for INTELSAT[4], i.e., 10 dBW/4 kHz, then considering the 73 dBW video EIRP, the required ratio of total output video power to output intermod power in a 4 kHz bandwidth (or V/Im in Figure 2), is 73 - 10 = 63 dB, assuming that an unmodulated video carrier will exist during some portion of the video transmission.

Since Figure 2 indicates that a 63 dB V/Im ratio would only be obtainable with greatly increased HPA backoff, use of energy dispersal techniques (trangular waveforms added to the baseband video in order to evenly spread unmodulated carrier power) would seem a reasonable way to reduce the required 63 dB V/Im ratio.

If one assumes a 2 MHz energy dispersal, then: 10 log (2 MHz) - 10 log (4 kHz) = 27 dB V/Im reduction can be obtained.

As a result we now need 36 dB V/Im ratio, as:

Required Video EIRP	73 dBW (14 kHz)
Less Intermod Limit	10 dBW/4 kHz
	63 dB
Less 2 MHz Energy Dispersal	27
	36 dB V/Im required.

Assuming the SNG unit transmit equipment (HPA, IPA, and up converters) intermod characteristics are similar to Figure 2, we can find the intersection of the V/Vo = 25 dB curve with the V/Im = 36 ordinate axis to determine the need for an HPA output backoff of approximately 2.5 dB.

Proceeding further, if we assume approximately 1.2 dB loss between the HPA and the antenna, then the need for a 600 watt HPA seems apparent:

Required Video EIRP:	73.0 dBW
Less Transmit Gain	49.0
RF Power at Feed	24.0 dBW
Plus Backoff Required for Intermod Protection	2.5
Plus HPA to Antenna Losses	1.2
	27.7 dBW
or	589 watts

If the frequency separation between the video carrier and the voice/data carrier is sufficient to use a diplexer combiner (this generally means the voice/data carrier is separated from the video by one other transponder), then a smaller (10 watt) HPA could possibly be used for the voice/data carrier and the primary HPA size could be reduced to as little as 400 watts, for this example. Alternatively, a 600 watt HPA could be implemented and the 2.5 dB output backoff retained as uplink fade margin for power control purposes.

ABSAT-ABC TELEVISION SATELLITE NEWS GATHERING SYSTEM

B. Greenberg, B. Stranathan
Capital Cities/American Broadcasting Company
New York, New York

Satellite communication has rapidly become a key element in the distribution of television signals. C Band, and now KU Band Satellites are a daily part of the Telecommunications picture. ABSAT will provide a fleet of mobile SNG vehicles located around the country, which will allow for rapid deployment and coverage of fast breaking news developments. This expanded coverage will enhance the affiliate stations ability to service its local viewers, as well as that of the ABC TV Network.

INTRODUCTION

C Band Satellite Program Distribution

Domestic satellite service has been a part of ABC's distribution for over ten years now. Internaltionally this has been the case on a more limited basis for twenty years.

Domestically, ABC began using satellites to provide point-to-point backhaul feed for News and Sports remotes. As the comfort factor with satellite transmission grew, ABC began to explore possibly replacing the 11,000 mile terrestrial affiliate interconnect with satellite service.

ABC's research and plan was based on three factors: (1) cost stability; (2) technical quality; and (3) operational flexibility. As point-to-point satellite use increased, ABC was convinced that satellite distribution offered superior technical quality to the landline system. ABC was also realizing certain operational advantages. However, it was the continued escalation of common carrier terrestrial tariffs that convinced ABC that satellite distribution was a viable alternative.

ABC's first terrestrial rollback occured in late 1982, but it was not until mid 1983, that the full satellite implementation program began to unfold.

The Andrew Corporation in association with Avantek has supplied ABC with its fully redundant affiliate earth Station package. A fixed rate/fixed term agreement with AT&T Communications provides the transponder backbone on Telstar 301 and 302. A section-by-section landline rollback plan was developed based on economic and operational criteria. To date, ABC has completed 110 stations. This includes the entire Central, Mountain and Pacific time zone affiliates previously served via common carrier terrestrial facilities. In the Eastern time zone, we have cut over the network south of Washington DC to Miami. By the end of 1986, ABC should complete implementation in the Northeast. The total station count at that time will be approximately 175. 1986 will also see the implementation of a computer real time management control system for the C-Band System.

Although ABC is realizing its original three objectives with its C-Band satellite plan, it also realized other new satellite technologies could potentially increase flexibility.

KU Band Satellite News Gathering

As the popularity of C Band increased, technology advanced and the first C Band transportable vehicle appeared on the roads six (6) years ago.

These vehicles, of necessity, sporting 5 meter diameter dishes were not the most agile and readily maneauverable vehicles on the road, but in a world of relativity, were indeed "portable", and have gone to various parts of the country as well as the world to provide news and sports coverage.

The launch and deployment of the KU Band (12-14 GHz) satellites recently opened up this technology for the TV broadcasters. Vendors and manufacturers are now rapidly developing hardware for this frequency range. The lack of terrestrial frequency congestion at KU Band gives the broadcaster a truly mobile vehicle whose range can be virtually "unlimited" from his station, and downlink. Thus, providing maximum flexibility and freedom for the News, Sports and other divisions within the Network, or station. Indeed, as we speak, several News Gathering Networks have sprung up utilizing KU Band technology at its heart.

ABC has watched the evolvement and use of the KU Band by broadcasters with interest. We believe its strenghts fit nicely with the emergence of Satellite News Gathering. KU Band's strength lie its potential for greater mobility, higher satellite power and exclusive use of its assigned frequency band. Taking advantage of these features, when combined with the increased appetitefor News information and the competitive nature of the news business has led ABC to announce a plan in concert with its affiliates to implement a fleet of approximately 50 KU Band mobile trucks. Known as ABSAT, this satellite news gathering service will begin to unfold during the next year.

ABSAT
Implementation

The initial targeted ABSAT cities include all of the top 30 ADI markets. Beyond that, cities targeted for trucks, include markets where current backhauling capabilities are not readily available, and geographically isolated sites where research show news events often occur. Current implementation plans call for the first units to be available in July of 1986. Once the program gets underway, ABC expects it to take approximately one year before the 50 markets become operational. Figure 1 represents a view of the initial ABSAT market locations.

ABC SATELLITE NEWS GATHERING PLAN

FIGURE

Operational Concept

ABSAT will provide service capabilities for distinct but interrelated users: (1) the network; (2) regional News One feeds; (3) local newscast operation. these operational modes are shown in Figures 2, 3, and 4.

LOCAL SNG OPERATION

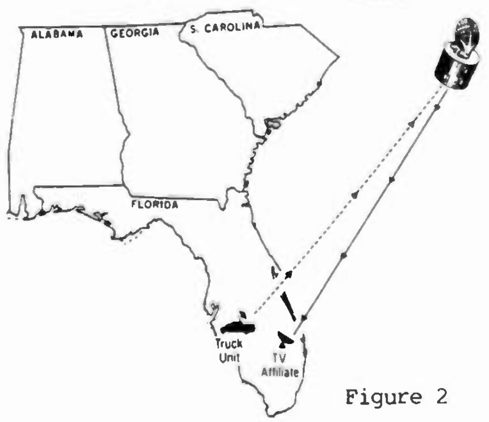


Figure 2

NETWORK SNG MOBILE ACCESS OPERATION

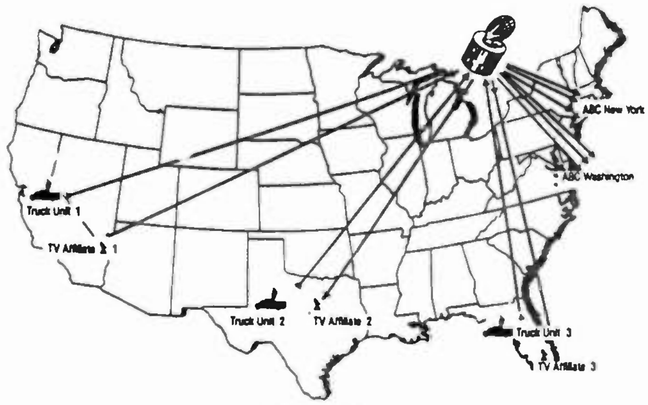


FIGURE 3

These vehicles which will be owned, maintained and operated by each affiliate, will provide the Network with an immediate news reach when requirements call for coverage of a story of great national interest, plus aid in the normal everyday program material backhauling process. ABSAT and the new national five region service called News One, willwork together in that the trucks will help bring local stories into the regional hub/bureau sites for turnaround as part of the edited product to be sent out in turn via the main C Band system. The real benefit of ABSAT, however, will be at the local station level, where the use of the truck will enhance the affiliates' news operation by expanding their news coverage area and at the same time, minimize on-air turnaround time. So, while the KU Band/SNG technology will service each group independently, together ABC will realize a tremendous news coverage advantage.

Regional ABC NewsOne Plan

FIGURE 4

Technical Operations

this paper is not a treatise on the operation and care of SNG vehicles or uplinks. However, suffice it to say that the adjustment of the antenna, once the vehicle is parked, leveled, and oriented in a north-south direction, will follow standard practice and techniques. Once the desired satellite is acquired, establishing communications with the satellite operator must be attempted. Depending on the satellite and communications system being utilized, the communications upconverter and receiver are adjusted to the appropriate frequencies of the "meet me" or coordination channel. After establishing contact and confirming uplink time and transponder frequency, the operator is free to go about the usual "show biz" tasks the SNG vehicle was assigned to accomplish.

PL, or duplex telephone communication is established from the vehicle to the station/studio via the transponder, the satellite operations master station and via a landline DDD Link to the studio. This DDD interconnect will be established from the studio. Once established, this interconnect will be made through a conference bridging device located at a master station located at the operations center. The telephone call will be patched from the master station to the assigned voice channel via the satellite to the SNG vehicle. IFB Communications is established in a similar manner from the studio to the vehicle in the field. Figure 5 depicts the communications path.

Typical Video/Communications Link

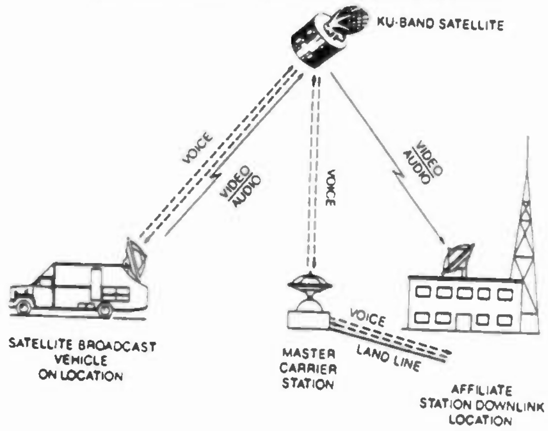


FIGURE 5

Initially, ABC does not plan to operate a master station on our premises to serve the affiliate members of ABSAT. However, ABC is working with several Satellite operators who have expressed an interest in managing local affiliate traffic requirements.

TECHNICAL DETAILS

Vehicle Description

The ABSAT system is geared to a mobile strategy. As such, the heart of the system, the uplink, becomes an integral part of the vehicle in which it is installed. Therefore, the detail of this vehicle becomes a part of ABSAT. In order to meet a varied range of station requirements, ABC has chosen to consider a wide range of vehicle sizes as suitable for this purpose. Therefore, vehicles whose GVW can range from 11,000 lbs. to 19,000 lbs. will be considered adequate for this purpose. The larger vehicle will be able to accomodate extra personnel, as well as production equipment, as determined by the station requirement.

Due to the satellite footprint of a given spacecraft, geographic location will also tend to dictate the vehicle size. Miami, Houston, and other extreme north and south locations in the United States tend to require larger antennas to ensure suffcient uplink power to fully saturate a chosen transponder, as well as act as an efficient receiver dish. A larger antenna, of course, will tend to eliminate the smaller, lighter weight vehicles from consideration. therefore, the dictates of station management, as well as technical requirements, will indicate the most effective vehicle size and type. Figure 6 show a typical vehicle.

Typical Satellite News Gathering Vehicle

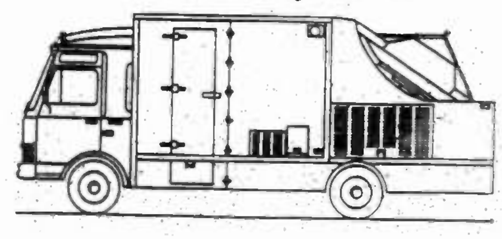


FIGURE 6

These vehicles will be self-sufficient, stand alone mobile platforms. To ensure this performance, each vehicle will be equipped with a power generator of sufficient size to operate the system. HVAC or environmental climatization will be included to allow for personnel comfort, as well as hardware efficiency, in all climate and weather conditions.

The KU Band frequencies allow for the use of smaller antenna sizes than the more popular and familiar C Band. The optimum size dish, fed with the maximum FCC allowable 280W, at the antenna flange will provide the capability to illuminate, and fully saturate transponders aboard the G-Star series of satellites, as well as the RCA K2, and in most locations of the continental United States, SBS-3. Therefore, utilizing this antenna system will allow for a highly mobile vehicle with a wide range of satellite choices and the power to acquire and saturate as necessary. The advent of satellites with dual polarization such as K2 and G-Star tends to present a problem to the uplink user. To allow for the most flexible usage scheme, a multi-port antenna feed is dictated, which will allow Horizontal and Vertical polarization flexibility. The two port scheme is adequate as long as video and communications can be transmitted in the same polarity. To allow for the ultimate in transmission capability, the four port feed is desirable. This will allow for either polarity transmission of video and communications, while maintaining receive capability. This feed mode in conjunction with a motorized remote control polarization system will allow ABSAT vehicles the freedom and mobility to operate in all areas of the country while maintaining the best antenna transmission characteristics. Therefore, ABC has specified the four port feed capability for the ABSAT system, to ensure Uplink agility.

An adjustable antenna mounting and positioning system is provided for rapid antenna deployment and positioning.

A unique scheme of HPA antenna mounting has allowed for an efficient installation which overcomes the average "plumbing" loss of 40% between the usual rack mounted HPA and the antenna flange. This allows for the utilization of a smaller 300 W HPA and an associated reduction in power as well as HVAC requirements.

Audio and video monitors are provided to ensure continuity, as well as to check system quality. A spectrum analyzer is an important element in the Uplinking process, and as such, is included as part of the monitoring system. All transmission facilities are frequency agile to allow the operator to acquire a wide gamut of KU Band satellites. The exciter, as well as the balance of the system has the ability to provide for "half transponder" or "two for one video" Uplinking and reception.

A duplex communications system is provided, as well as a simplex IFB channel.

Simplified Block Diagram

The simplified block diagram shown here in Figure 7, depicts the key elements of a typical ABSAT vehicle. The RF and communications systems will be purchased by the vehicle contractor from a vendor to be determined by ABC. This will provide a standard package of equipment in each vehicle which will ensure an accepted level of operation and performance.

ABSAT-FUNCTIONAL, TYPICAL

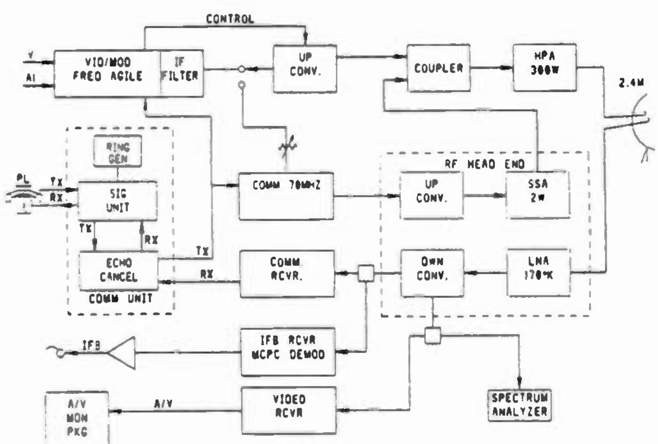


FIGURE 7

This standardization of equipment among the ABSAT vehicles will allow proper control of operation, as well as provide convenient engineering field modifications and changes.

As the state-of-the-art in communications equipment advances, new equipment such as Digital and Multi-channel can be readily added at the 70 MHz IF interface

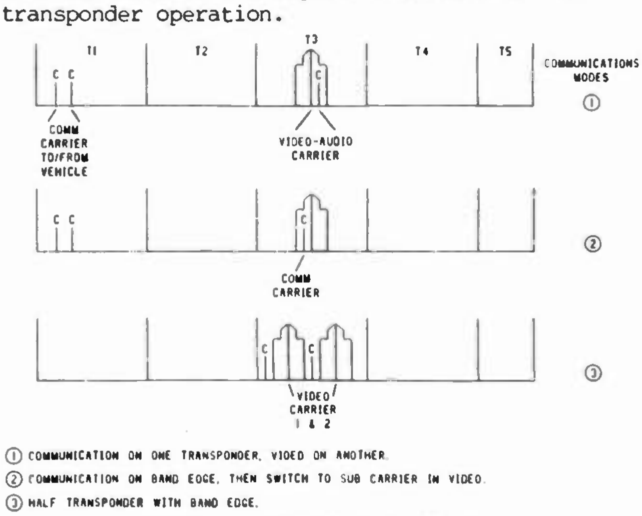
Communications

As in all teleproduction situations, communication is of paramount concern. Even more so in the SNG field, when attempting to communicate from a remote location to an operator who controls the transponder, or the home base studio, who may be rolling video tape in a recording session, as well as in live real-time broadcasting. "Can you hear me?", is an issue to be treated with diligence and concern.

ABSAT, as a system, will emerge in an environment of existing SNG vehicles, as well as news cooperatives, such as CONUS and Florida News Network. These systems operate over SBS-3 and GTE Satellites. Although different methods are utilized in each system, these communications schemes operate in the Analogue domain. Various communication modes are utilized while Uplinking program material by these services, and conceivably other, yet undevised schemes will emerge.

One of these schemes places a low power SCPC (Single channel per carrier) on the "band edge" or low frequency end of an assigned transponder channel. This will allow the SNG operator to speak to the satellite operator prior to his illumination of the assigned video transponder. PL type communication with the station or studio will then continue when video is Uplinked, via modulating a subcarrier in the base band video. This leaves this "meet me" or "2-way" channel free for use by other SNG vehicles in the field. IFB, or Interrupted Feed Back, for use by the talent on site is Down inked to the SNG vehicle via the satellite on a MCPC (Multi-Channel Per Carrier), on the transponder band edge. Some communications schemes allow full time PL communication over a separate transponder while uplinking video on another. This of course will incur extra costs for this extra transponder use.

The proliferation of SNG vehicles, as well as expensive transponder time has pioneered the "half" or "2-for-1" method of uplinking. As can be seen from Figure 8, two video carriers can share the transponder band width simultaneously. Of course care must be taken during this type of transmission in adjusting and balancing the Uplink power of each of these carriers to prevent cross modulation products from interferring with the video being transmitted. As before, the IFB communication to the SNG vehicle is contained on the band edge, while PL communication from the SNG vehicle is contained in the sub carrier of the base band video. This type of half transponder uplinking results in a somewhat reduced S/N figure, over that of full transponder operation.



① COMMUNICATION ON ONE TRANSPONDER, VIDEO ON ANOTHER.
② COMMUNICATION ON BAND EDGE, THEN SWITCH TO SUB CARRIER IN VIDEO.
③ HALF TRANSPONDER WITH BAND EDGE.

FIGURE 8 - COMMUNICATIONS MODES

With such a wide gamut of communications systems facing the operator of an SNG vehicle, unless he is committed to a given satellite operation, the communications system design must be extremely flexible to allow for compatability and freedom to operate in the domain of these various news services, as well as that of ABSAT. With this in mind, the ABSAT vehicle has included a communications package that will allow the operator to choose the mode of communication compatible with the satellite, transponder, operator, as well as the Network or service he is working with. Figure 8 indicates the various communications modes of ABSAT vehicles.

This communication interface occurs at the 70 MHz IF and as such, is compatible with any standard up/down converter in use. The communications up converter is frequency agile and is tuned accordingly. The IFB receiver is a separate package containing demodulator facility to extract the IFB audio from the received MCPC signal, as required. One advantage of the 70 MHz communications interface is that any new communication system can be added in the future, in a cost effective manner. Swapping the existing system or adding the new communications package will thereby augment the existing system with added capability. For instance, including Digital communication capabilities or adding Multi-channel communications in the future, can be accomplished in this manner, while retaining the basic communications equipment already installed.

The Down Link

The Down Link system, or receiver, will be installed at the station's pre selected site. A dish of 5.6 M will provide adequate system gain for satisfactory operations.

A frequncy agile down converter and receiver will ensure the selection of the proper KU Band satellite, as required. A power driven antenna mount will allow for ready adjustment of azimuth, as well as elevation to ensure proper acquisition of the selected satellite.

If a communications head end is required at the stations' location, this system can readily support the uplinking of an SCPC.

Of course, uplinking will require FCC liscensing prior to use.

The down link system will be purchased from a vendor to be determined, and recommended by ABC. As with the Uplink package, this standardization will allow for better control and performance.

FUTURE

As ABC looks to the future, it is dedicated to continue exploring distribution technology advancements that fall within the realm of out three basic building block foundations: cost, operation, and quality. We believe ABSAT represents the latest in this continued committment.

In addition, ABC is investigating several alternative satellite designs that combine in the same spacecraft, both C Band and KU Band capability in a switchable configuration that provides more power and bandwidth capabilities.

RADET—A NEW TOOL FOR NEWSGATHERING

J. Ramasastry, G. Knights, S. Yusem, S. Hilaris
Engineering & Development Department, CBS Broadcast Group
New York, New York

B. Miller
Marconi Corporation
Chelmsford, England

INTRODUCTION

Significant improvements in Ku-Band earth station technology and the availability of higher power, more sensitive Ku-Band satellite transponders have given the needed momentum for the recent explosive growth in Satellite News-Gathering (SNG) systems. Today, SNG vehicles of a variety of sizes are available in the marketplace. Several years ago, CBS made a decision to use C-Band (6/4 GHz) for its Network Satellite Distribution system because of the high degree of confidence in reliability and economics. However, Ku-Band was clearly more appropriate for newsgathering operations. CBS is committed to the use of Ku-Band technology for its newsgathering operations.

The first Ku-Band project CBS undertook was to develop a portable uplink for CBS News operations worldwide. The system was named the "Rapid Deployment Earth Terminal (RADET)". Some of the considerations that went into the design of the system are:

- Lightweight
  Total system (minus the generator) should weigh approximately 300 pounds, and no subsystem or unit should weigh more than 100 pounds;

- Transportability
  The system should be capable of being transported in a station wagon, helicopter or a passenger airplane;

- Satisfactory Signal Quality
  The system should be capable of delivering at least ENG quality video and audio signals to the studio;

- Ruggedness
  The system should be capable of withstanding shipping and deployment under a variety of logistics and weather conditions;

- Strict Conformance with the FCC's 2^{o} Spacing Criteria
  The antenna must be capable of meeting the 2^{o} spacing antenna pattern requirement criteria that the FCC has adopted for all satellite transmit earth stations;

- Remote Monitoring and Control
  In addition to regular voice communications between the RADET and the base station, the system should be capable of being controlled by the base station; the control signals generated by the base station are used by the operator to point the antenna precisely at the desired satellite; at the direction of the base station, the transponder center frequency and polarization could also be checked by the RADET operator.

CBS chose GEC/McMichael's (subsequently acquired by Marconi Communications of Chelmsford, England) News Hawk system as the basis for its RADET. Antenna and mount box were redesigned for improved performance, packaging and lighter weight. Communication and control systems were added. The system has been operating successfully in the field, and was recently used in the Phillipines to cover the Presidential elections.

Based on field experience, CBS is now working to provide augmentations and improvements to the system.

SYSTEM DESCRIPTION

The use of satellites, with their wide geographical coverage, provide an obvious solution for newsgathering problems; but earth terminal size, weight, and power requirements have been prohibitive until recent years. What was needed was a compact, lightweight satellite terminal which was small enough to be deployed rapidly by the normal means of transportation used by ENG crews, and which could be quickly set up and operated in hostile and difficult environments.

The CBS RADET terminal, based on the Marconi News Hawk design, has been designed specifically to meet the needs of television newsgathering teams. This conventional analog (NTSC/PAL) system is packaged in three flight cases and is readily transportable and easily deployed by two operators.

The three units are the Antenna assembly, the High Power Amplifier case assembly and the Electronics case assembly. The RADET system is shown in Figure (1).

R A D E T IN OPERATION IN PHILLIPINES

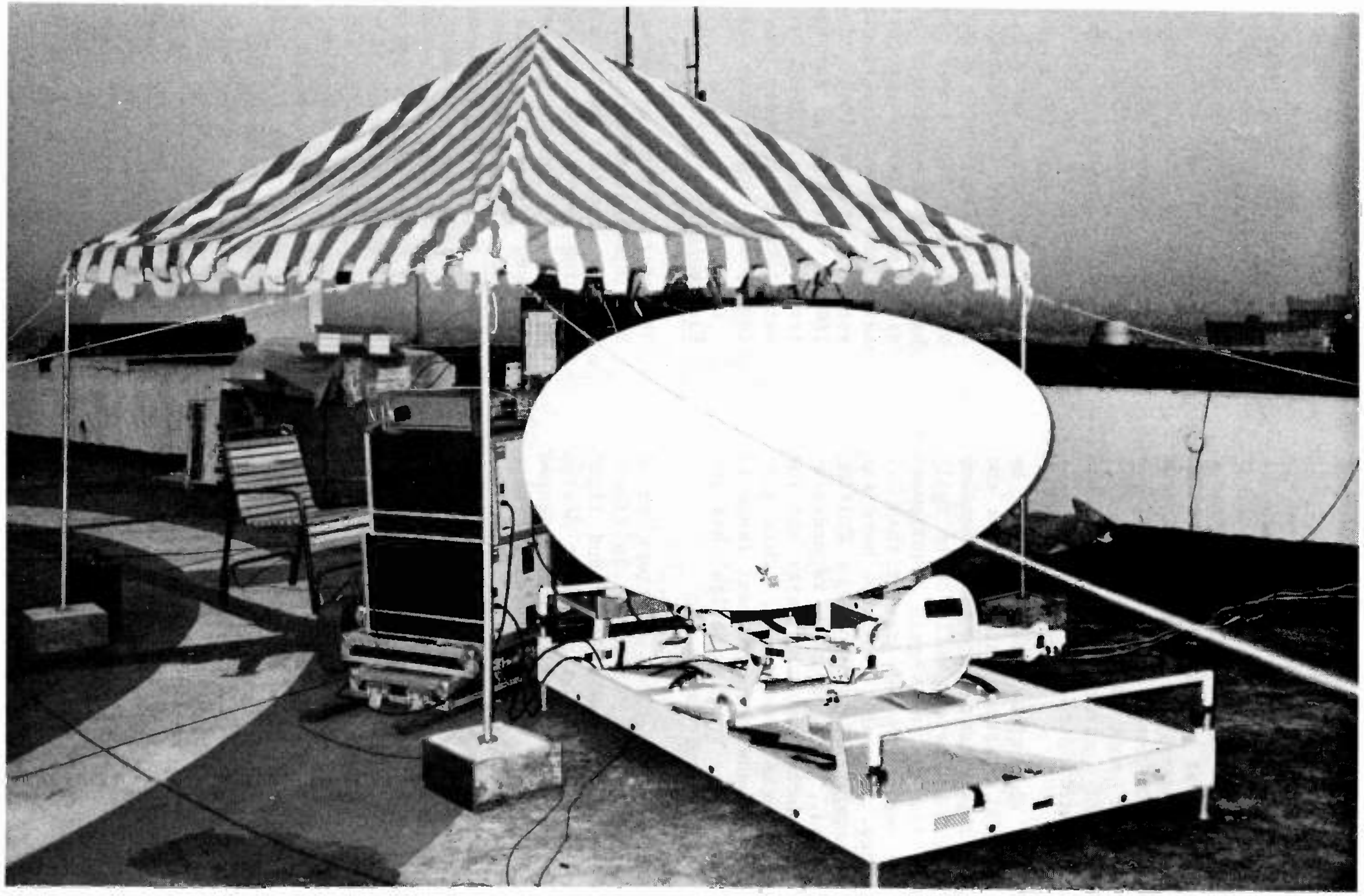


FIGURE 1

Antenna

Marconi's advanced satellite antenna design capabilities, dating back over twenty years, has made it possible to produce an antenna which can fulfill the conflicting requirements of a portable terminal: acceptable RF performance and compact dimensions. The antenna needs to be of sufficient size, so that its gain, together with a reasonably powered RF amplifier, provides a flux density at the satellite sufficient to achieve the desired C/N of the signal at the receiving terminal. The off-axis gain must also be well controlled to enable the 2^{o} satellite spacing criteria to be met. The antenna must, however, be sufficiently small that it can be easily handled by light aircraft, helicopters, vehicles and elevators etc.

These difficult objectives are achieved by using an elliptical aperture antenna. For the transportation requirement only one dimension can sensibly exceed 1 meter, while to be fully compliant with the off axis gain requirement of $29-25 \log \theta$, a diameter of greater than 1.7 meters is needed. Circular antennae have the problem of transportability unless a folding mechanism is used. This approach is undesirable due to the mechanical complexity and the long term performance uncertainty. This latter point will no doubt be a dominant issue in the future. No such "folding design" has yet met FCC 2^{o} spacing requirements.

The RADET has an elliptical aperture of 2 meters by 1 meter and is fabricated in fiberglass -- giving an extremely light and rigid construction. The one piece reflector design is diffraction optimized to give unprecedented aperture efficiencies for its small size antenna, while the elliptical shape allows preferential improvements in off-axis gain. The feed is offset and its subreflector and feed horn are supported on arms which allow them to fold into the main reflector for transportation. Figure 2 shows the excellent antenna radiation achievable with this antenna design.

CBS decided against using a segmented antenna due to uncertainties involved in maintaining the exact geometry of the reflector-feed configuration, and assuring that the antenna pattern does not undergo variations after continued use.

A specially designed, lightweight integral base allows azimuth movement and doubles as a transportation frame. Elevation is achieved by rotation of the main aperture on its support arms and is held by means of a friction clamp. A built-in inclinometer allows the base structure to be levelled while graduated elevation and azimuth scales assist in rapid satellite acquisition. An signal strength meter which may be extended from the electronics case enables the pointing and polarization to be optimized.

High Power Amplifier

The High Power Amplifier is based upon a rugged TWT providing an output of 270 watts. The amplifier is divided into two sections: An RF section comprising the TWT and associated RF protection, RF monitoring and filtering; and a power supply unit which provides the necessary voltages for the RF section and the logic control functions. The TWT has been designed for ruggedness and long life, and is a helix type with integral periodic permanent magnet focusing. The tube is conduction cooled and packaged with thermal overload protection. The package also includes a factory preset reference circuit which is used by the power supply to automatically set the anode and cathode voltages to their optimum values. This simplifies the tube replacement procedure and ensures that the correct operating condition is maintained at all times. Full protection against over-current, over-temperature and excessive reverse power conditions is provided. The high power amplifier flight case has a thermal management system for working in areas of extreme temperatures and also contains the power distribution system for the entire RADET terminal. The RADET also has a 160-watt TWT option for operating in the central continental United States areas where the satellite transponder can be saturated with less power (due to high satellite G/T).

Electronics Unit

The third flight case contains the low level RF, Intermediate Frequency and baseband electronics together with signal switching and patching and a thermal management system. A synthesized exciter accepts an input video baseband signal and three sound carriers for program, IFB, and engineering circuits. These sound carriers are added to the video as sound subcarriers and the composite signal is modulated to 70 MHz and fed into a double upconverter, the output of which is in the range 14 - 14.5 GHz, selected in 125 KHz steps. The output from this unit interconnects with the HPA via a rigid and flexible waveguide using quick release clamps and flanges for rapid set up. In addition, a pre-operational voice channel is provided, for use prior to video transmission. This channel is implemented by an automatic change of frequency and signal level of the exciter and switching to a narrow band audio input to the modulator in lieu of the video/subcarrier input. This pre-operational channel, together with the other audio and control carriers, is situated below the video carrier in the satellite transponder.

The receiving facilities of the RADET can be varied to meet Network requirements, but as a minimum would include receivers for monitoring the video transmission, receiving control and voice circuits (IFB, ENG) from the communicating base station and receiving the pre-operational channel from the base station. A Low Noise Converter is mounted adjacent to the

RADET ANTENNA RADIATION PATTERN

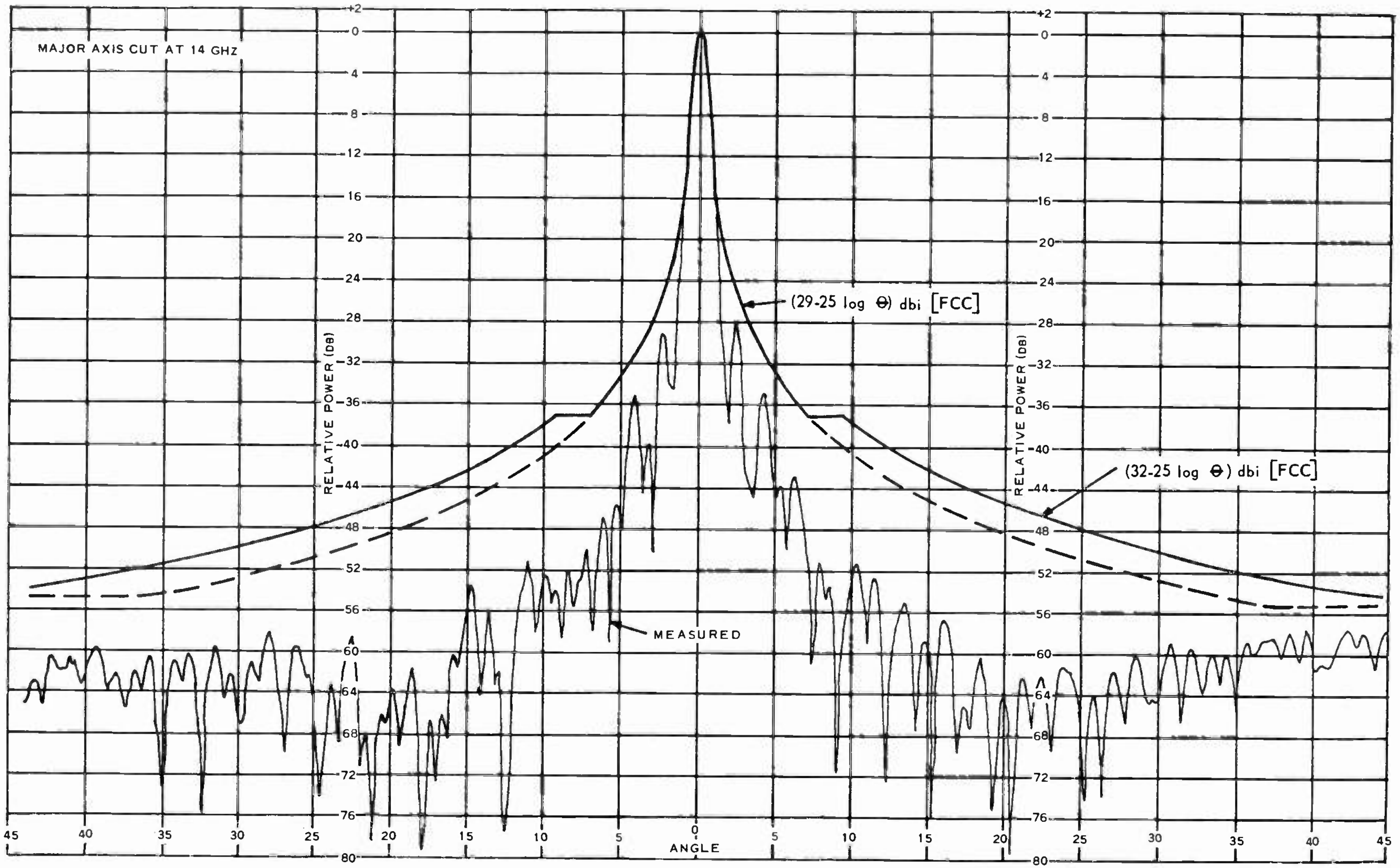


FIGURE 2

feed horn and supplies a signal in the frequency band 900-1700 MHz via a splitter to each receiver. The LNC is powered via the signal cable from a supply within the electronics unit. The receivers, which have common front ends, synthesize the signal to 600 MHz which is then demodulated in a Phase Locked Loop circuit.

In the monitoring receiver the output of the PLL is filtered to take off the sound subcarriers, which are demodulated for monitoring on headset/speaker. The video is made available on a patch panel for connection to a portable monitor.

For the control receiver the output of the PLL is demultiplexed to extract a control signal and two audio channels. When more than one portable terminal is using a common transponder there must be some formal method of control. It is also essential with the advent of these terminals that a safety management system is employed. CBS and Marconi have addressed this problem and made provisions in the RADET terminal to prevent mishaps. This is a modular facility that can be expanded into other areas of SNG. The system provided allows for the reception of a coded control signal transmitted by the controlling base station of the transponder which gives authorization for a portable terminal to transmit. Each terminal decodes the control signal and is only allowed to transmit when the appropriate signal is received. This prevents multiple illumination of the satellite transponder when several terminals are in the field. It also ensures a measure of safety; in the event of a terminal antenna being inadvertently moved off the satellite, for any reason, loss of this control signal causes the HPA to mute and turn off the RF radiation. The control signal also contains information as to whether the common pre-operational channel is being used by the base station or another portable terminal. This information is brought out as a visual indication to prevent over talking on this channel. This indication is necessary as the circuit quality from portable-to-portable terminal precludes normal audio monitoring.

The pre-operational receiver allows the terminal operator to have a two-way link with the base station for set-up purposes prior to video transmission. Use of the pre-operational channel overrides the HPA mute circuits via a press-to-talk switch on the transmit circuit of the terminal.

All the video and voice circuits are brought together on a switching and patch panel allowing duplex channel operation and complete operator flexibility.

Figure 3 shows the block schematic of the RADET terminal with additional Network audio channels.

The RADET system has been designed to run equally well from 115 Volt local power supplies or from a portable 3 KW generator. Full protection and distribution circuitry is provided within the equipment, and if external supplies are necessary an external transformer can be provided.

Specification (Nominal)

Antenna	2m x 1m
Frequency	10.95 - 14.50 GHz
AE Gain 10.95 GHz	43.0 dB
14.0 GHz	45.0 dB
Tx Bandwidth	40 MHz
Tuning	125 KHz
EIRP (270 W)	68 dBW
G/T	18.6 dB/K
IF Input/Output	70 MHz
Video Input	1 V p-p
Power	115 V AC

Handling

All equipment is mounted on subframes which are supported on shock mounts within the flight cases to protect from the shocks and vibrations encountered during transportation. The flight cases provide weather-proofing and are strengthened with integral plinths allowing handling by fork-lift trucks.

OPERATIONAL EXPERIENCE

CBS's operational experience with the RADET system met all expectations for the quality of the received picture, rapid set-up on site, and rapid transportation at low cost.

Two operational experiences showed these advantages for news applications. One involved live coverage of President Reagan's visit to Palm Springs and the other was live coverage of the elections in the Phillipines.

In both situations the RADET system was shipped to the remote site by normal air freight transportation as excess baggage thereby saving extensive costs of shipping larger systems. Upon reaching the site the physical setup for the system required approximately 20 minutes. Production personnel were pleased with the results in terms of signal quality, handling time and costs.

Palm Springs

In December 1985, the RADET system was needed for live coverage of President Reagan's visit to Palm Springs over a period of several days. The signal path consisted of the RADET uplink from Palm Springs to the G-STAR I satellite at 103°W, downlink to a 7-meter dish at Carteret, New Jersey, where the RADET base station was installed. A microwave link to New York, and fiber optic link to the CBS Broadcast Center completed the signal path. A 300-watt HPA was used by the RADET.

The RADET system used a steering signal from

R A D E T SYSTEM BLOCK DIAGRAM

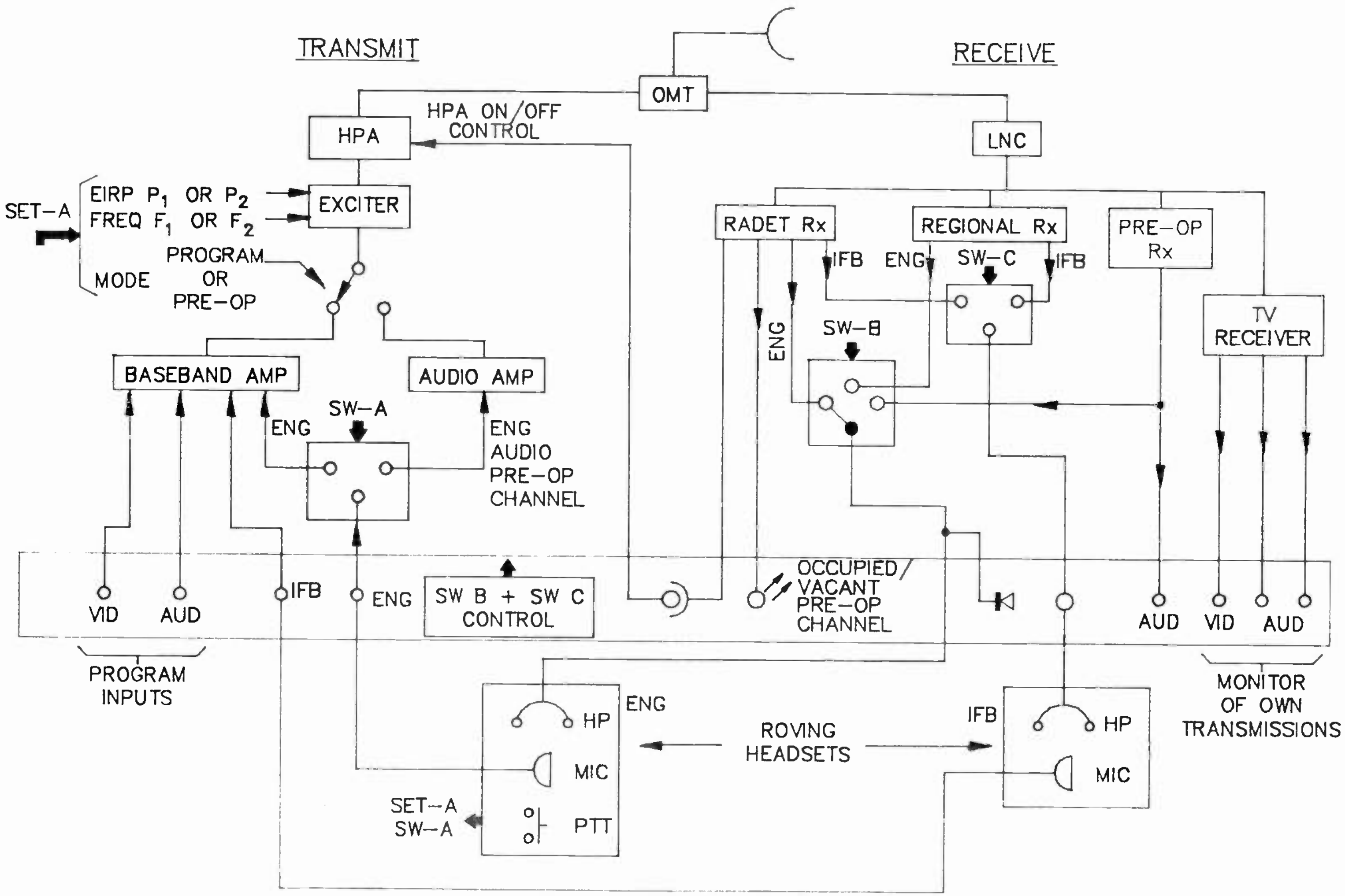


FIGURE 3

the base station as the means of accurately pointing the RADET antenna. Pointing of the antennae at Palm Springs was also accomplished by calculation of azimuth and elevation angles followed by operational coordination by phone with G-STAR's command center at Grand Junction, Colorado.

Reception in New York was considered very good by CBS News. In Washington, good reception was achieved using a 3.5-meter dish.

Phillipines

In February 1986, the RADET system was used for live coverage of the election in the Phillipines over a period of several weeks. The signal path consisted of the RADET uplink to Intelsat's Indian Ocean satellite, F5 at 63° East, C-Band cross-strapped downlink to Goonhilly, C-Band uplink to Intelsat's Atlantic Ocean satellite at 359° West, C-Band downlink to Andover, Maine, and terrestrial link to the CBS Broadcast Center in New York. The reverse path was used to accomplish a live interview between Dan Rather in New York and President Marcos in the Phillipines where the RADET was used for simultaneous transmission and reception.

For steering purposes British Telecom International (BTI) provided an unmodulated carrier signal from Goonhilly which was used by the RADET for a pointing adjustment with the aid of a spectrum analyzer. Transmission from the RADET to Goonhilly occupied 1/2 of the normal 72 MHz transponder bandwidth while transmissions from Goonhilly to the RADET used a full transponder. A 300-watt HPA was used by the RADET.

The quality of the received picture from the Phillipines was considered exceptionally good considering the double satellite hop. The unweighted video S/N ratio was measured at 40 dB in New York without any streaking or interference effects. Reception was excellent in the first hop to Goonhilly resulting in video S/N (unweighted) of 43 dB.

CONCLUSION

The RADET system is built to be compatible as an integral part of the much broader Ku-Band SNG network concept of CBS with respect to communications and control. The SNG network may consist of a combination of SNG vehicles and RADETs operating in the continental United States area and in foreign territories. CBS is continuing to modify the mechanical and electronic subsystem of the RADET to augment the communications system, improve its ruggedness and accommodate those features that the field technicians have found to be useful. Based on information available to date, CBS still believes that a segmented (petalized) antenna approach will not meet the FCC criteria and the high reliability levels required to operate a system on a continuous basis.

In summary, the RADET system is ideally suited for virtually any communication system application whether video or audio, which necessitates a small, compact satellite terminal.

THE EVOLUTION OF A SECOND GENERATION SATELLITE NEWS GATHERING SYSTEM

W. Vincent Walisko, Jr. and Kenneth C. Zolot
SPECTRA Communications, Inc.
Aldie, Virginia

ABSTRACT

There are many driving factors and considerations which have played a part in the evolution of SNG terminals to their current state. The specifics are examined. The problems and solutions of the antenna, HPA, communications package and other parts of the system are analyzed. The advantages to the SNG truck, van and fly-away are compared. Finally the composition of a second generation system is analyzed.

OVERVIEW

Satellite News Gathering (SNG) has been around for a long time. The very first transmissions of news across the Atlantic "via satellite" back in the 1960's were really the first form of SNG. The transition has been made from the huge 30 meter antenna of the early days of C-band satellites to today's totally portable KU-band antennas of less than two meters.

Along the way there were the transportable C-band antennas that became ubiquitous at the major sports events and occasionally made it to news events in time. The idea and desire was there but the technology had not yet caught up. Up until just the past couple of years, or since KU-band technology has become widely available, stations and news agencies couldn't go out and transmit stories back directly via satellite from the scene.

THE EMERGENCE OF KU-BAND

As KU-band first came on the scene people didn't trust it. The most common approach to KU-band was to spend more time doing tedious rain-fade availability studies than actual transmissions.

One of the first major votes of confidence for KU-band came when NBC announced plans to cut its land-lines and rely strictly on KU-band links. Many skeptics thought that NBC would suffer constant outages of their network. As NBC and others proved KU's reliability through repeated successful uses, people began to trust KU-band and realize that it would serve reliably.

THE KU-BAND PORTABLES

First there were four or five meter KU-band antennas transported on trailers, strangely reminiscent of the older C-band equipment. These trailers were usually towed by an ENG van or some other vehicle. Then came a new breed of vehicle - the SNG truck. The SNG truck looks like a fire truck and is a special purpose self-contained vehicle. It has all the equipment on-board, including an antenna, to communicate with the base, do production, and transmit the finished product via satellite. All this can be done in the field with no connections to external power or telephone lines.

Originally the SNG truck was equipped with about a 2.4 meter antenna and this was considered to be very small. But after repeated successful uses, the industry realized that this type of system was not only mobile and versatile but reliable too. Small antennas were proving themselves, but the large SNG trucks were cumbersome to maneuver and required special road-use permits and licences for its drivers.

THE FLY-AWAY

Then the concept of a "fly-away" SNG package came up. This is a small (less than two meter) antenna with all the necessary electronics packaged in flight cases. This allows the deployment of an SNG terminal to any place reachable by a commercial airline, helicopter, rent-a-car or mule (some weight restrictions apply here). Once on site all one need do is connect the electronics, deploy the antenna and acquire the satellite.

The disadvantage of the fly-away package arises when one wants extra equipment on the scene or protection from the elements. To accommodate these situations, the ideal system includes a very small vehicle, i.e. a Ford Econoline van, to transport the fly-away. Normally the equipment is operated in the controlled environment of the van. But sometimes the need arises to transport the equipment to a place that the van can't reach in the time available. Then the equipment is removed from the van, packed in flight cases, and "flown-away."

Here documented are some of the findings that came out of SPECTRA Communications' research and development on its recently-announced ROVER line of satellite news gathering systems. These systems are for use in fly-away, van, and combination configurations.

PUTTING TOGETHER AN SNG PACKAGE

The main constraint on the fly-away package is that it be easily moved by two people and positioned by one person. The space considerations are numerous: in order to transport the equipment, it may have to fit into a Leer jet or on a rent-a-car or some other small space. The equipment often will be lifted into vehicles, elevators, and other means of transportation. To meet these constraints, the system is broken up into four flight cases each weighing under 135 pounds, each with handles and wheels.

Since the system must be prepared to operate in many un-readied environments, it must run on standard electric current (110 volts) that can be found readily or supplied by any standard generator.

The main components of the fly-away system are 1) the antenna, 2) the HPA, 3) communications packages, and 4) the exciter/upconverter and other components.

1. THE ANTENNA

REQUIREMENTS

The antenna has to be small, portable, light, rugged and FCC compliant. This requires a precise surface tolerance. A flexible and portable mount system is also needed. The mount must be such that untrained operators can easily acquire the satellite.

The physical limitations of the KU-band antenna are such that we have yet to see a standard design antenna that is much smaller than 1.8 meters meet the FCC two degree spacing requirements. These requirements state that the antenna patterns must fall bellow the specified curve:
29-25 log (theta) from one to seven degrees and so forth, as designated in section 25.209 of the Report and Order in Satellite Orbital Spacing, Docket No. 81-704, FCC 83-184 adopted April 27, 1983.

The tight space requirements preclude the use of a one-piece 1.8 meter reflector. Furthermore, the antenna must be light enough to be easily carried by two people. The antenna must be rugged enough to withstand the many forms of transport and the handling of freight companies and individuals who are in a hurry to get it where it is going. It is an ambitious undertaking to design an antenna that meets these criteria while maintaining sufficient performance through repeated assemblies and disassemblies.

SOLUTION

For portability, a segmented antenna is ideal. This design allows the antenna to be packaged in a small flight case and still be large enough to meet FCC requirements. In this approach the big obstacle is to maintain the critical surface tolerance. The seams of the antenna must fit together in such a way that the surface is always reconstructed precisely. Also, quick-release hardware is required to optimize the time needed to assemble the antenna.

To meet these stringent goals we found it necessary to use a highly-refined fiberglass for light weight with aluminum reinforcements around the perimeter of each segment. The aluminum assures strength and maintained surface accuracy. Since the assembly involves metal-to-metal contact, there is no danger of wearing down the surface of the fiberglass during repeated assembly.

2. THE HIGH-POWER AMPLIFIER

REQUIREMENTS

The two main parts of the HPA are the power supply and the TWT (travelling-wave-tube). Most HPA's that supply sufficient outputs need large and heavy power supplies. This poses a direct threat to easy portability of a system. For this reason, the HPA is, in many ways, the most difficult component to fit into the fly-away package.

SOLUTION

To get the sufficiently powerful HPA down to a manageable weight, the only presently-available alternative is to separate the power supply from the tube. This is achieved in a variety of ways: by mounting the tube in a separate RF drawer, or on the back of the antenna. Soon the day will come when solid-state HPA's will eliminate this problem, but until then the two-part HPA seems to be the most manageable approach.

3. THE COMMUNICATIONS PACKAGE

REQUIREMENTS

It's not enough to have just a video transmitting capability. In order to gain access to a satellite for video use one must first establish voice contact with the satellite carrier. After the link is established it is usually necessary to be in continuous communication with the target news organization. Not only do the engineers need to be in touch to coordinate the signal, but the script often needs to be updated and on-air talent has to hear the program audio for cues and other interaction during the actual video transmission. When taking the system to a remote location, it is unlikely that there will be telephone service readily available. Often there is no coverage by cellular phones service either.

SOLUTION

The solution is to use the satellite to transmit and receive voice communications. There are many ways to achieve this. Most include at least one duplex audio channel, one simplex audio channel for interruptible fold-back (IFB), and a data channel.

These signals can be transmitted using the "single carrier per channel" (SCPC) format in analog or digital form The SCPC signal is a relatively low power narrow bandwidth signal that can fit on the band-edge of a video transponder or in the assigned part of a multiple use transponder. Subcarriers can also be used to transmit voice or data from the remote site to the base. Telephone lines must be available at the base to tie into the communications system. Thus the base communications system must also contain telephone switching equipment which will go on and off-hook concurrently with the operation of the instrument at the remote site.

Many specific pieces of equipment have been made to meet these needs. The actual piece chosen should depend on the exact application to which it will be put. For instance if an SNG package is to be used in conjunction with a network that already has a base communications package in place it would be an unnecessary expense to duplicate it rather than get a remote package which is compatible. In the absence of any existing system with which to be compatible there are some technically superior systems.

4. OTHER PARTS OF THE SYSTEM

REQUIREMENTS

The SNG package must accept audio and video inputs in standard format and allow for monitoring of both the outbound and return signal from the satellite. It is also necessary to have a system for finding the satellite.

SOLUTION

These remaining parts of the system are packaged together in a single electronics case. The video exciter accepts baseband audio and video signals and converts them to the appropriate KU-band frequency.

The monitoring gear includes a small screen monitor and a speaker which can be switched between the input signals and the signals from the satellite receiver, which is also part of this electronics case. This receiver and monitor are used to find the satellite during the set-up process. To find the satellite, one selects a known channel on the receiver and moves the antenna until an ideal signal-strength is achieved.

In the van, there is sufficient space for additional monitoring and signal routing equipment. The van also allows the room for editing and effects equipment which might be required. Editing capability is desirable to cut raw footage when trying to optimize use of valuable satellite time. It is also possible that switching and effects might be necessary in a situation where an event is being produced live in the field and fed back by satellite.

Also, generators are often needed both in the van and for the fly-away configuration, as one cannot always assume that the unit will be taken to a place where there is readily accessible power. The van and fly-away systems run on standard 110-volt electrical current. The van power is supplied by two on-board generators. For the fly-away, it often turns out that customers want to take the unit to its destination and arrange for the temporary renting of a generator on location. This eliminates the need for transporting a heavy generator. We were able to find a generator that weighs under 250 pounds that can be packed into flight cases and included as part of the fly-away system.

INTO THE FUTURE

Thus emerged the fly-away package as it stands today. As new technologies develop, changes in production equipment are sure to follow. Smaller antennas on new higher-frequency bands, coupled with light, solid-state amplifiers and more compact exciters and communications equipment may finally lead to the "carry-on" or so-called "brief case" earth station. SPECTRA Communications is happy to be able to help bring about this exciting new era of satellite communications.

DIGITAL TECHNIQUES SOLVE THE SNG COMMUNICATIONS PROBLEM

Heinz E. Wegener
Wegener Communications, Inc.
Norcross, Georgia

ABSTRACT

A Satellite News Gathering (SNG) system needs phone and data communications between the SNG truck and the studio. Many times the very nature of the news story covered makes it difficult, if not impossible, to establish communications with locally available telephones.

The following paper discusses how digital transmission techniques provide the optimum SNG communications system, considering many factors including transponder costs, ease of setup and satellite acquisition, reliability and maintainability of the equipment, cost of the remote and base station equipment, service support with readily available spares, flexibility in upgrading or reconfiguring the system, and the ability to add future products to the system to fully automate SNG communications system setup and monitoring.

SNG COMMUNICATIONS

Many SNG communications systems are standardizing on the following elements:

a. Two full duplex voice channels

b. One IFB voice channel

c. One two-way data channel

This configuration allows making two independent telephone calls from the SNG truck while listening to the IFB channel and being able to send news script and other hard copy data betwen the truck and the studio.

To minimize transponder costs and maximize the availability of the video transponder, communications must be established prior to and following the video transmission without using video transponder space. Pre-video communications allows the remote crew to properly align the antenna, confirm the video transponder number and transmission start time, transmit news script to the reporter, and conduct any other communications locally or worldwide needed to guarantee an effective live news feed. When video is transmitted, phone line communication is necessary for producer instructions, and post-video feed communications might include coordinating the end of video transmission instructions to the remote crew and any follow-up news instructions, and also continued live audio communications from the news location.

The availability of a data channel is key for hard copy transmission of newscript and for future upgrades of the SNG system to include automation of the antenna alignment, power setting, automatic transponder and phone line use logging and billing, etc.

HUB VERSUS DIRECT BASE STATION TO REMOTE TRUCK COMMUNICATIONS

As Figure 1 indicates, a hub communications system consists of one central earth station communicating with a number of SNG trucks and coordinating all aspects of their transmission, including allocation of video transponder time, communication channel assignment, and tying the phone lines into a local Private Branch Exchange (PBX) through which all telephone conversations are routed. This network is used primarily where several trucks are sharing common transponders, or where network feeds are originating from different parts of the country. As Figure 1 shows, the communications interface is always with the hub central station, although video is usually transmitted to another location, such as the television station that owns the truck.

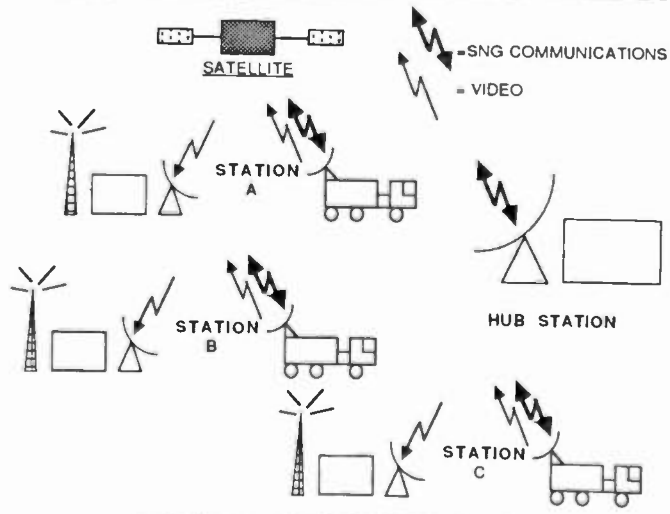


FIGURE 1. HUB SNG SYSTEM

All telephone conversations, including truck-to-truck, truck-to-television studio, etc., are routed through the hub PBX. Note that in truck-to-truck communications using this technique, the voice channels go to the satellite twice (called a "double hop"), which results in a 1/2 second delay in the telephone conversation, which is slightly distracting until one becomes accustomed to it.

The advantage of this system is that the hub serves as a traffic coordinator allowing optimum use of video transponder space. Also, each television station is a video receive-only station, and no manpower or equipment for the communications system is required.

Note that if the hub is located in New York and the truck is in Los Angeles, a "local" phone call made by the truck would be tariffed as a long distance call since the call between the hub in New York and the Los Angeles destination would probably be sent over conventional land lines.

Figure 2 shows a single base station to a single remote truck communications system. This system is used for local video transmission to a television station, and both communications and video transmission go to the local base station. Phone communications goes to the base station PBX and all coordination and alignment with the satellite transponder supplier routes via the PBX through land line networks.

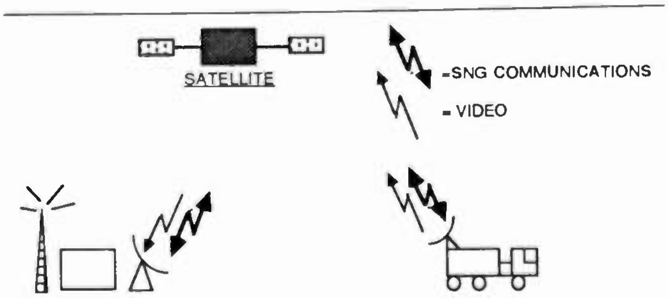


FIGURE 2. BASE STATION TO ONE TRUCK

If phone communications with other trucks is desired, it would normally be conducted as follows:

a. The local SNG truck talks to the base station PBX via satellite;

b. The base station PBX uses land lines to tie to another station PBX;

c. This second base station transmits via satellite to its SNG vehicle.

Direct truck-to-truck or station-to-station conversations are possible in both configurations, but compatible equipment must be available at all locations and careful coordination of communications is required. Many times in an optimized SNG communications system, the equipment required for the hub-to-truck communications is not the same as the return truck-to-base-station communications. This is due to the difference in antenna size of the base station and the trucks and also in the number of voice channels that need to be transmitted each way.

METHODS OF TRANSMITTING COMMUNICATIONS CHANNELS

Generally the communications channels are transmitted separately from video. The following lists some transmission techniques:

a. **Dedicated SCPC transponder for communications** -- Figure 3 shows a typical satellite transponder arrangement where one transponder is dedicated to single-channel-per-carrier (SCPC) transmission, and the other transponders are dedicated to video only. In this approach the communication channel, once assigned to the SNG user, remains fixed during the entire remote transmission. The video transponders are used to transmit only video. Using one antenna and power amplifier in this technique requires that the SCPC channel is on the same satellite and polarization as the video channel. A separate 14 GHz upconverter is generally required for the SCPC and the video carriers, and power combining occurs at 14 GHz. Use of a common power amplifier to transmit SCPC and video in different transponders also requires that the power amplifier be operated in its linear range to prevent intermodulation products from the power amplifier from spilling into other transponders. Typically this requires backing off the power amplifier a minimum of 3 dB below its saturated output power, which generally is a loss of hundreds of watts of transmitting capability. The highest level intermodulation products are third order products, which means that if transponder 5 (TP5) is used for SCPC and transponder 7 (TP7) is used for video, the intermodulation products will appear in transponders 3 and 9. (2 x TP 5 minus TP 7 and 2 x TP7 minus TP5).

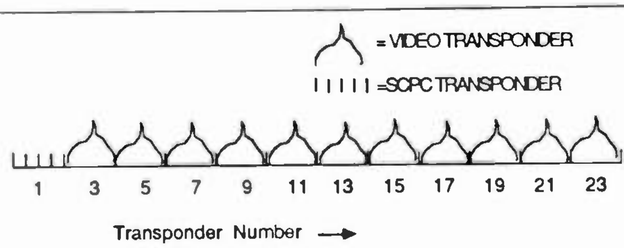


FIGURE 3. SINGLE SCPC AND REGULAR VIDEO

b. **Pre- and post-video transmission communications on a separate SCPC transponder and bandedge SCPC during video transmission** -- Figure 4 represents the satellite transponder arrangement with this technique. The SCPC transponder is used for phone and data communications prior to and following video transmission. Once a video transponder is assigned, complete two-way communications is conducted by injecting carriers at the lower extreme of the video transponder which is called bandedge SCPC. Since the video transponder rental normally includes use of the entire transponder, no additional charges for communications are incurred during that time period. Also the carriers previously used in the SCPC transponder are available for other users when video transmission begins.

Use of bandedge SCPC requires careful earth station alignment, and Appendix I lists some parameters and equipment considerations in using bandedge SCPC. Bandedge SCPC allows common use of video upconverters (with digital transmission -- in analog transmission this is not the case) and power amplifiers without concern for intermodulation products. In bandedge SCPC, intermodulation products of the bandedge carriers fall in the opposite end of the band. Typically, bandedge carriers are placed at the low end of the transponder, which puts the intermodulation products at the top of the transponder. In the event of multiple video channels per transponder, the intermodulation products of bandedge SCPC could prevent this from being a usable technique. A lot depends on the level of the video carriers and how closely they are operated to saturation.

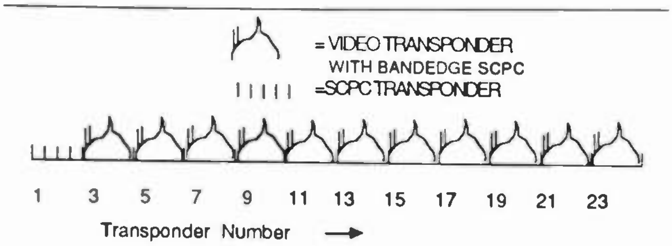


FIGURE 4. SCPC AND VIDEO WITH BANDEDGE SCPC

c. **Bandedge SCPC only** -- This approach allows phone and data communications only when the full video transponder is used. Generally this is not a very cost effective or practical technique, since communications is usually required well before video transmission begins.

d. **Bandedge from the hub or base station, and subcarriers from the truck to the base station** -- This technique has the same limitations as c in that communications cannot begin until video is transmitted.

e. **SCPC on a dedicated transponder for pre- and post-video transmission communications, and then use subcarriers above video for the return signal from the truck to the base station when video is transmitted** -- In this approach, the transmission from the hub or base station to the truck is always on an SCPC carrier in an SCPC transponder. The return transmission from the truck is an SCPC channel in the SCPC transponder during non-video transmission and is a subcarrier on the video channel when video transmission is initiated. This technique adds some complexity at the hub or base station in selecting where return communications originates (SCPC or subcarrier). The advantage is that when video is transmitted, only the video carrier is present, eliminating any problems due to intermodulation products as noted in paragraphs a and b.

ADVANTAGES OF USING DIGITAL TRANSMISSION TECHNIQUES FOR SNG COMMUNICATIONS

Digital transmission involves converting the analog voice channel to a digital data stream, multiplexing (combining) several digital channels on one large digital data stream, and modulating this digital data efficiently for transmission over the satellite. This is in contrast to analog transmisison whereby the voice channel directly modulates a carrier or several voice channels are multiplexed prior to modulating a carrier (FM modulation is normally used). Several years ago there was a large spectral efficiency and cost penalty incurred in using digital as opposed to analog techniques. However with significant advancements in forward error correction and data modem technology, and also through the use of large scale integration of key digital functions, digital transmission has clear advantages over analog in both spectrum efficiency and cost. The following are some advantages of a digital system.

a. **Transponder costs are substantially lower than analog** -- Due to the use of forward error correction (FEC) and efficient digital modulation techniques, the power required to transmit a digital communications channel can be significantly lower than an equivalent FM analog channel. Also by use of low data rate voice coders and phase shift keying (PSK) modems, the transmission bandwidth used is also lower than an analog channel. It should be noted that there is no analog equivalent to FEC and FEC techniques are continually being improved, promising even further improvements in efficiency using digital techniques.

b. **Earth station hardware can be tailored to optimize transponder and hardware costs** -- Utilizing FEC only in the path needed allows optimization of both hardware costs and transponder expenses. As an example, FEC is extremely useful in transmitting to smaller antenna terminals but may not be needed at all in transmission from a small terminal to a large antenna base station. Again there is no equivalent technique to allow doing this in analog transmission.

c. **Digital circuitry is more robust and less sensitive to performance changes** -- Use of channel identification codes in digital transmission allows "smart" acquisition of the proper data carrier without the use of high stability pilot frequencies as is required in an analog system. This eliminates the need for high stability frequency converters which many times utilize oven controlled crystal oscillator references to maintain the precise frequency accuracy needed in an analog system. The frequencies of those high stability converters can change due to shock and vibration, time and temperature. Also, the phase noise of the sources used in frequency translaters is not as critical in digital systems as it is for analog transmissions.

d. **Maintenance and calibration is easier and less frequently required** -- Again due to the absence of high stability frequency sources, the digital system does not require continuous monitoring of frequencies using high stability frequency counters which are themselves expensive and subject to performance changes because of the same parameters as noted in c above.

e. **Built in level of security** -- Due to the nature of digital transmission, there is a built in level of security of the communications. Further, if needed, hard encryption can be incorporated which is not possible in an analog system.

f. **Data channels are almost free** -- To add a data stream for hard copy communication, automation of level setting, automatic billing and usage logging, etc., can be added with an almost imperceptible increase in the composite data rate transmitted. In an analog system, having data channels frequently requires adding another carrier whose transmission parameters are identical to a voice channel.

g. **The transmission system is easily reconfigured** -- It is fairly easy to change the data rate of the voice channel coders or to replace a few voice channels with a program channel or a high speed data channel as the situation warrants, as long as the composite data rate is sufficient to accommodate the total data thru-put. As long as the data rate of the composite signal is the same, the transmission parameters do not change at all. In an analog case, to go to a high quality program channel requires a different transmission designator, and different equipment is required.

h. **Lower cost video "Common Equipment" can be used** -- Using certain data modems, it is frequently possible to use the up and down converters that are used for video transmission. This is a major advantage in the truck, both in cost and space savings, over an analog system. These components cannot be used in an analog system due to the relatively poor phase noise and frequency stability of the video frequency converters.

i. **Use of VSAT components guarantees excellent product support** -- Many elements of the Wegener Communications digital SNG communications system are modules also being used in high volume VSAT (Very Small Antenna Terminal) data distribution products. Due to the high volume of the VSAT components, a constant inventory of spare modules is assured and product support is guaranteed for many years.

j. **The future trend is for significant cost reductions with a digital system** -- Due to large scale integration of many of the key circuits in the digital system, and also high volume production of many of the RF components (which are used in VSAT products), the trend of terminal prices for the digital system is for continued cost reductions. This allows further reduction of transponder costs by incorporating more sophisticated FEC coders, or adding more automation to the SNG system in the future.

As the above shows there are many advantages in using a digital transmission system for SNG communications.

KEY ELEMENTS OF A DIGITAL SYSTEM

The following gives an overview of key elements of a digital SNG transmission system. Figure 5 is a general block diagram of major elements in a digital transmission system.

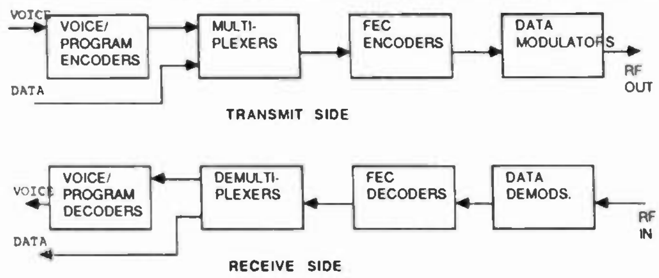


FIGURE 5. GENERAL DIGITAL SYSTEM BLOCK DIAGRAM

Voice Encoders and Decoders

There are currently three major types of voice coders in use as follows:

a. **64 kb/s A-law companded PCM** -- This is the most common and transparent encoding system and can fully transmit all phone line signals including high speed data and FAX.

b. **CVSD (Continuously Variable Slope Delta Modulation)** -- This is currently being operated as low as 32 kb/s per second and provides adequate transmission of telephone signalling and DTMF tones.

c. 32 kb/s **ADPCM** -- A CCITT specification for this adaptive differential PCM system is being developed for common use in telephone transmission systems.

Lower Data Rate Coders

Development is being conducted to further reduce the data rate of voice channels. Although fairly low data rate voice channels (<16 kb/s) are available that provide intelligible voice, they do not generally provide transparent transmission of signalling, DTMF, and data modem tones.

Program Channel Coders

Currently the more spectrum efficient coders consists of the Dolby™ Adaptive Delta Modulation System, which Wegener is using to transmit 15 kHz channels at data rates as low as 256 kb/s. Dolby™ ADM uses digital control channels with delta modulation to provide a high performance, low data rate program channel. Combinations of analog companding and digital transmissions, such as Wegener Communications PANDATA™ System, can transmit 15 kHz program channels at data rates as low as 200 kb/s and 7-1/2 kHz channels at data rates of around 100 kb/s.

Multiplexers

These devices combine various data channels into one composite data stream. Multiplexers are generally specified as synchronous and asynchronous in that they can multiplex synchronous or asynchronous data streams. The Wegener Communications FLEXMUX™ Multiplexer is capable of combining synchronous and asynchronous data channels on one composite channel and carrying individual clock frequencies through on synchronous data channels.

Multiplexers are typically identified as packet multiplexers or bit oriented multiplexers. Packet multplexers combine a number of bytes of data from one channel into one packet, which has information stored in it that determines where this packet of data belongs.

A bit oriented multiplexer combines channels on a bit-by-bit basis into a single frame with bits from different channels stacked at specific locations relative to the beginning of the frame. The bit oriented multiplexer is typically more robust under noise conditions in that it establishes frame lock by identifying a sequence on one bit in the frame. If the sequence is not detected, this demultiplexer typically tries again to identify the sequence, and only after not identifying the sequence over a fairly large percentage of frames will the multiplexer try to re-acquire framing. Of course when framing is re-acquired, a large number of data bits are lost. Wegener Communications supports both packet multiplexers and bit oriented multiplexers and the FLEXMUX™ is a bit oriented multiplexer.

Forward Error Correction Coders

These units provide error correction of data that has been corrupted by noise by encoding the data stream at the transmit end and adding extra bits to allow detecting bit errors and correcting the errors at the receive end. As a result of these mathematical processes, a certain coding gain is realized which is an indication of how much more the demodulated signal can be degraded before reaching an equivalent bit error rate of an unencoded signal. The forward error correction schemes are identified by the amount of coding gain they realize and the overhead bits used to achieve this forward error correction. The coding gain takes into account the increased bandwidth needed to accommodate the additional bits. Current forward error correction techniques typically have rates of one-half or greater (meaning that the thruput data is one-half of the transmitted data rate), and overhead as low as seven percent has been realized.[1]

There are two major forward error correction techniques called convolution coding and block coding. Convolution coding compares a current bit with one or more bits sent prior. Some common types of convolution coding are: Viterbi, Feedback, and Sequential. Due to the nature of convolutional coding, error bursts are not as easily corrected, and the length of error bursts corrected is typically less than 20 with convolution, where it is up to 100 with block coding.

In block coding, whole blocks of user data are loaded into registers and then processed through the encoding algorithms.[2] Because of how this coding is conducted, block coding is useful where a lot of data is lost at a time. Block codes have evolved from forward error correction techniques used for data retrieval from mass storage devices.

Other terminology used in forward error correction is soft and hard decision making. Soft decision making relies on information from the modem to optimize its forward error correction process, which improves the performance of the FEC coders. Hard decision simply looks at the data without any other inputs. Forward error correction is key in reducing the power required to transmit digital signals, and these decoders typically work with very poor input bit error rates (10^{-2} or 10^{-3} bit error rate).

Data Modulators and Demodulators

Data modulation can take place by amplitude shift keying, frequency shift keying (FSK) or phase shift keying (PSK). PSK provides the best efficiency and requires the lowest power in transmitting data. Also by use of multiple level phase shift keying, such as QPSK, bandwidth reductions can be realized. BPSK transmission has good noise performance, and also performs satisfactorily in the presence of low frequency noise such as is generated by frequency sources used in video exciters and receivers. Table 1 summarizes operational parameters of Wegener Communications BPSK and QPSK modems.

Table 1. BPSK and QPSK Modem Parameter

Parameter	BPSK	QPSK
E_bN_o (10^{-6} Bit Error Rate)	12.3 dB	12.3 dB
Occupied Bandwidth	Bit Rate	Half Bit Rate
Carrier Spacing Bandwidth	1.4 x Bit Rate	.7 x Bit Rate
Data Rates	4.8 kb/s - 1 Mb/s	9.6 kb/s - 2 Mb/s

Network Control Modules

This terminology is used by Wegener Communications to identify modules that use a data channel to remotely perform various functions, such as contact closures for controlling external equipment, DTMF tone signalling, transmitting addressed messages to various locations, etc. As mentioned earlier a small amount of data can easily be added to the system with no significant changes in transmission parameters to accommodate these modules to allow remotely controlling various devices.

Encryption/Addressing/Automatic Billing Systems

Encryption and addressing are functions that are uniquely possible only in a digital system. The entire composite data stream is encrypted, and the information on who is authorized to receive is also transmitted. Only people having authorized addresses and keys can receive the transmitted data. This may not be an important feature now, but if it needs to be added to the system later, only digital transmission can accommodate encryption and addressing.

Billing systems may also be key to fully automated hub stations. By uniquely identifying each operator and automatically logging their transponder usage for both video and communication applications, billing can be very accurate and detailed. Doing video transponder time logging and billing is simplified if the return transmission from the truck uses a digital subcarrier.

TYPICAL CONFIGURATIONS

The following discusses some specific systems configuration.

Separate SCPC Channel Used at All Times for Communications

Figure 6 is a block diagram of the system. Note that the hub needs to be only an SCPC transmit/receive station unless it is desirable to monitor video transmission. In this block diagram, all interfacing is done at one GHz with block conversion to 14 GHz and from 12 GHz. This allows full bandwidth tuning of SCPC channels.

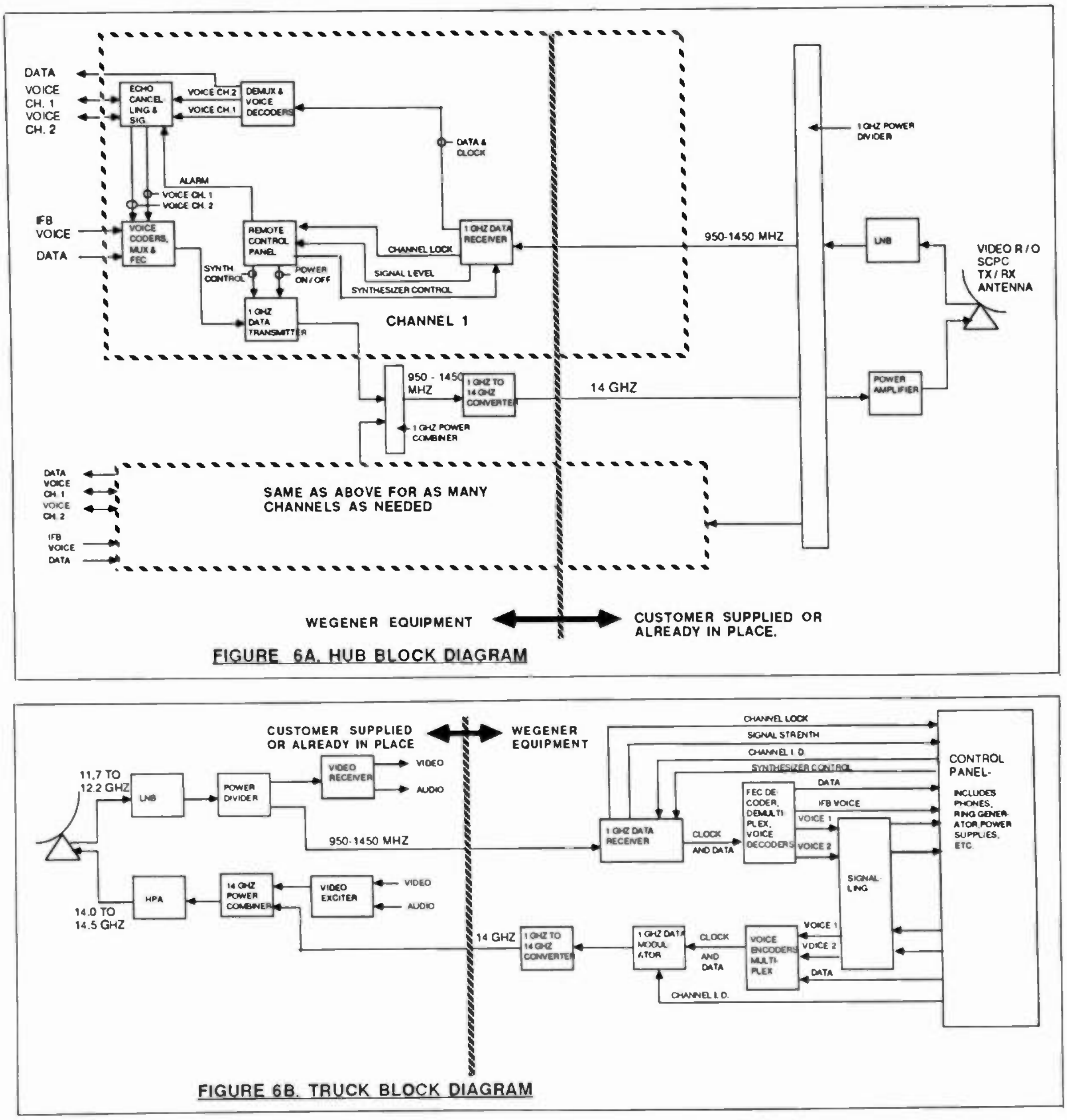


FIGURE 6A. HUB BLOCK DIAGRAM

FIGURE 6B. TRUCK BLOCK DIAGRAM

FIGURE 6. BLOCK DIAGRAM FOR SCPC ONLY SYSTEM

The truck side requires a separate rf upconverter and power combining occurs at 14 GHz. It may be necessary to power combine past the HPAs if the video power amplifier needs to be operated at or near saturation, due to intermodulation products falling into other transponders.

Use of Separate SCPC for Initial Communications and then Switching to Subcarrier for the Return Path

Figure 7a is a block diagram for the hub electronics and shows power combining at 1 GHz with upconversion to 14 GHz as with the previous system. The receive side, however, needs to select between data transmitted on subcarriers and data transmitted at SCPC to determine which carrier has the valid data. Switching between the proper input is conducted by the alarm/data switch which monitors the channel lock information originating from the data receiver and subcarrier demodulator, as well as an alarm signal from these two modules. A remote control panel allows manually selecting where data is received as well as controlling other functions, such as frequency selection, etc.

Figure 7b is a block diagram of the remote station, and the receive side is fairly identical to the SCPC-only system. However, on the transmit end, the data from the voice encoders and multiplex block goes to a subcarrier data modulator whose signal is split to go to the baseband input of the video exciter, and also to a subcarrier-to-70 MHz upconverter to provide

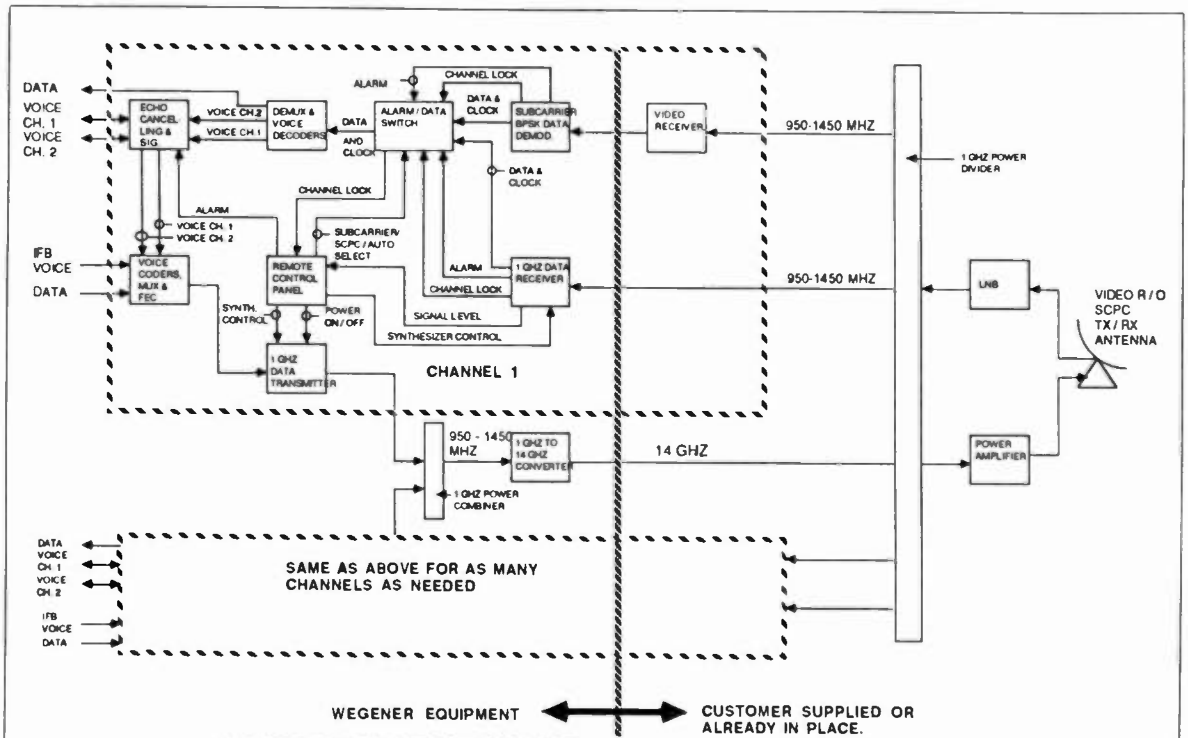


FIGURE 7A. HUB BLOCK DIAGRAM

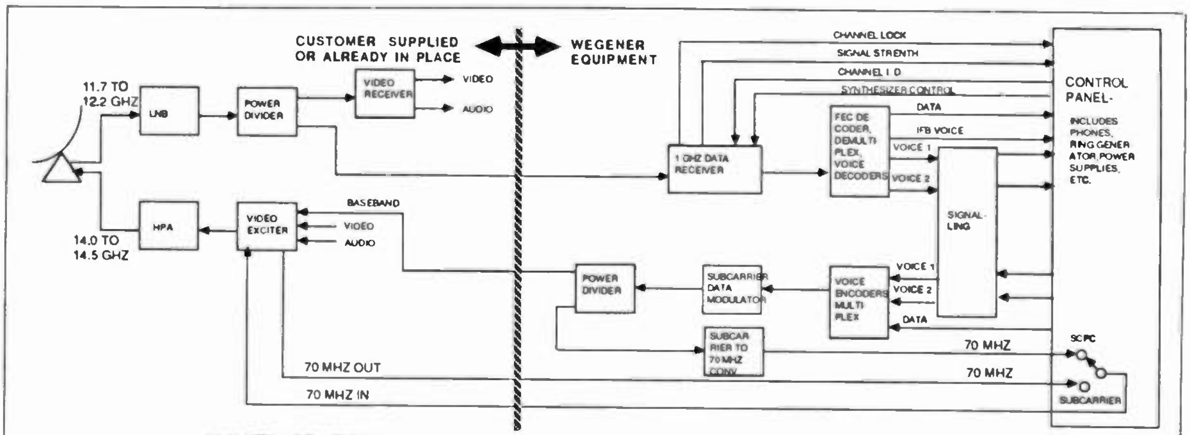


FIGURE 7B. TRUCK BLOCK DIAGRAM

FIGURE 7. BLOCK DIAGRAM FOR SCPC / SUBCARRIER SYSTEM

a 70 MHz output. This signal is switched between the 70 MHz output from the video exciter and allows the video exciter to be used as an SCPC upconverter when video is not being transmitted. Selection of SCPC or subcarrier return transmission is done manually, and adequate delays are built into the system to prevent phone conversations from coming off-hook.

SYSTEM PARAMETERS

Definition of Terms

E_b/N_o -- This is the energy per bit in a normalized (1 Hz) spectral noise density and expresses the performance of a demodulator in terms that are independent of data rate. Typically, data modems are specified as providing certain bit error rates at various E_b/N_o's.

C/N_o -- This is a carrier-per-noise power density ratio which defines the power level of the carrier required to attain a certain bit error rate performance, taking data rate into account. To convert E_b/N_o to C/N_o one adds 10 times the logarithm of the data rate. To convert an analog channel to C/N_o requires adding the carrier-to-noise ratio of the operating system to 10 times the log of the occupied modulation bandwidth.

Analog C/N_o :

$$C/N_o = C/N + 10 \log (IF_{BW} \text{ (Hz)})$$

Digital C/N_o :

$$C/N_o = E_b/N_o + 10 \log (\text{data rate (bits/s)})$$

EIRP (Effective Isotropic Radiated Power) -- This is the power required from the satellite to achieve a certain E_b/N_o at a receive earth station (watts). The lower the operational E_b/N_o the less power is required from the satellite. In SCPC, the tariff for transponder time is typically related to both power and bandwidth, and with a certain power there is a certain allowable bandwidth that can be used.

To calculate the EIRP required from the satellite, the following procedure is used:

a. Determine the data rate used for digital and the occupied bandwidth for analog.

b. Determine the minimum E_b/N_o for a corresponding minimum bit error rate for digital and the minimum C/N for acceptable transmission for analog.

c. Calculate the C/N_o of the carrier as previously indicated.

d. Add the amount of margin desired to the above calculated C/No number.

e. Turn to Table 2 and find the required satellite power matching the C/N_o desired with the antenna to be used. If the exact size antenna is not on this chart, just multiply the power for one of the listed antennas by the ratio of their diameters squared.

Example: For a 1.5-meter antenna, power required = Power for $1.2 \times (1.5/1.2)^2$ = 100 watts (for C/N_o of 60 dB - Hz)

f. Once power has been determined, calculate the available spectrum by determining how many kHz per watt are allowed by the satellite supplier. If more bandwidth is required than what is allowed, increase the power until the bandwidth required is met and determine the new power. Table 3 shows a summary of calculations that were made for a digital and analog system.

TRANSMIT POWER CALCULATIONS

The amount of power required to transmit this signal from the earth station depends on a number of parameters including the following:

Antenna size
Uplink margin
Saturation flux density
Saturated EIRP of the tranponder footprint
Noise figure of the satellite receive system

Table 4 shows calculations for a base station and a remote station with the following parameters:

Description	Characteristic	
	Base	Remote
Configuration	3 32 kb/s voice +1 1200 baud data	2 32 kb/s voice +1 1200 b/s data
TX Data Rate	204.6 kb/s	68.6 kb/s
Min E_b/N_o	8 (dB FEC usedf)	11
Corresponding C/N_o (dB - Hz)	58.1 (FEC used)	59.4
Antenna Size (m)	4.5	2.4
Uplink Margin (dB)	3	3
Downlink Margin (dB)	3	3
Operating C/N_o (dB - Hz)	61.1	62.4
Downlink Saturated EIRP (dBW)	40	40
Saturation Flux Density (dBW/meter^2)	-87 dBW	-87 dBW

Note: Power calculations are at TX waveguide flange and do not consider power loses up to the power amplifier.

OTHER CONSIDERATIONS

Multiple Video Per Transponder Operation

There is sufficient bandwidth and in many applications significant power available to allow multiple video per transponder operation. As in any multiple carrier per transponder situation, intermodulation products are a key consideration and how far the transponder output can be operated below saturation will determine the level of intermodulation products. This is an especially important consideration if using bandedge SCPC and testing should be conducted at the desired video operating levels to determine if intermodulation products are sufficiently low to allow bandedge transmission. Also the use of multiple equal-level carriers in a transponder transmission makes a transponder subject to "transponder capturing" which is where one of the carriers becomes signaificantly greater than the other and brings the transponder into saturation suppressing the level of all other carriers drastically. To prevent this, levels need to be very carefully set and monitored. Multiple video channels per transponder have been operated for many years and they can be used in this application as well, but careful consideration must be given to operating levels.

TABLE 2. CALCULATIONS OF REQUIRED EIRP FOR VARIOUS ANTENNA SIZES

SCPC CALCULATIONS

C/No INCREMENT 0.5

RX Noise (Kelvin)	265	265	265	265	265	265	265	265
RX Antenna Size (m)	1.2	1.8	2.4	3.0	3.3	3.7	4.5	6.0
RX Antenna Gain (dB)	41.0	44.5	47.0	49.0	49.8	50.8	52.5	55.0
Downlink G/T (dB/K)	16.8	20.3	22.8	24.7	25.6	26.5	28.2	30.7
	RX EIRP(scpc) (watts)							
C/No (dB-Hz) = 55.0	32.0	14.2	8.0	5.1	4.2	3.4	2.3	1.3
C/No (dB-Hz) = 55.5	35.9	16.0	9.0	5.7	4.7	3.8	2.6	1.4
C/No (dB-Hz) = 56.0	40.3	17.9	10.1	6.4	5.3	4.2	2.9	1.6
C/No (dB-Hz) = 56.5	45.2	20.1	11.3	7.2	6.0	4.8	3.2	1.8
C/No (dB-Hz) = 57.0	50.7	22.5	12.7	8.1	6.7	5.3	3.6	2.0
C/No (dB-Hz) = 57.5	56.9	25.3	14.2	9.1	7.5	6.0	4.0	2.3
C/No (dB-Hz) = 58.0	63.8	28.4	16.0	10.2	8.4	6.7	4.5	2.6
C/No (dB-Hz) = 58.5	71.6	31.8	17.9	11.5	9.5	7.5	5.1	2.9
C/No (dB-Hz) = 59.0	80.4	35.7	20.1	12.9	10.6	8.5	5.7	3.2
C/No (dB-Hz) = 59.5	90.2	40.1	22.5	14.4	11.9	9.5	6.4	3.6
C/No (dB-Hz) = 60.0	101.2	45.0	25.3	16.2	13.4	10.6	7.2	4.0
C/No (dB-Hz) = 60.5	113.5	50.5	28.4	18.2	15.0	11.9	8.1	4.5
C/No (dB-Hz) = 61.0	127.4	56.6	31.8	20.4	16.8	13.4	9.1	5.1
C/No (dB-Hz) = 61.5	142.9	63.5	35.7	22.9	18.9	15.0	10.2	5.7
C/No (dB-Hz) = 62.0	160.4	71.3	40.1	25.7	21.2	16.9	11.4	6.4
C/No (dB-Hz) = 62.5	179.9	80.0	45.0	28.8	23.8	18.9	12.8	7.2
C/No (dB-Hz) = 63.0	201.9	89.7	50.5	32.3	26.7	21.2	14.4	8.1
C/No (dB-Hz) = 63.5	226.5	100.7	56.6	36.2	30.0	23.8	16.1	9.1
C/No (dB-Hz) = 64.0	254.1	113.0	63.5	40.7	33.6	26.7	18.1	10.2
C/No (dB-Hz) = 64.5	285.2	126.7	71.3	45.6	37.7	30.0	20.3	11.4
C/No (dB-Hz) = 65.0	319.9	142.2	80.0	51.2	42.3	33.7	22.8	12.8
C/No (dB-Hz) = 65.5	359.0	159.6	89.7	57.4	47.5	37.8	25.5	14.4
C/No (dB-Hz) = 66.0	402.8	179.0	100.7	64.4	53.3	42.4	28.6	16.1
C/No (dB-Hz) = 66.5	451.9	200.9	113.0	72.3	59.8	47.5	32.1	18.1
C/No (dB-Hz) = 67.0	507.1	225.4	126.8	81.1	67.1	53.3	36.1	20.3
C/No (dB-Hz) = 67.5	569.0	252.9	142.2	91.0	75.2	59.8	40.5	22.8
C/No (dB-Hz) = 68.0	638.4	283.7	159.6	102.1	84.4	67.1	45.4	25.5
C/No (dB-Hz) = 68.5	716.3	318.3	179.1	114.6	94.7	75.3	50.9	28.7
C/No (dB-Hz) = 69.0	803.7	357.2	200.9	128.6	106.3	84.5	57.2	32.1
C/No (dB-Hz) = 69.5	901.7	400.8	225.4	144.3	119.2	94.9	64.1	36.1
C/No (dB-Hz) = 70.0	1011.8	449.7	252.9	161.9	133.8	106.4	71.9	40.5

Table 3. Communications System Parameter Summary and Comparison of Digital and Analog Transmission

	Hub to Truck (2.4m Antenna)		Truck to Hub (4.5m Antenna)		
Parameter	Digital	Analog	Digital	Analog	Comments
Modulation Type	BPSK	FM	BPSK	FM	
Number of Voice Channels	3	4	2	3	One analog channel used for data
Number of Data Channels	1-1.2 kb/s	0	1-1.2 kb/s	0	One voice channel used in analog system
Thru-put Data Rate	102.3	N/A	68.6	N/A	((N x 32) + 1.2)/.95
Operating C/N_o (dB-Hz)	61.1*	58.0	62.4	58.0	*3 dB rate. 1/2 FEC used 3 dB margin to 10 dB C/N and 10^{-5} BER
Number of Carriers	1	4	1	3	
Watts per Carrier	31.6	15.8	12.9	4.6	From Table 2
Total Power (watts)	31.6	63.2	12.9	13.8	No. carriers x (watts/carrier)
Spacing Allowed (kHz)	243	487	99	106	7.7 kHz/watt
Spacing Used (kHz)	287	180	96	135	45 kHz analog spacing; 2.8 x data rate w/FEC; 1.4 x without FEC
Power Adjusted for Bandwidth Reqd. (watts)	37.3	63.2	12.9	17.3	

Total Digital Transponder Power Required = 37.3 + 12.9 = 50.2 watts

Total Analog Transponder Power Required = 63.2 + 17.3 = 80.5 watts

TABLE 4. REQUIRED AMPLIFIER POWER (WATTS) FOR VARIOUS PARAMETERS (AT FLANGE)

C/No of carrier 58.1 (dB-Hz)
Noise temp of RX system 275.0 (Degrees Kelvin)
Downlink EIRP 40.0 (dBW)
Downlink margin 3.0 (dB)
Uplink margin 3.0 (dB)
Saturation Flux Density -87.0 (dBW/m 2)
Other Upl. Power Backoff 5.0 (dB)

ANTENNA SIZE	TX 1.2	TX 1.8	TX 2.4	TX 3.0	TX 3.3	TX 3.7	TX 4.5	TX 6.0
RX 1.2	17.61	7.83	4.40	2.82	2.33	1.85	1.25	0.70
RX 1.8	7.83	3.48	1.96	1.25	1.03	0.82	0.56	0.31
RX 2.4	4.40	1.96	1.10	0.70	0.58	0.46	0.31	0.18
RX 3.0	2.82	1.25	0.70	0.45	0.37	0.30	0.20	0.11
RX 3.3	2.33	1.03	0.58	0.37	0.31	0.24	0.17	0.09
RX 3.7	1.85	0.82	0.46	0.30	0.24	0.19	0.13	0.07
RX 4.5	1.25	0.56	0.31	0.20	0.17	0.13	0.09	0.05
RX 6.0	0.70	0.31	0.18	0.11	0.09	0.07	0.05	0.03

C/No of carrier 59.4 (dB-Hz)

ANTENNA SIZE	TX 1.2	TX 1.8	TX 2.4	TX 3.0	TX 3.3	TX 3.7	TX 4.5	TX 6.0
RX 1.2	23.76	10.56	5.94	3.80	3.14	2.50	1.69	0.95
RX 1.8	10.56	4.69	2.64	1.69	1.40	1.11	0.75	0.42
RX 2.4	5.94	2.64	1.48	0.95	0.79	0.62	0.42	0.24
RX 3.0	3.80	1.69	0.95	0.61	0.50	0.40	0.27	0.15
RX 3.3	3.14	1.40	0.79	0.50	0.42	0.33	0.22	0.13
RX 3.7	2.50	1.11	0.62	0.40	0.33	0.26	0.18	0.10
RX 4.5	1.69	0.75	0.42	0.27	0.22	0.18	0.12	0.07
RX 6.0	0.95	0.42	0.24	0.15	0.13	0.10	0.07	0.04

Vision for the Future

In the not too distant future the SNG communications system will be the central point of not only voice and data communications, but will also be used to fully automate the SNG setup, transponder acquisiiton, and level setting process. To do this will allow more rapid and accurate setup of SNG systems and will allow use of relatively untrained truck operators. The following is a typical setup scenario using an automated network management system:

> Picking up the phone in the SNG truck causes the onboard Diagnostic and Control Processor (DNP) to check the "meet me" channel for activity. If clear, it activates the SCPC carrier and communicates with a Network Management Processor (NMP) at the Hub via a low speed data channel multiplexed with the digital voice channels. the DNP on the truck tunes the SCPC equipment to an unused channel assigned by the NMP. The NMP makes the assignment only if it finds the truck identification code authorized in its log of scheduled events. If not scheduled, the NMP connects the truck to the operator, otherwise, the NMP connects the voice channel to an outside telephone line and logs the call.
>
> Meanwhile, using an IEEE interface to a spectrum analyzer, the NMP continuously monitors the SCPC carrier levels of both the truck and the Hub. It makes local adjustments directly and sets the truck's level via the Diagnostic and Control Processor (DCP) at the truck.
>
> The truck is free to attempt to activate video at any time. Before bringing up the carrier, the DCP on the truck checks with the NMP for authorization. If the time is not scheduled, truck and operator are notified and the carrier is inhibited, otherwise, the DCP activates the carrier

and the NMP logs the service. The two processors work together to restore SCPC levels and switch truck voice transmission to subcarrier mode. When the carrier is brought down, the DCP notifies the NMP which logs the time off.

The result of this process is that the personnel in the truck simply hear a dial tone when they pick up the SCPC phone. To put the video on the air at the appointed time, they simply throw a switch. The operator need not intervene at all.

In a digital system all elements are in place to implement a fully automatic SNG communications system.

APPENDIX I

PARAMETERS AND EQUIPMENT CONSIDERATIONS IN USING BANDEDGE SCPC

I. GENERAL

Bandedge SCPC generally combines a video signal in a partially saturated transponder with a bandedge carrier that is 15 to 20 dB below the video carrier. In order for this system to perform properly, some important precautions need to be taken.

First, the video signal generated by that transponder must have little or no energy at the frequency where the bandedge carrier is inserted. To ensure this requires good, sharp filtering at the exciter or a trap at the bandedge carrier frequency. Without this filter, occasional video peaks of energy can cause interference with the SCPC carrier. In data transmission interference with the data carrier can cause large blocks of data to be lost, and if multiplexers are used, frame lock can also be lost. In an analog audio carrier where proper and transparent companding is used, this interference is less objectionable.

Second, since the level of the bandedge SCPC is 15 to 20 dB lower than the video carrier, it is extremely important that adjacent satellite energy is kept well below this. Careful alignment of the antenna with regard to adjacent satellite interference is extremely important.

Third, the effects of cross polarization are much more noticeable in this system since again the carrier is 15 to 20 dB below video and often in a practical application, total cross polarization rejection of greater than 25 dB is not easy to obtain.

The above merely indicates the careful planning required in a bandedge SCPC application. Wegener Communications has been involved in successful bandedge SCPC transmission for several years and our experience is second to none in this area. However, anyone desiring to use bandedge transmission must be aware of the important parameters affecting proper operation of this technique.

II. SATELLITE CONSIDERATIONS

Cross polarization of all elements of the system, including the satellite, are important. Satellite cross polarization descrimination can vary at different points of the footprint and could cause a system to be inoperable in some parts of the country.

The information transmitted on opposite polarizations of the satellites, and on satellites adjacent to the operating one, can can be an important consideration in guaranteeing trouble-free bandedge service if that flexibility in selection of the transponder is available. A worst-case situation is where all transponders are video, and that is the environment that Wegener's bandedge experience has been in.

The saturation characteristics of the satellite transponder are also important in determining how much the video carrier needs to be backed off in order to accommodate the bandedge SCPC carrier, although generally the video carrier can be operated slightly in saturation.

To ensure trouble-free operation, it is generally advisable to conduct tests with the actual satellite and hardware that will be used.

III. EQUIPMENT CONSIDERATION

A. Antenna

Adjacent Satellite Descrimination -- In a video application, adjacent satellite descrimination of 20 dB or more will provide excellent video, however, in a bandedge SCPC application, this may not be adequate. The best approach is to use antennas which are qualified for two degree spacing and again, when in doubt, to conduct tests.

Cross polarization -- The feed is an important factor in determining cross polarization descrimination and also in adjacent satellite descrimination. The antenna system should be capable of cross polarization nulls in excess of 30 dB.

B. Video Receivers and Exciters

Note that in analog transmission, the phase noise of the video exciter and video receiver is not adequate to allow proper operation of bandedge SCPC. For analog applications a high-stability, low noise converter is required at both ends. For data, however, it is possible to use exciters and receivers whose phase noise is considerably worse than in an analog case. The actual acceptability will depend on the data rate and modulation type, and in all cases tests should be conducted to qualify the receivers and exciters as being usable.

Bandedge SCPC can be a very effective way of back-hauling signals and providing two-way audio and data transmission auxiliary to the main video carrier if proper equipment is selected and all the above factors are carefully considered. Wegener Communications will be happy to provide further guidance and assistance in successful implementation of this system.

[1] Special report. "The ABCs of FEC," by Edwin E. Mier, Data Communications Magazine, May 1984.

[2] Special report. "The ABCs of FEC," by Edwin E. Mier, Data Communications Magazine, p. 68, May 1984.

SNG, THE Ka BAND AND FUTURE SATELLITES FOR BROADCASTERS

W. Bramwell Flynn
DALSAT, INC.
Plano, Texas

The intent of this paper is to trace the evolution of satellites and their effect, through the broadcast industry, on the world. Through evaluation of the past to present we may look to the future.

On July 26, 1963 Hughes Aircraft launched its first geo-synchronous satellite. The satellite name Syncom I received signals from earth at 7.3 GHZ (gigahertz) and retransmitted them back to earth at 1.8 GHZ. The TWT (traveling wave tube) amplifiers used in the spacecraft allowed for 2 watts of power per transponder. Certain terms commonly used today to define spacecreaft performance such as G/T (gain to temperature; dB/°K), SFD (saturated flux density; dB watts/meter^2) and EIRP (effective isotropic radiated power; dB watts) were not even invented. A brief definition of these terms will be necessary for future evaluations.

- The term G/T also referred to as system "figure of merit" is a function of an antenna's receive gain versus its overall noise temperature. The analytical derivation is found by the following equation:

  $$G/T = G - T_S$$

  Where G is the receive gain of an antenna at its operating frequency in dB isotropic,and $T_S$is the system noise temperature which aggregately consists of antenna noise, noise contribution of receive front-end and cascaded amplifiers and miscellaneous noise due to transmission lines, switches, filters, etc., which is measured in degree's Kelvin.

G/T is a critical factor in both spacecraft and earth station performance.

- The term SFD defines the amount of power needed to saturate a satellite transponders TWT amplifier in dB watts per meter squared.

- The term EIRP defines the amount of power available from a satellite transpondeer when its TWT amplifier is saturated in dB watts.

The first systems used to communicate with Syncom I were both fixed and transportable earth stations. The systems ranging in size from 10 meter to 4 meter required HPA's (high power amplifier) which provided up to 3 kw of power.

Thus began the era of geosynchronous satellites. In the years to follow Intelsat, an International satellite communications consortium, launched satellites and constructed fixed earth stations throughout the world. Intelsat A earth terminals were defined and standardized as the gateway stations for connecting the continents. The standard Intelsat A antenna system measured 30 meters in diameter. Their abilities for voice, data, and video traffic brought the world closer. The C-band frequencies used were 5.925 to 6.425 GHZ transmitted to the satellite and 3.7 to 4.2 GHZ received from the satellite.

The domestic C-band satellites introduced in the early 1970's by companies such as AT&T, RCA, and Western Union brought video, voice and data communications into reality in the states. Along with this came the first video distribution network installed in 1977 for PBS (Public Broadcasting Network) followed by a radio distribution network for NPR (National Public Radio). Entrepreneurs, realizing the advantage in the point to multi-point distribution of video by satellite, ignited the cable television industry.

Another significant step in satellite communications was also occuring in the late '70's through a start up venture by IBM and Aetna Life. SBS (Satellite Business Systems) targeted at the private business sector planned their future around Ku-band satellites. The operating frequiences for domestic Ku-band are 14.0 to 14.5 GHZ transmit and 11.7 to 12.2 GHZ receive.

Along with Ku-band satellites came new satellite operating parameters, alleviation of terrestrial interference, relevant to C-band, and smaller aperature operating systems. There were many exciting advantages in Ku-band.

From the late '70's to the present, satellites offering both C and Ku-band frequencies, often referred to as hybrids, have been placed in orbit. Along with later generation Ku-band satellites these spacecraft offer enhanced operating parameters allowing even smaller more compact systems.

The evolution of satellites has brought us a long way from the '60's and the door is opening for yet another type satellite, Ka-band. Operating at 29.5 to 31.0 GHZ earth-to-space and 19.7 to 21.2 space-to-earth, even smaller more compact earth terminals lie ahead.

The network broadcasters utilization of satellites began in the 1970's with fixed video receive only C-band terminals, followed by fixed video up-link terminals. Transportable C-band video up-link systems generally owned and operated by specialized common carriers were used by the networks and their affiliates. But size, operating expense, and system cost made these impractical for integration into daily news gathering. Ku-band introduced the smaller more compact transportable systems allowing the networks and their affiliates a means to enhance their national, regional, and local news coverage.

Though Ku-band satellites introduced the broadcasters to satellite news gathering the types of transportable systems required for operations vary in size as a function of satellite parameters and geographic location.
Network news, along with affiliate news departments, desire suitcase portable video up-link systems and ENG size vans for remote satellite coverage. These capabilities are a strict function of satellite parameters and Ku-band could offer the best results.

The size requirements of a system are determined by the earth station transmit power capability and the satellite's input sensitivity as designated by SFD. Spacecraft G/T is also important due to its effect on carrier to thermal noise on up-link performance. The satellites EIRP is important with respect to down-link carrier to thermal noise, however, the receiving terminal can be sized accordingly for the necessary requirements.

To see how these parameters dictate the outcome, the appropriate end-to-end link calculations and their definitions must be explained.

The nominal carrier to thermal noise margin of a system may be expressed as follows:

$C/N = C/N_{up} + C/N_{down} + C/I$ (power addition)

Where:

C/I=Carrier to interference.

Equations for C/N are given by:

$C/N_{up} = A_o - SFD - G/T_s - BO_i - 10 \log BW - K$

$C/N_{dn} = P_{sat} - FSL + G/T_e - 10 \log BW - K$

Where:

A_o=SL(Spreading Loss)-FSL (FSL= Free space loss)

NOTE: SL-4 Pi r^2(r=distance to satellite in meters)

SFD= Saturation flux density in dBW/m^2
G/T_s= Spacecraft antenna gain to system noise temperature in dB/Kelvin
BO_i= Input backoff from saturation
BW= Occupied bandwidth of the carrier in Hz
K= Boltzman's constant in dBw/K-Hz

In the previous equation the SFD and G/T, varies with spacecraft design and geographic operating location for a transportable system. The SFD value along with BO_i and up-link spreading loss term define the required up-link EIRP from a transportable for proper operation. The equation to determine this value is:

$EIRP_{tx} = A_o + FSL + SFD - BO_i$

Where:
FSL= Free Space Loss

SFD = Saturation Flux Density to the transmitter geographic location

BO_i = input backoff from saturation point of satellite transponder. This value, BO_i, should ideally be 0 dB for video transmission, as saturation is preferred for max EIRP from a satellite transponder.

When required EIRP of a up-link earth station has been solved the antenna size and HPA requirements can be determind.

Figure 1 shows isotropic antenna gain performance as a function of antenna size and frequency. The antenna size is the critical factor to a compact system. The factors affecting antenna size are compliance to FCC regulations for 2 degree satellite spacing, and maximum allowable transmitter power at the antenna feed. As industry demands smaller and smaller antennas, the limiting factor will then be a function of energy density specifications allowed by the FCC, which permit up to 33 dBW (2000 watt) of power at the flange of C-band antennas, and 24.5 dBW (281 watts) power at the flange of Ku-band antennas.

We can derive the required equipments for operation on C, Ku and Ka-band satellites as a function of their SFD in conjunction with HPA restriction.

The first example will explain the requirements of C-band transportables used today. The early satellite parameters for C-band assumed - 83 dBW/M^2 SFD with a corresponding -6 dB/°K G/T

$EIRP_{tx} = Ao + FSL + SFD - BO_i$

Where:

FSL= 199.6 dB

Ao= -37 dBm^2

FD= -83 dBw/M^2

BO_i = 0 dB

$EIRP_{tx}$= 79.6 dBw

The EIRP of a earth station is achieved by:

EIRP = G antenna (dBi) + P_{HPA} (dBW)

Where:

[Gant = transmit antenna gain]

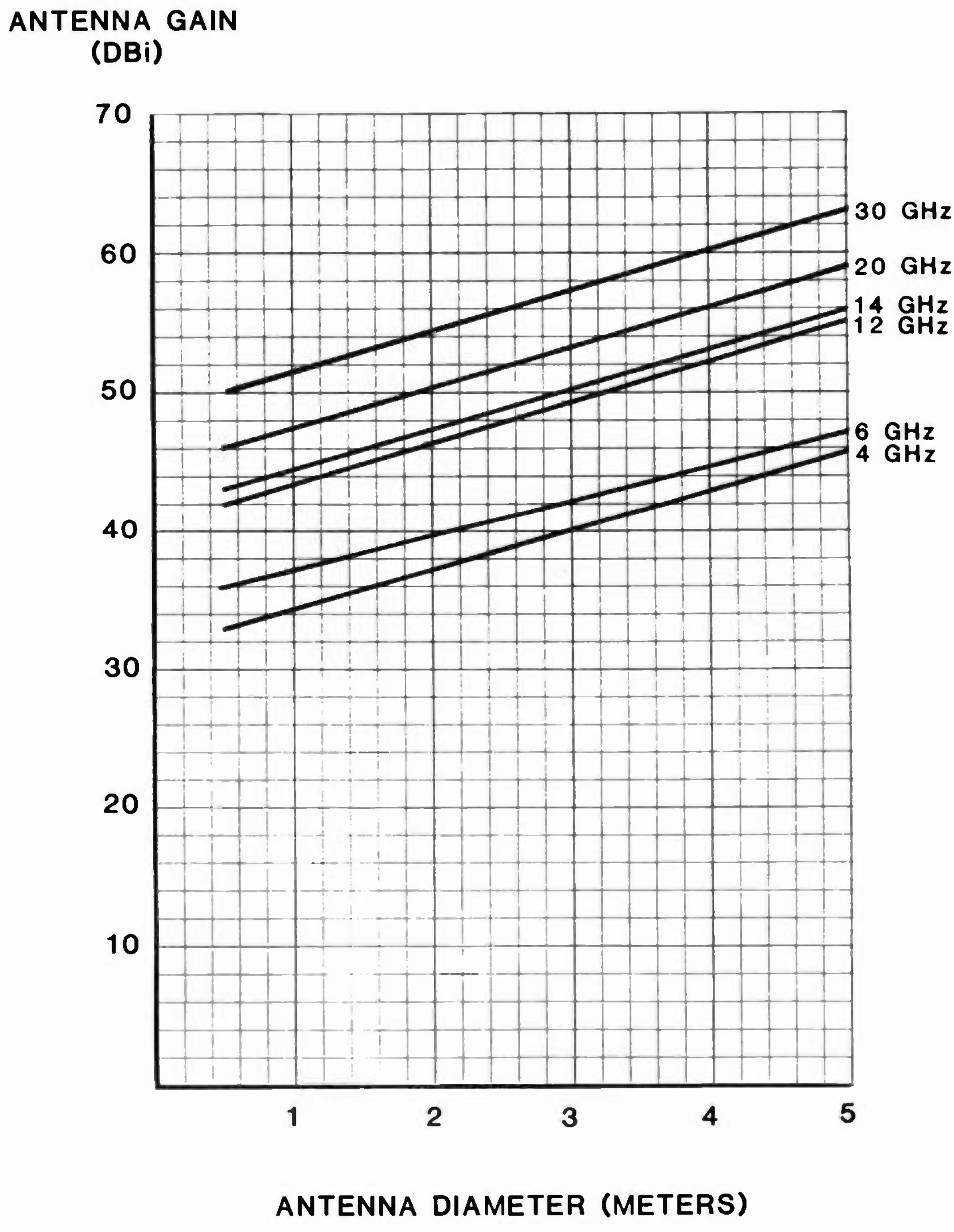

ANTENNA GAIN
(DBi)
70
60
50
40
30
20
10
30 GHz
20 GHz
14 GHz
12 GHz
6 GHz
4 GHz
1
2
3
4
5
ANTENNA DIAMETER (METERS)

FIGURE 1

The previous equation defines the required up-link EIRP for C-Band saturation. Given the FCC limit for 33 dBW of HPA power at the flange of the antenna we can now solve for the required antenna gain.

$$\begin{aligned} G_{ant} &= EIRP - P_{HPA} \\ &= 79.6 - 33 \\ &= 46.6 \text{ dBi} \end{aligned}$$

Refering to figure 1, we see the minimum required antenna operating at 6 GHz is a 4.5 meter. The majority of C-Band transportables operating today have 4.5 meter antenna systems. Though larger antennas are an alternative they complicate packaging and deployment time of a transportable system. Because of the prime power requirements of a 3 KW Klystrom amplifier, magnified by the need for redundant electronics, these systems are too large and bulky for affiliate news gathering on a daily basis.

Ku-band, allowing smaller transportable systems has introduced mobile news gathering to network affiliates. The systems, though more compact still vary in size due to antenna requirements as a function of satellite parameters with respect to geographic location. A new variable, rain attenuation required consideration when defining the operating margins of a system. The original Ku-band satellites were less sensitive than current satellites. The optimum operating points of these satellites provide -86 dBW/m^2 SFD with corresponding -3 dB/°K G/T.

The required earth station EIRP for these parameters are:

$$\begin{aligned} EIRP &= A_o + FSL + SFD - BO_i \\ &= 44.3 + 206.9 - 86 - 0 \\ &= 76.6 \text{ dBi} \end{aligned}$$

Given the previously mentioned HPA power restriction of 24.5 dBW at the flange of the antenna the minimum required antenna gain is:

$$\begin{aligned} G\ antenna &= EIRP - P_{HPA} \\ &= 76.6 - 24.5 \\ &= 52.1 \text{ dB}_i \end{aligned}$$

Referring to figure 1 the antenna size required to saturate is 3.6 meters. Though the SFD design criteria represents fringe area operation, stations may require the ability to access and saturate transponders from these locations. When rain attenuation is factored into the design requirement, and maximum antenna aperture versus transportable packaging is considered, a 4.5 meter antenna will allow for 2 dB of margin.

The later generation Ku-band satellites with improved operating parameters, bring the broadcaster closer to van style satellite transportables. They also permit the use of fly-away units. These satellites with fringe area operating points of -93 dBW/M^2 SFD's and -.5 dB/°K G/T's bring up-link EIRP requirements to:

$$\begin{aligned} EIRP &= A_o + FSL + SFD - BO_i \\ &= -44.3 + 206.9 - 93 - 0 \\ &= 69.6 \text{ dB}_i \end{aligned}$$

The minimum antenna gain required is then:

$$\begin{aligned} G\ ant &= EIRP - P_{HPA} \\ &= 69.6 - 24.5 \\ &= 45.1 \text{ dB}_i \end{aligned}$$

The antenna operating at 14 GHZ whose gain is 45.1 dB_i referencing figure 1 is 1.5 meters. If a minimum acceptable margin for fringe area operation is 2 dB, a transportable or fly-away incorporating a 2 meter antenna could do the job. Antennas which meet 2 degree compliance and are acceptable for transportable antennas are limited to 4.5, 3.7, 3.0, 2.3, 1.8 and 1.5 meter. For this reason fly-aways and transportables are being designed around 1.5 meter and 1.8 meter antennas. Though low operating margins occur with these systems, transportable size requirements are the driving factor.

In conclusion of our Ku-band evaluations for the two classes of satellites considered, Table 1 defines the operating margins as a function of antenna size. The HPA size used for this tabulation allows for 24.5 dBW of power. Negative margins are equal to $B0_i$ which is the input back-off from saturation.

On December 15, 1983 Hughes Communications applied to the FCC (Federal Communications Commission) for authorization to construct, launch and operate a Ka-band satellite telecommunications system operating the 30/20 GHZ frequency range. The first of two planned satellites could be ready for launch in 1988 with the second ready for 1989. The spacecraft design incorporates high-power spot beams covering an area with a radius of 150 miles. Preliminary spacecraft parameters available at this writing would allow -92 dBW/M_2SFD, 17.9 dB/°K G/T and down-link EIRP of 58 dBW at beam edge. Let us evaluate what this means for the future of transportable and fly-away video systems.

Let us assume an HPA power restriction for our analysis of 24.5 dBW.

$$\begin{aligned} EIRP &= A_o + SL + SFD - BO_i \\ &= -50.4 + 213 - 92 - 0 \\ &= 70.6 \text{ dBW} \end{aligned}$$

The required antenna gain will then be:

$$\begin{aligned} G_{ant} &= EIRP - P_{HPA} \\ &= 70.6 - 24.5 \\ &= 46.1 \text{ dB}_i \end{aligned}$$

Referring to figure 1, the necessary antenna size operating at 30 GHZ would be .83 meters. A system design incorporating an antenna of this size would be ideal for a broadcaster's fly-away requirements. Transportable vans could fall directly into the ENG class of vehicle. Table 2 defines the up-link margins for Ka-band operation. The equations and assumptions are the same used in Table 1 for Ku-band.

The operating margin of a system, with respect to transponder input back-off is important as it relates to up-link C/N. As these C/N's vary due to weather related fades so vary the margins above the demodulator operating threshold.

TABLE 1

Ku-band Up-Link Margins

Spacecraft SFD = -86 dBW/M^2

Antenna Meters	(Gain dB_i)	BO_i(dB)	Margin (dB)
1.5	(45.5)	6.6	-6.6
1.8	(46.7)	5.4	-5.4
2.3	(49.2)	2.9	-2.9
3.0	(50.5)	1.6	-1.6
3.7	(52.7)	-	-.6
4.5	(54.0)	-	+1.9

Spacecraft SFD = -93 dBW/M^2

Antenna Meters	(Gain dB_i)	BO_i(dB)	Margin (dB)
1.5	(45.5)	-	+.4
1.8	(46.7)	-	+1.6
2.3	(48.2)	-	+4.1
3.0	(50.5)	-	+5.4
3.7	(52.7)	-	+7.6
4.5	(54.0)	-	+8.9

TABLE 2

Ka-Band Up-Link Margins

Satellite SFD = -92 dBW/M^2

Antenna Meters	(Gain dB_i)	BO_i(dB)	Margin (dB)
.50	41.7	4.4	-4.4
.83	46.1	0	0
1.00	47.6	-	+1.5
1.50	51.2	-	+5.1
1.80	52.8	-	+6.7
2.30	55.0	-	+8.9

Figure 2 is a curve of output back-off as a function of input back-off of a TWT typical to those used in satellite transponders. This curve will aid in our analysis of end-to-end performance at C, Ku and Ka-band.

In C-band operations a 3 dB fade margin in up-link and down-link C/N is quite adequate for yielding uninterruptable performance. Using the C/N up link equation and the satellite parameters of -83 dBW/M^2 SFD,and -6 dB/°K G/T let us solve for a typical up-link C/N:

$$C/N_{up} = A_o + SFD + G/T - BO_i - 10 \log BW + 228.6$$

Where

A_o = -37 dBM^2
SFD = -83 dBW/M^2
G/T = -6 dB/°K
B/O_i = O (assumes saturation)
BW = 36 MHZ (full transponder video)

hence:

$$C/N_{up} = -37-83-6-0-75.6+228.6$$
$$= 27 \text{ dB}$$

Solving for down-link C/N:

$$C/N = EIRP - FSL + G/T - 10 \log BW + 228.6$$

Where

EIRP = 34 dBW (assumed worse case)

FSL = 196 dB at 4 GHZ

G/T = 28 dB/°K (to Gant= 49 dB_i,and

T_s= 140°K)

BW = 36 MHZ (full transponder video)

Which equals:

$$C/N = 34-196+38-75.6+228.6$$
$$=19 \text{ dB}$$

It can be shown that the nominal end-to-end C/N with a C/I = 25 dB is:

$$C/N_{nom} = C/N_{up} + C/N_{dn} + C/I$$

$$=10 \log 1/(1/10^{27}+1/10^{1.9}+1/10^{2.5})$$

$$=17.5 \text{ dB}$$

The next step in our program is to identify the up-link and down-link margins in this model. A minimum acceptable C/N_{nom} for video transmission is 10.5 dB. Impulse noise on video occurs at this value. By using the equation for C/N_{nom} and assigning it the value of 10.5 we can solve for the variance values of C/N up and C/N down at impulse.

$$C/N = 10 \log 1/(1/10^{1.05}-1/10^{1.9}-1/10^{2.5})$$
$$= 11.3 \text{ dB}$$

Our up-link C/N margin is then the difference:

$$M=27-11.3$$
$$= 15.7 \text{ dB}$$

This says the up-link, excluding its effect on down-link, could take a 15.7 dB fade. What about down-link?

$$C/N = 10 \log 1/(1/10^{1.05}- 1/10^{2.7}- 1/10^{2.5})$$
$$= 10.8 \text{ dB}$$

The down-link margin is then 8.2 dB (19-10.8)

A fade on the up-link effects input back-off, dB for dB. A satellite transponders down-link EIRP will drop as a function of this input back-off as defined in Figure 2. This effect will cause the downlink C/N to change with up-link C/N. This change limits the actual amount of up-link C/N margin. Because the up-link margin is greater than the down-link margin this model is considered to be down-link limited.

Repeating the analysis for the Ku-band satellites and beginning with the case where SFD is -86 dBW/m^2 and G/T is 0 dB/°K:

$$C/N_{up} = A_o + SFD + G/T - BO_i - 10 \log BW + 228.6$$
$$C/N_{up} = 44.3-86+0-0-75.5+228.6$$
$$=22.8 \text{ dB}$$

Solving for C/N down assuming a satellite EIRP of 38 dBW (fringe area), space loss at 12.0 GHZ of 205 dB, G/T of 31.6 (7 meter antenna):

$$C/N_{dn} = 38-205+31.6-75.5+228.6$$
$$= 17.7 \text{ dB}$$

$$C/N_{nom} = 10 \log (1/10^{2.28}-1/10^{1.77}-1/10^{2.5})$$
$$= 16.0 \text{ dB}$$

The up-link and down-link margins assuming a 10.5 dB threshold are then:

$$C/N_{up} = 10 \log 1/(1/10^{1.05}-1/10^{1.77}-1/10^{2.5})$$
$$= 11.6 \text{ dB.}$$

The up-link margin is then:

$$M=22.8-11.6$$
$$= 11.2 \text{ dB.}$$

$$C/N_{dn} = 10 \log 1/(1/10^{1.05}-1/10^{2.28}-1/10^{2.5})$$
$$= 10.9 \text{ dB}$$

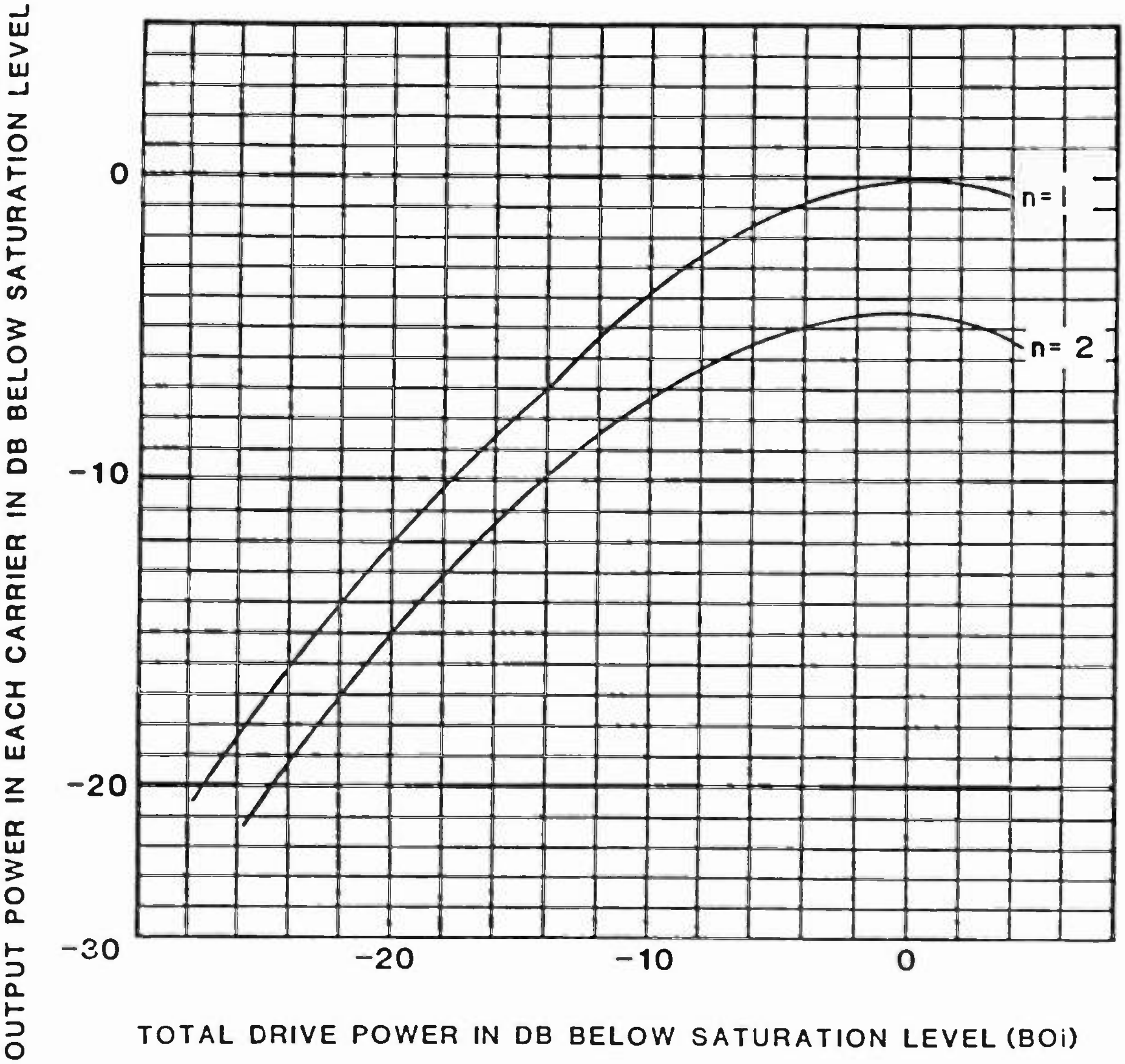
The down-link margin is then:

$$M=17.7-10.9$$
$$= 6.8 \text{ dB}$$

Again we are down-link limited, however, the gap between up-link and down-link is closing.

The next Ku-band case assumes an SFD of -93, G/T of -.5 dB/°K and EIRP of 42.9. This models the latest Ku-band satellites operating at fringe areas:

For this use:



NOTE :

n DESIGNATES THE NUMBER OF CARRIERS THROUGH THE TWT

FIGURE 2

OUTPUT VS INPUT BACKOFF FOR A TWT

$$C/N_{up} = -44.3-93.5-0-75.5+228.6$$
$$= 15.3 \text{ dB}$$

$$C/N_{dn} = 42.9-205+31.6-75.5+228.6$$
$$= 22.6 \text{ dB}$$

$$C/N_{nom} = 1/10 \log 1/(1/10^{1.53} + 1/10^{2.20} + 1/10^{2.5})$$
$$= 14.2 \text{ dB}$$

Up-link and down-link margins are:

$$C/N_{up} = 10 \log 1/(1/10^{1.05} - 1/10^{2.26} - 1/10^{2.5})$$
$$= 10.9 \text{ dB}$$

The up-link margin is then:

$$M = 15.3-10.9$$
$$= 4.4 \text{ dB}$$

$$C/N_{dn} = 10 \log 1/(1/10^{1.25} - 1/10^{1.53} - 1/10^{2.5})$$
$$= 12.5 \text{ dB}$$

The down-link margin is then:

$$M = 22.6-12.5$$
$$= 10.1 \text{ dB}$$

A significant occurence has happened in this model. The system has become up-link limited. The reason this has occurred is that the sensitivity of the spacecraft (SFD) is high while the G/T is low, causing the up-link to approach its thermal noise threshold. There are several ways to increase the up-link C/N. For every dB into saturation on the spacecraft, a dB of up-link C/N may be added. This means is generally restricted to a 3 dB point but has its advantages due to the non-linear TWT characteristics as a function of BO_i. The second means of increasing up-link C/N is by changing the spacecraft SFD which is ground commandable. We can see from the up-link C/N equation changing SFD from -93 to -90 gains 3 dB in C/N. However, realize both cases require a 3 dB increase in the transportable up-link EIRP. We sacrific operating margins for small aperature fly-away and van type transportables with these satellite parameters.

Through previous analysis for Ka-band up-link EIRP requirements, we saw very small aperature antenna capabilities. The satellite parameters allow an SFD of -92 dBw/M^2 with a corresponding G/T of 17.9 dB/°K. 150 mile radius spot beams yield 58 dBW EIRP's at beam edge. The up-link C/N for this type system is:

$$C/N_{up} = A_o + SFD + G/T - BO_i - 10 \log BW + 228.6$$
$$= -50.4-92+17.9-0-75.5+228.6$$
$$= 28.6 \text{ dB}$$

In solving for the down-link C/N, FSL at 20 GHZ equals 209.5 dB, and G/T is 32.2 dB/°K (assumes a 4.5 meter antenna with a T_s of 600°K):

$$C/N_{dn} = EIRP - FSL + G/T - 10 \log BW + 228.6$$
$$= 58-209.5+32.2-75.5+228.6$$
$$= 33.8 \text{ dB}$$

$$C/N_{nom} = 10 \log 1/(1/10^{2.86} + 1/10^{3.38} + 1/10^{2.5})$$
$$= 23 \text{ dB}$$

The up-link C/N margin is:

$$C/N_{up} = 10 \log 1/(1/10^{1.05} - 1/10^{3.38} - 1/10^{2.5})$$
$$= 10.7 \text{ dB}$$

Margin is then:

$$M = 28.6-10.7$$
$$= 17.9 \text{ dB}$$

The down-link C/N margin is:

$$C/N_{dn} = 10 \log 1/(1/10^{1.05} - 1/10^{2.86} - 1/10^{2.5})$$
$$= 10.7 \text{ dB}$$

Margin is then:

$$M = 33.8-10.7$$
$$= 23.1 \text{ dB}$$

A significant improvement in margins has occurred in this model. The reason being the spacecraft G/T of 17.9 dB/°K has increased the up-links C/N while allowing minimum up-link EIRP requirements with respect to the spacecraft SFD of -92 dBW/M^2.

The future satellites which support the broadcasters needs for news gathering must be designed with their interests in mind. As we have seen in the previous analyses system size is a function of satellite operating parameters. When designing a system that will saturate a satellite transponder where SFD is at maximum sensitivity only two variables exist, antenna gain and HPA power. When HPA power is restricted, adjustment of antenna gain, which relates directly to aperature size, is the only means to achieve saturation. This restricts the broadcaster availability to suite case, and mini-van type systems for news gathering.

As we progressed from the early days of satellite communication we have seen the developments of C-band operations. Improved spacecraft parameters yielding higher down-link EIRP's, SFD's and G/T's for CONUS coverage have enabled smaller fixed earth station systems. Standardization by the networks, and syndicators for distribution have caused antenna farms to spring up at affiliate stations. Environmental effects on C-band are minimal allowing 3 dB or better system margins to yield 99.99 percent transmission availabilities. Terrestrial interference has caused problems but shielding methods can correct this. A controlled C-band network offers a viable medium for distribution of video. However, antenna size and HPA requirements coupled with constant frequency coordination to eleviate interference have ruled out this medium for portable news gathering systems.

Though domestic Ku-band satellites have only been available a short time their role in the broadcaster's future is evolving quickly. This is apparent through NBC's commitment for distribution of its network programing through Ku-band. Affiliate stations investing in transportable systems for local, regional and national news gathering, have greatly enhanced their information content to their viewing audience. Network news utilization of fly-away units have brought us closer to international events using intelsat satellites. As we have seen, only through the variance in satellite parameters are we able to achieve the more compact system. But as it exists today these parameters can cause us to be up-link limited affecting system availa-ability for video distribution. The degredation to operating up-link margins associated to these parameters, are acceptable because their ability allows the smallest type portable system for breaking news. However, these operating parameters will not suffice network distribution which requires increased margins to achieve proper availability due to rain loss effects in vulnerable geographic locations. A typical margin for a rain belt city, such as Houston, requires 8.2 dB for a 99.9 percent availability. This means a system designed to operate up to this rain effect would be unavailable for 8.75 hours over a one year period.

The satellites incorporating Ka-band are just around the corner. As we have seen through the modeling of one such satellite planned, dynamic capabilities are apparent. Though rain effects are not clearly determined, theoretical computations for Houston would require 10 dB margins for a 99.6 percent availability. Experiements planned by the Europeans and Americans on the first Ka-band satellites yielding measured data, such as the experiement conducted for NBC regarding Ku-band, will supply more accurate data for design requirements. Ka-band, may not suffice for a 24 hour network distribution system, but certainly will play a significant role in the future of news gathering.

In conclusion the satellites being used today with their life expectancy of 8.5 to 10 years will require replace-ment. Current plans for new satellites offer us important food for thought. These plans will offer Ka-band, and hybrid satellites, with C, Ku and Ka-band. Cross-strapping capabilities on hybrid satellites will allow any of the transmission frequencies up, to be translated to any of the frequencies for down-linking. Plans also call for interconnection of satellites through space. Imagine several satellites designed around the broadcasters requirements, utilizing cross-strapping of three frequency formats capable of line-of-sight interconnecting through 100 GHZ links in space. Built as a series of satellites the goal would be to link the continents of the world allowing a signle hop distribution of video, voice or data from any point in the world. Moveable spot beams on these satellites would allow coverage, for breaking news, from any point. The dynamic operating parameters associated to these spot beams would enable a news crew to carry their up-link in a suit case.

The time is now for the broadcasters to evaluate and define their requirements for the future. A group of planners incorporating broadcast news, engineering, and traffic personnel along with satellite design engineers could focus their energies and bring these satellites to reality by the early 1990's.

UHF-TV KLYSTRON MULTISTAGE DEPRESSED COLLECTOR PROGRAM - SECOND REPORT

Earl McCune
Varian Associates, Inc.
Palo Alto, California

1. INTRODUCTION

In June 1984, this program to incorporate depressed collector technology into UHF-TV klystrons was initiated. By using this new technology significantly improved transmitter efficiency is anticipated. This development is supported by a cooperative group including NASA, NAB, PBS, transmitter manufacturers and Varian. The goals and objectives and preliminary design considerations were described at the 1985 NAB Engineering Conference (1). During the past year, a final design has been achieved and is presently under construction. This paper describes the design along with anticipated performance characteristics for the experimental model klystron.

2. PROGRAM SCHEDULE

The overall program schedule is shown in Figure 1. Tasks 1 and 2, computer simulation and computer aided design are complete and have resulted in a design on paper which meets all the objectives of the program. Also completed are all of the drawings necessary to fabricate the design.

Task 3, materials evaluation, addressed the task of developing a coating material of low secondary yield for the collector electrodes. This task is also complete, having developed a carbon coating using a sputtering technique. Samples have been coated and evaluated with satisfactory results. Equipment has been acquired to allow coating of full size collector electrodes.

Tasks 4 and 6 address construction of test models. The final collector design is being implemented and collector assembly is under way. Assembly of a VKP-7555S klystron is also under way to provide a test vehicle for evaluating the collector design.

Task 5 addresses the development of a suitable test facility. Test equipment design is complete and power supply construction is proceeding and nearing completion. Tasks 5 and 6 are provided by Varian to allow test and evaluation of the collectors produced in Task 4.

The final task, performance demonstration, is soon to begin as we evaluate our first experimental model.

3. PROGRAM ACCOMPLISHMENTS

Starting with the preliminary collector design which was described previously, we optimized the electrode geometry to achieve maximum collector efficiency. Also incorporated into the design was

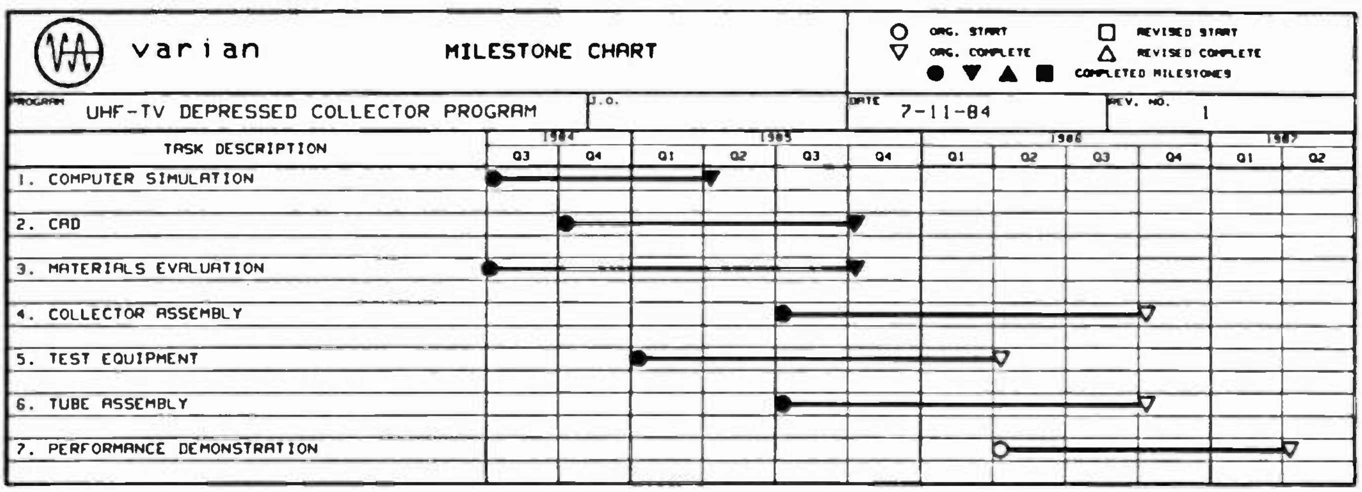


Figure 1

the electron beam reconditioning described by Kosmahl (2). Beam reconditioning is achieved by including a transition region between the klystron cavities and the collector with an intermediate value of magnetic field. This refocusing region allows expansion of the electron beam with a corresponding reduction in space charge field.

Figures 2, 3 and 4 show the calculated electron trajectories for the final optimzied design for three values of rf output power. Also determined were the trajectories for the no-drive case where the current all goes to electrode 4. The computer results provide current and power dissipation values for each electrode. The current and power values

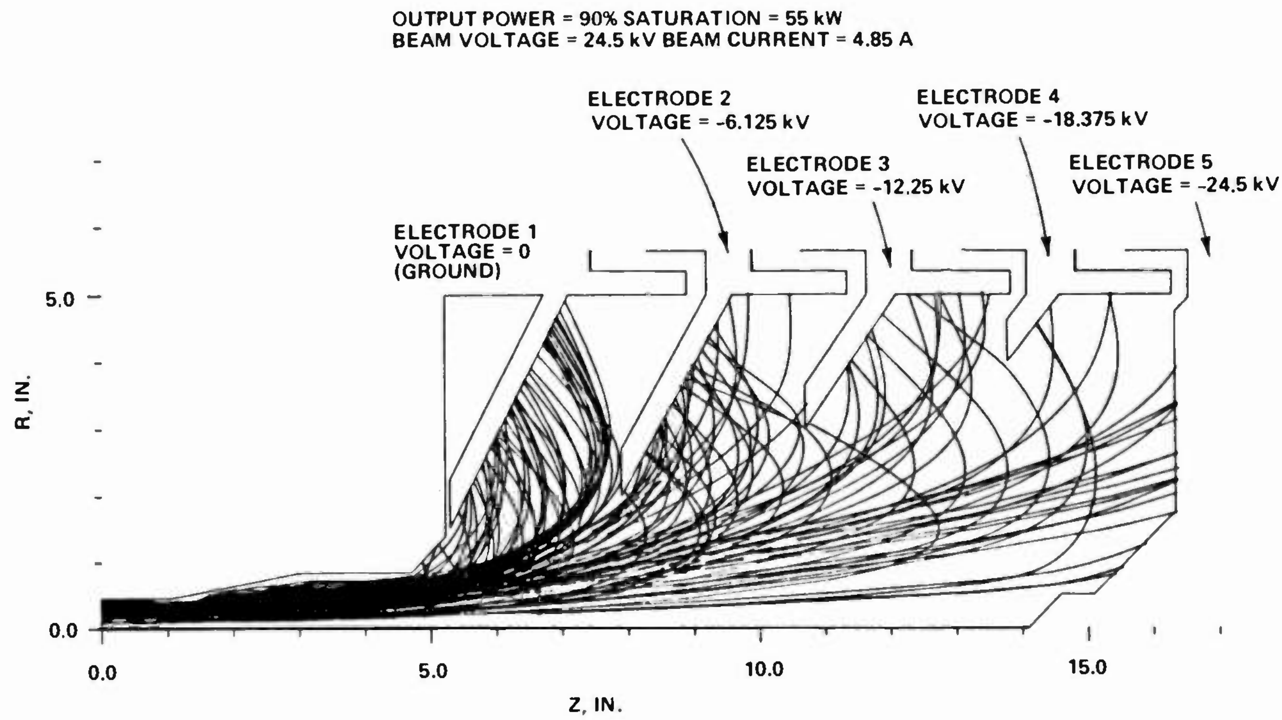


Figure 2. Collector Electron Trajectories

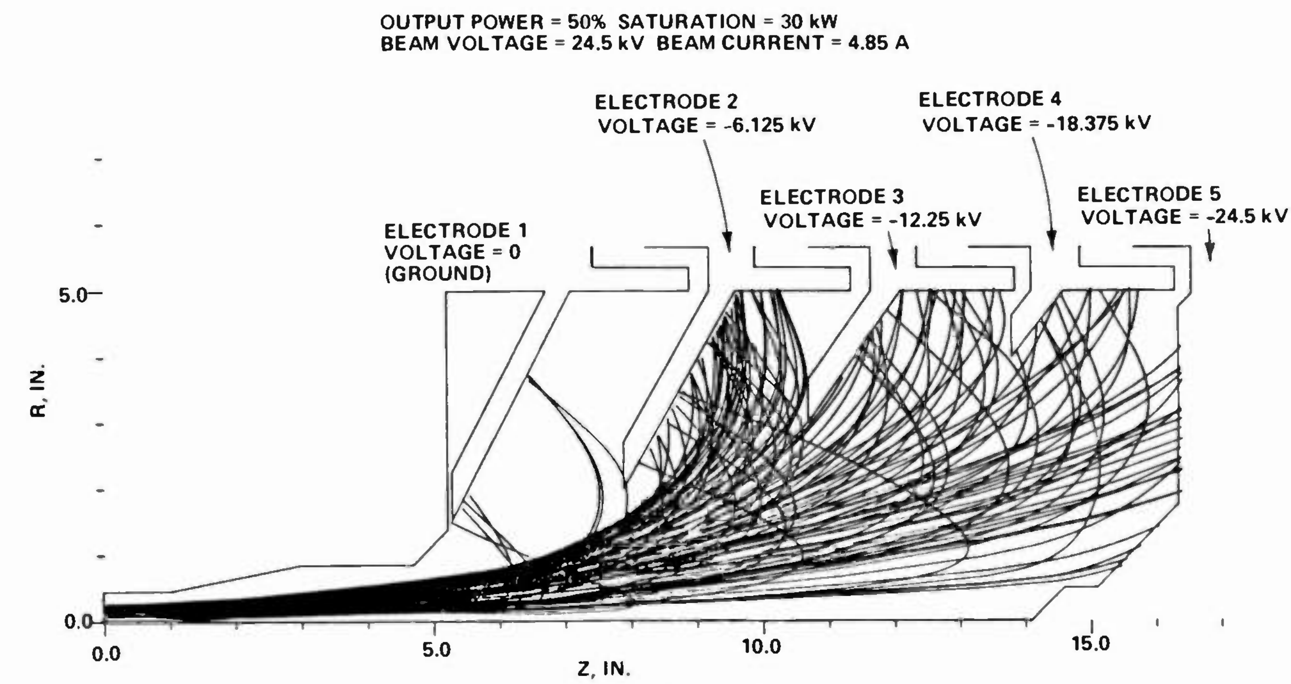


Figure 3. Collector Electron Trajectories

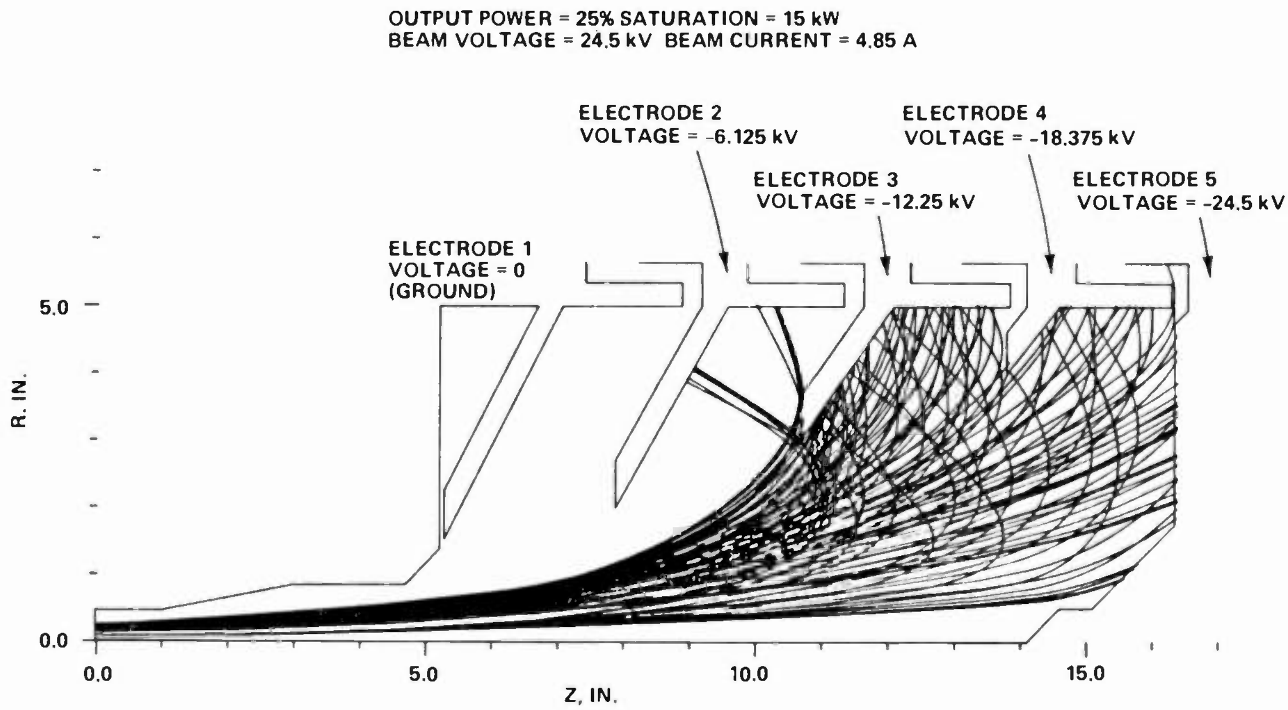


Figure 4. Collector Electron Trajectories

were adjusted to account for the estimated effect of secondary electrons. A secondary yield ratio of 0.5 was used for the estimate which is appropriate for carbon coated electrodes. The resulting current and power distribution for the electrodes is listed in Table 1. This data can be used to calculate klystron efficiency which is plotted as a function of power level in Figure 5. For comparison, the corresponding efficiency values for a standard klystron are also plotted. This same information can be displayed in another way as in Figure 6. Here the power distribution is shown as a function of rf power level and the relative levels of rf output power, collector dissipation power and recovered power are indicated.

An important part of the design effort was the development of a carbon coating technique which minimized the adverse effects of secondary electrons. NASA investigators had previously determined that carbon provided a good surface for low secondary yield (3,4). We were able to reproduce their results and produced sample copper electrodes with sputtered carbon coating with acceptable characteristics. The measured secondary yield is shown in Figure 7. The average electron velocity when used in the depressed collector klystron will be 3000 V; extrapolating the data of Figure 7 to that value indicates a secondary yield well under 0.5.

Table 1
Collector Current and Power Distribution

Beam Voltage = 24.5 kV
Beam Current = 4.85 A

RF Output Power	Electrode Current/Power					Collector Efficiency
	1	2	3	4	5	
0 kW	0 0	0 0	0.05 0.9	4.8 29.2	0 0	74.6%
15	0 0	0.5 3.6	2.45 10.8	1.4 8.4	0.5 8.3	69.8%
30	0.3 1.5	2.1 11.8	1.0 4.8	1.0 5.5	0.45 8.5	63.0%
55	2.1 10.0	1.3 5.0	0.65 3.1	0.5 2.8	0.3 7.3	53.7%

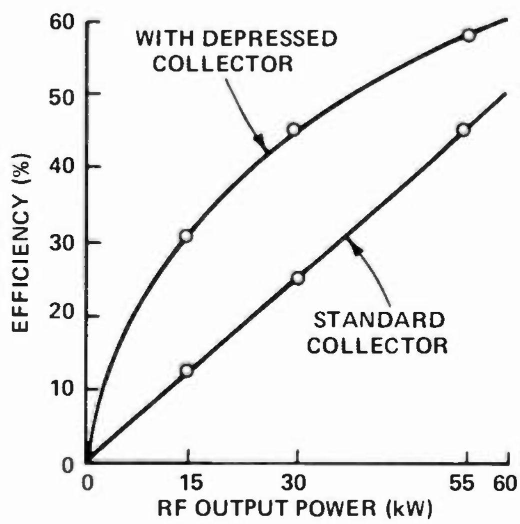


Figure 5. Klystron Efficiency

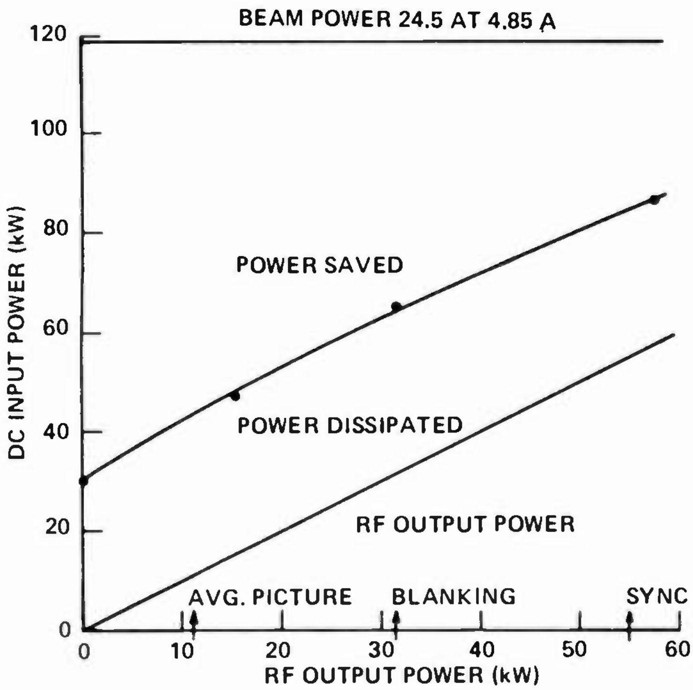


Figure 6. Power Distribution

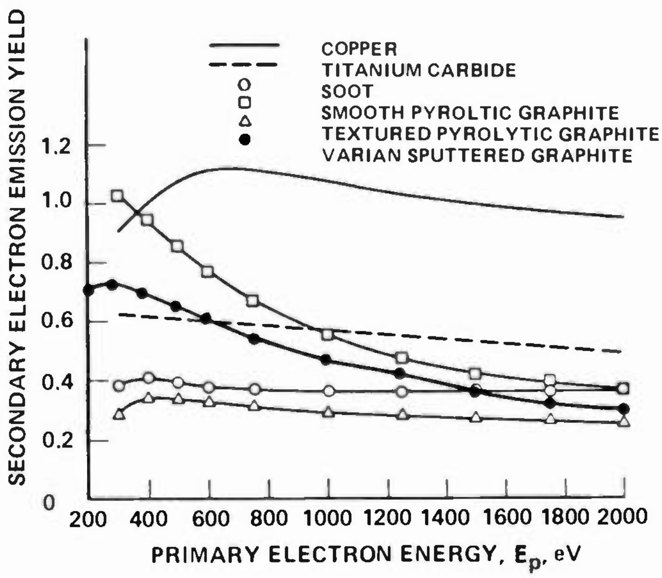


Figure 7. Secondary Electron Emission Yield

4. PERFORMANCE CHARACTERISTICS OF MSDC KLYSTRON

The data of Table 1 can be used to determine the operating conditions for TV performance. When operating with an average TV signal the calculated beam input power is 47 kW. This results in a figure of merit of 117% (peak power divided by beam input power). The dc input power requirement is reduced from 118 to 47 kW.

The final collector design which is being constructed uses electrodes that are water cooled which will allow calorimetric power measurements to determine correlation with the predictions of Table 1. The size of the experimental model is comparable with the standard klystron; it operates in the same focusing magnet.

5. CONCLUSIONS

The MSDC klystron development program is continuing to follow the schedule of Figure 1. A final design has been achieved which is being implemented as the first experimental model. There is every reason to expect the klystron performance to meet the program objectives.

REFERENCES

1. McCune, E.W.: "UHF-TV Klystron Multistage Depressed Collector Program - A Progress Report", NAB Engineering Conference, Las Vegas, April 1985.

2. Kosmahl, H.G.: "Modern Multistage Depressed Collectors - A Review", Proceedings of the IEEE, November 1982.

3. Wintucky, E.G.; Curren, A.N.; Sovey, J.S.: "Electron Reflection and Secondary Emission Characteristics of Sputter-Textured Pyrolytic Graphite Surfaces", NASA Technical Memorandum 81755, April 1985.

4. Curren, A.N.; Jensen, K.A.: "Secondary Electron Emission Characteristics of Ion-Textured Copper and High Purity Isotropic Graphite Surfaces", NASA Technical Paper 2342, July 1984.

USING KLYSTRODE TECHNOLOGY TO CREATE A NEW GENERATION OF HIGH EFFICIENCY UHF-TV TRANSMITTERS

N. Ostroff and A. Whiteside
Comark Communications, Inc.
Colmar, Pennsylvania

This paper discusses the use of the Varian/Eimac 60kW klystrode as the final amplifying device in a new series of high power UHF transmitters from Comark. The ultra high average efficiency of the klystrode will be discussed as well as the support systems required to use the device. Issues of reliability, performance and economics will also be presented. A cost of ownership table will be developed and the results presented. The significance of the klystrode's efficiency will be clearly demonstrated by a five year cost savings of $100,000 over the best klystron performance currently available.

I. INTRODUCTION

Comark Communications, Inc. is extremely proud to be able to present to the UHF broadcast industry an exciting technology which offers really significant advances in transmitter efficiency and simplicity. In cooperation with the Eimac division of Varian, Inc., Comark has taken the recent advances in klystrode tube development and created a new generation of highly efficient UHF transmitters with figures of merit exceeding 120%. This new series of transmitters is based on Comark's popular "S" series designs and is designated the "SK" series.

This paper will discuss the advantages gained through the use of klystrodes and will include data showing actual performance. Certain tube operating requirements will be discussed. Issues of klystrode/klystron compatibility and reliability will also be explored as well as the economic advantages to the broadcaster of the klystrode's high efficiency.

The performance advantages of this new device, including its simplicity, should make it the standard UHF power amplifying tube type in the years to come. It is incorporated in Comark's new "SK" series of UHF high power transmitters.

II. THE KLYSTRODE AND THE EQUIPMENT DESIGNER

A. Historical Perspective

The klystrode is not a new concept. In the late 1930's, CBS was searching for a simple method of generating UHF power to permit the commercial development of their UHF color television system. A contract was let to RCA to develop a high power UHF amplifying tube. The device that was created was a cross between the tetrode and the modern day klystron. It was named the klystrode. Figure 1 is a schematic of a typical klystrode showing the grid and collector structures and Figure 2 is a photograph of a klystrode without its external RF circuits or focusing coils.

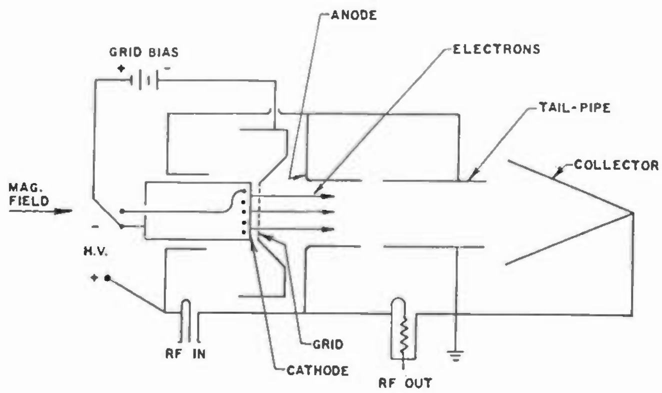


Fig. 1. Klystrode Schematic

The physical advantage of this device over the tetrode is that it makes the cathod-grid-collector structure virtually independent of transit time effects. Thus, the cathode can be made large and the electron beam density kept low. The result is high grid reliability and long tube life with simple internal structures. The disadvantage of the klystrode structure is its lack of klystron type gain.

Thus, in the 1940's, when electric power was inexpensive and UHF drive power was very difficult to generate, a klystron having 40dB of gain was very appealing compared to a klystrode having 23dB of gain. Thus, the klystron became the preferred amplifying device over both tetrodes and klystrodes for the next four decades.

In the mid 1980's it is possible to develop solid-state UHF drive power relatively easily. The costs of operating modern klystrons in Class A are far greater than the cost of higher power solid-state drivers. Thus, the klystrode once again becomes a serious contender for UHF power amplifying applications.

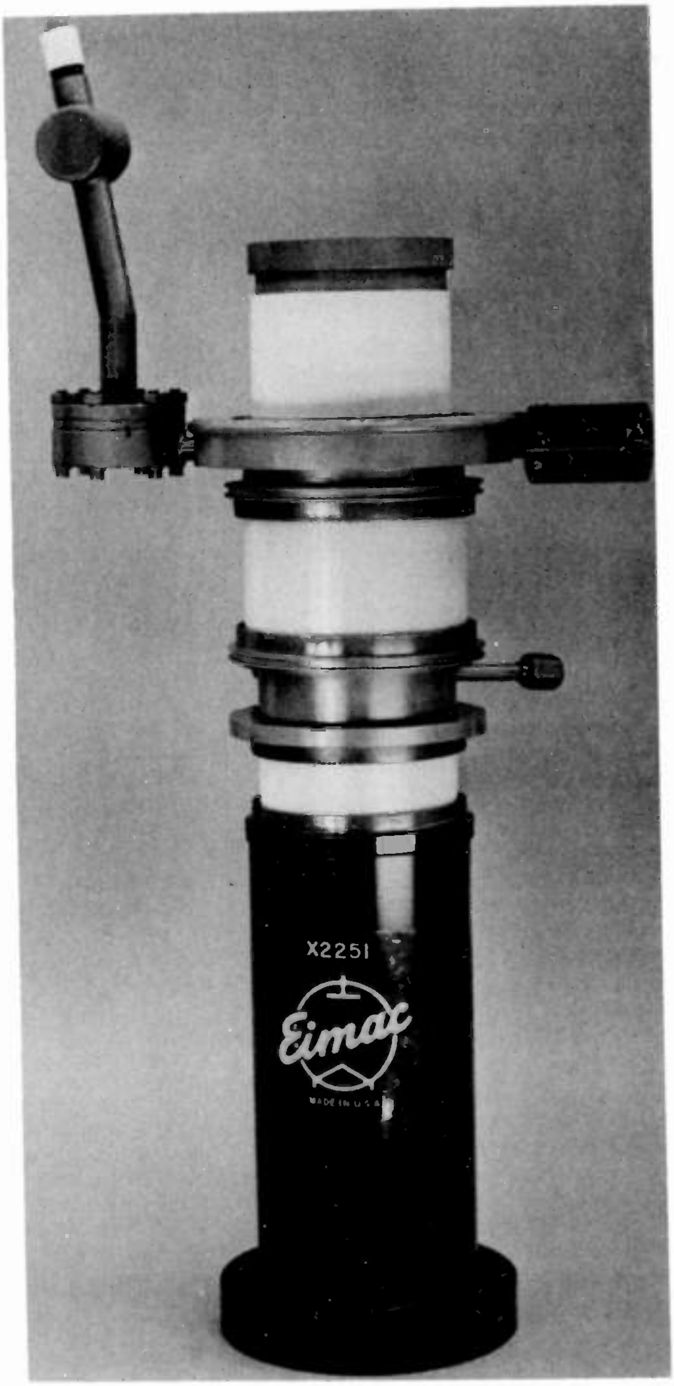


Fig. 2. Klystrode less external RF circuit and magnet assembly

B. Class A Versus Class B Operation

Modern UHF transmitters use klystrons operating in Class A. Class A means that the tube is biased to draw a continuous D.C. current equal to the highest value necessary to meet instantaneous R.F. output requirements.

The tube is biased to draw this high current whether RF drive is, or is not, applied, and regardless of the drive level. Successful attempts have been made to reduce this very inefficient operation by applying a pulsing technique to the tube bias which switches the device between peak sync and black level operating points coincident with the video drive requirements. The most successful effort with this technology has achieved a 77% beam efficiency or figure of merit.[1,2]

Beam pulsing of klystrons involves the external control of beam current and its improvements are limited, on a best efforts basis, to the ratio between black level and peak sync power. Some thought has been given to full time beam modulation of klystrons but the linearity correction requirements including frequency response changes and ICPM generation are currently beyond the state-of-the-art.

Now consider the Class B operating klystrode. In Class B, because of the tube geometry, the RF drive power automatically controls the beam current. Thus, when the video is at white level, the beam current is low and as the picture power increases toward black level, the beam current automatically follows. For a 64kW peak sync power output, the instantaneous beam current will be 3.9A, but at black level it is only 2.7A and at mid-gray levels, the beam current is only 1.4A.

Under these conditions, the figure of merit will equal 123%, where

$$\text{Figure of Merit} = \frac{\text{Peak RF Sync Power Out}}{\text{Average Picture Power DC Input Including Sync and Blanking}}$$

Thus, Class B operation gives the broadcaster a power cost which is based on actual transmitted RF power output, not on a fixed DC tube power consumption.

A comparison of the Class A klystron and the Class B klystrode will easily show that todays UHF broadcaster can expect to reduce his power bill, attributable to the tubes, by up to 50%. Of course, the VHF broadcaster has been aware of this for years and takes full advantage of Class B type service.

C. Klystrode Support Systems

The klystrode is more like a tetrode than a klystron, from a designers point of view. Aside from the high negative beam voltage and the focusing field requirements, the device can be biased and controlled much like a tetrode.

A major consideration in the use of the klystrode is, however, the beam supply. All UHF high power transmitters today use Class A operation. This puts a constant current load on the beam supply regardless of picture content. Thus, no significant regulation or video by-passing is required for klystron operation. In fact, poor regulation tends to protect the tube.

When klystrodes are employed, the beam supply must be designed or modified to provide excellent no load to full load regulation and to also provide a low source impedance for all video frequencies. Beam lead impedance and shielding must also be considered.

Happily, these requirements are already being met in VHF transmitters. It is only necessary to adapt these techniques to the higher (30KV) voltages of the klystrode beam.

Unfortunately, with stiffer beam supplies, the tube protection mechanism is seriously reduced. In the event of a high voltage failure, the conventional beam supply should limit the energy dissipated in an arc. The klystrode supply, being stiffer, will not provide as much protection. Therefore, it is necessary to include some form of high voltage triggered crowbar to limit beam supply arc energy.

A simple triggered spark gap designed into the equipment, and fired by the rate of change of the beam voltage, $\frac{dv}{dt}$, solves the problem without difficulty. The spark gap is placed in such a way as to minimize instantaneous RF generation during the discharge. Thus, internal cabinet components are protected as is the tube structure.

The klystrode uses a convergent beam gun to form the electron beam. This beam, being self-focusing to some extent, requires relatively low focus power. In fact, only one air-cooled focus coil is employed. The focus power is 50 VDC at 6 Ampres maximum for a 64kW tube. Here is yet another significant power savings over any klystron of similar power rating.

The klystrode uses a water-cooled collector and body and forced air for the RF circuits. Water cooling permits the use of glycol and outdoor heat exchangers and is compatible with many existing installations.

Unlike the klystron, the klystrode has simple RF circuits and tuning structures. The output circuit uses a pair of over-coupled, double-tuned cavities driven from a single output gap. These cavities are mounted together and clamped to the tube in the same conventional fashion that is used in todays external cavity klystron designs. The RF circuits tune much like tetrode circuits except for the considerable isolation between the tubes input and output. The input tuning is virtually independent of output adjustment.

Input tuning uses a unique re-entrant double tuned cavity device mounted in line with the tube. This device matches the tube's input impedance over the desired bandwidth.

Figure 3 shows a dual trace of amplifier beam current and RF output over a channel bandwidth. It should be noted that tuning the klystrode relies on the independence of the input circuit from the output tuning. Thus, a display of beam current can be used to establish proper input tuning and bandwidth before any adjustments need be made to the output tuning. This really simplifies amplifier set up and removes the mystery sometimes found in klystron tuning procedures.

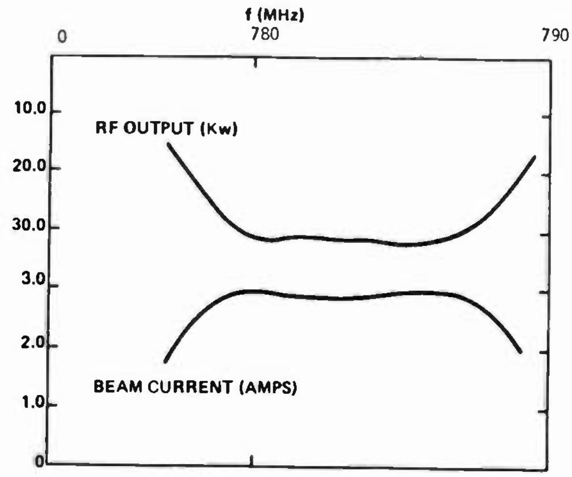


Fig. 3. X2251A Klystrode
Swept Beam Current & Power Output
Versus Frequency - TV Visual Conditions
Bandwidth = 8 MHz ± 0.25 dB

The current versions of the 60kW klystrode require two tubes to cover the entire UHF band. The X2252 covers 600 to 820 MHz and the X2253 covers 470 to 600 MHz.

III. EQUIPMENT

A. Compatibility With Klystrons

The Comark "SK" series of 60kW transmitters is based on the Comark "S" Series designs that have been operating successfully in the field for several years. In fact, the modifications required to the "S" series systems and hardware in order to create the "SK" transmitter, have been relatively minor.

It was the intent of Comark's design team to develop the "SK" series equipment in such a fashion as not to preclude later substitution of klystron devices. This makes the "SK" transmitter completely compatible with either klystrodes or klystrons. Since the "SK transmitter is based on the current "S" series equipment, retrofit of klystrodes into existing installations is entirely feasible.

The fundamental system changes that are required involve providing extra RF drive, higher beam voltage, beam crowbar protection and sync modulation. Certain other proprietary modifications are also necessary to realize the full potential of the klystrode.

B. Linearity

Upon first inspection, the fact that the klystrode operates in Class B and the klystron in Class A would tend to lead to the conclusion that the klystrode must be more non-linear. This would be an incorrect assumption.

The Class A operation of modern klystrons is very non-linear as a result of the industry's demands for higher efficiency. The Class A klystron is always pushed toward saturation at high output powers. Further, if pulsing is used, the tube may be within 5% of saturation at black level. This situation leads to very non-linear performance. Comark and others have developed very powerful IF linearization techniques to permit such operation and still achieve excellent demodulated video. The linearization of pulsed klystrons, however, requires sophisticated modulators and skilled station operators.

The linearity precorrection of a klystrode in comparison to the pulsed klystron is extremely straight foward.

The increasing beam current of the klystrode with increasing drive tends to maintain a good linearity characteristic. In fact, the klystrode's linearity characteristic is very much like that found in modern VHF tetrode amplifiers.

Figure 4 is a plot of the klystrode's transfer characteristics. There are three regions of interest. They are; small signal, mid-range and high level.

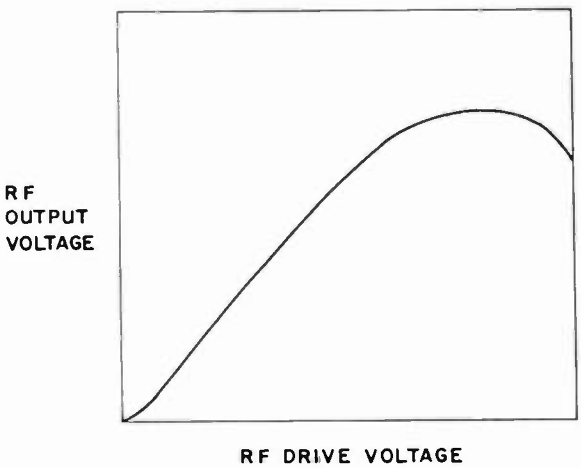


Fig. 4. Klystrode Transfer Characteristic

Since the klystrode is a Class B device, it will have a turn-on non-linearity at small signal levels. This effect can be easily corrected by providing enough idle DC current to place the tube on its mid-range characteristic. At 64kW, an idle current of less than 200ma is sufficient. Thus, in fact, the klystrode is actually operating as a Class AB amplifier.

In the mid range, the tube is essentially linear with good correlation between its input and output.

At high levels, the tube displays a saturation characteristic that needs to be precorrected through the use of IF predistortion. The amount of predistortion required is significantly below that currently being applied to correct pulsed klystron amplifiers and is easily obtained.

When the klystrode is properly tuned, the overall frequency response changes with drive are very small and match the normal range found in other devices (less than 0.5dB).

Other non-linearity characteristics, such as differential gain, differential phase and low frequency non-linearity are well within the range of most IF correction systems.

A very interesting characteristic of the klystrode is its low output ICPM. The klystrode does not use velocity modulation to bunch the electron stream. The stream is bunched and controlled by the action of the grid. Thus, the phase of the output RF is not severely affected by the power level extracted from the tube. The result is a low ICPM characteristic very similar again to the VHF tetrode. This low ICPM makes the klystrode a perfect device for stereo service.

Actual measurements of ICPM, without precorrection, show levels of 2° or less. The ICPM from equivalent uncorrected klystrons, under pulsed conditions can exceed 45°.

C. Multiplex and Aural Operation

The Comark "SK" series transmitters are designed to operate the visual or aural tube in multiplex service in the event of a tube or system failure. The klystrode performs very well in multiplex operation, providing good intermodulation and out-of-band spurious results.

The klystrode, in aural service, provides up to 12.8kW of CW output at an efficiency of 60% and an RF gain of 23dB. This high RF to DC efficiency is another example of the advantages of Class B service. Beam voltage is, of course, the same as in visual service.

D. Driver Requirements

As discussed earlier, the major drawback of the klystrode is its relatively low gain when compared to a klystron. A gain of 20 to 23dB is typical of the 64kW klystrode. While this is high compared to tetrodes, it still requires significant drive power to be developed. For example, at black level, 280 Watts of drive is required. If nothing is changed, the peak sync drive power requirement would be 640 Watts. While this is not out of the question, it is expensive to provide this power just for sync purposes. (Note: The sync drive power increases non-linearity above black as a result of the tube's saturation characteristics.)

Comark, in conjunction with Varian/Eimac, has developed a simple bias switching system which removes the requirement for such high sync driving power.[2,3]

The sync generation system relies on the ability to change the high power gain of the klystrode by changing its operating bias point. Therefore, a sync bias point and a video bias point can be established. The criteria for the sync bias point is that the klystrode gain increase will provide sync output power with normal black level drive power applied to the tube.

The biasing scheme on the klystrode is quite simple. A low DC voltage in the cathode return normally establishes the operating point. While simple cathode bias resistors can be used, a more stable configuration uses zener diodes.

To create the sync bias point and a video bias point, two zener diode voltages are created in the cathode return. A simple transistor switch is used to select at which point the tube will be operated. This switch is controlled by a fiber optic delivered signal and is powered from the floating filiment supply. Unlike klystron pulsers, this system is controlling voltages well under 100 VDC and is not charging or discharging large device capacitances.

The advantages of the pulse modulation system in the "SK" transmitter is that less than 300 Watts of solid-state drive are required to produce 64kW of peak output. The drive signal to the klystrode provides a pedestal level drive without sync. In the unlikely event of a transistor switch failure, drive sync can be reinserted and the tube operated at approximately 3dB reduced output.

The 300 Watt solid-state driver is composed of several hybrid-combined output and drive stages. This parallel approach provides high reliability and good soft failure characteristics. The driver technology is well known, field-proven and is currently being used in Comark's "T" series of UHF tetrode transmitters which provide output powers up to 10kW.

IV. RELIABILITY

If the klystrode has a reliability weakness, it could very likely be found in the fact that the device uses a grid. The klystron, of course, does not have such an intercepting electrode.

It would be easy to draw the conclusion that since the klystrode is grided, it will be less reliable than the klystron. This is too simplistic an analysis. In fact, the klystrode operating at high efficiency can be shown to have expected life times comparable to klystrons. In properly designed support systems, the klystrode will survive catastrophic failures that currently destroy klystrons.

As discussed earlier, the klystrode structure allows for a very large cathode and grid area. This is possible since transit time effects, which limit tetrode size, are not significant in the klystrode structure design. Thus, the electron beam density in the klystrode's grid is far below that found in tetrodes. Further, with the use of pyrolytic graphite grids, which are dimensionally stable at high temperatures, the grid life becomes a minor reliability consideration.

In short, the klystrode life is long compared to other grided tubes like tetrodes, because the klystrode designer is free to make the cathode as large as necessary to obtain this long life. With large, low temperature cathodes, the electron beam density is low through the grid. This results in long grid life. The klystrode designer can certainly offer a cathode-grid structure which compares favorably in life terms to the klystron itself.

Another consideration may be the survivability of the grid under internal arcing conditions. While grid damage is possible during an arc, it has been amply demonstrated, in actual tubes, that the arc goes to the heavy metal focus electrode and not to the grid itself. This fact, combined with the fast, triggered spark gap, minimizes both grid damage and body damage during internal discharges.

Finally, the klystrode is not the only high power electron tube with a gridded gun. Many travelling wave tubes are in service with such guns. These grids are used for pulsing, but the structures are essentially the same. These TWT devices are flying in demanding military and space service and are recording excellent lifetimes.

The life determining components of the klystrode are more similar to the klystron than the tetrode. The major tetrode failure, the grid, has been shown to be a less significant factor in end-of-life than the cathode, which is designed and operated in accordance with klystron experience.

The klystrode offers so many advantages that the unfounded fear of a grid should not prevent its adoption as a major new device to improve the economics of UHF broadcasting.

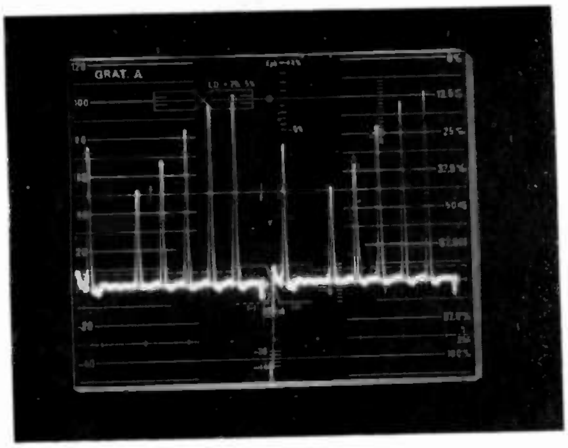
V. VERIFICATION OF 30KW PERFORMANCE DATA

Comark's decision to proceed with the "SK" series design was based, in some part, upon measured parameters presented by Eimac at NAB, April 1985.[2] These results were from a 30kW, X2251 klystrode operating at 785 MHz.

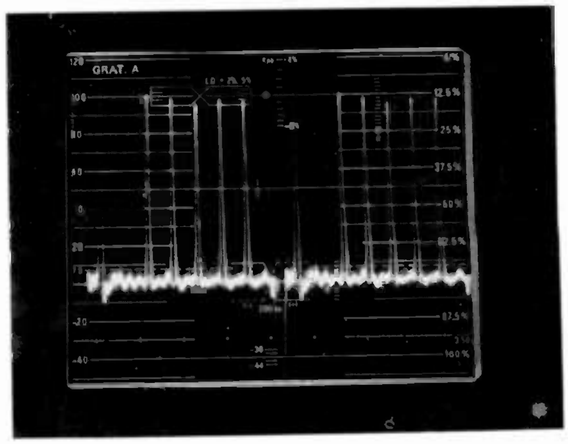
Obviously, one of Comark's first goals was to verify the data and, using the CTE-20 exciter with a Comark/Marconi B7500 modulator, attempt to correct the klystrode non-linearities.

Both objectives were achieved with little difficulty. The results are presented in tabular form (Table 1) with selected key photographs (photos 1 to 6).

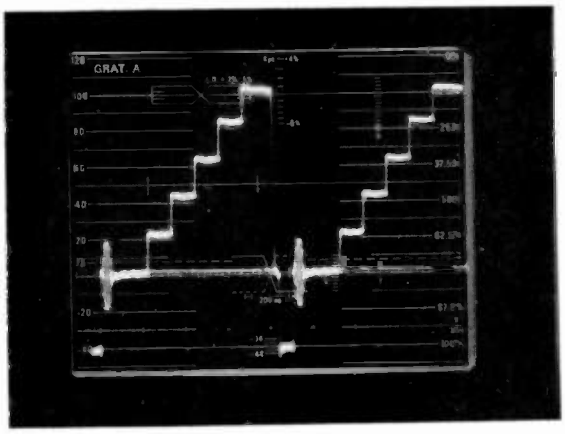
The linearity performance was much as predicted and was readily corrected with the B7500 (see photos 1, 2 and 3). Differential gain and phase were brought to within $\pm 3\%$ and ± 2 degrees, respectively. Of particular interest was the almost total lack of incidental carrier phase modulation, less than 3 degrees (uncorrected) as evidenced on the sync pulse of photograph 4 and the ICPM display of photograph 5. As mentioned earlier, this will be a significant advantage when stereo TV sound is considered.



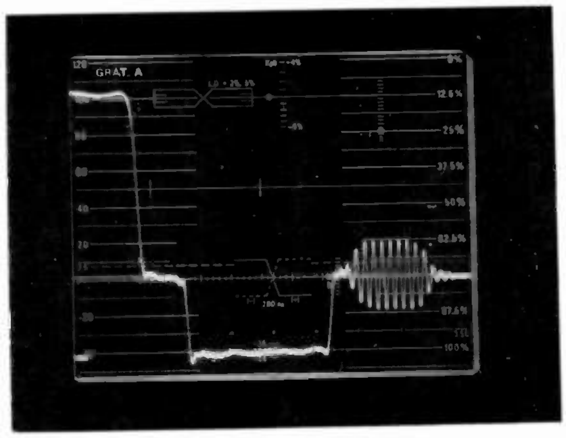
P1. Klystrode Output
Low Frequency Non-linearity - Uncorrected



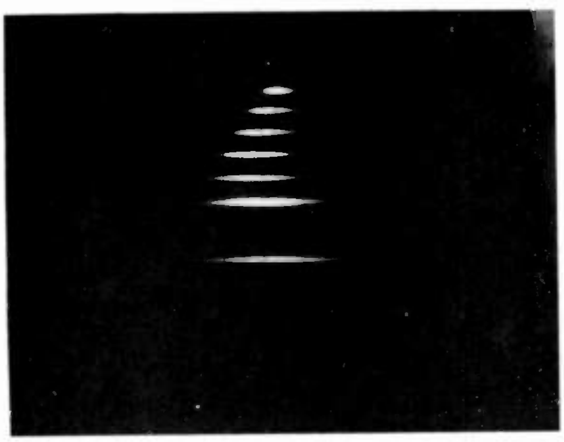
P2. Klystrode Output
Low Frequency Non-linearity - Corrected



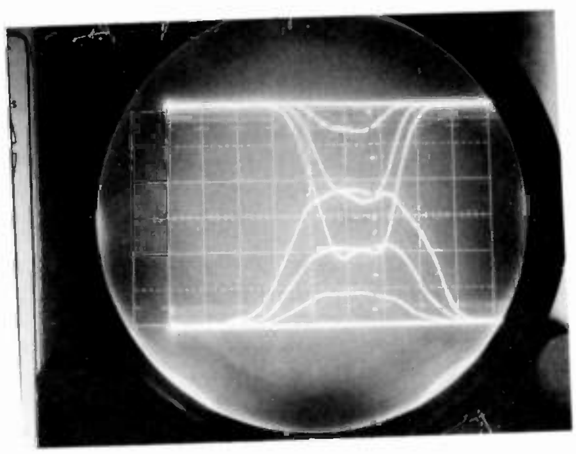
P3. Klystrode Output
Stairstep - Corrected



P4. Klystrode Output
Sync Region - Corrected



P5. Klystrode Output
ICPM - Uncorrected



P6. Klystrode RF Output Vs. Frequency (Top)
Klystrode Beam Current Vs. Frequency (Bottom)

The frequency response versus brightness was examined. Photograph 6 shows both collector current and frequency response at the three levels of black, mid-picture and white. The scales are arbitrary but the flatness at the different levels can readily be seen.

All in all, the klystrode showed no characteristics which are beyond the capability of modern drives. If anything, this device is much simplier to correct than pulsed klystrons.

VI. CONCLUSIONS

The Varian/Eimac klystrode UHF power amplifying tube and its incorporation into the Comark "SK" series of transmitters has been discussed. The compatability of the "SK" series with both klystrons and klystrodes was also developed.

The unique high efficiency of the klystrode is derived from its Class B operating mode. This operation creates certain requirements in the transmitter support system which is addressed in the "SK" series.

The reliability of the klystrode was shown to approximate the life expectancy of the klystron and a cost of ownership was developed based on this conclusion.

The single most important conclusion to be drawn from this paper is that the klystrode offers truly significant operating cost advantages over any other high power amplifying device presently in service or under development.

Specifically, the klystrode will provide a five year cost of ownership advantage of $100,000 at the 60kW level. Correspondingly, higher savings will be realized for higher power transmitters.

The klystrode, with its simple support systems, represents a new technological advance not seen in UHF TV power transmission in 35 years.

TABLE 1

30kW TEST RESULTS

Peak Power Output	30 kW
Carrier Frequency	785 MHz
Bandwidth	8 MHz
Beam Voltage	25 kV
Beam Current (P.S.)	2.85 A
Beam Current (B.L.)	1.90 A
Beam Current (A.P.)	1.05 A
R.F. Power Output (P.S.)	33 kW
R.F. Power Output (B.L.)	18.8 kW
R.F. Power Output (A.P.)	6.4 kW
R.F. Drive Power (P.S.) See Note 1	180 W
R.F. Drive Power (B.L.)	100 W
Grid Voltage (w.r.t. Cathode) See Note 1	-50 V
Average Efficiency (Figure of Merit) See Note 1	102%

Note 1. No sync pulsing was done during these tests. In order to stay within the IPA capability, the Grid Voltage was reduced, thus, giving a higher beam current, and hence output power for a given drive input. This gave the klystrode a slightly higher gain and lower efficiency than reported by Eimac.

VI. COST OF OWNERSHIP COMPARISONS

It seems reasonable, in preparing data for a cost-of-ownership comparison, to use a life figure for a klystrode which is the same as that for the klystron (viz. 30,000 hours in visual service and 40,000 in aural service).

These life figures are reasonable for this comparison based on the earlier reliability discussion. It also seems reasonable to start with this comparison as a frame of reference.

Table 2 was prepared assuming these figures for klystrons and klystrodes operating in a 60kW transmitter.

The results of the comparison are quite staggering, indicating a potential savings of about $100,000 in the first five years over the klystrode's closest rival.

One can see from Table 2 that, in fact, the klystrode could have an average life as low as one third that of the klystron and still be competitive with present day pulsed transmitters. The simple support circuitry alone would than make the klystrode a serious competitor.

TABLE 2

COST OF OWNERSHIP COMPARISON
KLYSTRODE VS. MODERN PULSED KLYSTRONS

	KLYSTRODE X2252		EEV K3672		VARIAN "S" SERIES VKP7553S	
	Vis	Aur	Vis	Aur	Vis	Aur
Output Power (kW)	64	6.4	64	6.4	64	6.4
Sync Conversion Eff. (%)	54.7	55	44	35	52	30
Figure of Merit (%)	123	-	70	-	75	-
Beam Power (kW)	52	11.6	91.4	18.3	85.3	21.3
Focus & Filament (kW)	.44	.44	1.6	1.6	2.7	2.7
Total Power (kW)	52.44	12.04	93.0	19.9	88.0	24.0
Drive Power (kW)	0.28	.032	.02	.01	.05	.01
A.C. Input for Drive (kW)	1.0	-	-	-	-	-
Total Average Power Consumption (kW)	65.48		112.9		112.0	
Average Life (khr.)	30	40	30	40	30	40
Replacement Interval (yrs.)	4.57	6.1	4.57	6.1	4.57	6.1
Replacement Cost (K$)	29	29	29	29	49.5	49.5
Replacement Cost/Year (K$)	6.35	4.75	6.35	4.75	10.83	8.11
Total Replacement Cost/Year (K$)	11.1		11.1		18.94	
Operating Cost/Year (K$ for 18 hr/day; 7¢/KW hr.)	30.1		51.9		51.5	
Total Cost of Ownership (K$/year)	41.2		63		70.44	

Notes:

1. Figure of Merit = $\frac{\text{Peak Sync Power (kW)}}{\text{D.C. Beam Input Power for Average Picture}}$

2. Average picture = 0.45 x Peak Sync Power

3. Comparison does not include initial outlay for accessories, e.g. circuit assembly and magnets, variable visual couplers, pulsers, etc. These are considered "fixtures" of the transmitter.

4. The sync conversion efficiency figures were taken from manufacturer's data sheets.

5. The Figures of Merit were taken from data sheets or from published data.

BIBLIOGRAPHICAL

[1]Ostroff, N., Whiteside, A., and Howard, L.F., "An Integrated Exciter/Pulser System For Ultra High Efficiency Klystron Operation", Comark Communications, Inc., and Marconi Communication Systems Ltd.

[2]Badger, George M., "The Klystrode™, A New High-Efficiency UHF TV Power Amplifier", Varian/Eimac.

[3]Shrader, Merrald B. and Preist, Donald H., "Klystrode™ Update", Varian/Eimac.

A CYLINDRICAL SURFACE NEAR-FIELD TEST FACILITY FOR UHF TELEVISION ANTENNA EVALUATION

Kerry W. Cozad
Harris Corporation/Broadcast Group
Quincy, Illinois

This paper describes an outdoor, cylindrical, near-field antenna range being used by the Harris Broadcast Group located in Quincy, Illinois. In addition to its far-field range, the near-field facility was designed to aid in the alignment and testing of the Harris Wavestar^{tm} UHF antenna product line, as well as other UHF broadcast antenna types.

The hardware and physical layout, as well as an introduction to the measurement capabilities and limitations of the facility are presented.

History

The Broadcast Antenna Test Facility of the Harris Broadcast Group is located near Palmyra, Missouri on a bluff overlooking the Mississippi River flood plain. The primary pattern testing facility is a ground reflection far-field range with a range length of 15,830 feet. The transmitting antenna and transmitter is located on a small plot of land in the middle of a farm field. The turntables which hold the antennas under test are located 240 feet above the flood plain on the edge of a bluff. The ground level variance between the test and transmitting antennas is less than ± 1 foot. This provides an excellent condition for a ground reflection range, and the facility has performed well for over ten years.

However, with an increased workload brought about by the introduction of the Wavestar^{tm} antenna product line in 1983, a new testing range was needed. Due to the difficulty of developing a new turntable location for use with the far range, alternative testing procedures were investigated. Because of the design simplicity of the Wavestar^{tm} antenna and its physical compatibility, a cylindrical surface near-field test facility was developed and designed by Harris engineers. The primary consultant for the project was Dr. Edward B. Joy, of the Georgia Institute of Technology. (Dr. Joy has been involved with near-field testing procedures since 1967 and is a recognized expert in near-field facilities design and procedures.)

Design

Physically, the facility was designed to support the test antenna in a horizontal position. This provides a simpler mechanical design, as well as provides for a method of working on the antenna without removing it from the range, (Figure 1). The antenna is supported at the ends by adjustable wooden supports. A motorized fiberglass cart operates on a set of tracks below the antenna. The cart supports the measurement probe and provides a work platform for technicians. The cables used to transfer the measurement data to the recording and

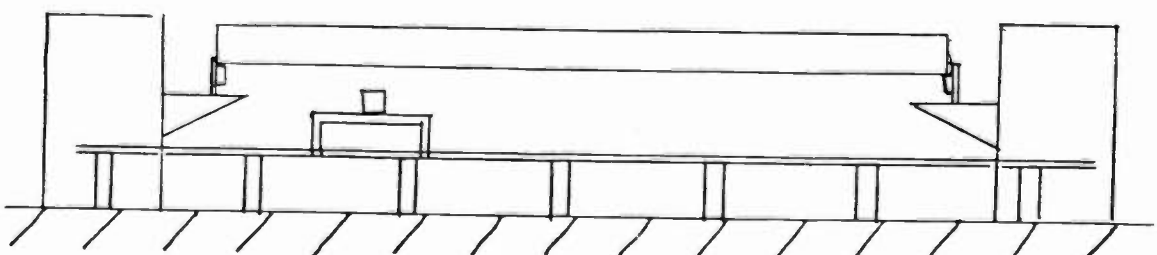


FIGURE 1A

HARRIS BROADCAST GROUP

CYLINDRICAL SURFACE NEAR-FIELD RANGE

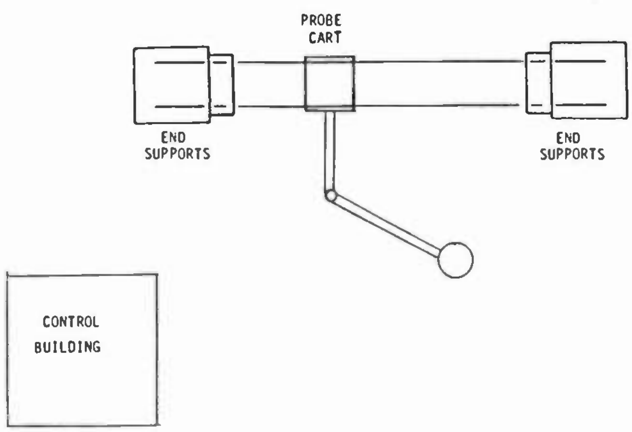


FIGURE 1B

HARRIS BROADCAST GROUP

CYLINDRICAL SURFACE NEAR-FIELD RANGE

computational equipment are guided from the cart by a "support arm" and then are run underground to the control building. Here the data is collected and mathematical analysis is performed. A CRT monitor displays the various compiled data results and hard copies are also provided, (Figure 2).

This paper is not intended to provide a detailed mathematical analysis of the pattern generation from the measured data. The mathematicl basis is the use of Fourier transforms to transform the measured amplitude and phase in the near-field of the antenna at various points along the array to the respective far-field components and thus provide a far-field radiation pattern of the antenna. The major error contributions come from reflections off of surrounding objects and the coupling between the measurement probe and the test antenna.

The measurement probe being used is a standard, open-ended rectangular waveguide. The characteristics of the probe are well documented and are used in a "probe compensation" subprogram during computation. Reflections are minimized through the use of RF absorber material on reflecting surfaces near the range. The effects of these areas are shown in Figures 3-6. A pattern measured on the far-field range is included for comparison as Figure 7.

Specifications

The electrical and mechanical specifications were developed in order to achieve the following accuracies:

Elevation Plane Pattern	$\pm$ 2 or 3 Percentage Units from Actual
Azimuthal Plane Pattern	$\pm$ 2 or 3 Percentage Units from Actual
Beam Tilt	$\pm$ .05°
Null Fill	$\pm$ 2 or 3 Percentage Units from Actual
Directive Gain	$\pm$ .2 dB

Due to the fact that the near-field measurement technique is effectively immune to most environmental factors, the accuracy and repeatability of the measurements is very high. The slight changes seen in successive measurements while varying the absorbing material densities illustrates the relative insensitivity of the measurements to range condition. Also, the close agreement with far-field patterns demonstrates good performance from both ranges. Coupled with the fact that the antenna under test is not subject to repeated moves between the test range and the ground for alignment purposes, the near-field facility provides consistent, accurate data, reduced test time and minimal risk of equipment damage.

Conclusions

The Harris Near-Field Test Facility is presently being subjected to a range performance evaluation. It is, however, being used during the testing procedures for the Wavestar^{tm} antenna product line. Due to the very positive results from preliminary evaluation such as the included pattern data, it is foreseen that the near-field range will eventually be used for final pattern performance evaluation and documentation on UHF broadcast antennas. To this end, it is intended to provide documented test data on the near-field range evaluation at the NAB Convention in 1987.

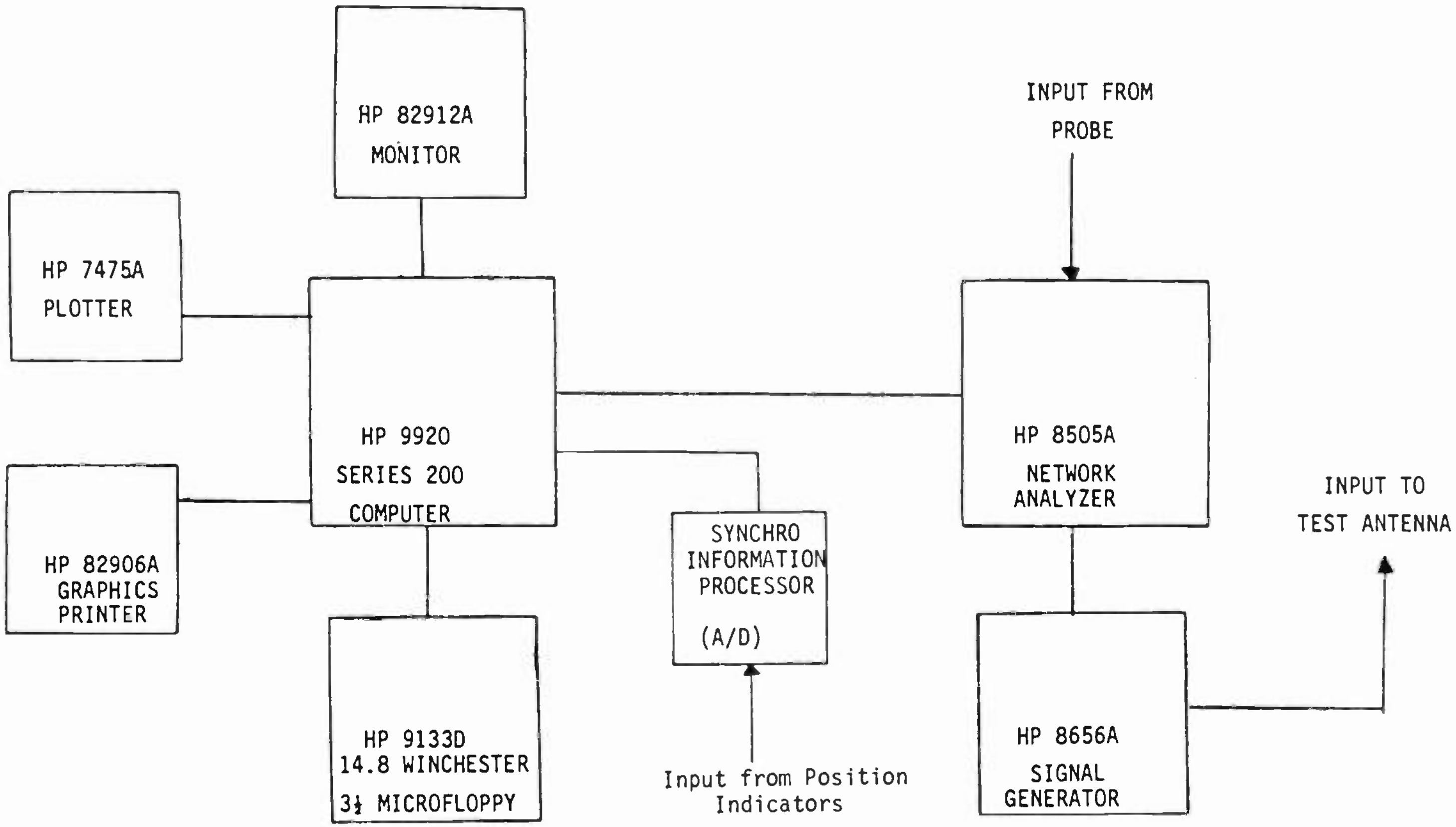


FIGURE 2

HARRIS CYLINDRICAL SURFACE NEAR-FIELD RANGE

EQUIPMENT DIAGRAM

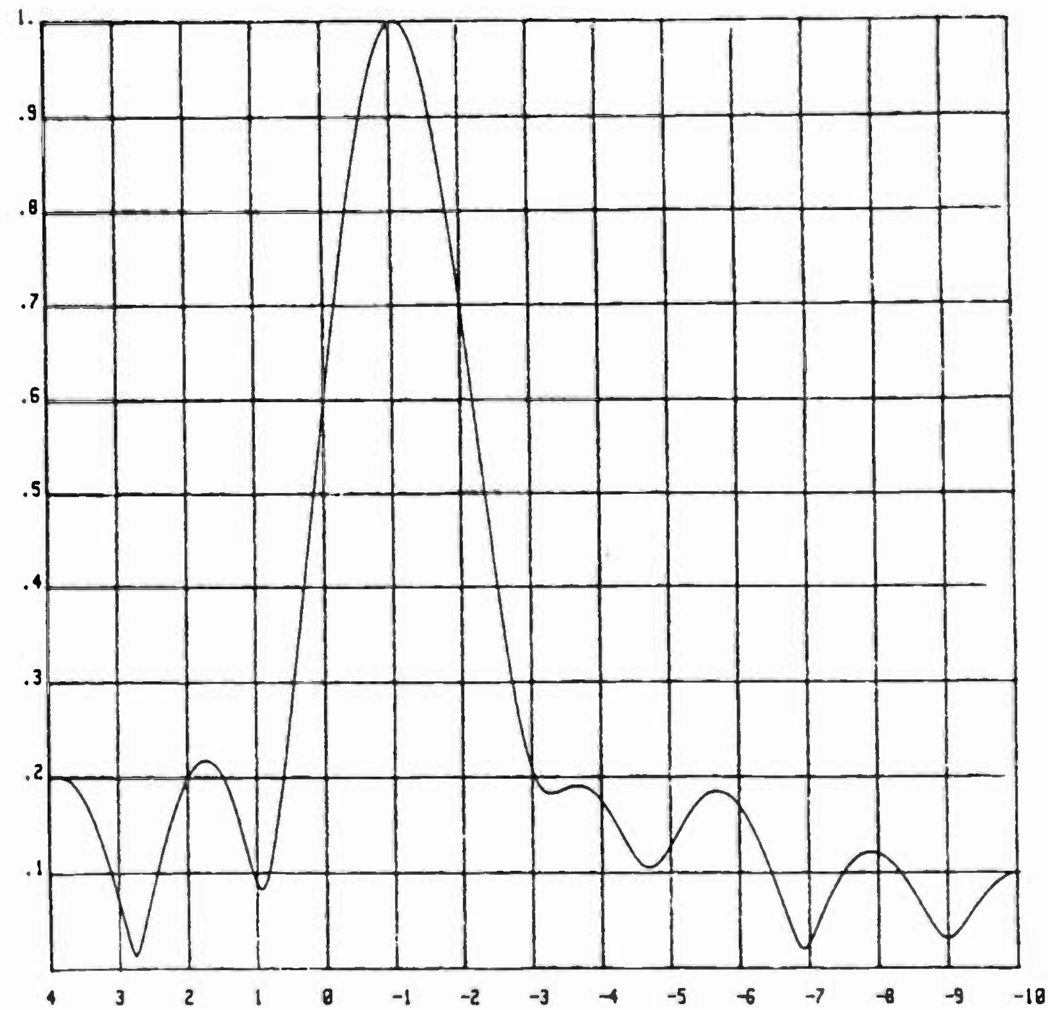


FIGURE 3

ALL ABSORBER USED

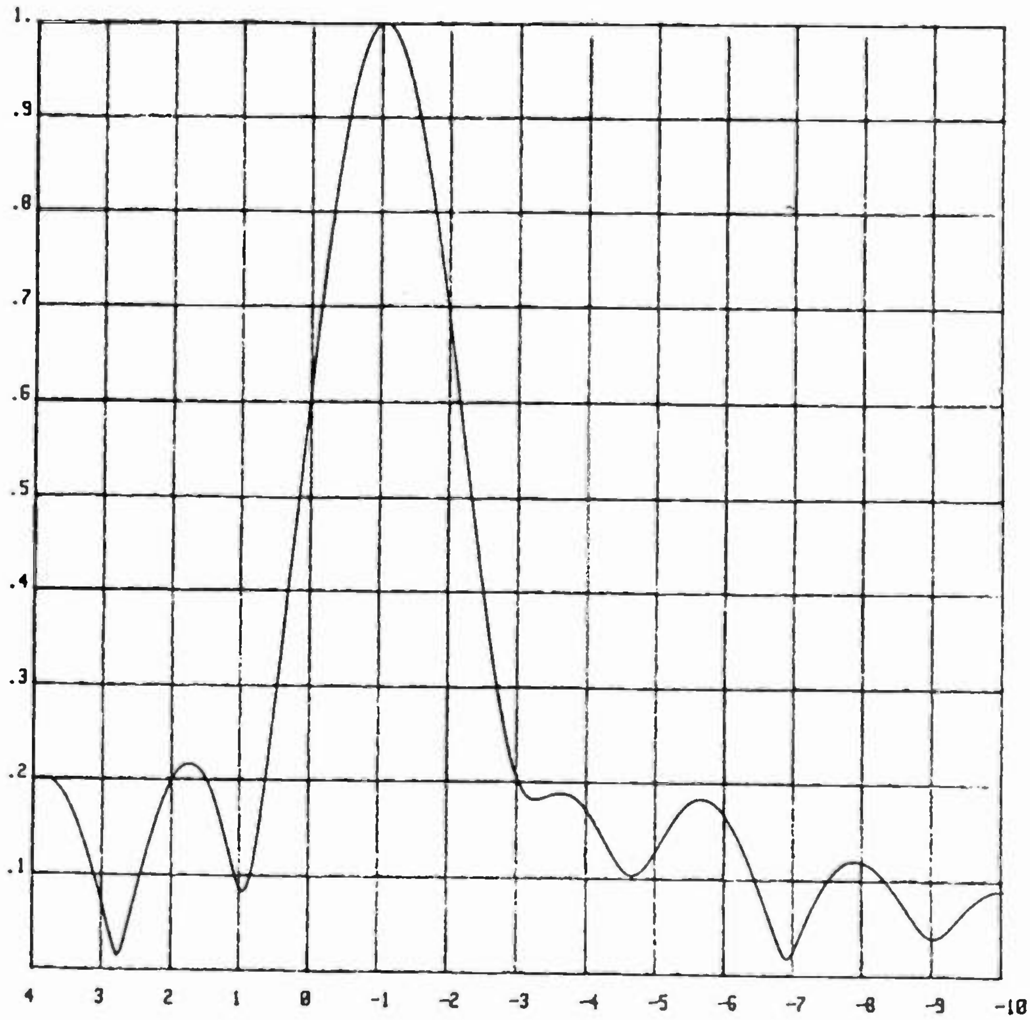


FIGURE 4

ABSORBER REMOVED FROM ARM

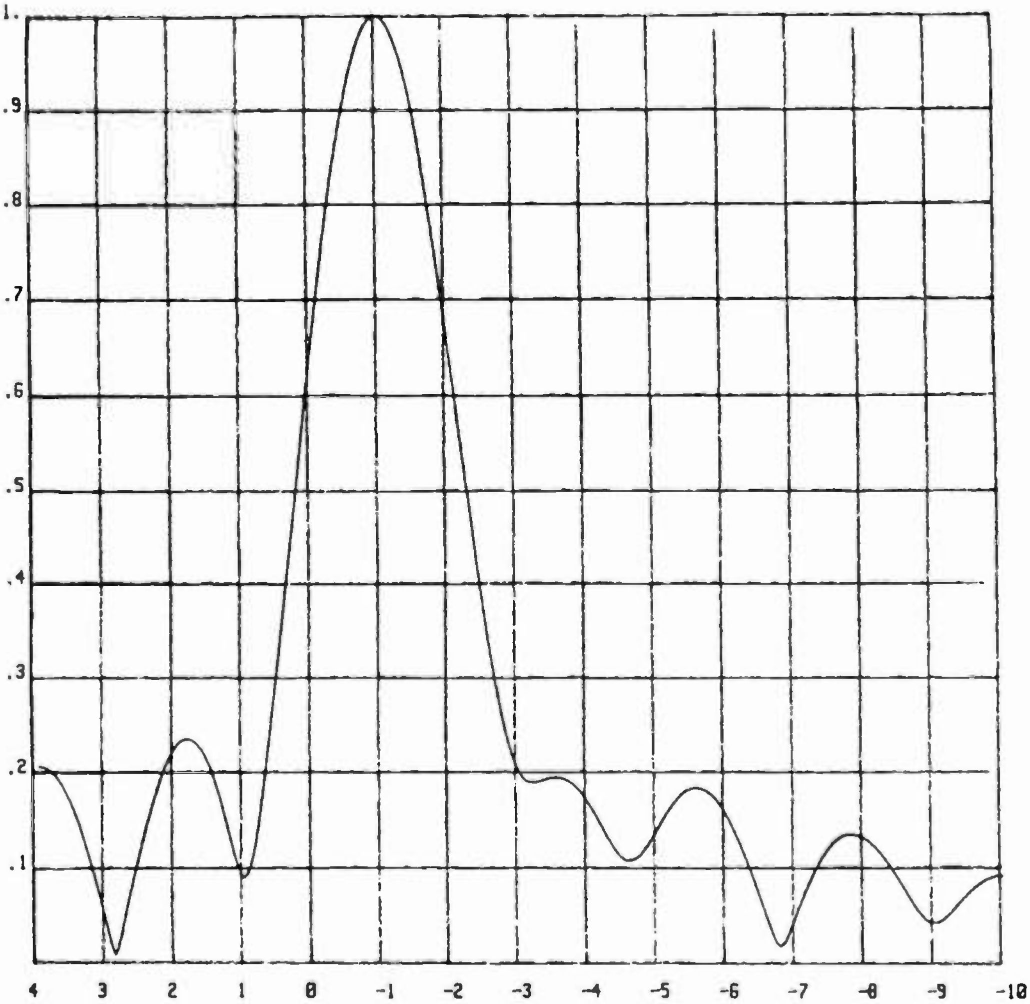


FIGURE 5

ABSORBER REMOVED FROM CART

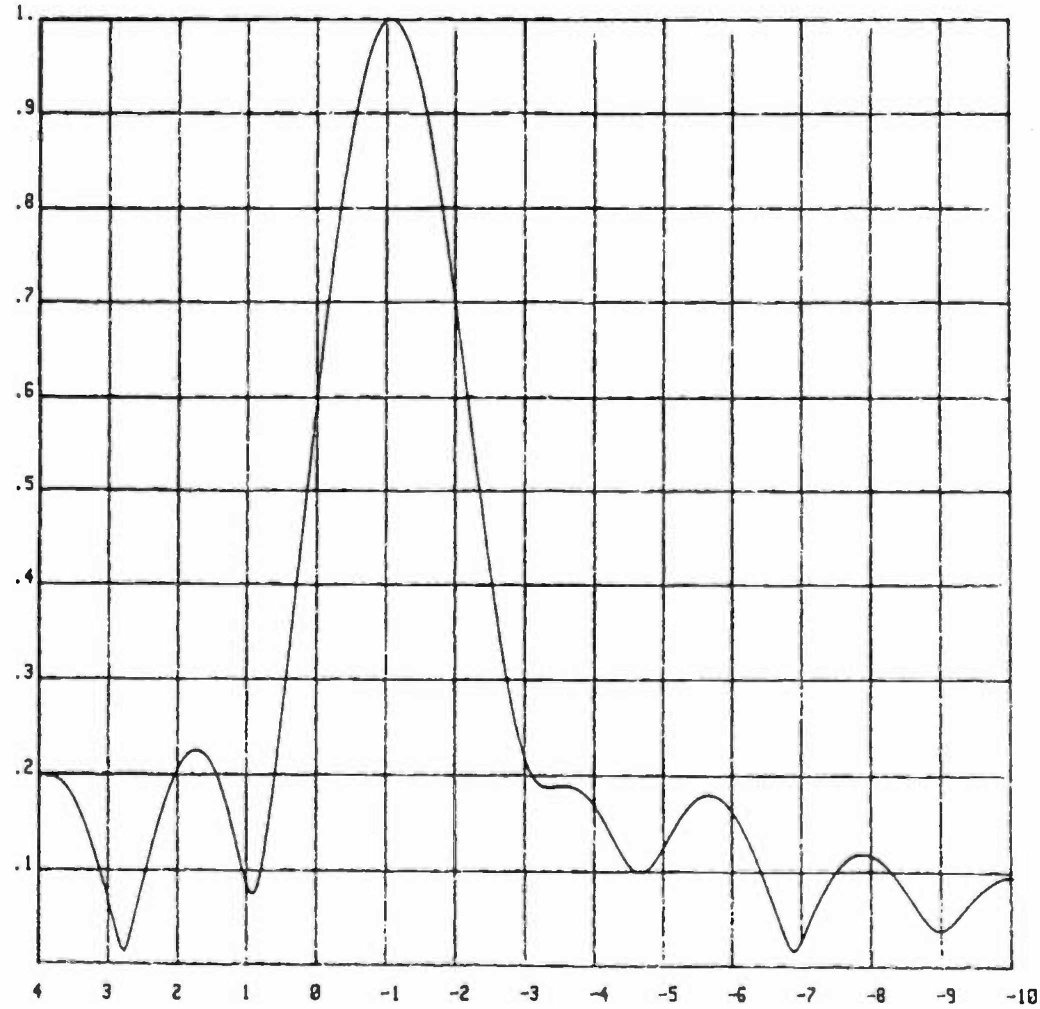


FIGURE 6

ABSORBER REMOVED FROM TRACK

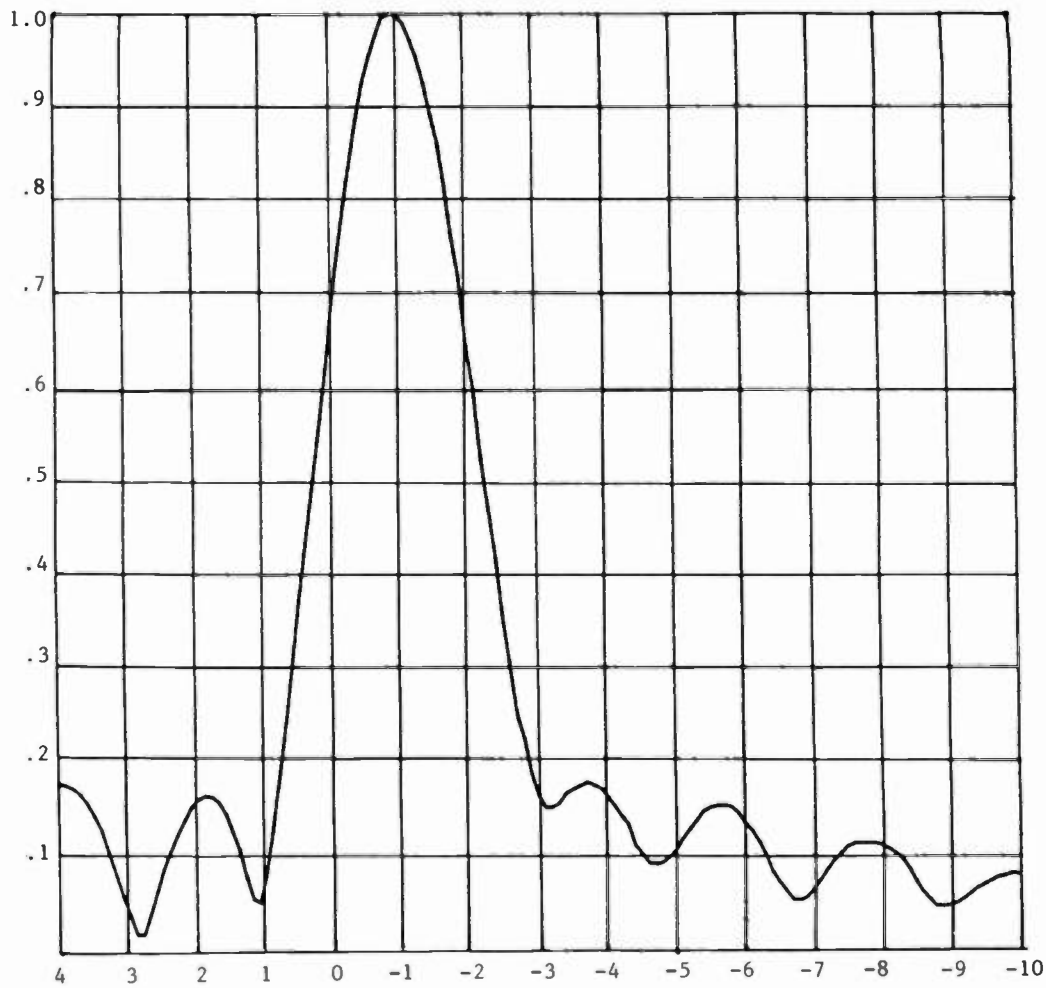


FIGURE 7

MEASURED FAR FIELD PATTERN

KLYSTRON OPERATING EFFICIENCIES: IS 100 PERCENT REALISTIC?

R. Heppinstall
English Electric Valve Company Limited, U.K.

INTRODUCTION

During the last decade considerable efforts have been made towards improving klystron operating efficiencies in U.H.F. T.V. transmitters. The progress made has been remarkable and transmitter energy bills have been much reduced. Efficiency improvements have been achieved in two areas. Firstly, the inherent efficiency of the klystron itself has been increased to the mid forties. Secondly, dramatic improvements have been obtained by the adoption of pulsing techniques, in which the beam power is at a lower, but constant, value during the picture period than it is during the sync. pulse period. Operating efficiencies of more than 70% have been achieved. The practical realisation of these higher efficiencies has required the development of exciters capable of much greater degrees of correction.

The possibility of making a further appreciable improvement in operating efficiency by adopting other operating techniques has been under consideration for some time. Multistage depressed collector and full time modulation techniques are both being actively investigated.

This paper reviews beam current control techniques and discusses the question - Is an operating efficiency of 100 percent a realistic aim?

DEFINITION OF KLYSTRON EFFICIENCY

There have been many discussions on the efficiency of klystrons operating in U.H.F. T.V. transmitters and occasionally confusion has arisen because of the different definitions which have been used. It is necessary therefore to define the terms used in this paper.

The inherent klystron efficiency, or beam conversion efficiency, at any particular R.F. output power level is defined as

$$\eta_i = \frac{P_o \times 100}{P_b} \% \qquad (1)$$

where P_o is the R.F. output power level
and P_b is the beam power necessary to achieve that output power.

The operating efficiency in a U.H.F. T.V. transmitter is defined as

$$\eta_o = \frac{P_p \times 100}{P_{av}} \% \qquad (2)$$

where P_p is the peak sync. output power level
and P_{av} is the average beam power used by the klystron to transmit the T.V. signals.

The value of η_i is determined by the design of the klystron whereas the value of η_o is determined by the value of η_i and the klystron operating mode. For a klystron operating in a pulsed mode on System M and assuming that the inherent klystron efficiency at black level is the same as that at the peak sync. level then

$$\eta_o = 1.69 \; \eta_i. \qquad (3)$$

For a klystron operating in a full time modulation mode the constant in equation (3) is considerably higher.

BEAM CURRENT CONTROL TECHNIQUES

Beam current control techniques for improving klystron operating efficiencies require an ability to change the beam current in accordance with the video level. In pulsing, the beam current is changed from one level during the sync. pulse to another, constant, level during the picture period. In full time modulation the beam current is changed throughout the video waveform in a manner related to the luminance level, the relationship depending upon the exact mode of operation. The magnitude of the beam current can be varied by changing the voltage of a suitable electrode in the electron gun. The electrode may be the modulating anode of a klystron of conventional design. Alternatively it may be the electrode of a suitably designed klystron (BCD or Beam Control Device) in which, essentially the electrode is the focus electrode isolated from the cathode. A further alternative is to use the control grid of a gridded tube. The beam performance characteristics of these three methods of beam current control can be represented mathematically by the equations

$$i = K_1 V_a^{3/2} \qquad \text{(modulating anode)}$$

$$i = \frac{K_2 V_a^{3/2}}{(1 - \mu R_{BCD})^{3/2}} \qquad \text{(BCD electrode)}$$

and

$$i = K_3 V_a^{3/2} (1 + \mu R_G)^{3/2} \qquad \text{(grid)}$$

where the parameters are

i	:	Beam current
K_1, K_2, K_3	:	Perveance parameters
μ	:	Amplification factor
V_a	:	Modulating anode voltage
R_{BCD}	:	Ratio of BCD voltage to modulating anode voltage
R_G	:	Ratio of grid voltage to modulating anode voltage.

Typical values of the perveance and amplification factor are given in Table 1 for modulating anode control, for BCD klystrons for 30KW and 60KW transmitters and for a gridded klystron.

Table 1 : Beam Control Parameters.

	Microperveance	μ
Modulating anode	1.5 to 2.0	-
K3271BCD	1.5	6
K3672BCD	2.0	6
K3217HG	0.65	43

The typical values quoted in Table 1 can be used in conjunction with the equations given above to estimate the magnitude of the voltage swings required to achieve 40% and 60% reductions in beam current for klystrons operating in transmitters giving peak sync. output power levels of 60KW and 30KW. These estimates are shown in Table 2.

Table 2 : Predicted Control Voltage Swings.

Transmitter Output Power (KW)	HT (KV)	I (A)	Va (KV)	Vg (V)	V_1 (V)	V_2 (V)	Gun Type
60	25.5	5.3	19.1	-	5500	8700	Mod. anode
60	25.5	5.3	19.1	-	1300	2700	B.C.D.
60	25.5	5.3	20.2	470	270	430	Gridded
30	23.0	3.1	16.2	-	4700	7400	Mod. anode
30	23.0	3.1	16.2	-	1100	2300	B.C.D.
30	23.0	3.1	14.2	330	190	300	Gridded

HT	Beam voltage
I	Beam current
V_a, V_g	Modulating anode voltage and grid voltage relative to cathode to obtain stated beam current
V_1, V_2	Predicted voltage swings required to reduce beam current by 40% and 60% respectively.

Voltage swings of the order of those indicated by the values of V_1 in Table 2 are required if a klystron is to be operated at optimum efficiency in the pulsed mode. Transmitter manufacturers have designed and are now manufacturing all solid state beam pulsers capable of producing voltage swings of up to 3000 volts. They have gained widespread acceptance. Pulsers containing hard valve stages are used to produce the large mod. anode voltage swings required for optimum performance.

Pulsing has become established as a reliable technique for obtaining high klystron operating efficiencies. The promise of obtaining even higher operating efficiencies by employing a full time modulation mode is being actively investigated. However since much greater beam current reductions are needed the choice of klystron type for such an investigation is restricted. The values of V_2 in Table 2 are estimates of the voltage swings which, theoretically, would be required to produce reductions of 60%. In practice the voltage which can be applied to the electrode of a B.C.D. klystron is limited by the need to avoid breakdown between the electrode and the cathode. The specified maximum voltage for the K3672BCD klystron is 1400 volts whereas that for the K3271BCD klystron is 1250 volts. Thus whilst the pulsing technique can be successfully applied to both klystrons neither can be used for full time modulation tests, when much greater beam current reductions are required. The use of a modulating anode would be difficult due to the very high voltage swings required. Consequently investigation of full time modulation has been conducted using a K3217HG klystron - a gridded tube which has achieved a life to date in excess of 22,000 hours at the B.B.C. Crystal Palace Transmitter Station in London, U.K.

R.F. PERFORMANCE CHARACTERISTICS

The operation of a klystron in a pulsed mode or in a full time modulation mode can only be achieved if exciters having appropriate features are available. Some of these features can be determined from an examination of klystron transfer characteristics. For pulsed operation it is essential that the exciter can provide a very high level of linearity, differential gain and phase correction, since the transfer characteristic in the picture region is such that the klystron is close to saturation at black level - see curve A of Figure 1. For optimum performance it may also be necessary that the exciter can provide negative R.F. sync. pulses - that is, a lower drive level at peak sync. than at black level. These problems, including adjusting the time delays through the various signal paths to produce a satisfactory output signal, have been resolved. Suitable exciters have been manufactured and much improved klystron operating efficiences have been achieved.

The prospect of changing the beam current in accordance with the instantaneous luminance level opens up the promise of obtaining even higher operating efficiencies. A most interesting possibility is to change the beam current in such a manner that the relationship between the input cavity drive power and the klystron output power is linear - as shown in line B of Figure 1. B.B.C. engineers have investigated this mode of operation in detail (Ref.1,2). Suitably corrected video waveforms have been applied to the grid and to the input cavity so as to achieve an output signal waveform satisfying the specification requirements of system I. It should be noted that in order to achieve this performance a grid pulser based on a linear amplifier rather than a voltage switching system is required. The results correspond to an operating efficiency of 83%. A first experimental transmission using the system was made in July 1985.

The B.B.C. experiments have demonstrated the feasibility of operating a U.H.F. T.V. gridded klystron in a full time modulation mode. It is therefore worthwhile to speculate how a gridded tube might be operated in such a mode so as to obtain optimum operating efficiency rather than a linear transfer characteristic. Certainly a higher operating efficiency will be obtained if the transfer characteristic is as shown by curve C of Figure 1, for at any particular output power within the picture region the beam current requirement is less than that required in the linear mode. However it is apparent that since the curvature of curve C is in the opposite sense to that of curve A an R.F. exciter having correction in the opposite sense to that normally employed is required. The optimum situation may be that depicted by line D, in which the R.F. input power level is a constant and the R.F. amplitude variation is obtained solely by grid control, although phase corrections on the R.F. input signal will probably still be needed.

The operational efficiency of the various alternatives depicted in Figure 1 can be estimated from the beam current requirements at average picture level (11.5 KW for a 40KW transmitter). The

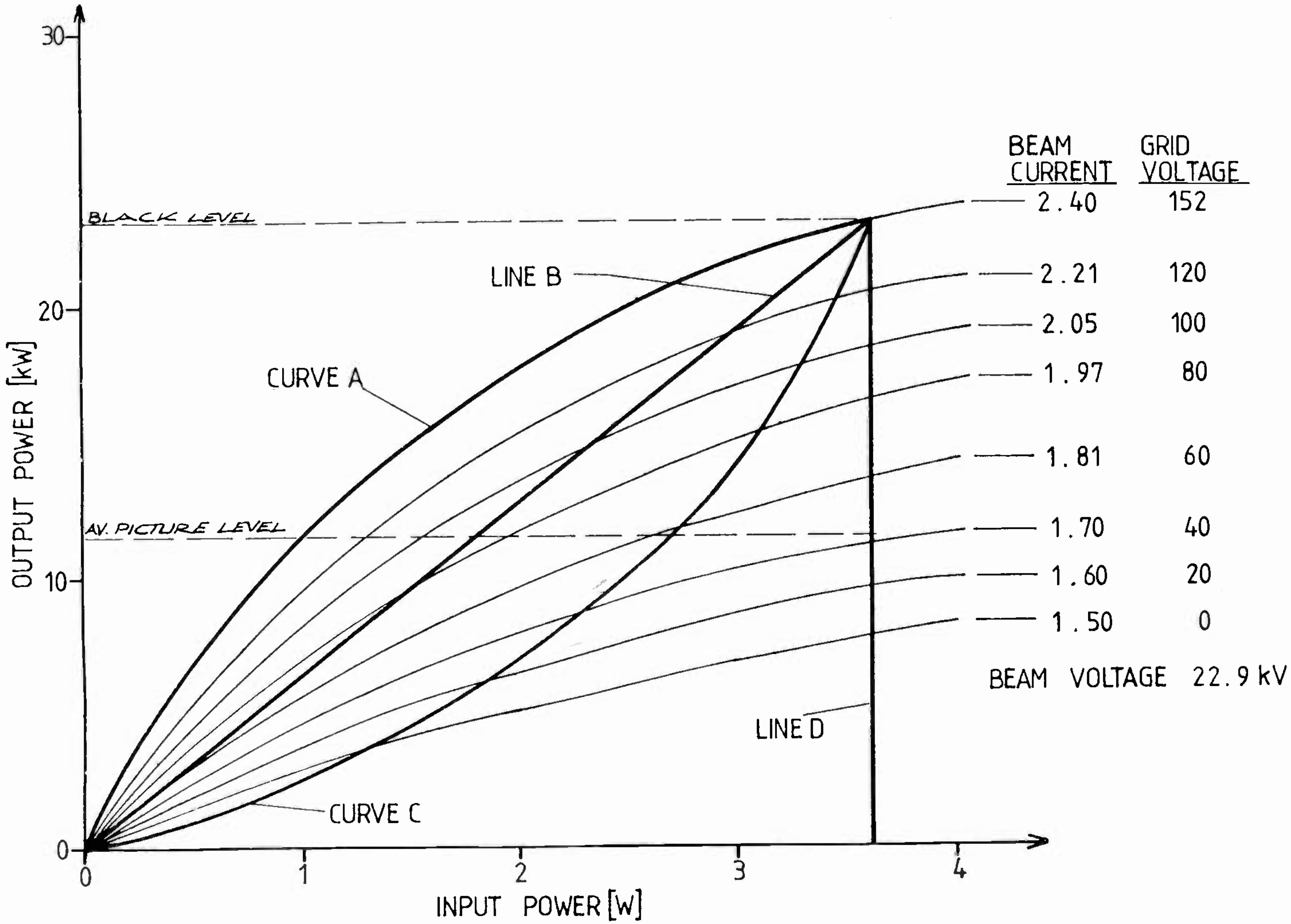


Figure 1: K3217HG TRANSFER CHARACTERISTICS [PICTURE REGION]

values are:-

Characteristic	Operating Efficiency
Unpulsed	42
Curve A	70
Line B	83
Line D	96

The K3217HG klystron has an inherent efficiency of 42%. Calculations indicate that a klystron having an inherent efficiency of 45% (typical of the present generation) would give an operational efficiency of 103% if the charactistic Line D is used. Thus gridded klystrons might be used to obtain operating efficiencies in excess of 100% if suitable exciters and grid drives are developed and any associated problems related with operating under conditions of line D are resolved.

Various authors have quoted the operating efficiency, or figure of merit, for the gridded klystron, the klystrode and the multi-staged depressed collector. Considerable care must be taken when comparing these figures to ensure they are based on the same criteria. Generally the figure of merit is taken to be the ratio of the peak sync. power to the D.C. beam input power for average picture. However in one case (Ref. 3) the average picture is taken to be at a power level of 0.2875 of the peak sync. power level whereas in another (Ref. 4) it seems to have been at a power level of 0.2025 of the peak sync. level. This difference is considerable and figures of merit based on these two different criteria should not be employed when device performance is being compared. Qualitatively, the work outlined above suggests that if a gridded klystron were to be operated in a full time modulated mode at optimum efficiency then its figure of merit would be comparable to that of a klystrode or a multi-staged depressed collector klystron.

DISCUSSIONS AND CONCLUSIONS

Component manufacturers are presently investing considerable effort into development work aimed at reducing the costs of operating U.H.F. T.V. transmitters. The klystrode, the multi-staged depressed collector klystron and the gridded klystron are all being actively investigated. The work done by the B.B.C. engineers has demonstrated that full time modulation is a feasible mode of operation of a gridded klystron. Examination of the transfer characteristics has indicated an objective for future development - the operation of a gridded klystron in a full time modulation mode at optimum efficiency. The predicted efficiency is comparable to that reported and predicted for the klystrode and the multi-stage depressed collector. The successful completion of the development would have considerable benefits to the transmitter user since the gridded klystron is a high gain device with a robust grid structure. It also avoids the use of additional collector power supplies and problems associated with the liquid cooling of electrodes at high voltages. As it is based on existing klystron designs it offers the possibility not only of being installed in the new generation of transmitters but also of being retro-fitted into existing transmitters with relatively few modifications.

REFERENCES

1. "Klystron efficiency improvements : full time modulation"
I. Tupper; BBC Transmitter Department Technical Services Report No. 1/85

2. "Klystron efficiency improvements : full time modulation"
I. Tupper and R. Heppinstall; NTG Conference May 1986

3. "Klystron efficiency improvements in UHF vision transmitter"
I. Tupper: Paper 5, IEE Colloquium on Efficiency Improvements in UHF Transmitters, Digest No. 1984/22

4. "Klystrode T.V. amplfier performance at U.H.F."
D. Priest and M. Schrader; IBC, 1984

ACKNOWLEDGMENTS

The author is grateful to the Technical Director of GEC for permission to publish this paper.

CIRCULARLY AND ELLIPTICALLY POLARIZED BAND IV/V UHF TELEVISION TRANSMITTING ANTENNAS FOR BROADCAST

Geza Dienes, Sr. Research Engineer
Andrew Corporation
Upland, California

A tutorial review of the factors affecting TV reception is presented with emphasis on the importance of polarization match between receiving antenna and the field surrounding it. The need for distinguishing receive sites with and without outdoor antennas is proposed and their differing requirements is explained. The rationale for using circularly or elliptically polarized UHF television transmitting antennas is developed.

I. PURPOSE OF TRANSMIT FACILITY

It is assumed that the purpose of a transmitting facility is to provide, at the user's site, the maximum possible signal level matching the polarization of the user's antenna. For the purposes of this discussion we will assume a typical horizontally polarized transmit antenna, and that everything has been done to optimize the transmit facility. That is, the maximum allowable ERP is being radiated, the best location, the highest practical transmit antenna height has been selected such that most users will have line of sight propagation, etc.

II. FACTORS AFFECTING RECEPTION

A. Factors concerning propagation.

1. The signal strength at a given receiving location is affected by the distance of that location to the transmitting facility. The laws of physics dictate that the further away a receiving location is from a transmit facility the lower the signal strength arriving from the transmitting site.

2. Terrain - The propagation of electromagnetic waves is affected by the terrain over which it travels. For example; dense vegetation, forest, bushes, etc. will greatly attenuate a signal traveling along ground and hilly terrain will provide obstructions, such that line of sight between the transmit and receive facilities may not exist.

B. Polarization Match.

1. It is essential that the field existing at the receiving site be of the same polarization as the receiving antenna polarization is. An outdoor television antenna receives horizontal polarization and will be unresponsive to vertical polarization, regardless of how much energy there may be in vertical polarization. A total polarization match between the receive antenna and the existing field around it may not be necessary but we must keep in mind that the receive antenna will be responsive only to that portion of the existing polarization that matches the receiving antenna's polarization, (i.e. horizontal).

C. Factors concerning receive site.

1. Signal level at the antenna. - In many cases the signal level at the antenna is basically a function of the distance from the transmitter and the terrain. However for locations that are obstructed or inside some buildings local conditions will also affect the signal arriving at the receiving antenna.

2. Polarization at the antenna. - Again in general for line of sight reception to an outdoor antenna the polarization arriving at the antenna is the same as that of the transmit antenna which is in most cases horizontal. However, for obstructed sites or for sites inside buildings the polarization at the antenna may be random.

3. Transmission line from antenna to receiving set. - The energy lost in the transmission line that connects the television set to the receiving antenna will reduce the amount of energy transferred from the receive antenna to the set and is consequently a very important factor, especially if the transmission line is long.

4. Sensitivity of the TV set and other television set parameters. - The sensitivity, and noise level produced by the TV set, and many other factors will influence the quality of the television picture produced by the set. It is well known that a highly sensitive set will produce a good quality picture whereas a set with low sensitivity might not for a given input level.

We have very little control over parameters of a receive site that relate to its location, such as its distance from the transmitting site and terrain and those parameters that have to do with existing site conditions such as what the receiving system consists of, i.e. antenna, transmission line, and television set, the quality of the installation and the quality of its components. We will however examine the signal strength around the receiving antenna and the polarization of that signal.

III. A FEW WORDS ABOUT POLARIZATION

In the way of a quick review a simplified description of what polarization and a generation of circular and elliptical polarization is all about may be in order.

Arbitrary polarization may be described with the following simple equation:

$$\vec{E}(t) = \vec{E}_x \cos(\omega t) + \vec{E} \cos(\omega t + \delta)$$

All quantities in parenthases after co-sine are of course in either electrical degrees of radians, appropriate for the machine that evaluates them.

E_x and E_y are two orthogonal vectors.

$$\omega t = \frac{2\pi}{F} t$$

When F is frequency in hertz and t is time in seconds.

There are some special cases of the above equation for linear and circular polarizations.

1. Linear polarization occurs when $\delta = N\pi$ where N is any integer such as N = ± 0, 1, 2, ...

   What this means, of course, is that linear polarization will occur any time the two vectors are in phase or exactly out of phase and where the magnitude of each vector producing the resultant may be anything.

2. Circular polarization is another special case of equation one and occurs when $E_x = E_y$ and $\delta = \frac{N\pi}{2}$ where N = ± 1, 3, 5, or any odd integer.

3. All other combinations of E_x, E_y and Δ will result in elliptical polarization.

   In case of a elliptically polarized signal the tip of the resultant vector, E_t , describes an ellipse and this ellipse may be obtained by incrementing ωt through one wavelength, (2π or 360 degrees). The ratio of the resultant vector maxima to its minima is the measure of the axial ratio and is typically used to define the quality of circular polarization. For a perfectly circularly polarized field the axial ratio is 1 or 0dB, meaning that the resultant vector of equation 1 is of the same magnitude for any value of t . In simple terms this means that power transfer to a linearly polarized antenna will be the same from this field regardless of the orientation of the antenna in respect to the incoming field. Therefore a horizontally polarized antenna will receive just as much signal as a vertically polarized antenna.

   In general we'll see that any polarization may be described as a combination of two mutually perpendicular fields with a specified amplitude ratio and phase shift between them.

IV. GROUPING OF RECEIVE SITES

We may arbitrarily divide all receiving sites into two groups;

a.) Those with an outdoor receiving antenna, and

b.) Those with only the antennas supplied with the TV set (rabbit-ears, loop, vertical whip, etc.).

Whether a particular site belongs to one group or the other is basically controlled by the existing VHF transmitting facilities. Typically those sites that get adequate reception of all existing VHF channels without an outdoor receiving antenna system will not have one, and those sites which do not get adequate reception of all VHF channels will install an outdoor receiving antenna.

Generally one expects to get adequate reception of all VHF channels without an outdoor antenna within 25-35 miles of a VHF transmitting site. Most locations within this radius will not be equipped with an outdoor receiving antenna. Locations further away will most likely install an outdoor antenna to improve their reception. As fair quality TV receive antennas will provide for the reception of both VHF and UHF channels, reception in both of these catagories will be improved by the installation of the outdoor antenna.

V. EXAMINE RECEPTION AT GROUP I

Receivers in this group, equipped with an outdoor receiving antenna, are fairly far away from the transmitting site and typically will have line of sight propagation. The signal strength at these sites is a function of the distance between the receiving site and the transmitting site, and of course the function of the terrain. The polarization travelling the line of sight path is typically not very much distorted and will arrive more or less as transmitted (horizontal) matching the polarization of the outdoor TV antenna.

Those sites that are obstructed for some reason, either because they are behind hills or perhaps even past the theoretical radio horizon, will have much reduced signal strength, due to blockage by the obstruction. The field arrives at the obstructed site via diffraction or reflection instead of a direct path. The diffracted or reflected field will most likely not have horizontal polarization due to the affect of the diffraction, reflection, etc. Quite often to locations that are obstructed there are several possible signal paths resulting in a fairly confused and highly frequency sensitive polarization as well as field strength.

VI. EXAMINE RECEPTION OF GROUP II

Those locations fairly close to the transmitting site and without an outdoor receiving system fall within Group II. The antenna in this case is that supplied with the television set which is typically a vertical whip, a set of rabbit-ears, or for UHF-TV a small loop or dipole antenna.

The receiving antenna in this case is inside a building or some sort of habitation, enclosed by walls of various materials. The first concern we have is whether or not any energy is able to propagate into the enclosure so that a measureable or even significant amount of field is produced within the enclosure, i.e. the building.

A. Attenuation due to propagation through wall.

The attenuation of electromatic waves caused by propagation through a medium is proportional to the thickness of this medium in terms of wavelength, inversely proportional to the conductivity of this medium, and is dependent on whether or not the medium is homogenious, i.e. has the same response for various polarizations, etc.

Walls of single family home or small apartment buildings are typically made of a wood frame with some kind of covering. Vertical as well as horizontal metallic members may be included within this wall such as water pipes, gas pipes, conduits, electrical wiring, etc. It is not possible to generalize but one would expect that for higher frequencies, i.e. UHF vs VHF frequencies, where the wall appears to be thicker the attenuation will be higher. It would also seem that walls having predominantly horizontal metallic members would affect horizontal polarization, and walls containing predominantly vertical members will affect vertical polarization more than others. Be as it may the important thing to realize that unless there is some propagation of electromagnetic waves through the wall of an enclosure or room there will be absolutely no energy within this room and any further discussion of reception is academic. Provided we assume there is some propagation through the wall of the enclosure we may go to the next step and consider;

B. Space Standing Waves.

Space standing waves are standing waves much akin to standing waves in a transmission line produced by discontinuities within that line. Space standing waves however by implication must be three dimensional, i.e. containing some sort of repetative, time independent distribution along all three of the X, Y, and Z axis.

Once energy has passed through the wall of an enclosure, it will propagate through the space within the walls and then seeing the discontinuity at the other end of the enclosure will partially be reflected and produce space standing waves, of various intensity. The higher the discontunity of the wall for a particular frequency the greater the difference between minima and maxima of the standing waves will be. In extreme cases the standing waves could reach the condition where at minimums there will be absolutely 0 field left and at maximum the field will be double from the condition where there are no standing waves. Since the enclosure's size, and all of the parameters of this enclosure are frequency and/or polarization dependent the standing wave distribution within the enclosure will be a function of both frequency, and polarization. The standing wave distribution will be different for each channel, for each frequency within each channel and for each polarization. For example; a standing wave maxima at the given location may occur at channel 2 however a standing wave maxima will not necessarily be in the same location for even visual carrier and aural carrier of channel 2 and will certainly be different for the visual carrier of any other channel. In extreme cases where the nulls of the space standing waves within the enclosure are very deep a condition may occur that forces the user to physically move his television set from one location to another in order to receive a given channel.

C. Polarization.

We have seen that the standing waves developed by reflection from the walls and other objects within the enclosure create nulls and peaks of field distribution within the enclosure, due to the interaction of incident and reflected waves. The reflected waves coming from various portions of the enclosure do not, in general, have the same polarization. A new polarization will be created by the sum of the incident and various reflected waves arriving at a given location with their various and typically highly diverse polarizations. The case may therefore occur where we will have, at a given location, a space standing wave maxima for horizontal polarization and a space standing wave minima for vertical polarization, or vise versa. If at a particular location where the television set is, the horizontal polarization has a standing wave minima and vertical polarization has a standing wave maxima, then the necessity for adjusting the receive antenna polarization to vertical will arise. Either that or one will physically have to move the TV set to someplace else where the conditions are more favorable.

All of this is highly undesirable because it forces the user to make drastic modifications, i.e. change the location of his TV set to get adequate reception. It is especially distressing for UHF channels where conditions within an enclosure are typically more unfavorable as opposed to a VHF channel. Fiddling with the loop antenna or physically turning, moving, lifting, or relocating the TV set may be necessary to get an acceptable signal at a particular UHF channel. As users are unlikely to do this, UHF channels are at a marketing disadvantage in that a user will simply flip through his dial and reject any channel with unacceptable performance.

D. Measured TV set patterns.

In the appendix you will find the results of some measurements which Andrew has conducted in order to determine the typical polarization received by a television set with a loop antenna attached to its UHF antenna terminals. The measurements indicate that a system such as described here, will more favorablly respond to a circularly polarized wave than to any linear polarized wave, the significance of which will occur as we go on later.

VII. CONCLUSION

Reasons for circular or elliptical polarization.
As we have seen from the discussion above, in all of those areas where we do not have line of sight propagation from a transmitting site to a receiving site the field intensity and the polarization of the field at the receive antenna is greatly a function of a number of parameters totally out of our control. We have noted that these parameters are both frequency and polarization dependent. In case of obstructed sites the field arrives at the site via either reflection or refraction or both. Reflection and refraction are not the same for all polarizations, therefore each polarizaiton (V or H) transmitted, will produce a different field at the receive site. One or the other may be missing. In case of a site inside an enclosure the field first of all must pass through the wall of the enclosure. The walls of typical buildings most likely effect the way each polarization passes through it to a different degree. The magnitude of the field for each polarization is likely to be different inside the enclosure even discounting any other factor. Within an enclosure space standing waves will be present which are different for vertical and horizontal polarization. It is therefore reasonable to assume that if one transmits both polarizations at the same time, then at a point in space within the enclosure, on a statistical basis, there will be a much greater likelyhood of some energy at some polarization to be present.

When considering power transfer from a linearly polarized field to a linearly polarized antenna we note that the linearly polarized antenna will only respond to that portion of the linearly polarized field which impinges upon the antenna. The field impinging on the antenna will be proportional to the co-sine of the angle between the linearly polarized antenna and the linearly polarized field. If the antenna is orthogonal to the field there will be absolutely no power transfer from the electric field to the antenna. This means that there is always the possibility of a linearly polarized antenna to receive absolutely nothing from a field existing around it providing they are orthogonal. In order to alleviate this problem we time shift one linear polarization in respect to the other by 90 electrical degrees. The resulting elliptically or circularly polarized field will never have a value less than the smaller of the two linear fields producing it. The electric field therefore impinging on a linearly polarized field will never be less that the smallest linear component transmitted. To put it another way, it is impossible to prevent power transfer from an elliptically polarized field to a linearly polarized antenna.

This brings us to the next requirement which is that we must transmit the two vertical and horizontal polarizations in a 90° phase quadrature.

VIII. REQUIREMENTS TO PRODUCE CIRCULAR/ ELLIPTICAL POLARIZATION

We have seen that the requirement of a 90° phase shift between the two polarizations is essential. We will now examine how to provide this and how to maintain the phase quadrature throughout the azimuth pattern of the antenna.

It is a fairly simple matter to provide the necessary time delay between two radiators, one of which is vertically and one which is horizontally polarized, to achieve phase quadrature of the energy propagating to these devices. An observer out in space, however does not see what enters the radiating element, he sees what arrives at the point of observation from he radiating elements. Consequently the radiation characteristics of both vertical and horizontal radiators must be taken into account. This means that the radiation patterns of the vertically polarized radiator and horizontal polarized radiator must be matched both in amplitude and in phase in order to maintain the proper conditions of elliptical polarization for the entire azimuth coverage of the antenna.

Amplitude matching of the azimuth patterns of the two orthogonally polarized linear radiators is a fairly difficult job. But even more important and even more difficult is the phase matching of the azimuth patterns.

The requirement for phase matching implies that the phase centers of the radiators of both polarizations must be coaxially located (or nearly so) which completely excludes combinations of vertical and horizontal radiating elements that are not located essentially on the same vertical axis. Combinations of vertical and horizontal elements that have a significant lateral displacement that will have a different polarization at each azimuth angle. See Fig. 1.

Andrew therefore has developed combinations of horizontally and vertically polarized radiating elements with very closely spaced phase centers. In order to produce a circularly or elliptically polarized field these elements are then interlaced within one aperture.

IX. CIRCULAR POLARIZED / ELLIPTICALLY POLARIZED ANTENNA CONFIGURATIONS

In order to produce circularly or elliptically polarized television antennas Andrew uses full aperture interlaced vertical/horizontal polarized elements. There are as many horizontal polarized as vertical polarized elements within the aperture. This assures that the vertical radiation pattern of the vertically polarized array closely matches the vertical radiation pattern of the horizontally polarized array. All radiators are coaxially located which assures azimuth phase match.

To produce circular polarization the energy coupled to the vertically polarized antenna section will be the same as that coupled to the horizontally polarized antenna section, that is 50% to each.

In order to produce elliptical polarization more energy will be coupled to the horizontally polarized antenna section than to the vertically polarized antenna section by the appropriate amount. In this manner it is possible to utilize the available transmitter output so that the optimum ratio of horizontal vs vertical polarization is radiated.

In many cases it turns out that there is more advantage to be gained by radiating less than the full possible ERP in the horizontal polarization in order to divert some of the energy available to the vertical polarizaton. Consider for example that diverting 20% of the available transmitter output power from the horizontal to the vertical polarization will reduce the ERP radiated in the horizontal polarization by approximately 1dB and increase the ERP radiated in the vertical polarization to be only 6dB below that of the horizontal polarization. This may be an excellent trade-off in that a 1dB reduction in ERP may look significant in terms of marketing but most likely is insignificant in terms of perceived performance, whereas providing close in users with a vertical field strength of only 6dB below that of the horizontal is a very significant improvement, especially at problem locations.

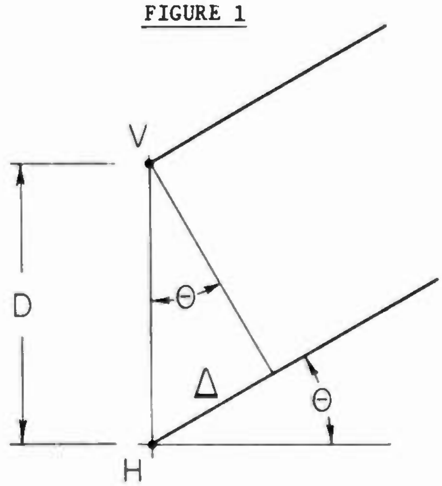
With the judicious selection of transmitter, transmission line and antenna parameters in may cases it will be possible to radiate either CP or EP with a significant level of vertical polarization.

SUMMARY

A well designed circularly or elliptically polarized UHF-TV transmit antenna appears to provide superior results in those areas where the receive location is blocked from having direct line of site. Providing both vertical and horizontal polarization assures a better chance of penetrating enclosures that may have a polarization selective wall and reaching blocked sites via reflection or refraction.

Experience seems to confirm this supposition. All transmit sites equipped with Andrew designed elliptically or circularly polarized antennas report excellent performance even in hard-to-reach areas. In fact the quality of reception is reported to improve over the entire service area. A user list of such Andrew antennas follows.

FIGURE 1



V = V POL PHASE CENTER

H = H POL PHASE CENTER

V TO H PHASE SHIFT = $\Delta = \frac{2\pi D \sin\theta}{\lambda}$

PHASE SHIFT MUST BE MINIMIZED BY MINIMIZING THE DISTANCE D

ANDREW CIRCULAR/DUAL/ELLIPTICALLY POLARIZED
ANTENNAS ON-AIR/UNDER CONSTRUCTION*

STATION	LOCATION	CH.	YEAR	INPUT POWER
KSPR-TV	Springfield, MO	33*	1985	119KW
KONG-TV	Seattle, WA	16*	1985	110KW
KPST-TV	Vallejo, CA	66	1985	110KW
KRRT-TV	Kerrville, TX	35	1985	118KW
KTZO	San Francisco, CA	20	1985	145KW
KCPM-TV	Chico, CA	24	1985	60KW
KMJD-TV	Pine Bluff, AR	38	1985	110KW
WGBS-TV	Philadelphia, PA	57	1985	120KW
KTZZ-TV	Seattle, WA	22	1984	75KW
WBFS-TV	Hollywood, FL	33	1984	119KW
WCAY-TV	Nashville, TN	30	1983	110KW
KIHS-TV	Los Angeles, CA	46	1983	110KW
WMKW-TV	Memphis, TN	30	1982	110KW
KINT-TV	El Paso, TX	26	1982	55KW
KXLI	St. Cloud, MN	41	1982	110KW
KYNE-TV	Omaha, NB	26	1980	60KW

TYPICAL UHF-TV RECEIVING LOOP ANTENNA MEASURED PATTERN DATA

The following azimuth pattern measurements were made in the Andrew California anechoic chamber to provide factual data concerning set-mounted loop antenna pattern characteristics.

A Radio Shack UHF-TV loop antenna was connected to the antenna terminals of a typical wood cabinet, 25" console television receiver with a horizontal chassis. A matching transformer was attached to the 300 ohm UHF twin lead input at the UHF tuner. The output of the matching transformer was connected to the anechoic chamber measurement instrumentation. A synchronized polar plotter recorded the attached field patterns as the TV receiver was rotated over 360 degrees. Three source signals were measured; linear horizontal polarization, linear vertical polarization, and right hand circular polarization. Overall receiver gain was maintained constant for horizontal linear polarization and vertical linear polarization measurements to insure the same dB levels.

Measurements were repeated for channel 14, channel 43, and channel 69 for three different loop antenna mounting positions. Position I (UP) was made with loop vertical (terminals at the bottom of the loop). Position II (FLAT) was made with the loop flat (terminals at the front of the loop, loop pointing away from the back of the receiver). Position III (SIDE) was made with the loop terminals on the left side (when facing the measurement source and the loop attached to the back of the television receiver at the antenna input terminal strip. All measurements are in relative dB field with each major division representing 2.5dB.

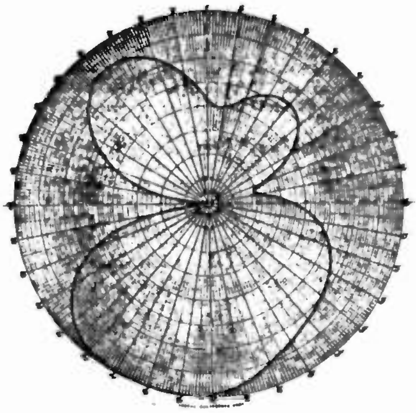
General conculsions are: (1) UHF loop receiving antennas do intercept vertical polarized radiation. (2) Circular polarizaiton provides the greatest probability of maximum received signal with random orientation or positioning of the loop receiving antenna.

MEASURED PATTERNS OF A UHF LOOP ANTENNA
INSTALLED ON A TYPICAL AMERICAN FAMILY TV SET

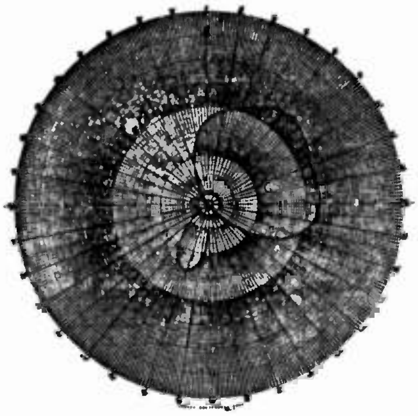
ANDREW

CHANNEL 14 WITH LOOP UP, FLAT, AND SIDE
HORIZONTAL, VERTICAL, AND RIGHT HAND CIRCULAR POLARIZED

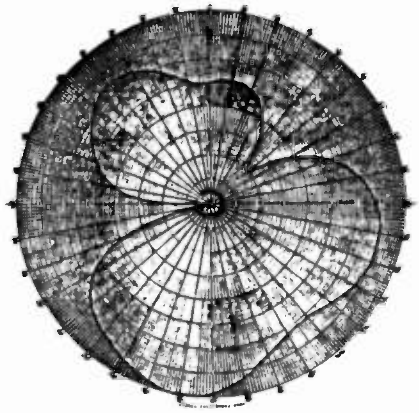
LOOP UP
HP SOURCE



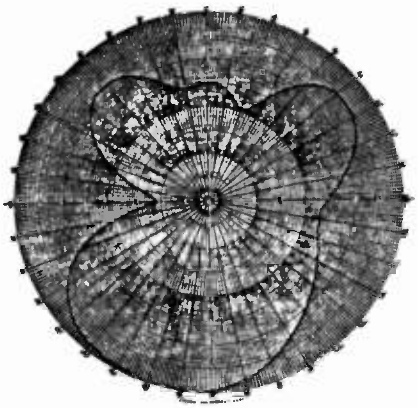
LOOP UP
VP SOURCE



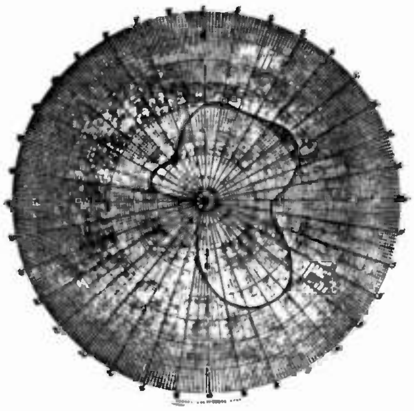
LOOP UP
RHC SOURCE



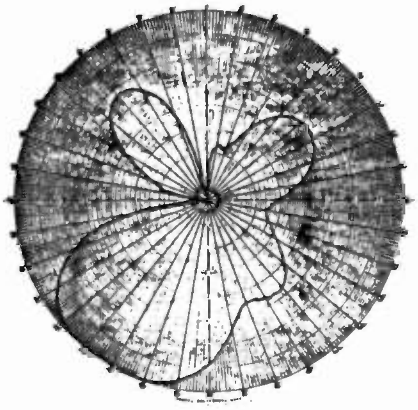
LOOP FLAT
HP SOURCE



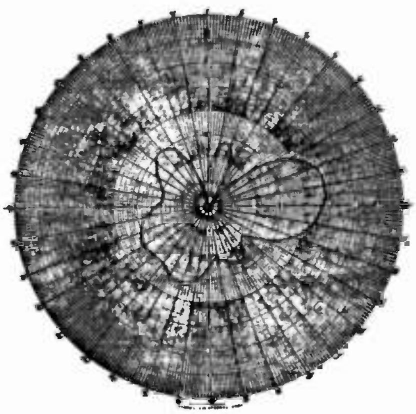
LOOP FLAT
VP SOURCE



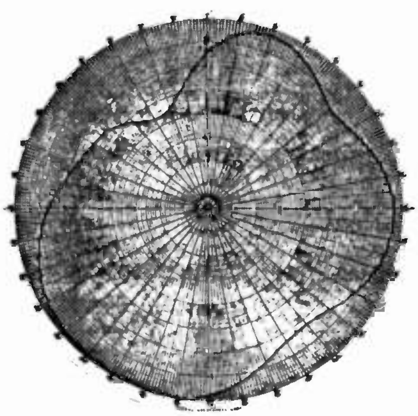
LOOP FLAT
RHC SOURCE



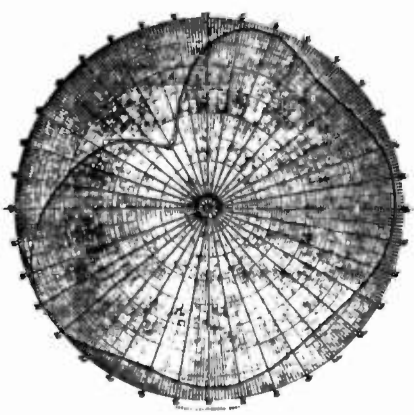
LOOP SIDE
HP SOURCE



LOOP SIDE
VP SOURCE



LOOP SIDE
RHC SOURCE



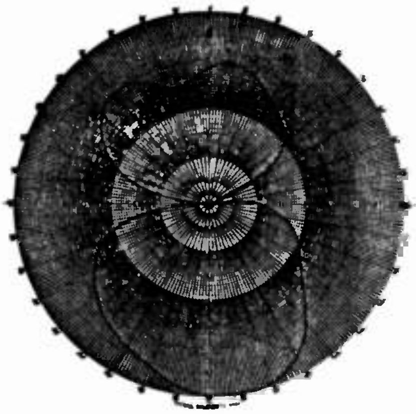
LTK/djo

MEASURED PATTERNS OF A UHF LOOP ANTENNA
INSTALLED ON A TYPICAL AMERICAN FAMILY TV SET

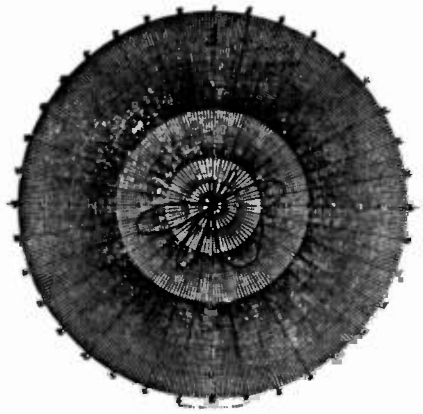
ANDREW

CHANNEL 43 WITH LOOP UP, FLAT, AND SIDE
HORIZONTAL, VERTICAL, AND RIGHT HAND CIRCULAR POLARIZED

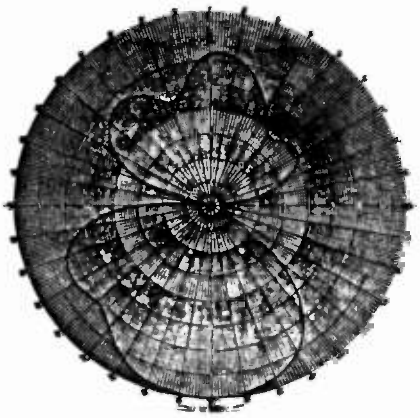
LOOP UP
HP SOURCE



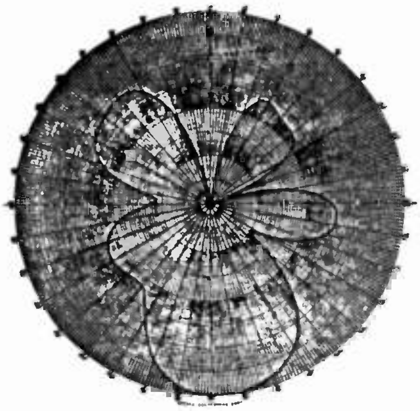
LOOP UP
VP SOURCE



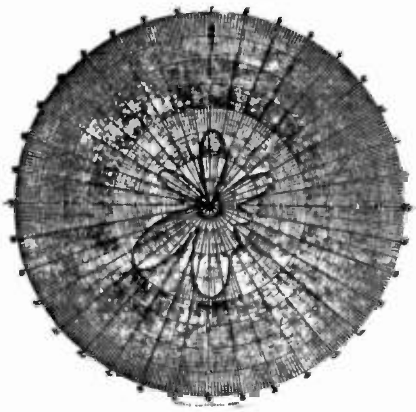
LOOP UP
RHC SOURCE



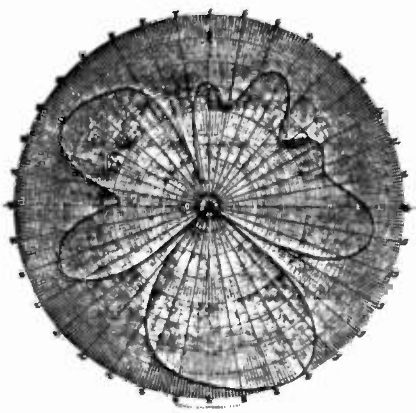
LOOP FLAT
HP SOURCE



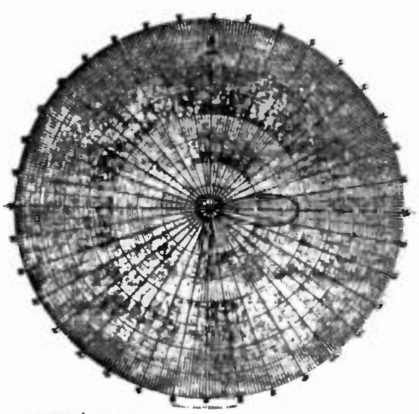
LOOP FLAT
VP SOURCE



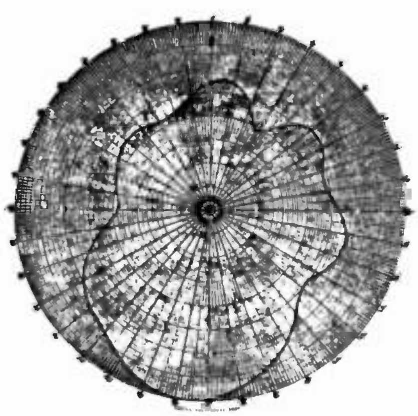
LOOP FLAT
RHC SOURCE



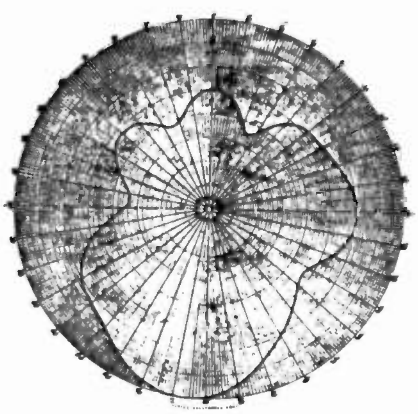
LOOP SIDE
HP SOURCE



LOOP SIDE
VP SOURCE



LOOP SIDE
RHC SOURCE



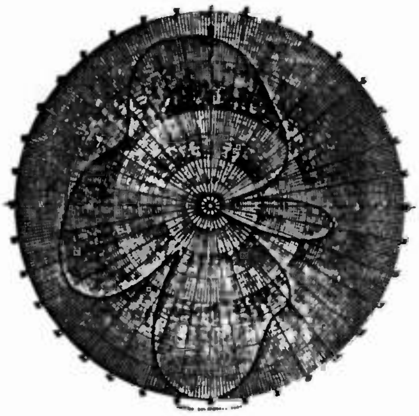
LTK/djo

MEASURED PATTERNS OF A UHF LOOP ANTENNA
INSTALLED ON A TYPICAL AMERICAN FAMILY TV SET

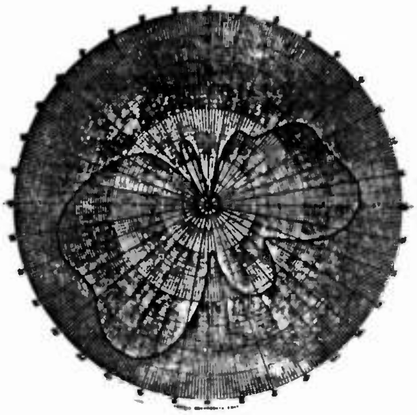
ANDREW

CHANNEL 69 WITH LOOP UP, FLAT, AND SIDE
HORIZONTAL, VERTICAL, AND RIGHT HAND CIRCULAR POLARIZED

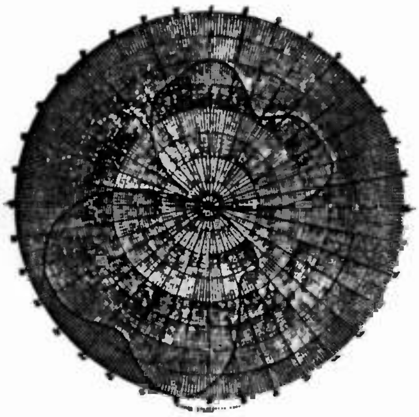
LOOP UP
HP SOURCE



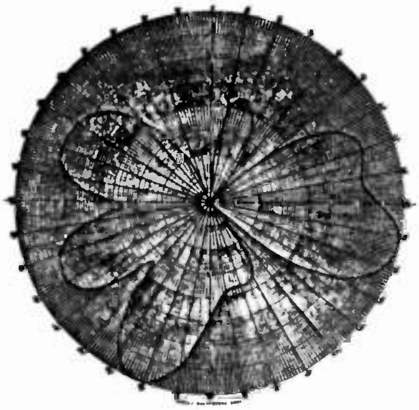
LOOP UP
VP SOURCE



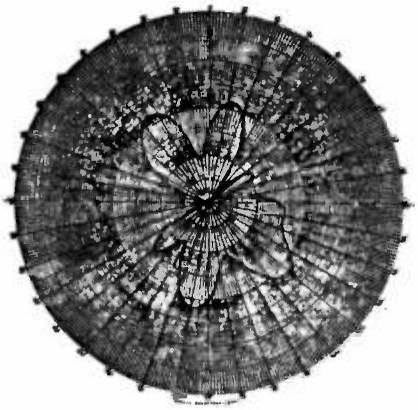
LOOP UP
RHC SOURCE



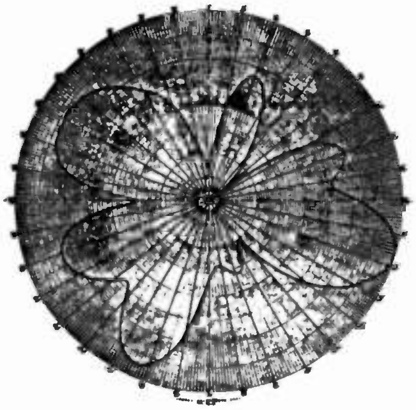
LOOP FLAT
HP SOURCE



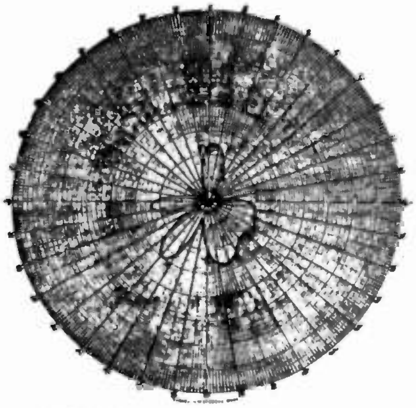
LOOP FLAT
VP SOURCE



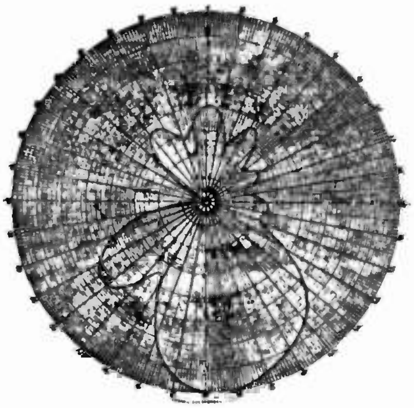
LOOP FLAT
RHC SOURCE



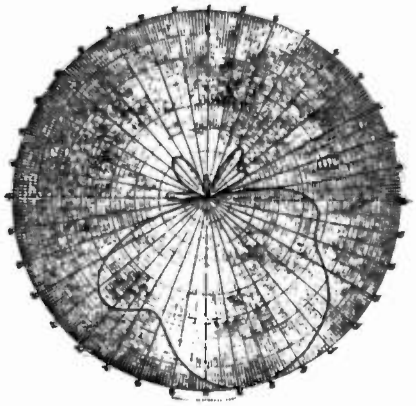
LOOP SIDE
HP SOURCE



LOOP SIDE
VP SOURCE



LOOP SIDE
RHC SOURCE



LTK/djo

MODERN DEVELOPMENT IN ENG TRACKING ANTENNA DESIGN

Sujay Verma
M/A-COM MAC, Inc.
Burlington, MA

INTRODUCTION

Autotracking of airborne targets over the last four decades has primarily been accomplished by using a sequential lobing, conical scan, and simultaneous lobing or monopulse type antenna systems. All these systems position in angle the particular antenna by a servomechanism actuated by an error signal.

In the field of electronic news gathering (ENG), the single axis or azimuth-only monopulse sequential-lobing type antenna systems have been in wide use in recent years. However, unlike manual or steerable antenna systems, these systems are inherently more expensive to build as they use more a complex antenna feeds and associated electronics to generate the error signal for antenna pointing.

The NAVTRACK™ subsystem described in this paper is designed to convert the existing M/A-COM Superscan™, Miniscan™, and Microscan™ steerable tracking antenna system to a dual-axis (azimuth and elevation) auto-tracking system. This system utilizes a more cost-effective approach to the design by making use of a relatively simple antenna feed system and eliminating the need for the electronics associated with monopulse type systems.

NAVTRACK™ employs a fully automatic AUTO-ACQUIRE feature to acquire a telemetry channel transmission from an airborne target. Having found the target, the telemetry data provides target bearing, range, and altitude information which allows NAVTRACK™ to dynamically position and maintain the antenna on boresight with the target.

The range and bearing data is generated by the LORAN-C Receiveror similar navigation computer, which is part of the M/A-COM SkyPod™ airborne tracking system. The altitude data generated by the altimeter encoder is multiplexed with the range and bearing data. After modulation, it is transmitted in the direction of the central receive station on an audio subcarrier, where the data is decoded and processed for positioning the ground antenna.

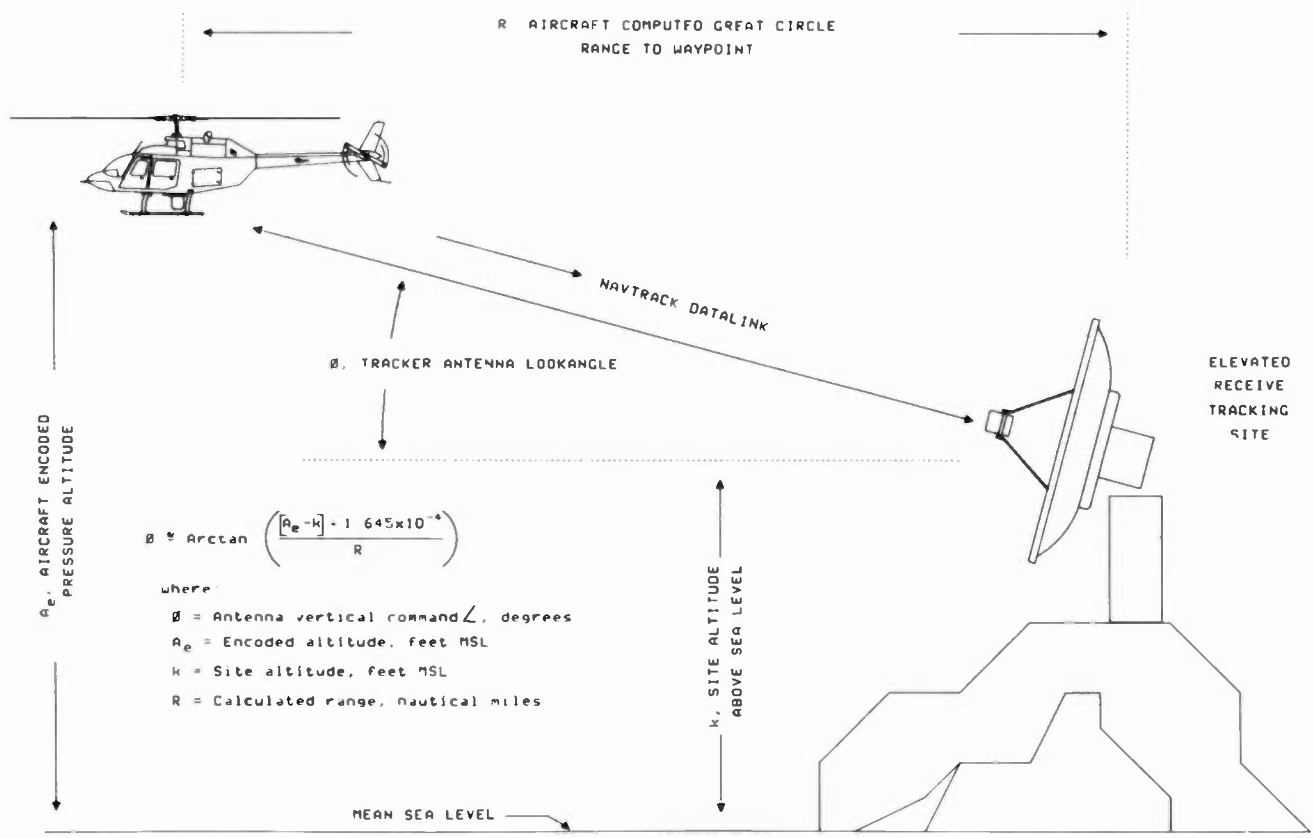
AIRBORNE EQUIPMENT

Figures 1 and 2 show the standard RF and NAV control block diagrams for the Airborne Sky-Pod™ ENG System. A complete description of the many different types of NAV systems and the operation of the SkyPod™ system is beyond the scope of this paper as it is well documented in individual equipment manuals.

The steerable dual-polarized antenna with 16 dBi gain shown in Figure 1 is steered in azimuth by an onboard slaved and stabilized compass/navigation system. The 3 dB beamwidth of the antenna at 2 GHz is normally 20° in azimuth and 30° in elevation. Wider elevation beamwidth helps to overcome the aircraft banking problem which normally occurs during fast heading changes. Polarization of the antenna is remotely selectable between vertical and circular. The steerable antenna can, after initial setup, automatically track a designated microwave receive (or transmit) ground site, independent of aircraft heading changes. However, the basic system has a major drawback that the antenna cannot adjust the required bearing as the aircraft position changes. A more accurate and trouble-free antenna steering system can be accomplished if the computed navigational data is directly coupled to the antenna servo drive loop. In such a design, as shown in Figure 2, the operator choosed to either manually control the antenna as described above or to let the NAV System drive it automatically. However, when the latter mode is selected or preset, no operator attention is normally required for repeatedly accurate results. Also, by using a suitable airborne navigational interface, the antenna steering becomes independent of aircraft heading and position which renders the system fully automatic and requiring no adjustment during a particular ENG operation.

Choice of a particular type of NAV equipment (Loran-C, VLF/Omega, etc.) is dependent upon the kind of coverage which exists in the area of operation and to some extent on the cost of the equipment.

Although the basic design of the NAVTRACK™ subsystem is based around LORAN-C, it can very easily be adapted to work with other types of NAV equipment as shown in Figure 3. The main reason for selecting LORAN-C is based on the fact that it is fully usable for low altitude rotocraft operations common to airborne ENG applications. Also, once accurate latitude and longitude coordinates for a designated receive site have been properly entered as a waypoint in NAV memory, consistently accurate antenna positioning becomes a reality. The system block diagram of SkyPod™ including the NAVTRACK™ Airborne Unit (NAU-1000) is shown in Figure 3. The NAVTRACK™ subsystem package consists of two units; an Altitude Encoder and a Data Multiplexer/FSK Modulator. The Data Multiplexer/FSK Modulator unit has been designed to accept serial range/bearing data from existing SkyPod™ NAV Bearing Convertor (BCN-100). It also receives and processes the altitude data from the



BASIC ALTIMETRY ELEMENTS, NAVTRACK ELEVATION MODE

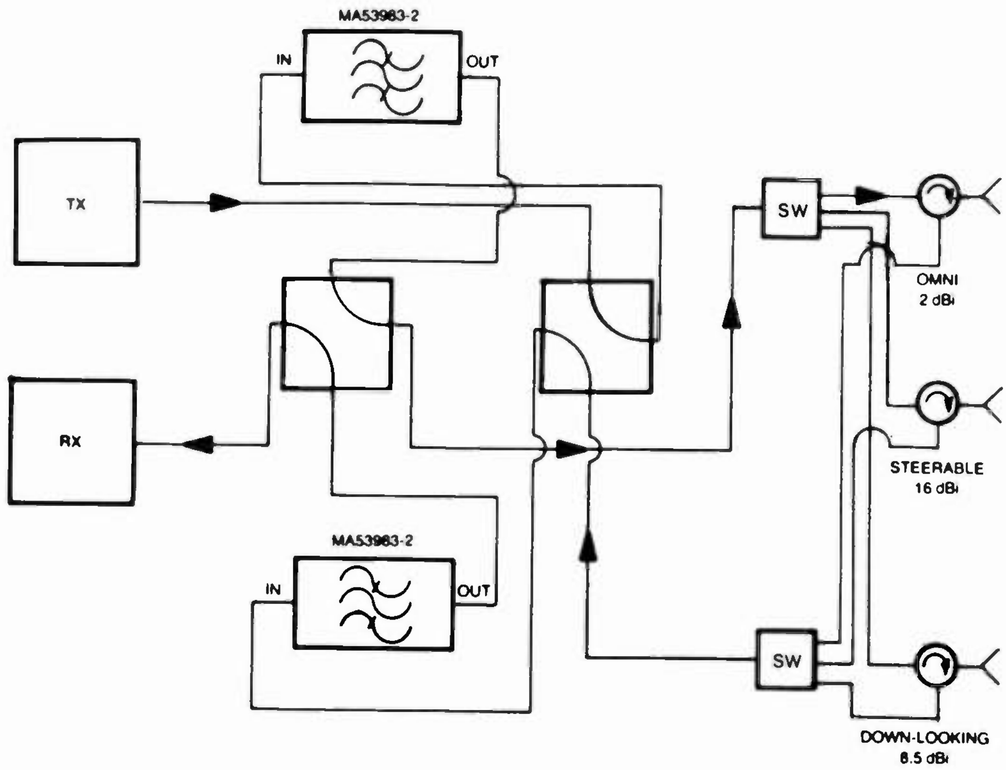


Figure 1. SkyPod™ RF System Block Diagram

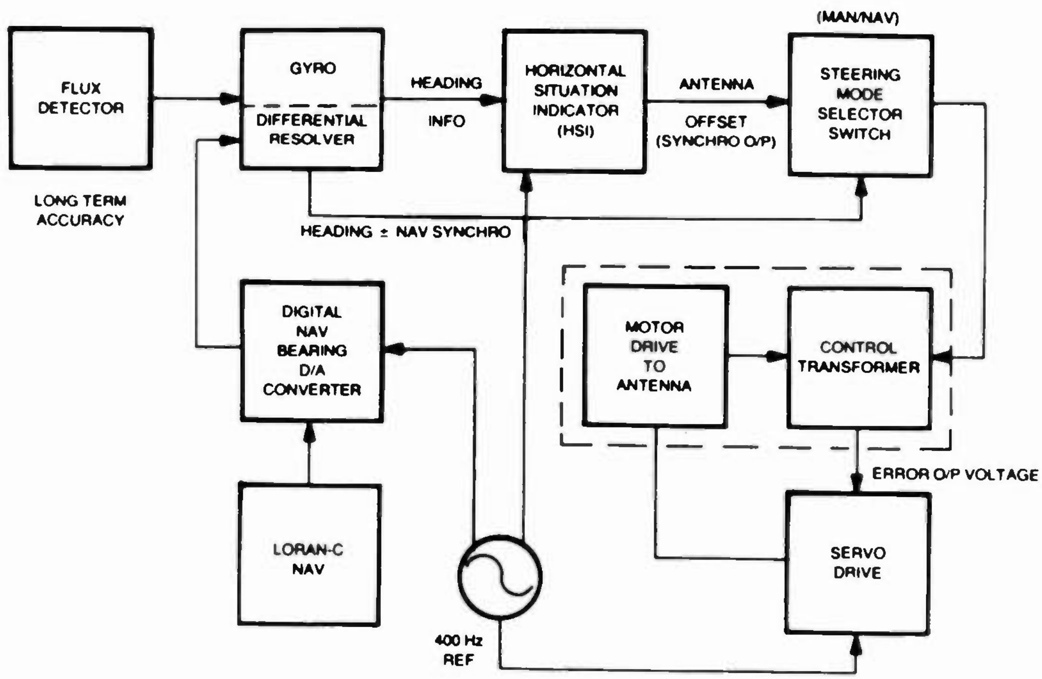


Figure 2. SkyPod™ NAV Control System Block Diagram.

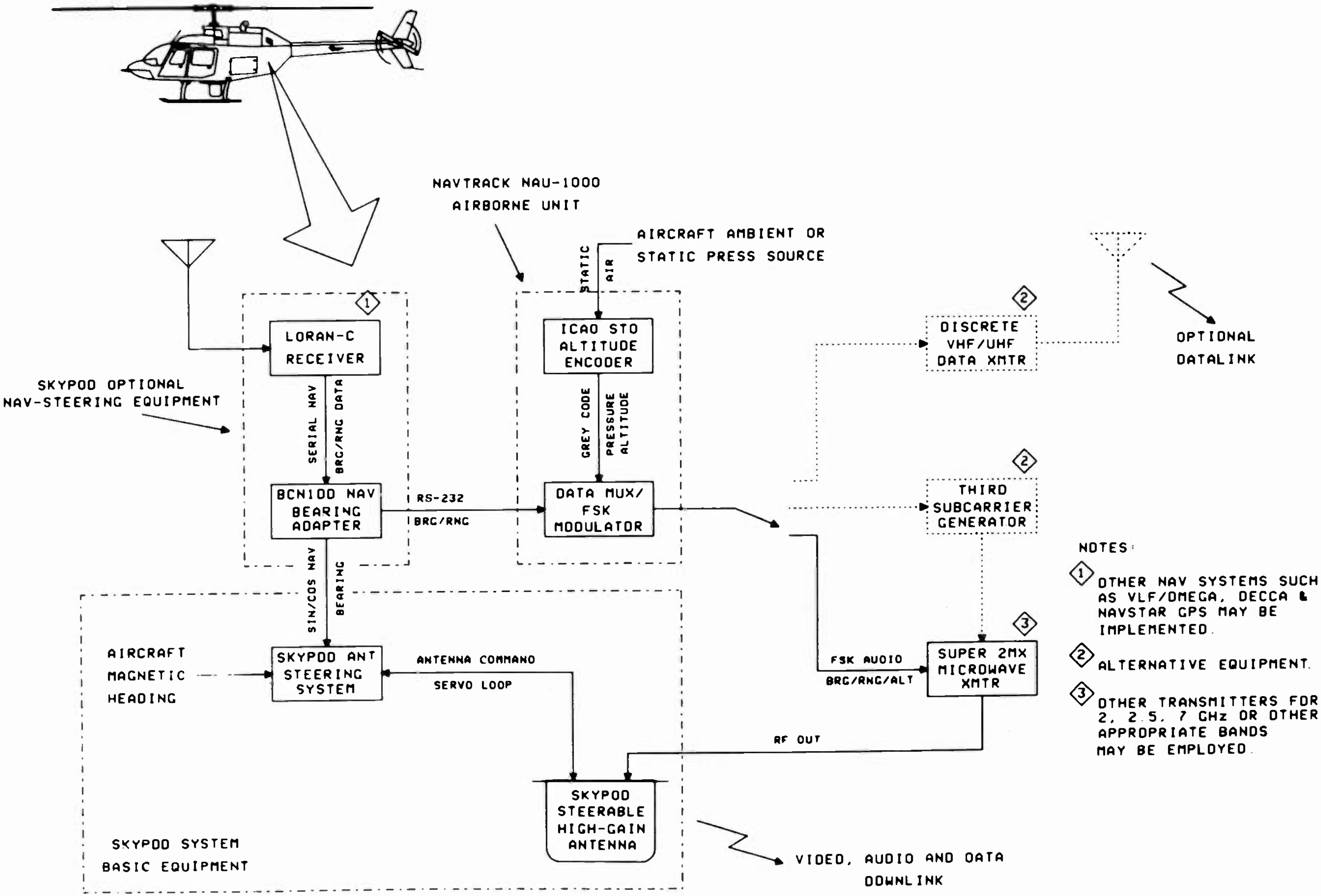


Figure 3. NAVTRACK™ Airborne Subsystem Block Diagram

altitude encoder and provides the multiplexed modulated data output at a rate of 1200 baud for downlinking. The combined range/bearing data output from the multiplexer in serial digital RS232C format is updated approximately every one second regardless of any change in input parameters. A data update rate of one second has been chosen to satisfy the requirement for maximum rate of change of range/bearing and altitude, which may be encountered in any practical situation in an ENG operation.

The multiplexed data is fed to one of the audio inputs of the M/A-COM Super 2MX or MA-2MX Transmitter downlinking via the steerable high gain antenna. Provision is also made for a dedicated audio channel or a VFH/UHF data link in the event that existing audio channels cannot be made available for transmitting NAVTRACK™ data (Figure 3).

GROUND EQUIPMENT

The M/A-COM Superscan™, Miniscan™ and Microscan™ tracking antenna systems are designed to track an airborne target. They use a microprocessor-based controlling the antenna positioning system in both steerable and monopulse autotrack versions.

The main drawback of a steerable-only system is that it requires a continuous manual adjustment in both azimuth and elevation of antenna position in order to keep the target on antenna boresight. Even in the case of the autotrack versions, the operator has to initially acquire the target using the manual controls before switching to automode. Initial acquisition of target invariably requires considerable effort as both the airborne and ground antenna positions have to be adjusted simultaneously. Also the operators at both ends (airborne and ground) have to be in constant communication with each other in order to maximize the received signal strength before transfering the control from manual to auto-mode.

Performance of this type of autotrack system is adequate as long as the changes in elevation angle remain within a few degrees as the antenna autotracks only in the azimuth plane. The actual limit of variation of elevation angle for a satisfactory performance is mainly dependent upon the particular ground system in use.

The NAVTRACK™ system has been designed to overcome most of the constraints encountered in the monopulse or sequential lobing type autotrack systems. It offers a low-cost solution to the autotrack problems as well as providing a more user-friendly system.

Figure 4 shows a block diagram of the ground-based NAVTRACK™ subsystem together with a typical interface to existing ground-based central receive systems. The NAVTRACK™ option to the Superscan™, Miniscan™, and Microscan™ systems provides the capability for dual-axis tracking of an airborne target. It employs a fully automatic AUTO-ACQUIRE algorithm to acquire a telemetry channel transmission from the target. In the standard system, range/bearing and altitude data, after reception, is processed and decoded by the NAVTRACK™ Ground Unit (NGU-2000) and presented to the MAC-200 Slave Controller to generate the appropriate command signal to the antenna positioning system.

As in the case of the NAVTRACK™ Airborne Unit, the NGU-2000 has been designed to accept a composite video signal as used in the case of a dedicated NAV data audio channel or a VHF/UHF data link signal.

The NAVTRACK™ Data Processor Unit located inside the MAC-200 Slave Controller is designed to generate appropriate drive signals associated with an individual antenna drive system. Using the range and altitude data, the Data Processor Unit computes in real time the acutal ground antenna elevation angle to the airborne target after allowing for the site height correction, which can be implemented by setting the switches located inside the MAC Slave Controller. The ground antenna azimuth angles are computed from the received bearing data.

Various modes of operation of the NAVTRACK™ System, shown in Figure 5, are described in the following paragraphs including certain exceptions which apply to Microscan™ systems.

MANUAL STEER. In this mode, the antenna azimuth and elevation can be manually controlled locally by operation of the joystick; from the Master site by operation of the AZ and EL slew buttons; or via the use of dialed AZ and EL positioning commands. MANUAL STEER MODE is entered upon application of power to the MAC-200 Remote Controller, upon actuation of the "MAN" front panel button, or upon failure of AUTO-ACQUIRE sequence to acquire the NAVTRACK™ signal. In MANUAL STEER MODE, the "MAN" front panel display is ON, the "AUTO" display is OFF, and the AZ and EL readouts display the current antenna position.

NAVTRACK™ MODE. This mode is entered from MANUAL STEER MODE if navitation data is available when the "AUTO" button is actuated. Also, NAVTRACK™ MODE is entered automatically if navigation data becomes available while in AUTO-ACQUIRE or SECTOR-SEARCH modes. In NAVTRACK™ MODE, the manual steer antenna positioning controls continuously adjusted to the position specified by the most recent navigation data. If the navigation data becomes unavailable, antenna movement is suspended and the current position is maintained until data again becomes available, or until a one second data-loss timeout occurs. If data again becomes available, normal NAVTRACK™ MODE

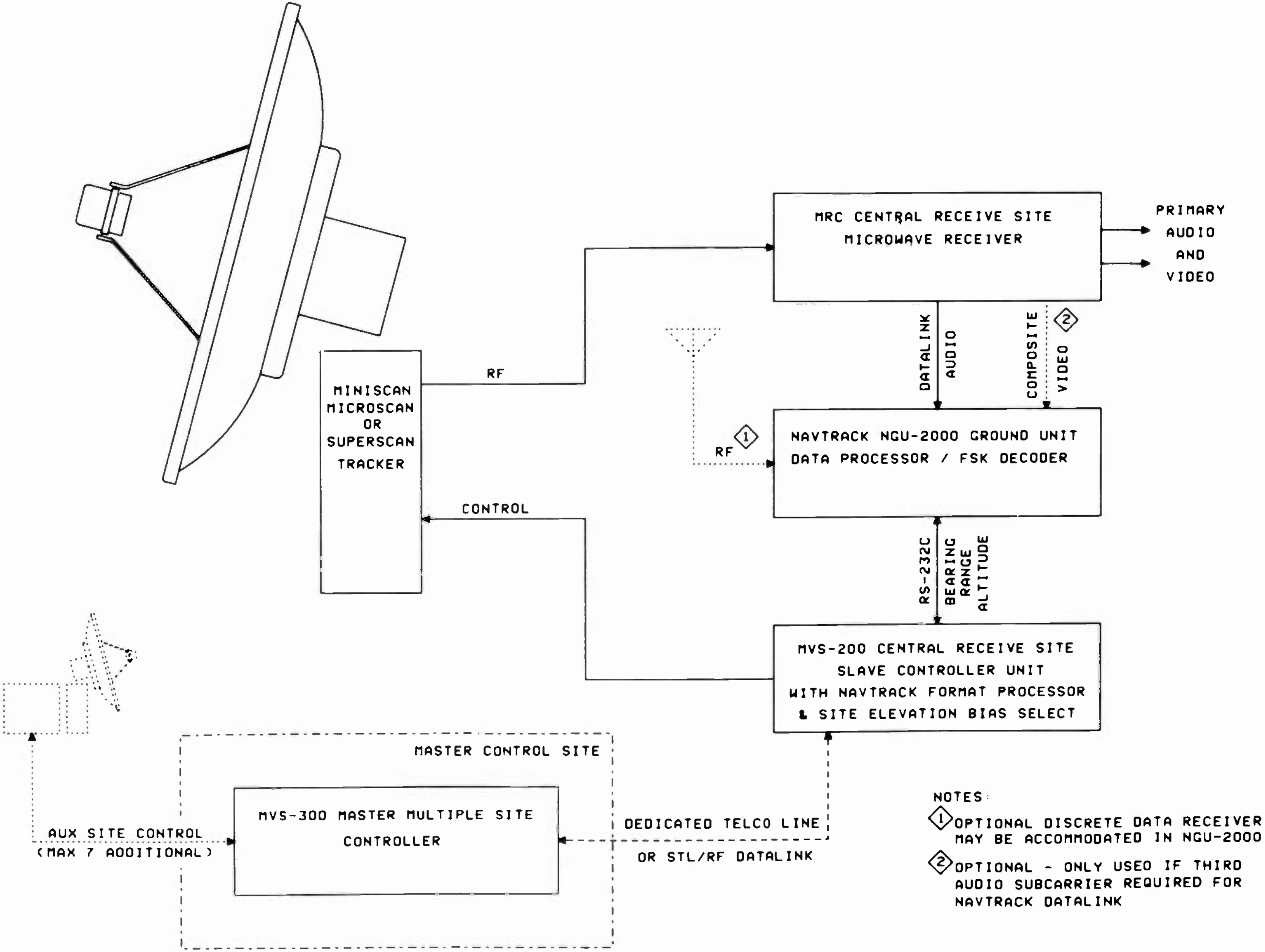


Figure 4. NAVTRACK™ Ground-Based System Block Diagram

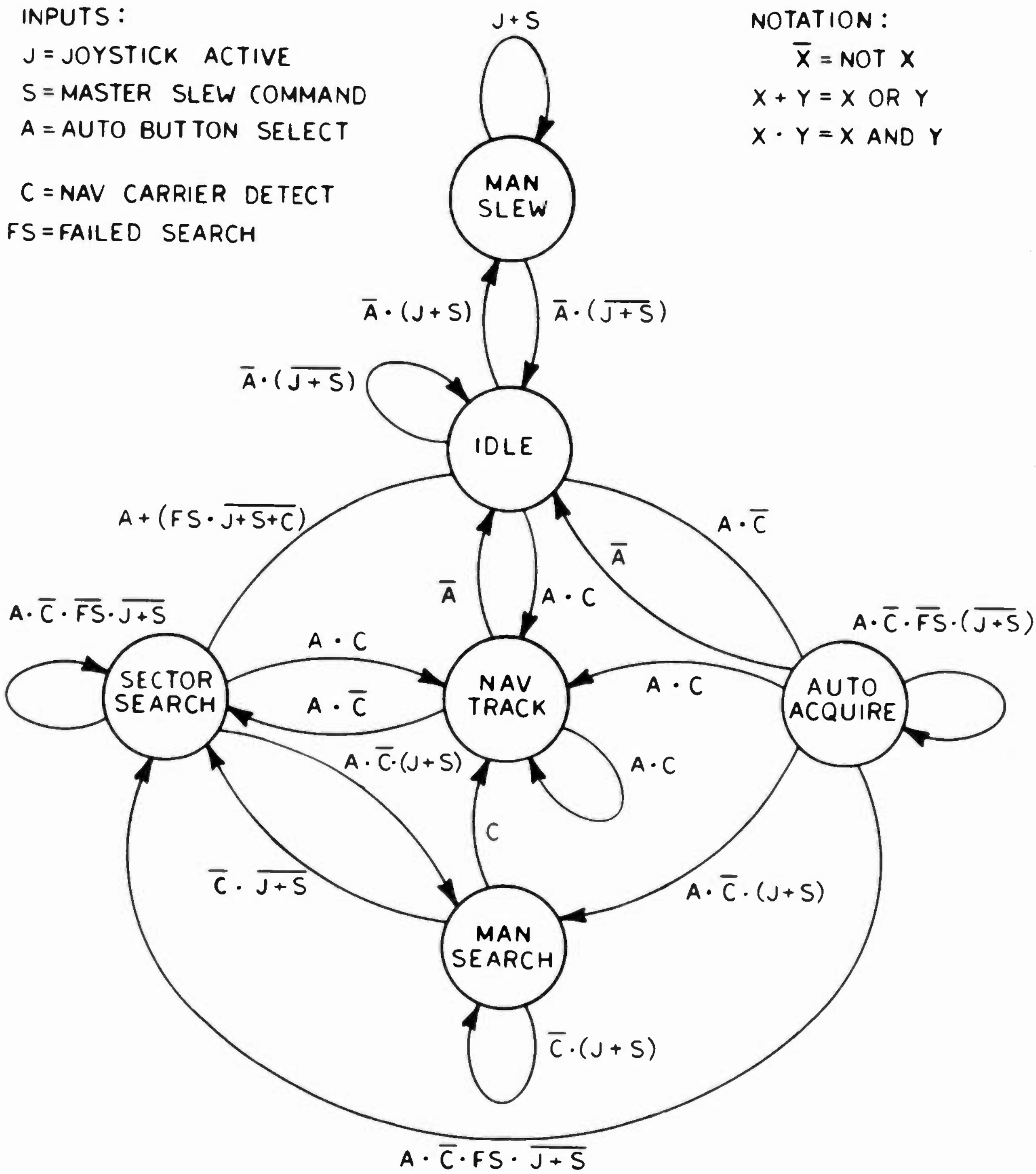


Figure 5. NAVTRACK™ Mode Transitions

operation is resumed: However, if the timeout expires and data has not again become available, SECTOR-SEARCH MODE is automatically entered. NAVTRACK™ MODE is exited if the "MAN" button is actuated or if a data-loss timeout occurs. In NAVTRACK™ MODE, the "MAN" display is OFF, the "AUTO" display is ON, and the AZ and EL readouts display the current antenna position.

In systems equipped with a MICROSCAN™ pedestal, an azimuth limit exists, imposing a 4° deadband in which the antenna cannot be positioned. Should the target enter the deadband, the antenna will remain at the deadband boundary until the target crosses the center of the deadband. If the navigation data remains available, the antenna commences a "reverse" slew to the opposite deadband boundary in an attempt to recover the target. If data is lost, however, AUTO-ACQUIRE is used to recover the target.

AUTO-ACQUIRE MODE. This mode is entered from MANUAL STEER MODE if the "AUTO" front panel button is actuated by the operator while navigation data from the telemetry channel is not available to the MAC-200 Remote Controller. AUTO-ACQUIRE MODE may also be automatically entered if SECTOR-SEARCH fails to find the target before exhausting its limited-angle search pattern. In AUTO-ACQUIRE MODE, the antenna positioning functions of MANUAL STEER MODE remain active to allow the operator to manually position the antenna to the approximate target location. The operator may steer the antenna until navigation data becomes available, or he may relinquish manual control to the automatic SECTOR-SEARCH mechanism once the antenna has been placed in the general vicinity of the target. During AUTO-ACQUIRE, the antenna continually moves in the spiral rectangular search pattern, covering a 360° azimuth sector with incrementing elevation steps attempting to locate a position where navigation data becomes available. AUTO-ACQUIRE is terminated if the operator activates the manual steer controls, if the MAN button is actuated, if the telemetry data becomes available, or if the search sequence is exhausted. While in AUTO-ACQUIRE MODE, the "MAN" display is OFF, the "AUTO" display is ON and the AZ and EL readouts display the current antenna position.

SECTOR-SEARCH MODE. This mode is entered from NAVTRACK™ if navigation data is lost, or from AUTO-ACQUIRE MODE if the joystick is temporarily actuated to steer the antenna to the approximate position of the target. The SECTOR-SEARCH mechanism activates automatically if manual controls are deactivated and remain inactive for an interval of one second. During SECTOR-SEARCH, the antenna continually moves in a spiral rectangular search pattern attempting to locate a position where navigation data becomes available. During the spiral search, the antenna scans a ± 10° azimuth arc and an increasing elevation angle arc. The elevation scan starts at 1° and increases by 1° on each azimuth scan, reaching a maximum elevation scan of ±5°. SECTOR-SEARCH is terminated if the operator activates the manual steer controls, if the MAN button is actuated, if the telemetry data becomes available, or if the search sequence is exhausted. While in SECTOR-SEARCH MODE, the "MAN" display is OFF, the "AUTO" display is ON and the AZ and EL readouts display the current position.

SYSTEM PERFORMANCE

The overall accuracy of the NAVTRACK™ System is primarily dependent on two factors:

1. accuracy of the LORAN-C
2. accuracy of the altimeter.

The obsolute accuracy of the LORAN-C system varies from 0.1 nm (nautical mile) to 2.5 nm depending on the location within the coverage area. However, as the repeatable accuracy variance is typically less than 0.01 nm, the error in computed bearing angle can be considered insignificant.

The altimeter-encoder used in the NAVTRACK™ System is sensitive to the atmospheric pressure and temperature changes. The altitude data available from this unit in the standard system uses a pressure value of 1013.25 millibars (29.9213 in Hg) at a temperature of 15°C (59°F). As pressure and temperature vary, it causes the altitude data of the target to deviate from the true value. Also the encoder itself may contribute to tracker elevation errors as it has a tolerance of ±50 feet with a 100 foot resolution.

Although pressure error-producing effects, and to some degree some of the temperature, could be largely eliminated by sensing the atmospheric pressure at both the airborne and the known ground site. This is deemed unnecessary as the elevation error is expected to be approximately ±0.5° for a typical variation in weather pattern.

It has been shown that the M/A-COM steerable antenna system, when used in conjunction with NAVTRACK™ System, has considerable advantages over any tracking system currently in use for ENG operations; as it is capable of fully automatic operation requiring no initial setup time either at the airborne or ground end of the system. Also, use of this system eliminates the need for an experienced operator to be present during the ENG operations.

SPECIFICATIONS	SUPERSCAN II™	MINISCAN II™	MICROSCAN™
General	High performance, heavy duty tracking antenna system for maximum range and reliable operation in hostile environments.	Lightweight tracking ENG antenna system with downlook capability that is ideal for terrestrial links.	Very lightweight, dual band tracking antenna system. Transmit mode available for mobile applications.
Operating Frequency Band			
Steerable or Navtrack	1.990 to 2.110 GHz 2.450 to 2.500 GHz 6.425 to 6.525 GHz 6.875 to 7.125 GHz	1.990 to 2.110 GHz 2.450 to 2.500 GHz 6.425 to 6.525 GHz 6.875 to 7.125 GHz	1.990 to 2.110 GHz 2.450 to 2.500 GHz 6.425 to 6.525 GHz 6.875 to 7.125 GHz
Antenna Options			
Type	6 foot parabolic	2 x 4 foot truncated parabolic or 4 foot diameter parabolic	29.5 inch diameter (0.75M) offset reflector
Gain			
@2 GHz	31 dBi	26 dBi (4 Ft.) 24 dBi (2x4 Ft.)	21 dBi
@7 GHz	39 dBi	36 dBi (4 Ft.) 34 dBi (2x4 Ft.)	32 dBi
Gain (−3 dB Beamwidth/°)			
@2 GHz	6.3	7.7 (4 Ft.) 7.0 (2x4 Ft.)	11.5
@7 GHz	1.7	2.2 (4 Ft.) 2.0 (2x4 Ft.)	3.7
Polarization	vertical, horizontal, right or left circular, selectable	vertical, horizontal, right or left circular, selectable	vertical, horizontal, right or left circular, selectable
Azimuth Coverage	360° continuous, motorized	360° continuous, motorized	0-355° motorized
Slew Rate			
Navtrack	10°/sec maximum	10°/sec maximum	10°/sec maximum
Manual Tracking			
From Slave	0 to 12°/sec, continually variable	0 to 12°/sec, continually variable	0 to 11°/sec
From Master	4°/sec (slow), adjustable* 10°/sec (fast), adjustable*	4°/sec (slow), adjustable* 10°/sec (fast), adjustable*	3.5°/sec (slow), adjustable* 10.5°/sec (fast), adjustable*
Tracking Accuracy	± 1.0° nominal	± 1.0° nominal	± 1.0° nominal
Elevation Tilt	+ 15 to − 25° motorized	+ 20 to − 25° motorized (4 Ft.) + 40 to − 5° motorized (2x4 Ft.)	+ 25 to − 15° motorized
Low Noise Preamplifiers (Optional)			
2 GHz	1.6 dB NF at 24 dB or 35 dB gain	1.6 dB NF at 24 dB or 35 dB gain	1.6 dB NF at 24 dB or 35 dB gain
7 GHz	3.0 dB NF, 30 dB gain	3.0 dB NF, 30 dB gain	3.0 dB NF, 30 dB gain
Others	bypass control, switchable 7 GHz Block Downconverter	bypass control, switchable 7 GHz Block Downconverter	bypass control, switchable 7 GHz Block Downconverter
Power Requirements			
Voltage			
Standard	115 Vac, 50 to 60 Hz	115 Vac, 50 to 60 Hz	115 Vac, 50 to 60 Hz
Optional	230 Vac	230 Vac	230 Vac
Consumption (@115 Vac)			
With Heater	1.75 kW	1000W	450W
With Heated Radome	3.75 kW	2 kW	–
Weight	400 lbs.	155 lbs.	95 lbs.
Environmental (Pedestal)			
Temperature			
Operating	−30 to +70°C	−30 to +70°C	−30 to +70°C
Storage	−50 to +85°C	−50 to +85°C	−50 to +85°C
Humidity	0 to 95%, no condensation	0 to 95%, no condensation	0 to 95%, no condensation
Wind Load			
Operating	60 mph	60 mph	60 mph
Survival	125 mph	125 mph	125 mph

*Approximate preset speed.

SUPERSCAN™/MINISCAN™/MICROSCAN™ SPECIFICATIONS

ANTENNA CONTROLLERS

Master/Slave Telco Interface .... dedicated Telco 2-wire or 4-wire unconditioned (USOC Series 3202)

Power Requirements
- Standard .... 115 Vac, 50 to 60 Hz
- Optional .... 230 Vac

Environmental
- Temperature
  - Operating .... 0 to 40°C
  - Storage .... −20 to +60°C
- Humidity .... 0 to 95%, no condensation

Master/Slave Mounting .... 3 vertical rack spaces, 19 inch rack

WINTERIZING KITS (Optional)

Radomes .... antenna dish heated or unheated or total enclosure; not available on 2 x 4 dish.

COMPATIBLE CENTRAL ENG RECEIVERS (Optional)

MA-MRC .... 2/2.5 GHz bands (inclusive), 7 GHz optional, 30 RF Channels, 3 IF Bandwidths (10, 15, and 20 MHz), remote subcarrier frequency control

CONTROLS AND INDICATORS

MAC-200 Slave Controller
- Analog Meters .... 2: signal strength and tracking error
- Digital Displays .... 2: azimuth and elevation
- Joystick
  - Azimuth .... slew right/left
  - Elevation .... up/down
- Pushbutton Switches .... polarization: vertical, horizontal, right/left circular; automatic or manual mode; local or slave control; lamp test or communication lock; power ON/OFF; LNA bypass; band

MAC-300 Master Controller (Optional)
- Analog Meters .... 2: signal strength and tracking error
- Digital Displays .... 3: azimuth, elevation, and RF channel
- Pushbutton Switches .... two banks of 16 switches (each) plus power ON/OFF switch provide control/status of up to 8 different (optional) ENG receive sites; 8 memory preset positions per site Az/El

Some other control functions include .... local control indicator; auto/manual mode; azimuth (slew right/left–fast/slow); antenna polarization select; RF channel select; and 16 digital and 4 analog functions such as tower lights, heaters, air conditioning, and illegal entry.

All specifications are subject to change without notice.

SKYPOD II™ SPECIFICATIONS

STEERABLE DUAL DISC-ROD™ RADIATORS

Frequency Bands
- Standard .... 1.990 to 2.110 GHz
- Optional .... 2.300 to 2.690 GHz

Beamwidth (−3 dB)
- Horizontal Azimuth .... 20° nominal
- Vertical .... 30° nominal

Antenna Gain .... 16 dBi

VSWR .... 1.5:1 maximum

Polarization .... vertical and right-hand circular (switchable)

OMNI-DIRECTIONAL, HORIZONTAL-LOOKING ARRAY

Frequency Bands
- Standard .... 1.990 to 2.110 GHz
- Optional .... 2.300 to 2.690 GHz

Antenna Gain .... 2 dBi nominal

VSWR .... 1.5:1 maximum

Polarization
- Standard .... right-hand circular
- Optional .... left-hand circular

DOWN-LOOKING ANTENNA

Frequency Bands
- Standard .... 1.990 to 2.110 GHz
- Optional .... 2.300 to 2.690 GHz

Beamwidth (−3 dB) .... 60° nominal

Antenna Gain .... 8.5 dBi

VSWR .... 1.5:1 maximum

Polarization
- Standard .... right-hand circular
- Optional .... left-hand circular

ENVIRONMENTAL

Temperature Range .... −20° to +130°F

Shock and Vibration .... as encountered with normal helicopter operation

Humidity and Salt Spray .... the unit is sealed against hostile environmental conditions

SKYPOD II™ SYSTEM SUB-ASSEMBLIES

Antenna Pod Unit
Control Display Unit
Horizontal Situation Indicator
Directional Gyro
Magnetic Flux Detector
Remote Slave Panel
Servo Drive Unit

All specifications are subject to change without notice.

NARROW DEVIATION AURAL STL SYSTEMS RELIEVE BROADCAST AUXILIARY FREQUENCY CONGESTION

Michael D. Callaghan
KIIS AM/FM - Los Angeles, California
Barry Victor
The Victor Group - Los Angeles, California

(ABSTRACT: This paper presents a proposal to add narrow deviation microwave channels to the existing 950 MHz. S.T.L. band in an effort to relieve congestion. A tentative band plan is advanced, and the results of field tests are covered.)

Trying to locate a vacant aural microwave channel in a market like Los Angeles has historically been a vain and frustrating task. There just aren't any left to be found.

For decades, this area has been one of the most congested S.T.L. markets in the country. We not only have the problem with most of the F.M. transmitters being bunched at Mt. Wilson, but we are also faced with a deluge of A.M. stations spread out around the basin. Each available channel is used by a number of stations, and any possibility of squeezing more users on any of them is remote.

The recent arrival of A.M. stereo and the unbelievable increase in the cost of phone lines have made it that much more imperative that as many stations as possible be accommodated in the microwave spectrum.

For years we have naively sat back and thought that the Commission was going to help us find more space; we felt secure that they'd allot more channels either close to the 950 MHz band, on unused UHF channels, or in other bands.

Users aren't the only ones taking part in this misconception - manufacturers have even had 1.8 Ghz export equipment ready on the shelf waiting for that band to open. They're still waiting, and it's still on the shelf.

Those of us that thought 950 would be opened up are finding just the reverse; cutbacks are taking place. Now, those of us below 945 are being left with no place to go.

As A.M. stereo unfolds into prominence, it becomes increasingly important for A.M. facilities to take advantage of microwave technology.

The main problem, again, is that the channels just aren't available.

Recent tests by the Southern California Frequency Coordinating Committee reveal that there may be a way around this problem by using narrow deviation technology.

Advances in S.T.L. receiver design, including superior I.F. filter factors, better selectivity, and improved front ends work together to allow fully acceptable performance from narrow deviation systems. Marti Radio regularly exports microwave transmitters with just +/- 25 kHz. deviation to foreign countries. (In contrast to the some +/- 60 kHz. deviation most systems employ.) Two of these narrow systems will fit into a 100 kHz. wide channel, offering stereo capabilities in one-fifth the spectrum currently allotted for a single microwave system.

Noteworthy also is the fact that most users of microwave channels don't occupy the whole spectrum they're assigned. A full composite system with subcarriers rarely exceeds 375 Khz. of bandwidth. This means there should be about 250 Khz. of space between two adjacent channels. In theory, this could support as many as four of the narrow deviation systems, although two seems more practical.

A proposed band plan to add these channels is shown in Figure A. Current 950 MHz S.T.L. assignments are 500 kHz. apart. By inserting two new 'narrow deviation' channels between each of these allocations, we would gain an additional 30 channels. This plan provides for existing composite and dual split licensees to remain, although future split applicants may be requested to reduce offsets to 100 kHz. above and below the channel center rather than the now prevalent 125 kHz. This would provide further guard band protection.

(The Commission has issued a Notice of Proposed Rulemaking, (Docket # 85-36) to break the 950 band into 25 kHz. segments. As such, each of the narrow band channels could be assigned two of these segments. A stereo licensee could receive two for the lower channel, two for the upper, and two in the center for a guard band. This makes six total, for a maximum combined bandwidth of 150 kHz.)

The new narrow deviation systems would require tighter frequency specifications than current units. To avoid the transmitter wandering out of the receiver passband, or the receiver drifting off channel, maximum drift would probably be best limited to +/- 5 kHz. This corresponds to a tolerance of .0005 %. Seeing that current production 950 MHz. transmitters typically hold frequency to within 3 kHz., the tighter restriction should pose no problem. New generation I.F. filters promise sufficient adjacent channel rejection from other narrow-deviation systems. There is nothing lacking in current technology to keep this concept from working.

So it was with a great deal of enthusiasm that recent tests were conducted by the committee to see how effective narrow deviation microwave systems could be toward solving our congestion.

A group of tests were run on the 15.4 mile path between Hollywood and Mt. Wilson during May, 1985, using two sets of export equipment obtained from Marti Radio. The specifications Marti supplied looked encouraging. It seemed we could expect excellent results with even weak received signals. (See Figure B.) This data was confirmed with bench tests indicating that using deviations of +/- 15 kHz., a recovered signal strength of just 50 uv. was enough to obtain 60 db. signal to noise from the receiver.

The two systems used in the tests (Marti T-10's and R-10's) were set for deviations of 25 Khz. and 50 Khz., using 75 uSec deemphasis. The results measured confirmed the plausibility of the idea.

From the 25 kHz. system, signal to noise ratios in excess of 66 db. were achieved, with a worst case harmonic distortion of less than 0.7 percent. The 50 kHz. system was only marginally better. This performance is entirely satisfactory for one channel of an A.M. stereo station. (See Figure C.) Two cross-polarized channels could carry complete stereo programming within a 100 Khz. spectrum allocation.

The results were promising enough that the test data was included in a filing the Society of Broadcast Engineers made in response to Docket 85-36 in June. It was the only set of field measurements filed in response to that Docket.

To simulate worst case conditions, another set of measurements between Hollywood and the KFWB transmitter site 8 miles away in Montecito Heights, near Dodger Stadium, were run. The signal grazed over the top of a hill, and the received signal strength was just 50 uv. We found similar promising audio results, but the location and height of the receiver dish was critical in preventing multipath interference.

The significance of coordination was brought home during a third set of experiments, however. Using some prototype narrow band equipment from T.F.T. and once again shooting from Hollywood to Mount Wilson, the tests were suspended because a station operating a composite system on an adjacent channel 250 KHz. away complained of interference. Both systems were using the same polarization. The earlier tests in which KIIS and the test frequency were separated by a mere 125 KHz. caused no problem to the composite KIIS PCL-606/C system, even though the polarizations were also the same. It's now evident that painstaking selection of frequencies, high performance antennas, evaluation of the performance of existing equipment on adjacent frequencies, cross polarization and complete path and power engineering studies will be necessary to achieve the success we seek.

Even considering these efforts, the potential advantages far offset the disadvantages. It's been years since new channels were available to Los Angeles broadcasters, and this development promises to allow many stations new independence in operating without the restrictions of leased phone lines.

Research and further tests continue on this concept. A number of S.T.L. manufacturers are exploring narrow deviation systems and cooperating in the tests. By this time next year we envision narrow-deviation microwave links to be accepted as just another of the frequently employed techniques used by broadcasters to lessen expenses and provide the best service feasible to listeners.

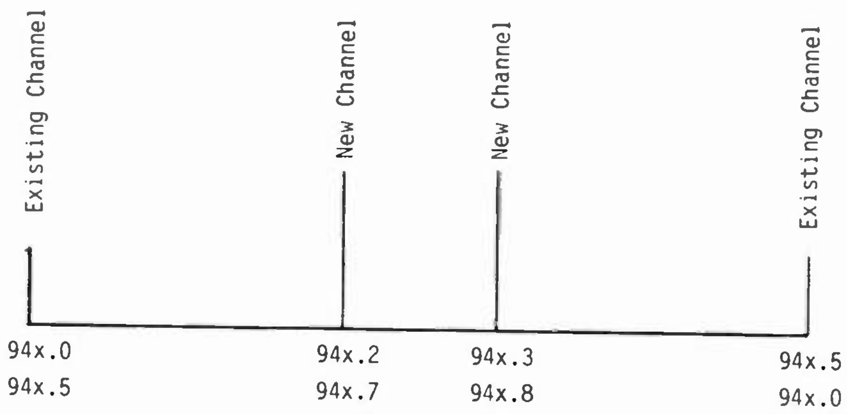
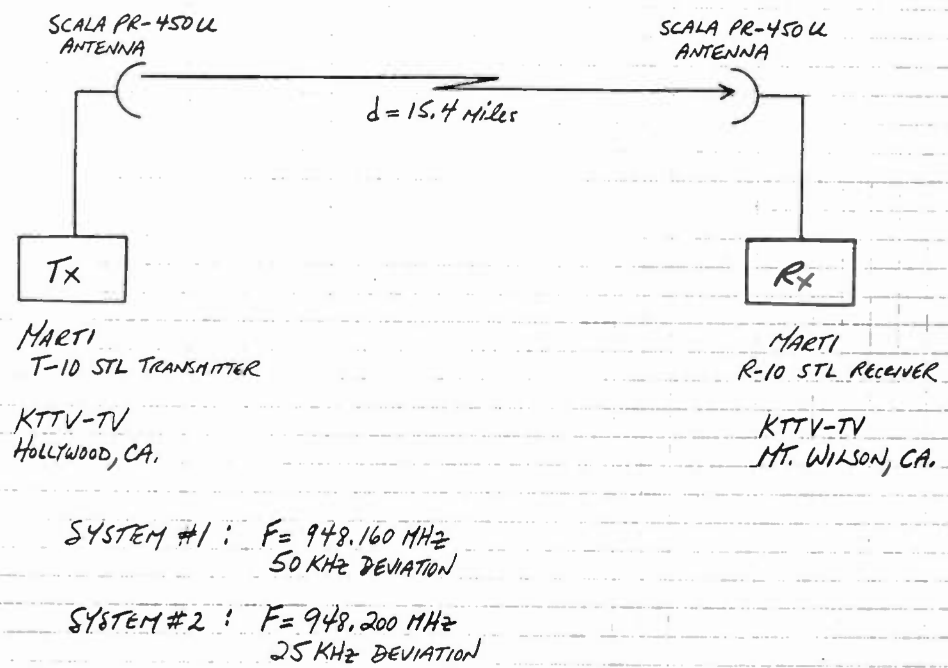
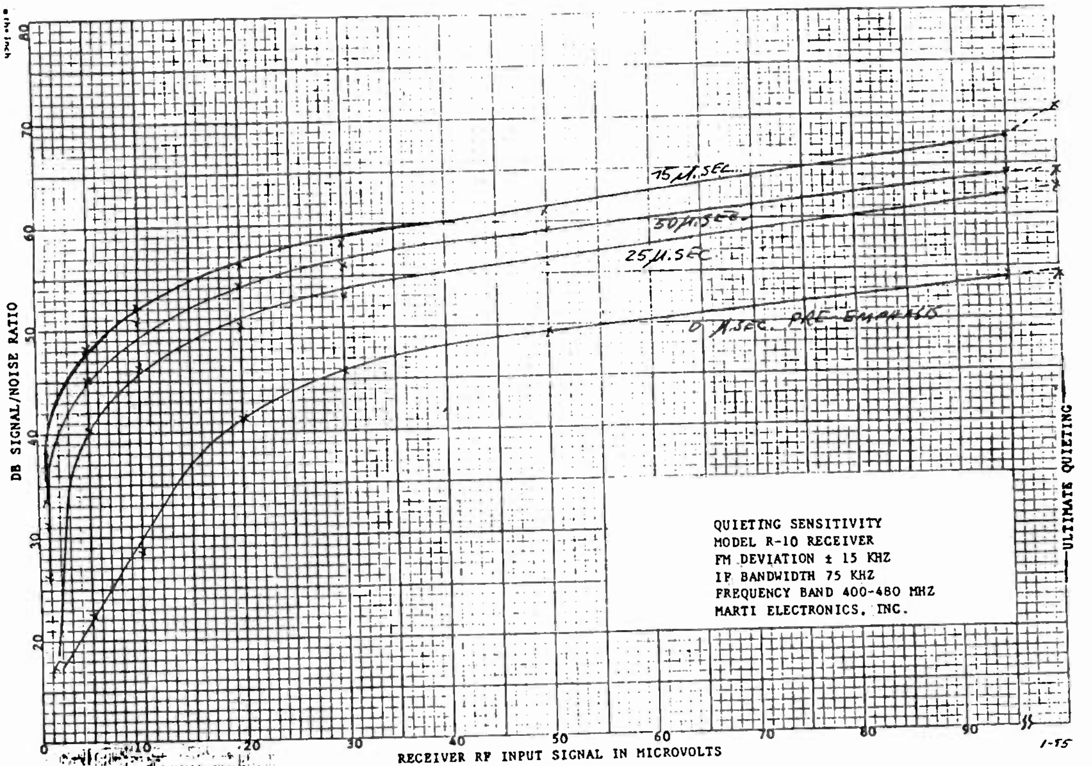


FIGURE "A"

Proposed Narrow Channel Band Plan



Mount Wilson Test Configuration



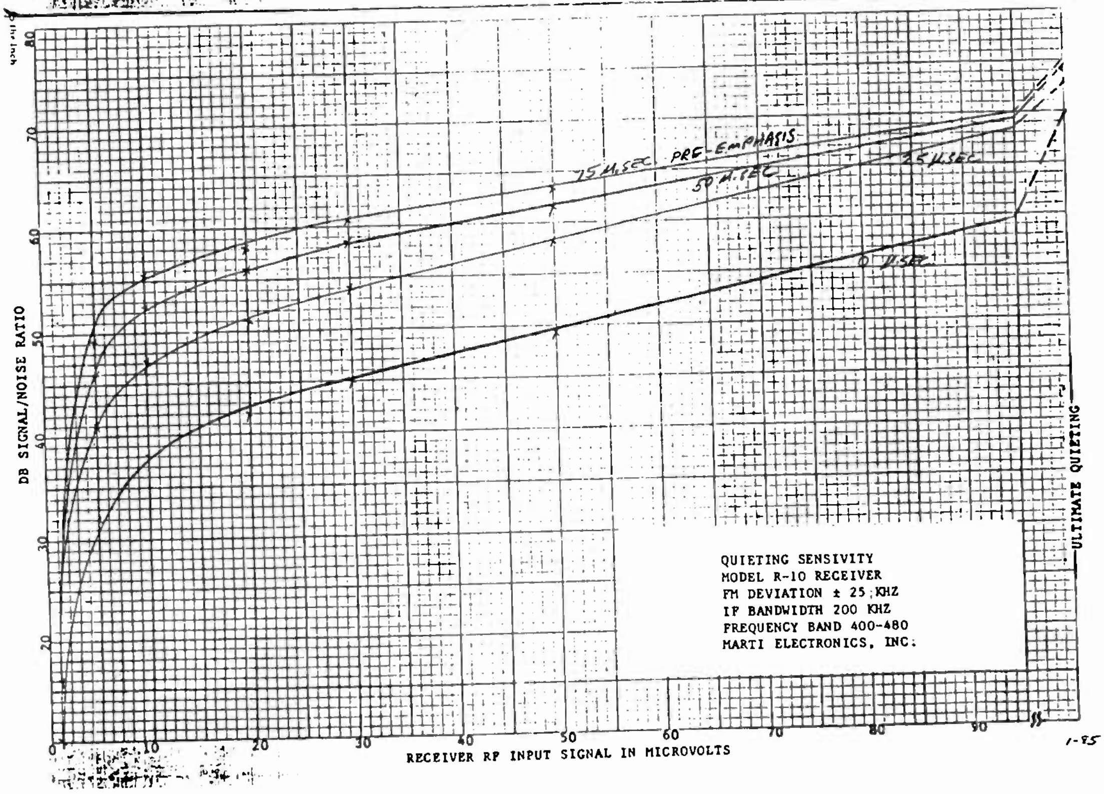


FIGURE "B"

RECEIVER PERFORMANCE

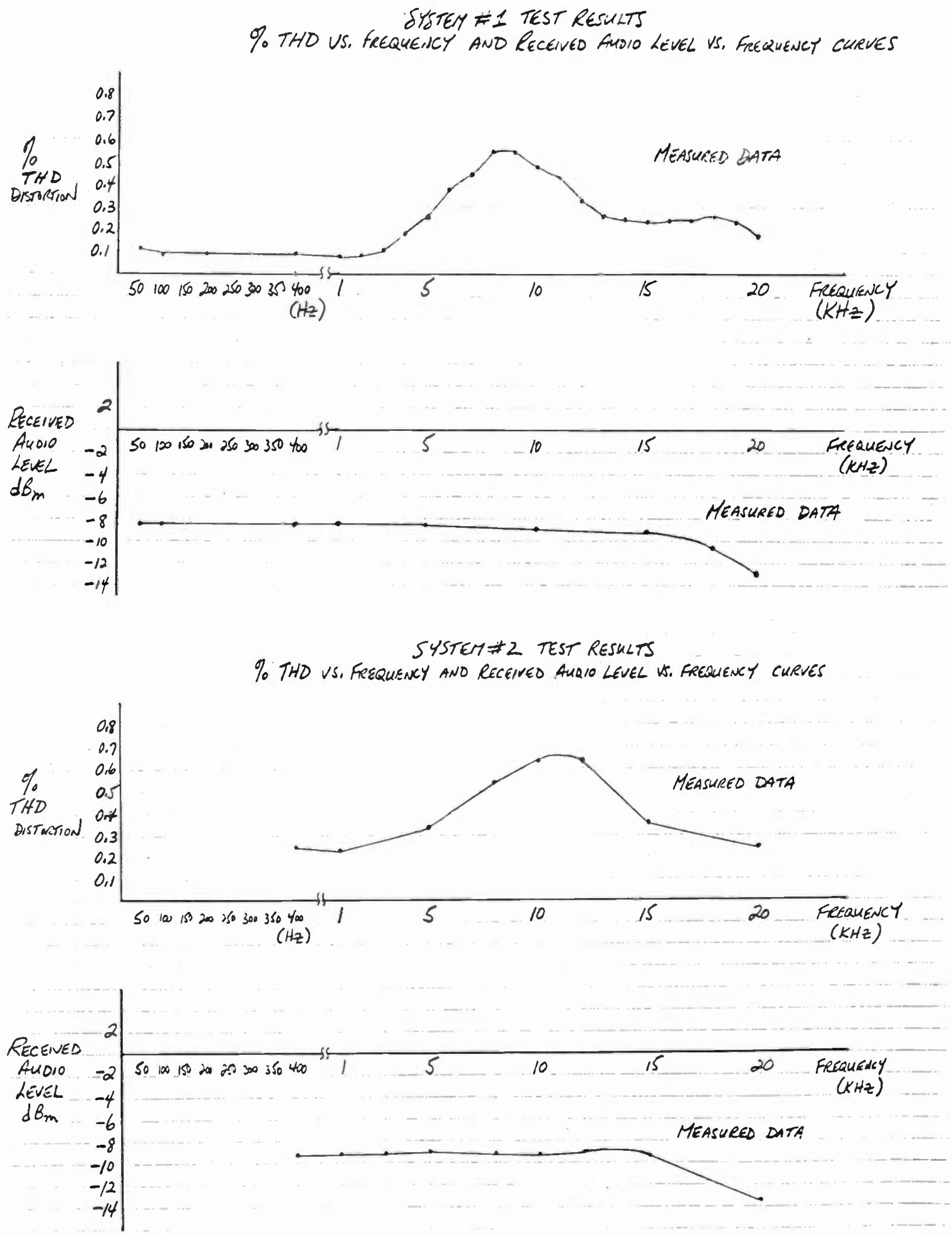


FIGURE "C"

Overall System Performance

RADIOFREQUENCY RADIATION AND FCC ACTIONS UNDER THE NATIONAL ENVIRONMENTAL POLICY ACT

Robert F. Cleveland, Jr.
Office of Engineering and Technology
Federal Communications Commission
Washington, District of Columbia

(The views expressed are those of the author and do not necessarily reflect the views of the Federal Communications Commission.)

ABSTRACT

Human exposure to radiofrequency radiation has been identified by the FCC as an area for environmental evaluation under provisions of the National Environmental Policy Act. This paper summarizes the Commission's actions and other matters related to this issue that are of interest to the broadcast community.

BACKGROUND

The National Environmental Policy Act of 1969 (NEPA) requires that all agencies of the Federal Government evaluate the potential impact of their actions on the "quality of the human environment."[1] Those actions deemed to have possibly significant environmental impact must undergo a thorough analysis to determine whether the action in question is justified. Thus, actions taken by the FCC in authorizing facilities that may affect the human environment are subject to such an environmental analysis.

In the early 1970's, the Commission adopted rules to implement NEPA as it pertains to FCC actions. Several potentially significant environmental effects were identified as cause for analysis. However, the issue of human exposure to radiofrequency (RF) radiation was referenced only in an appendix to the rules. At that time the RF issue had not generated the widespread publicity and concern that has developed in recent years.

In 1979, recognizing the growing interest in this issue, the Commission released a Notice of Inquiry and opened General Docket 79-144 inviting comment on the FCC's responsibilities, if any, in this area and asking for responses to several specific questions.[2] As a result, a 1982 Notice of Proposed Rule Making was released proposing to make the issue of exposure to RF radiation an area for environmental evaluation under the FCC's rules.[3]

Subsequently, in 1985, the Commission, citing its legal responsibilities under NEPA, adopted a Report and Order specifically amending Part 1, Subpart I, of the FCC Rules and Regulations to provide for analysis of environmental problems created by RF radiation.[4] The amendment stated that future applications submitted to the Commission will be subject to environmental evaluation as outlined in the Rules if the facility or operation in question could cause human exposure to RF radiation in excess of specified guidelines. In the absence of an official U.S. Government RF standard, the Commission chose to rely on the 1982 guidelines recommended by the American National Standards Institute (ANSI) for purposes of evaluating exposure.

FCC RULE AMENDMENT

The Commission's 1985 Report and Order amended the FCC Rules and Regulations by adding a new category to the list of agency "actions" likely to have a significant environmental effect. That new category is human exposure to RF radiation at levels in excess of the specified protection guides. The amendment became effective on January 1, 1986.

If an applicant has reason to believe that Commission approval of his application would result in operation of a facility that could cause exposure in excess of the guidelines, then he must so indicate on his application and an environmental statement or assessment must be filed along with the application. It is then up to Commission staff to review the submission and determine whether further environmental analysis is required, e.g., preparation of an "environmental impact statement," or whether the application can be amended to reduce or eliminate the potential exposure problem.[5]

The rule amendment covers Commission actions relative to: (1) broadcast facilities authorized under Part 73 of the Rules; (2) broadcast facilities authorized under Part 74, Subparts A and G; (3) satellite-earth transmitting stations authorized under Part 25; and (4) experimental radio stations authorized under Part 5. The amendment applies to applications for new facilities in these categories as well as to renewals and modifications in existing facilities.

A Further Notice of Proposed Rule Making, issued at the same time as the Report and Order, proposed to exclude categorically all other FCC-regulated transmitters from the provisions of the Order, with the exception of shipboard satellite-earth stations.[6] This proposed exclusion was based on the relatively low powers, intermittent use, and inaccessibility of the RF sources proposed for exclusion, making it unlikely that they could cause exposures in excess of the guidelines. Examples of RF sources proposed for exclusion are those used for microwave point-to-point radio, land-mobile communications, amateur radio facilities, and cellular radio.

The process of compliance with the provisions of the FCC's environmental guidelines is by self-certification. That is, it is up to the applicant to determine whether or not an RF environmental problem may or could exist and, if so, to submit the required environmental statement or assessment. If an applicant determines that there is not a problem, then a simple indication of this conclusion at the appropriate location on an FCC form (or by a written statement if the form does not contain an environmental question) is all that would be necessary.

Guidance on compliance with the RF exposure guidelines and more detail on FCC procedures can be found in a technical bulletin (OST No. 65) issued by the Commission in 1985 and discussed below.[7] For further information on the FCC's environmental processing procedures, the previously mentioned items in Docket 79-144 should be consulted as well as the actual Rules in Part 1.

THE ANSI RF PROTECTION GUIDES

NEPA requires that environmental impact be evaluated regardless of whether government standards are currently in force or whether the FCC has the expertise to establish such standards. Due to the fact that no enforceable Federal Government standard exists for human exposure to RF radiation, the Commission had to look elsewhere for a threshold to use in evaluating RF environmental problems. It was the Commission's decision that the best available and most widely-supported standard of this type was the one issued in 1982 by the American National Standards Institute (ANSI).[8]

The ANSI "radio frequency protection guides" are frequency-dependent limits recommended for "safe" exposure to RF radiation. The guidelines cover the electromagnetic frequency range of 300 kHz to 100 GHz, and the limits are given in terms of mean-squared electric and magnetic field strength and in terms of plane-wave, or free-space, power density. The ANSI protection guides are reproduced in Table 1.

Table 1

RADIO FREQUENCY PROTECTION GUIDES

1	2	3	4
Frequency Range (MHz)	Electric Field Strength E^2 (V^2/m^2)	Magnetic Field Strength H^2 (A^2/m^2)	Power Density (mW/cm^2)
0.3-3	400,000	2.5	100
3-30	$4,000(900/f^2)$	$0.025(900/f^2)$	$900/f^2$
30-300	4,000	0.025	1.0
300-1500	4,000(f/300)	0.025(f/300)	f/300
1500-100,000	20,000	0.125	5.0

Note:
f = frequency in megahertz (MHz)
E^2 = electric field squared
H^2 = magnetic field squared
V^2/m^2 = volts squared per meter squared
A^2/m^2 = amperes squared per meter squared
mW/cm^2 = milliwatts per centimeter squared

The following equation expresses the mathematical relation between these quantities in the far-field of an antenna, where the electric and magnetic field vectors and the direction of propagation can be considered to all be mutually orthogonal:

$$S = \frac{E^2}{3770} = 37.7\ H^2$$

where:

S = power density in milliwatts per square centimeter (mW/cm^2)
E = electric field strength (in volts/meter)
H = magnetic field strength (in amperes/meter)

In the near field of a transmitting antenna the term "far-field equivalent" or "plane-wave equivalent" power density is often used to indicate a quantity calculated by using the near field values of E^2 and H^2 as if they were obtained in the far field. However, in the near field, ANSI specifies that the only applicable protection guides are the mean-squared electric and magnetic field strengths, and values for plane-wave equivalent power density are given for reference purposes only.

The ANSI protection guides were arrived at by determining where the threshold for clearly adverse effects was believed to occur and then incorporating an additional safety factor of ten. The frequency-dependence of the guidelines is due to data showing that the human body absorbs RF energy at some frequencies more readily than at others. The most restrictive limits are recommended in the frequency range of 30-300 MHz where human absorption is at the highest rate. The least restrictive limits are recommended in the frequency range of 300 kHz to 3 MHz where absorption is lowest. Different limits are recommended for frequencies above 1500 MHz and for frequencies intermediate to the above ranges. Basically, the ANSI curve is a "mirror-image" outline of the human RF absorption curve, which is usually defined in terms of specific absorption rate (SAR) measured in watts per kilogram (W/kg).

It is important to remember that the ANSI protection guides constitute exposure guidelines and apply only to locations that are accessible to people. This is not an emission standard proscribing certain levels regardless of location.

The ANSI standard is intended to apply to both non-occupational, i.e., public, exposure as well as to exposure of workers. It is also a time-averaged standard. This means that the values given in Table 1 should not necessarily be considered as absolute ceiling levels which must never be exceeded. Rather, exposures are to be averaged over a certain period of time, in this case any six-minute period. As will be discussed later, this time-averaging provision is of particular importance with respect to occupational and transient exposures, where a certain amount of exposure to levels in excess of the values listed in Table 1 may be necessary.

Since the ANSI guidelines apply to exposure regardless of the RF source, in mixed or broadband fields, where a number of different frequencies may be present, the contributions from all sources must be taken into account. When the recommended limits for the frequencies involved at a given site are different, e.g., UHF-TV and FM radio, then ANSI specifies that the fraction of the limit in each frequency range should be determined and the sum of all fractions should not exceed 1.0.

FCC TECHNICAL BULLETIN

As mentioned previously, in order to assist applicants in evaluating compliance with the RF rule amendment, a bulletin (OST Technical Bulletin No. 65) was issued in 1985 by the Commission's Office of Science and Technology (now Office of Engineering and Technology). This bulletin provides applicants with information, tables, equations, and other aids to facilitate determining whether an RF problem might exist. The bulletin was not, however, intended to establish mandatory procedures for evaluating compliance.

The bulletin is organized into six major sections dealing with: (1) background information; (2) prediction methods; (3) RF measurements and instrumentation; (4) controlling exposure; (5) references; and (6) appendices containing tables, figures, and a reprint of relevant sections of the ANSI guidelines. Although much of the information in the bulletin is relevant to RF sources in general, the primary focus is on the broadcast environment.

The Environmental Protection Agency (EPA) has developed a computer model for estimating power density in the vicinity of FM broadcast stations. This model takes into account effective radiated power, height of the antenna above ground, signal polarization, type of antenna, and number of bays in the array. A detailed discussion of the model is given in an EPA report issued in 1985.[9]

Data from the EPA model was used to prepare the figures and tables found in the bulletin. For example, Table 2, taken from the bulletin, shows minimum heights for single FM antennas that would be required to be sure that RF levels anywhere on the ground did not exceed ANSI's recommended limits. For different combinations of total ERP and bay number, two values are given corresponding to either a "worst case" prediction (assuming dipole elements) or the "best case" achievable using available antennas.

The bulletin also contains several EPA-generated figures for use in predicting ground level power densities around single FM towers. For example, Figure 1 is a plot of "plane-wave equivalent" power density versus distance from the base of a tower with antenna center of radiation at 50 meters above ground. Power densities for various numbers of bays are given. By using such figures, an applicant can determine the extent of a potential exposure level and the distance at which a restrictive barrier might have to be located. In addition to these figures, the bulletin includes a figure showing "main beam" minimum distances required for compliance with the ANSI guidelines for single FM antennas. In all cases these figures were generated assuming worst-case conditions, and they should, therefore, be overly conservative.

Table 2

MINIMUM HEIGHT FOR SINGLE FM ANTENNAS (METERS ABOVE GROUND TO RADIATION CENTER)
REQUIRED FOR COMPLIANCE WITH ANSI LIMITS ANYWHERE ON THE GROUND

TOTAL H+V POWER (ERP) in kW	Number of bays: 2	4	6	8	10	12
0.5	4.1	4.1	4.1	4.1	4.1	4.1
	1.9	1.2	1.0	1.0	0.9	0.9
3	10.0	10.0	10.0	10.0	10.0	10.0
	4.7	2.9	2.6	2.4	2.3	2.2
10	18.3	18.3	18.3	18.3	18.3	18.3
	8.6	5.3	4.7	4.4	4.2	4.0
25	28.9	28.9	28.9	28.9	28.9	28.9
	13.6	8.4	7.4	6.9	6.6	6.3
50	40.9	40.9	40.9	40.9	40.9	40.9
	19.3	11.9	10.5	9.7	9.3	8.9
75	50.0	50.0	50.0	50.0	50.0	50.0
	23.6	14.6	12.8	11.9	11.4	10.9
100	57.8	57.8	57.8	57.8	57.8	57.8
	27.3	16.9	14.8	13.8	13.1	12.6
125	64.6	64.6	64.6	64.6	64.6	64.6
	30.5	18.9	16.6	15.4	14.7	14.1
150	70.8	70.8	70.8	70.8	70.8	70.8
	33.4	20.7	18.1	16.9	16.1	15.4
175	76.4	76.4	76.4	76.4	76.4	76.4
	36.1	22.3	19.6	18.2	17.4	16.7
200	81.7	81.7	81.7	81.7	81.7	81.7
	38.6	23.9	21.0	19.5	18.6	17.8

*NOTES:
(1) Above numbers apply to single FM antennas for which base of supporting tower is at approximately the same level or higher than surrounding terrain.
(2) For each entry, higher number represents "worst" case, i.e., dipole element, and lower number represents "best" case achievable using typically available antennas.
(3) For intermediate values interpolate between tabulated numbers.

In complex situations where multiple emitters are present, most of the tables and figures in the bulletin would not be useful, and actual field measurements would probably be necessary. The section of the bulletin on measurements and instrumentation should be consulted for guidance in that area.

For AM broadcast towers, the bulletin makes use of the EPA's data derived from use of the Numerical Electromagnetic Code (NEC), developed for linear antennas by the Lawrence Livermore National Laboratory. Since at AM frequencies environmentally significant RF fields would occur relatively close to the tower, i.e., in the close-in near field, both electric and magnetic field strengths must be evaluated. Table 3, taken from the bulletin, shows worst-case distances from single AM towers where the model predicts various electric and magnetic field strength levels would occur. Values in this table are "worst case" and apply to any frequency or electrical height. Also, the EPA/NEC model is believed to be overpredictive of actual electrical and magnetic field strength. Therefore, in many cases Table 3 may overestimate the required distances, but in no case should it underestimate them.

In addition to Table 3, the FCC bulletin contains figures of predicted field strength versus distance for AM towers of various electrical heights. These figures, also based on the EPA/NEC model, can be used to predict worst-case field strengths at given distances from a tower.

The bulletin also describes calculational methods for television broadcast antennas and for aperture antennas. In addition, tables are included for predicting minimum "worst-case" distances required for compliance with ANSI guidelines for single VHF and UHF television antennas.

CONTROLLING EXPOSURE TO RF FIELDS

In dealing with possible human exposure to RF radiation, two categories of exposure must be considered. The first is exposure of the general public, and the second is occupational exposure, i.e., exposure of people during the course of their jobs.

Evidence accumulated to date indicates that the great majority of broadcast stations do not create situations where the public can be exposed to levels in excess of the ANSI protection guides.[10] Even at so-called "hot spots," recently surveyed by the FCC and EPA, RF levels were generally below the ANSI limits in publicly accessible areas.[11, 12]

In the few cases where public exposure may be a problem, several options are available to the broadcaster for minimizing or eliminating the exposure potential. The simplest way to solve a problem is by restricting access to the problem area by use of fencing and/or warning signs. The figures found in the FCC bulletin can be useful in determining how far from the tower a fence would have to be placed. Also, broadcasters will be interested to know that the NAB has recently made available RF warning signs which meet ANSI specifications.[13]

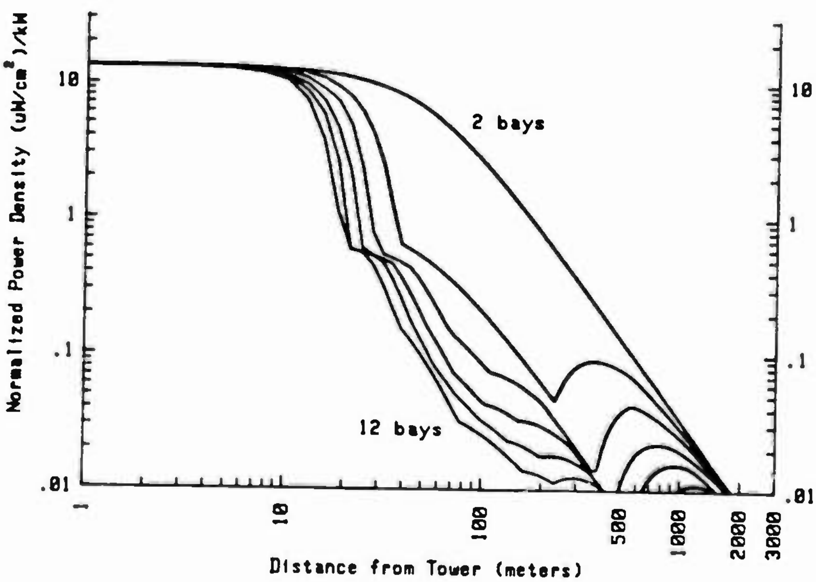


Figure 1. Plane-wave equivalent power density normalized to 1.0 kW total ERP (H+V) for FM antennas having 2, 4, 6, 8, 10, and 12 bays. Antenna height to center of radiation = 50 meters.

Source: EPA Office of Radiation Programs

In the case of FM broadcast facilities, a more expensive solution could involve the use of a different or redesigned antenna system to minimize downward radiation. Some commercially available antennas are very effective in this regard. Also, schemes for altering the spacing between elements in an FM array may prove effective. The FCC bulletin and the 1985 EPA engineering report, mentioned previously, provide more detail on this topic and on exposure mitigation in general. Of course, more drastic corrective measures would include increasing antenna height above ground or actual relocation of a tower, measures which would generally be looked upon as last resorts.

The problem of occupational exposure may be more difficult to solve. The ANSI guidelines apply to human exposure regardless of whether the person exposed is at home or in the workplace. Furthermore, the Commission has said that, in cases involving RF radiation, NEPA applies to all exposures, including occupational exposure.

When considering the problem of protecting workers, limiting the time of exposure is probably the most efficient and practical way to comply with the ANSI protection guides. Since the ANSI guidelines are based on a time-averaging provision, short periods of exposure above the recommended limits are allowed as long as the average exposure over any six-minute period is at or below the recommended limit. Table 4 gives selected exposure times that would be allowable in a six-minute period at various power density levels.

Of course, the use of Table 4 would assume that one knows the power density or field strength at the location in question. For near-field situations relevant to occupational exposure such information can probably only be acquired by actual measurements. The FCC bulletin, and other references listed there, can be consulted for information on RF measurements and instrumentation. Also, personal dosimetry devices may soon be commercially available to measure RF levels to which an individual may be exposed. It

Table 3

DISTANCES (IN METERS) AT WHICH FIELDS FROM AM STATIONS
ARE PREDICTED TO FALL BELOW VARIOUS ELECTRIC FIELD STRENGTHS
(*See notes below)

Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Transmitter Power (kW)								
		50.00	25.00	10.00	5.00	2.50	1.00	0.50	0.25	0.10
25	0.06	109	83	60	47	37	27	22	18	13
50	0.13	65	51	37	29	23	18	14	11	8
75	0.19	49	38	28	23	18	13	11	8	6
100	0.25	40	31	23	19	15	11	9	7	5
150	0.38	30	24	18	15	11	8	6	5	4
200	0.50	25	20	15	12	9	7	5	4	3
300	0.75	20	16	11	9	7	5	4	3	<2
400	1.00	16	13	9	7	6	4	3	<2	<2
500	1.25	14	11	8	6	5	3	3	<2	<2
632 (ANSI)	1.58 (ANSI)	12	9	7	5	4	3	<2	<2	<2
750	1.88	11	8	6	5	4	3	<2	<2	<2
1000	2.50	9	7	5	4	3	<2	<2	<2	<2

*Notes: (1) This table can be used for any AM frequency or electrical height.

(2) The entries in this table apply to both electric field strength and the corresponding magnetic field strength (assuming impedance of free-space equals 400 ohms).

has been reported that at least one such device will be small enough to be conveniently portable and will measure both peak and cumulative exposure.

In addition to controlling exposure through time-averaging, other work practices may be used to reduce exposure. These include reducing power during maintenance and other tasks that require worker exposure, attenuating exposure levels by appropriate use of shielding, and the use of auxiliary transmitters when work is being performed on the main transmitter. Protective clothing is available, but it has been reported that such clothing only works well at microwave frequencies.

TYPICAL EXPOSURE SITUATIONS

Recently the FCC issued a Public Notice discussing in detail exactly what is expected of broadcasters in situations where exposure to RF radiation is an issue.[14] The major points of this Notice are reproduced below. The term "high RF level" means an intensity of RF radiation, whether from single or multiple sources, which exceeds the ANSI guidelines. The information below applies also to high RF levels created in whole or in part by reradiation. Typical exposure situations, and how they should be dealt with, are as follows:

(A) High RF levels are produced at one or more locations above ground level on an applicant's tower.

If the tower is marked by appropriate warning signs, the applicant may assume that there is no significant effect on the human environment with regard to exposure of the general public.

(B) High RF levels are produced at ground level in a remote area not likely to be visited by the public.

If the area of concern is marked by appropriate warning signs, an applicant may assume that there is no significant effect on the human environment with regard to exposure of the general public. It is recommended that fences also be used where feasible.

(C) High RF levels are produced at ground level in an area which could reasonably be expected to be used by the public (including trespassers)

If the area of concern is fenced and marked by appropriate warning signs, an applicant can assume that there is no significant effect on the human environment with regard to exposure of the general public.

(D) High RF levels are produced at ground level in an area which is used or is likely to be used by people and to which the applicant cannot or does not restrict access.

Table 4

Exposure Times Allowed by ANSI Guides at Various Power Densities* in a Six-Minute Period

Exposure Level (mW/cm^2)	Exposure Time Allowed	Time Out of Field
1.0	6 min	----
1.5	4 min	2 min
2.0	3 min	3 min
3.0	2 min	4 min
5.0	1 min 12 sec	4 min 48 sec
10.0	36 sec	5 min 24 sec

* "Plane-wave equivalent" power densities. The corresponding electric and magnetic field strengths would be the only quantities of actual relevance in near-field situations.

The applicant must submit an environmental assessment. This situation may require a modification of the facilities to reduce exposure or could lead to a denial of the application.

(E) High RF levels are produced in occupied structures, on balconies, or on rooftops used for recreational or commercial purposes.

The applicant must submit an environmental assessment. The circumstances may require a modification of the broadcasting facility to reduce exposure or could lead to a denial of the application.

(F) High RF levels are produced in offices, studios, workshops, parking lots or other areas used regularly by station employees.

The applicant must submit an environmental assessment. The circumstances may require a modification of the facilities to reduce exposure or the application may be denied. This situation is essentially the same as (E). It has been included to emphasize the point that station employees as well as the general public must be protected from high RF levels. Legal releases signed by employees willing to accept high exposure levels are not acceptable and may not be used in lieu of corrective measures.

(G) High RF levels are produced in areas where intermittent maintenance and repair work must be performed by station employees or others.

ANSI guidelines also apply to workers engaged in maintenance and repair. As long as these workers will be protected from exposure to levels exceeding ANSI guidelines, no environmental assessment is needed. Unless requested by the Commission, information about the manner in which such activities are protected need not be filed. If protection is not to be provided, the applicant must submit an environmental assessment. The circumstances may require corrective action to reduce exposure or the application may be denied. Legal releases signed by workers willing to accept high exposure levels are not acceptable and may not be used in lieu of corrective measures.

The Notice stated that a convenient rule to apply to all situations involving RF radiation is the following:

(1) Do not create high RF levels where people are or could reasonably be expected to be present.

<u>and</u>

(2) Prevent people from entering areas in which high RF levels are necessarily present.

FUTURE ACTIVITIES

The FCC has developed an inter-agency agreement with the Office of Radiation Programs of the Environmental Protection Agency to support studies and other activities related to potentially significant RF radiation problems. To date this agreement has been instrumental in preparation of the OST technical bulletin and in performing measurement surveys in Honolulu and at Cougar Mountain, Washington. Additional activities are expected under the terms of this agreement, including one or two additional measurement surveys in 1986.

Broadcasters should be aware of the probability of future standard-setting activities in the RF area. It is certainly possible that future standards could be more restrictive than the present ANSI guidelines, at least with regard to exposure of the public. Already, for example, the Commonwealth of Massachusetts, Multnomah County, Oregon, and Portland, Oregon have approved or plan to approve regulations limiting public exposure at levels at least five times more restrictive than the ANSI limits.

Other organizations, including the International Radiation Protection Association (IRPA), the National Council on Radiation Protection and Measurements (NCRP), and the Federal Government's National Institute for Occupational Safety and Health (NIOSH) have either drafted or approved guidelines lower than ANSI's for public exposure, occupational exposure, or both. In addition, the ANSI standard itself is scheduled for revision in the next few years.

Probably of greatest importance, the EPA's Office of Radiation Programs has been developing, over a period of years, "Federal Guidance" for exposure of the general public to RF radiation. The Guidance, if ultimately approved, would be used by other agencies of the Federal Government in protecting the public from exposure to RF radiation, and the levels adopted could be lower than the current ANSI limits.

Regardless of the levels ultimately used for controlling RF exposure, it is important for the broadcast community to recognize the significance of this issue and deal with it in an open and forthright manner. Education of the public and employees concerning this subject should help to alleviate irrational and unnecessary fears brought about by frequently incorrect and distorted information that has appeared in recent years. In that regard, the FCC will continue to assist and work with the broadcast community to the greatest extent possible.

REFERENCES

[1] 42 U.S.C. §4321 et seq.

[2] Notice of Inquiry, General Docket 79-144, 44 Fed. Reg. 37008 (1979), 72 F.C.C. 2d 482 (1979).

[3] Notice of Proposed Rule Making, Gen. Docket 79-144, 47 Fed. Reg. 8214 (1982), 89 F.C.C. 2d 214 (1982). Also, 47 Fed. Reg. 10871 and 47 Fed. Reg. 27384 (1982).

[4] Report and Order, Gen. Docket 79-144, 50 Fed. Reg. 11151 (1985), 100 F.C.C. 2d 543 (1985).

[5] Of relevance here is FCC General Docket 79-163, "Amendment of Environmental Rules in Response to New Regulations Issued by the Council on Environmental Quality," Notice of Proposed Rule Making, 44 Fed. Reg. 38913 (1979). A subsequent item in this proceeding, expected to be released by the Commission before the middle of 1986, may result in certain changes in Part 1, Subpart I, of the Rules effecting environmental processing procedures.

[6] Further Notice of Proposed Rule Making, Gen. Docket 79-144, 50 Fed. Reg. 10814 (1985), 100 FCC 2d 568 (1985).

[7] "Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radiofrequency Radiation," OST Technical Bulletin No. 65, prepared by Robert F. Cleveland, Technical Analysis Division, Office of Science and Technology, Federal Communications Commission, Washington, D.C. 20554. Copies may be ordered from the National Technical Information Service (NTIS), (800) 336-4700, order number: PB 86-127081 or from the FCC's contractor for public records duplication, International Transcription Services, Inc., 2100 M Street, N.W., Washington, D.C. (202) 857-3800.

[8] "American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz," (ANSI C95.1-1982). Copyright 1982 by the Institute of Electrical and Electronics Engineers, Inc. Complete copies of this and other ANSI publications available from ANSI, 1430 Broadway, New York, New York 10018. Telephone (212) 354-3300.

[9] Gailey, Paul C., and Richard A. Tell, "An Engineering Assessment of the Potential Impact of Federal Radiation Protection Guidance on the AM, FM, and TV Broadcast Services," U.S. Environmental Protection Agency, Report No. EPA 520/6-85-011, April 1985. NTIS Order No. PB 85-245868.

[10] Tell, R. A. and E. D. Mantiply, "Population Exposure to VHF and UHF Broadcast Radiation in the United States," Proceedings of the IEEE, Vol. 68(1), pages 6-12, January 1980.

[11] "Radiofrequency Radiation Measurement Survey, Honolulu, Hawaii, May 14-25, 1984," Nonionizing Radiation Branch, Office of Radiation Programs, U.S. Environmental Protection Agency, P.O. Box 18416, Las Vegas, Nevada 89114.

[12] "An Investigation of Radiofrequency Radiation Exposure Levels on Cougar Mountain, Issaquah, Washington, May 6-10, 1985," prepared for the FCC by the Electromagnetics Branch, Office of Radiation Programs, EPA. Copies may be ordered from International Transcription Services, Inc. (see reference 7).

[13] For further information contact NAB Services, 1771 N Street, NW, Washington, DC 20036. Telephone: (800) 368-5644.

[14] Public Notice, "Further Guidance for Broadcasters Regarding Radiofrequency Radiation and the Environment," Mimeo No. 2278, January 28, 1986.

REAL-TIME DATA AVERAGING FOR DETERMINING HUMAN RF EXPOSURE

Richard A. Tell, Chief, Electromagnetics Branch
U.S. Environmental Protection Agency
Las Vegas, Nevada

ABSTRACT

Use of time-averaged exposure can be helpful in determining compliance with the recent FCC Report and Order pertaining to radiofrequency (RF) radiation at facilities where personnel may be intermittently exposed to relatively intense RF fields. This paper describes a measurement system solution to this heretofore technically difficult measurement task. The system consists of a small, portable data logger used in conjunction with a broadband, isotropic field-strength meter to acquire maxima, minima, and averages of the field-strength data during the measurement process. The most significant feature of the described system, which can be used by broadcast personnel to avoid exceeding human exposure limits even though the instantaneous field strengths may greatly exceed recommended continuous exposure values, is its real-time display of the most recent 6-minute time-averaged period. RF susceptibility tests of the configured system as well as examples of how the system may be employed by broadcasters in common field measurement problems are discussed.

INTRODUCTION

New Federal Communications Commission (FCC) rules require that each broadcast station license applicant determine that radiofrequency (RF) emissions from their facilities do not expose employees and the general public in excess of the American National Standards Institute (ANSI) radiation protection guide (RPG), and certify results of this determination on the application forms (1). Although the FCC Report and Order cites the ANSI RPG, it should be noted that other exposure criteria exist and even others may be promulgated. Regardless, the procedures described below can be conceptually applied to any standard for RF exposure. Exposure determinations may be accomplished through a calculational procedure or via direct field strength measurements at the broadcast facility. Dependent upon the facility type (AM, FM, TV), power levels, and antenna radiation pattern details, a calculational determination may be sufficient. In other cases on-site field strength measurements will prove to be the only reliable method for assessing exposure levels. Those cases requiring measurements will generally involve at least momentary exposure to fairly intense RF fields and require consideration of the time-averaging provision of the RPG. It will be seen that compliance measurements in accordance with the time-averaging provision are complex and heretofore technically difficult. This paper focuses on the use of a recently developed system based on the integration of a microprocessor data logger with a broadband, isotropic field-strength meter for easy and accurate measurement of time-averaged RF exposure levels in typical broadcast environments close to antennas.

The RPG is embodied in the ANSI standard C95.1-1982 "American National Standard Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 300 kHz to 100 GHz" (2). Table 1 provides the electric and magnetic field strengths and power densities permitted by the ANSI RPG for broadcast stations. The RPG is based upon limiting RF exposure levels (electric and magnetic field strengths) such that the resulting rate of energy absorption within the body (referred to as the specific absorption rate or SAR) does not exceed a value of 0.4 watts per kilogram of body weight (0.4 W/kg) when averaged over the entire body mass. The 0.4 W/kg SAR value incorporates a safety factor of 10 from the SAR value concluded by ANSI to be hazardous (i.e., 4 W/kg). The ANSI RPG limits are frequency dependent and may be expressed in three ways:

TABLE 1. ANSI C95.1-1982 RADIOFREQUENCY PROTECTION GUIDES FOR BROADCAST BANDS. THE VALUES REPRESENT THE MAXIMUM PERMISSIBLE EXPOSURE LEVELS WHEN AVERAGED OVER ANY 6-MINUTE TIME PERIOD.

Frequency Range	RMS Electric Field Strength (V/m)	RMS Magnetic Field Strength (A/m)	Power Density (mW/cm²)
AM Radio	632	1.58	100
FM Radio and VHF-TV	63.2	0.158	1
UHF-TV			
ch-14	79.2	0.200	1.57
ch-69	103	0.258	2.67

electric and magnetic field strength, electric and magnetic field strength squared, and power density.

A particularly significant aspect of these limits is that they are defined by ANSI to be averaged over any six-minute period. For example, in the VHF broadcast spectrum of 30-300 MHz, the time-averaging provision implies that the product of power density (mW/cm^2) and time (up to 6 minutes) shall not exceed 6 $mW \cdot min/cm^2$. That is,

$$S\ (mW/cm^2)t(min) \leq 6\ mW \cdot min/cm^2$$

Thus, for periods less than 6 minutes, RF exposures greater than the continuous exposure limit of 1 mW/cm^2 are permitted. Table 2 illustrates, for example, how the short-term (less than 6 minutes) exposure limit for the VHF band varies for different exposure times. In each of these examples, following the exposure, there must be no additional exposure during the remaining time within the 6-minute period.

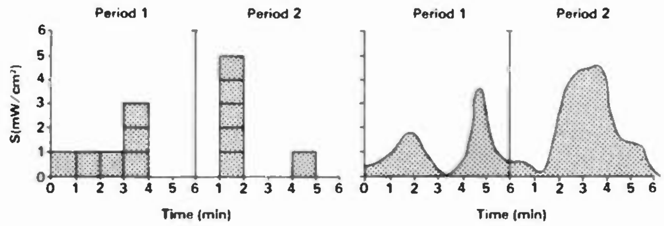
TABLE 2. SINGLE SHORT-DURATION RF EXPOSURE PERMITTED BY ANSI IN THE FREQUENCY RANGE 30-300 MHz.

Time (min)	Permitted S(mW/cm^2)*
6 (or greater)	1.0
5	1.2
4	1.5
3	2.0
2	3.0
1	6.0

*Exposure permitted in any 6 minute period

Figure 1(a) provides a more precise illustration of the concept of exposure time averaging for the RPG. Any combination of power density and time is permitted as long as the total area under the curve does not exceed 6 $mW \cdot min/cm^2$. This corresponds to a true average of the instantaneous values of power density over any 6 minute period. In reality, of course, the actual exposures are most likely continuously varying as illustrated in Figure 1(b). Determining compliance with the time-averaged exposure limitations of the RPG can, therefore, become complicated.

Despite the inherent complexity of determining the time-averaged value of exposure, this feature of the RPG will be crucial to many broadcasters in their efforts to show compliance with the new FCC requirements. This is especially so in the occupational context where employees are exposed periodically to relatively intense RF fields such as when performing work on antenna towers.



(a) (b)

Figure 1. Illustration of ANSI time averaging of RF exposure for the 30-300 MHz band. For any 6 minute period the area beneath the curve must be $\leq$ 6 $mW \cdot min/cm^2$.

DATA AVERAGING IN RF COMPLIANCE MEASUREMENTS

The recent advent of small, portable microprocessor-based data loggers represents a major advance in the measurement of many time varying quantities. Data loggers are devices designed to allow automatic recording of data during prescribed time periods for subsequent evaluation. In some cases, numerous useful functions are provided such as automatic calculation and retention of the maximum, minimum, and average values of a measured parameter. Use of such a device in conjunction with an appropriate field-strength meter can provide a direct method for the broadcaster to ascertain precise time-averaged RF exposure values as specified in the RPG. Without such instrumentation, it is virtually impossible to determine the actual time-averaged value of RF exposures, particularly where the exposure level is constantly changing either because of a time variant field or movement of personnel through fields of widely different strengths.

This paper describes an evaluation of a new product, Holaday Industries (3) model HI-5000 SX, designed specifically for the measurement and recording of time-averaged RF exposure levels. The system consists of a specially modified version of a portable data logger manufactured by Metrosonics Inc. (4) configured with a Holaday broadband, isotropic field-strength meter. The data logger, model HI-3320, modified to Holaday Industries specifications, provides several highly useful functions necessary for FCC RF compliance measurements. This evaluation was performed because of EPA's interest in RF exposure measurement systems. The choice of the Holaday system for this evaluation should not be construed as an endorsement of Holaday Industries' products but the selection was made because the instrument currently represents the only system of its kind that performs the important time-averaging function.

Figure 2 is a photograph of the instrument. A 16 position membrane keypad is used for programming the data logger. The unit

Figure 2. Holaday Industries Model HI-3320 portable data logger.

is powered by a single 9-volt battery for total portability.

This system provides the following measurement capabilities:

(a) a programmable measurement period which can be set to any value from 1 second to 4 hours;
(b) the determination of the minimum, maximum, and average value for each sample period;
(c) the computation and continuous display of a sliding 6 minute time-averaged value (current 6-minute average or CSMA) of the RF exposure level and retention of the maximum sliding 6-minute average (short-term exposure level or STEL);
(d) the setting of an alarm level which can be used to switch on and off an external alarm if the instantaneous field exceeds the preset level.

The system, which incorporates a solid-state memory, allows the output, at a later time, of RF exposure data acquired during the measurement process. This can be accomplished by visually observing the display and manually stepping the instrument through the readout of the historical data or connecting the data logger to a printer or computer for automatic dumping of the data. This feature then provides a way of developing a documented record of exposure time histories.

Undoubtedly, however, the most powerful feature of this system is its ability to determine and display a continuously updated sliding 6 minute time-average of the RF field level (CSMA). This CSMA corresponds to a real-time measurement of the RF fields as averaged over any 6 minute period. The most significant aspect of this real-time feed-back feature is that it allows the broadcaster to knowledgeably manage RF exposure of personnel by selecting optimum work practices suited to specific exposure situations and avoiding exposures which exceed the RPG. In other words, even though the instantaneous exposures may be varying rapidly with maxima far exceeding the continuous RPG limits, the time-averaged value may be continuously monitored with ease to avoid non-compliance with the standard.

In addition to these features the unit may be programmed to provide the indicated values in whatever units the user desires. For example, the data logger can present the displayed values in units of field strength squared or power density, whichever is more convenient to the user.

Figure 3 shows how the data logger is interfaced to one of the Holaday broadband field-strength meters via the recorder output jack. The recorder output from the field-strength meter is a 0 to 1 volt signal that varies in proportion to the analog meter reading. The data logger is programmed so that 0 volts into it corresponds to 0 on the field-strength meter and 1 volt corresponds to full scale. Normally, the data logger should be programmed such that the full scale voltage of 1 volt actually corresponds to the full scale calibration on the field-strength meter. As an example, if the field-strength meter is set for a range of 0 to 10^4 V^2/m^2, then the data logger can be programmed to read this range. The Holaday Industries line of broadband,

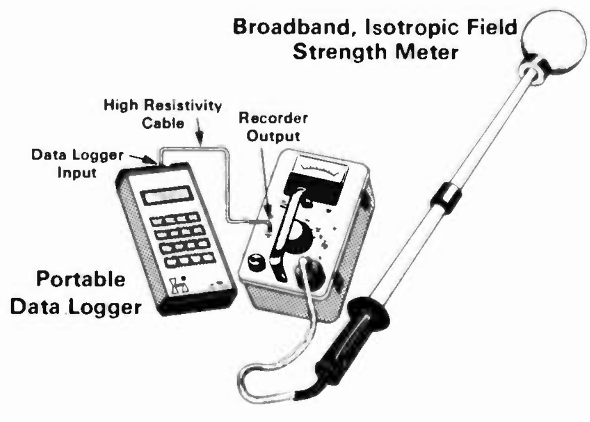


Figure 3. Interconnection of portable data logger and broadband, isotropic field-strength meter.

isotropic field strength meters employ a full-time automatic zero function which completely eliminates drift and permits reliable readings down to approximately 3-5 percent of full scale; this is approximately a 13 dB dynamic range.

The Holaday field-strength instruments provide a recorder output voltage which for single, continuous wave, unmodulated signals can exceed three times the full scale value and which still tracks the field level even though the analog meter reading is no longer useful. If the data logger is programmed to use a 5 volt input range (the next range possible on the data logger up from 1 V) then a total dynamic range of approximately 18 dB can be achieved. The extra dynamic range could be useful when employing the measurement package in RF environments having a wide variation in field strengths. Accurate use of this extra dynamic range will, however, depend upon the nature of the modulations on the various signals making up the exposure environment. In the case of single FM broadcasters, this feature should be very effective. Figure 4 is a photograph of the Holaday model HI-5000 SX system showing the model HI-3320 portable data logger configured with the model HI-3001 broadband field strength meter.

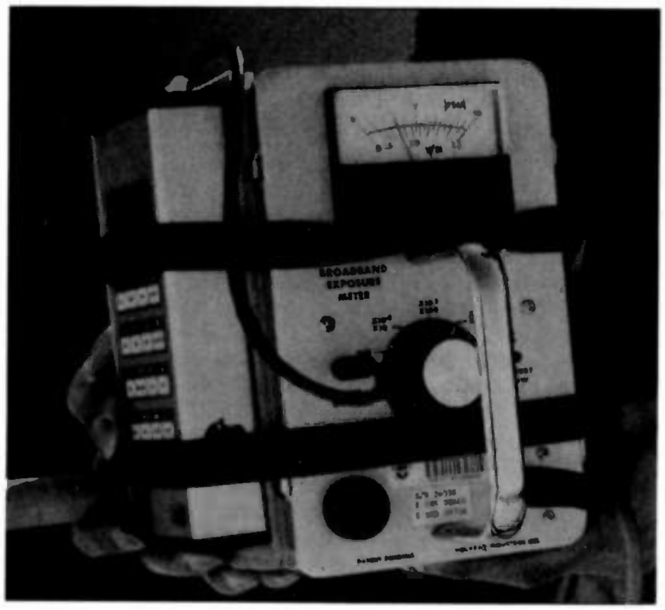


Figure 4. The Holaday model HI-5000 SX system configured with Holaday model HI-3001 field-strength meter. Velcro straps secure the data logger to the side of the field-strength meter.

RF SUSCEPTIBILITY TESTING OF THE DATA LOGGING FIELD MEASUREMENT SYSTEM

No matter how sophisticated the capability of the data logging system, it must be capable of proper operation in high-strength RF fields without failure or distortion of the recorder output voltage readings. This is a special concern since the data logger's intended purpose is to average field-strength readings in possibly very intense fields. Thus, the configuration of data logger and field-strength meter (model HI-5000 SX system) was evaluated in a transverse electromagnetic (TEM) cell driven with a 2-kW linear power amplifier. Figure 5 depicts the test set-up.

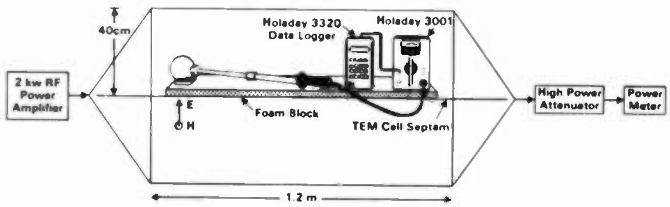


Figure 5. RF susceptibility test set-up for evaluating the data logger-field measurement system.

The maximum field strength achievable with this test set-up was 750 V/m. The evaluation consisted of comparing the data logger display with the analog reading on the field-strength meter. This test revealed that within the readability of the analog meter, the data logger faithfully tracked the recorder output without apparent deviation with field strengths as great as 750 V/m. The test was repeated at various frequencies from 1 MHz to 100 MHz with no apparent effect. A special cable constructed from a high resistivity material (mica and carbon impregnated teflon) is provided to eliminate RF signal pickup which could then enter the data logger circuitry through its high impedance input terminals.

SOME APPLICATION EXAMPLES

Area Surveys

A problem often encountered in performing area RF surveys is that of nonuniform fields and determining a spatial average of these fields so that a realistic picture of the typical exposures to passers-by can be developed. Also, particularly troublesome in many area surveys is the existence of so-called hot-spots or localized points where the RF field strength may be substantially higher than the ambient field levels. Again, characterizing these fields from a practical standpoint is difficult. This process has been hampered in the past because of the somewhat arbitrary nature of mentally averaging the meter readings to obtain spatial averages. In some environments this can be a serious problem since fields may vary both with height above ground and with the presence of foliage on trees such that the fields may vary by as much as a factor of 2 to 10 in terms of power density or field strength squared. One method of using the data logger field measuring system to obtain spatial averages of exposure fields is programming it to sample for predefined periods which correspond with the length of time it takes to perform a planar scan of the fields at a given point. If, for example, it takes 25 seconds to accomplish a uniform velocity planar scan, the data logger can be programmed to sample the output of the field-strength meter as rapidly as 4 times per second and then present the maximum, minimum, and average values of the measured fields. Figure 6 illustrates the planar scan measurement and Table 3 is derived from the data output from the data logger when connected at a later time to a printer. Each line of the data display shows the statistics of the measurement at a given point, including the average of each sample period.

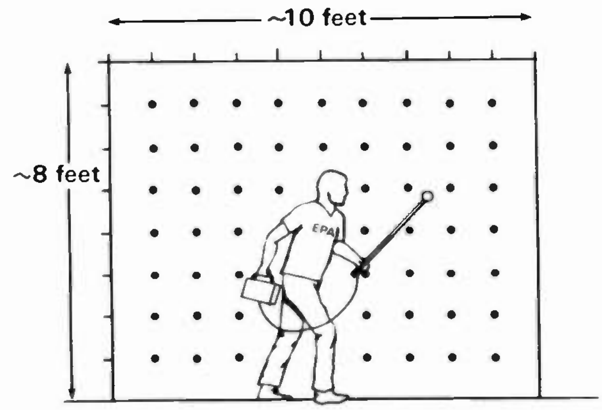


Figure 6. Performing a planar scan of RF fields as part of an area survey.

TABLE 3. DATA LOGGER OUTPUT FOR A SERIES OF PLANAR SCANS OF RF FIELDS AT A SINGLE LOCATION TO DETERMINE THE SPATIAL AVERAGE. EACH PLANAR SCAN LASTED 25 SECONDS.

		Measured Power Density (mW/cm^2)		
User	Trial No.	Min.	Avg.	Max.
A	1	0.130	0.635	1.041
	2	0.170	0.621	1.069
	3	0.170	0.617	1.033
	4	0.211	0.587	0.992
B	1	0.213	0.609	0.983
	2	0.171	0.603	0.986
	3	0.213	0.610	0.975
	4	0.212	0.520	0.981
C	1	0.129	0.541	0.956
	2	0.140	0.632	0.945
	3	0.150	0.453	0.682
	4	0.134	0.517	1.000

The significance of this capability is that, to a very large degree, it reduces subjectivity in the measurement process. Table 3 presents the results of planar scans performed by three different individuals of the same approximate spatial area. The measurements were repeated for a total of four trials by each individual. Individual C had never performed a survey measurement before. As can be seen, the average values of power density obtained at a given point are very similar, regardless of the fact that different individuals performed the measurements. The absolute worst-case difference between any of these average values is only 1.5 dB. The average difference between the two experienced individuals, A and B, was only 0.2 dB! Thus, in addition to providing objective and accurate measurements of the spatial average of RF fields, use of the data logger can reduce the disparity between survey data obtained by different personnel at the same facility.

Tower Climbing - An area of particular concern to FM broadcasters is the possible high-level exposure of personnel when working on antenna towers where the individual may approach or work very near to a side-mounted antenna. In this case, very high level fields may be present and an accurate assessment of the time-averaged RF exposure is exceedingly cumbersome, if not impossible, without real-time data averaging. Without a data-averaging capability some broadcasters may have to declare certain areas on the tower off-limits except when the transmitter is not operating, usually a rare occasion. In some cases, of course, even time-averaged exposures may exceed the RPG. By using the real-time feed-back of the most recent sliding 6-minute average, the climber can attempt to adjust his exposure to avoid exceeding the RPG time-averaged limits. In addition, following the tower work, a permanent record of exposures, including the highest time-averaged value during any 6 minute period, can be created. Figure 7 shows the application of the data-logging field measurement system in a typical tower climbing situation with the RF measurement probe positioned above the climber's head with hands free and the instrumentation accessible for observation of readings. Table 4 is a printout obtained from the data logger of the time history of RF exposures incurred during a tower climb where the principal exposure source was an FM side-mounted antenna. The duration of the tower climb was approximately 14 minutes which resulted in 431 sampling periods of 2 seconds each. For brevity, Table 4 was formatted such that collections of 10 sample periods were grouped together in each line. For each 2-second sample period, the data logger stored a single maximum, average, and minimum value based on the previous 8 readings (4 readings/second). Thus each line in Table 4 represents 20 seconds of time and 80 readings. The report output includes a histogram showing graphically the distribution of measurement statistics for each sample period. The histogram assists in visually determining the highest exposure periods associated with the tabular data to the left. The printout can be produced with a header which identifies the

Figure 7. Using the portable measurement system for documenting time-averaged exposures during broadcast tower climbing. The system is being carried in a specially fabricated bag, similar to a camera bag, and the probe is supported above the climber's head by a harness assembly.

pertinent programming parameters of the data logger and includes the highest 6-minute time-averaged (STEL) value obtained during the entire measurement process. The data logger automatically inserts the date and time every 20 lines in the report. The @ sign on the bottom line indicates that the last sample period was interrupted. This occurred at the end of the climb after dismounting the tower and terminating the logging function. The information including the 10-fold reduction in lines, is automatically formatted by the data logger according to the input provided by the user.

AM Tower Tuning - Another example of the management of personnel exposure via real-time RF exposure time-averaging is the adjustment of AM radio antenna towers where localized magnetic fields can often be extremely intense. These exposures occur when personnel must be in close proximity to the inductors of the tower impedance matching circuitry. Again, by using the continual display of the sliding 6-minute time average (CSMA), maintenance procedures can be developed which preclude exceeding the RPG.

These three examples introduce only a few of the practical possibilities for assessing compliance with the RPG for RF fields when short-term exposures may exceed the continuous exposure limits. The technology is here to permit much more sophisticated approaches to documenting RF radiation exposures and to put the broadcaster in the position of knowing how, in many cases, to adjust exposures before exceeding the RPG rather than finding out too late.

TABLE 4. TIME HISTORY DUMP FROM DATA LOGGER SHOWING THE DISTRIBUTION OF MEASUREMENT STATISTICS OF RF EXPOSURE DURING A TOWER CLIMB.

```
HOLADAY HI-3320 SN 1177 V1.3  5/85

CURRENT DATE:  2/10/86
CURRENT TIME: 13:11:17

CALIBRATION
 0.0000   V =    0.00   mwc2
 1.0000   V =   26.52   mwc2

LOWER ALARM:    0.00   mwc2
UPPER ALARM:    0.00   mwc2

UNITS: mwc2

INPUT READS:   0.32   mwc2
TEST STARTING DATE:   2/10/86
TEST STARTING TIME:   9:59:38
 ELAPSED TIME:  0 DAYS  0:14:23
OVERALL AVG:    1.13   mwc2
OVERALL MIN: -  0.11   mwc2
MIN OCCURRED  2/10/86 @ 10:01:14
OVERALL MAX:    6.55   mwc2
MAX OCCURRED  2/10/86 @ 10:10:29
STEL:     2.00   mwc2
STEL OCCURRED  2/10/86 @ 10:05:58


    MIN         AVG         MAX

DATE:  2/10/86  TIME:  9:59:38
 -  0.01     -  0.01       0.02
 -  0.03     -  0.01       0.04
 -  0.01     -  0.01       0.06
 -  0.04     -  0.01       0.02
 -  0.11     -  0.01       0.07
 -  0.01        0.72       0.94
    0.43        0.64       1.01
    0.00        0.33       0.88
    0.41        0.83       1.25
    0.33        0.71       0.88
    0.04        0.57       0.96
    0.41        0.48       1.00
    0.39        0.68       1.28
    0.36        0.83       1.32
    0.41        0.50       0.92
    0.37        0.44       0.61
    0.06        0.41       0.52
    0.40        0.50       0.94
    0.39        0.52       1.28
    0.40        1.12       1.70

DATE:  2/10/86  TIME: 10:06:18
    0.45        0.93       1.71
    0.47        1.12       1.73
    0.51        1.14       1.71
    0.02        0.92       1.67
    0.02        0.85       2.12
    0.04        1.26       2.56
    0.88        1.22       1.81
    0.96        1.22       1.67
    0.91        1.40       2.70
    1.28        2.20       3.40
    1.71        2.32       2.97
    2.10        3.93       6.41
    3.08        4.60       6.55
    2.55        4.80       6.38
    1.70        3.36       6.37
    1.28        2.08       3.03
    0.84        1.69       2.96
    0.00        0.91       2.16
    0.00        0.43       0.92
    0.40        0.97       1.57

DATE:  2/10/86  TIME: 10:12:58
    0.40        0.97       1.70
    0.04        0.88       1.61
 -  0.01        0.26       0.84
 @  0.00        0.00       0.02
```

REFERENCES

1. Federal Communications Commission (1985). General Docket 79-144, Federal Register, Vol. 50, pp. 11151-11160, March 20, 1985, 100 F.C.C. 2d 543.

2. American National Standards Institute (1982). American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz, ANSI C95.1-1982. Copyright 1982 by The Institute of Electrical and Electronics Engineers, Inc. Copies may be ordered from ANSI, 1430 Broadway, New York, NY 10018, (212) 354-3300 or (212) 354-3473, or from: Standard Sales - IEEE, 445 Hoes Lane, Piscataway, NJ 08854.

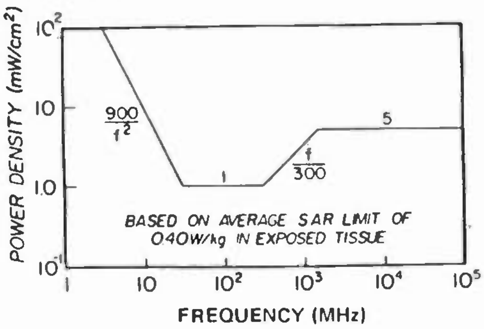
3. Holaday Industries, Inc., 14825 Martin Drive, Eden Prairie, MN 55344. (612) 934-4920.

4. Metrosonics Inc., Box 23075, Rochester, NY 14692. (716) 334-7300.

THOUGHTS ON ANSI-C95.1-1982 COMPLIANCE

Donald E. Lincoln, Director of Engineering
Sutro Tower, Inc.
San Francisco, California

The purpose of this presentation is to give an overview of how one tower management company is handling the new FCC mandated ANSI-C95.1-1982 non-ionizing radiation standards. Some examples will be given as to what proceedures have worked for us and suggestions will be made as to possible ways of complying with the new rules.



Before getting into the main purpose of this paper, it might be well to give a brief background and description of Sutro Tower. In 1968 the tower corporation was formed by a consortium of the four main VHF television channels in the area, (Channel 2, Cox Broadcasting Company; Channel 4, Chronicle Broadcasting Company; Channel 5, Westinghouse Broadcasting Company and Channel 7, American Broadcasting Company). The tower company leases space within the transmitter building and on the tower to any qualified area broadcaster on an equal basis. The lessees are responsible for their own installations and all common areas are maintained by the tower company.

This 977 foot high, candelabra type, self supporting tower is shared by nine television and four FM stations. In addition there are a number of other services from telephone company microwave to business radio for taxicab dispatching.

On January 1, 1986 the new FCC regulation adopting ANSI C95.1-1982 non-ionizing radiation standards became effective. This regulation will have dramatic impact on many broadcasters. The ruling will place a new burden on broadcasters to comply with even more stringent standards. With the older and less stringent values, in most cases compliance was not a problem.

There have been stories about specific situations where there was a radiation problem, but for the most part broadcasters were not put into the position of proving compliance. The new rules change that. Now as a part of the license renewal process, each broadcaster must certify that his broadcast operations do not exceed the guidelines and do not present a hazard to either the station personnel OR to the general public.

The one big advantage to a site such as Sutro is that the majority of the antennas are located almost 1,000 feet above ground level. At other multiple use sites the antennas are mounted on shorter towers, in a cluster or on a multiple array on a building roof. At these locations there can be problems with overlapping fields and high density fields. In the case of an AM/FM installation where the FM antenna is mounted on the AM tower there can be a power density problem. Each site has its own particular set of conditions. The input from an engineering consultant is always helpful and will give your radiation study the stamp of impartiality.

Most stations will not present a hazard or be in excess of recommended values of non-ionizing radiation. In some cases, fences may have to be moved back or erected. Removal from the proximity of the radiation source will, in most cases, put the station in compliance. In this situation the inverse square law works to the broadcaster's advantage. Individual stations or an AM-FM site can probably get into compliance by restricting access to the area of the antennas.

AM stations are permitted a much higher level of power density and should not experience difficulty in complying with the 100mw/cm^2 value allowed in the frequency range of 535 to 1605 kHz. FM broadcasters are faced with a more difficult task because of the power density problems. Many FM stations, particularly stations in a residential neighborhood, will probably exceed the limits due to the antenna patterns. In the case of FM, restricting access or shielding certain high density locations may well be enough. Each case must be determined on its own and there can only be general advice about how to solve a hot spot or trouble area. Removal from the proximity of the radiation source will, in most cases, put you in compliance. Areas frequented by operating personnel may require special attention.

In October of 1981 Sutro Tower commissioned Hammett & Edison, Consultants to do a non-ionizing radiation study of the tower and premises as the result of an OSHA inquiry. This study determined that there was no threat to any personnel at the site, in light of the then applicable standards. Only two locations exceeded the 10 milliwatt level and these were very small areas on the tower which were posted as to the hazard. In August of 1985, because of the number, frequency range, and power levels of the various stations using the tower, it was decided to have Hammett and Edison do a new radiation study of the tower, the building and the surrounding residential neighborhood. We needed a new set of readings for two reasons: there were two UHF stations under construction at the tower and we wanted to have an updated set of readings for our other tenants to use for license renewal. We intended to repeat the measurements after the two UHF stations began broadcasting in order to see if there was a material difference in readings caused by the addition of the new stations.

The data derived from the latest study was not significantly different from the values obtained in 1981. The differences can be explained by measurement technique and the fact that there were about twice the actual number of sample locations for the 1985 study. As of this date, we have not done the follow-up set of measurements because there is still one UHF station to commence operations. From the readings obtained in August of 1985 it appears that the majority of the higher readings are from the FM stations rather than the TV stations. A sample of the readings with Channel 20 in operation reveals virtually no difference from the readings obtained before it began broadcasting from Sutro.

The readings were obtained with a Holaday Industries Model HI-3001 broadband field strength meter. Both the magnetic and electrostatic probes were used. The Holaday meter was backed up with another instrument of the same type. The readings obtained from the two Holaday HI-3001 field strength meters were remarkably similar. When readings above 1.0 milliwatt were encountered, a Potomac UHF field strength meter was used to determine what proportion of the reading was due to the UHF signal from each of two UHF channels then broadcasting. In the range from 300 to 1,500 MHz it is necessary to know the power densities of the individual stations to determine whether the site is in compliance with the ANSI standards. The rules state that for bands with different exposure limits, the fractional portion of each band be determined and that the sum not exceed unity.

It is fortunate that the non-ionizing radiation levels encountered at the top two levels of the tower were of a fairly low magnitude. As mentioned when the 10 milliwatt standard was in effect there were only two spots which required limiting time of exposure. Now with the one milliwatt standard, we were in the position where it required limiting access to the top two levels of the tower. The power density levels encountered were not excessive, in fact for the most part the levels were barely above the limit. Nonetheless the levels were in excess and we determined to comply. It should be pointed out that the standards are for individual stations, but in a multiple use site such as Sutro, it was decided to have the tower company determine the compliance proceedures for all tenants. Since any area on the tower is potentially available to any tenant, we decided to initiate safety measures which would apply to all concerned. With this in mind, access to levels 5 and 6 was restricted by installing a special key-lock in the tower elevator cab which would not allow anyone to proceed past the fourth level without the special key. This key is kept in the Engineering Office and is issued only to personnel who have legitimate business and the tower's higher levels. Another safety feature was to paint the inside of the rigger's shack, which is located on the sixth level catwalk, with a special conductive paint which is some

30% copper by weight. This coating has an attenuation characteristic of 40db in the frequency range from 1.0 Megahertz to 1.0 Gigahertz. It has a low resistance and can be soldered when dry. As an additional measure, we are introducing the use of RF attenuating protective clothing. The low power density within the covered legs of the tower offer areas where the riggers and painters can safely operate without protective clothing. Only the open areas of the fifth and sixth levels of the tower are in excess of the radiation levels.

Thus by limiting the whole body absorption, using protective clothing, and limiting the time of exposure, we feel anyone working at the higher levels will be protected. Whenever work must be done above the sixth level on the antenna stacks all stations transmitting from that level must use their standby antennas anyway.

Take the example of a multiple use site where there are a number of antennas on separate towers, located adjacent to each other. A set of readings is obtained and it is determined that a site is in compliance based solely upon the readings obtained from its own transmitter. However it is noticed that the overall spectrum readings are in excess of the standard and further you determine that the higher readings are being caused by your neighbor whose management does not speak to your management - what do you do? The standard is explicit, your site is in violation due to your neighbor's signal. This sort of situation will require diplomacy and could well be handled by some sort of committee with all of the stations participating. In most areas of the country there is some group or professional society which might be called upon to mediate differences. Co-operation is essential in this sort of situation as it affects the welfare of all of the broadcasters using the site. Remember that the EIC, (Engineer in Charge), of the local FCC field office has the power to enforce compliance.

It is sometimes very difficult to coordinate a specific action among all of your own tenants. For example, changing lamps in a beacon located atop the main antenna array. With nine television stations and four FM stations it is a hairy task to coordinate everyone transferring to his auxiliary antenna in order to allow the riggers to climb the main antenna stack. We have three 24 hour TV stations and four which broadcast up to 22 hours daily. It is always "rating week" or some other type of special period. Sometimes it is necessary to require that the work must be done on a certain date. When this is done, it usually rains. Nonetheless, it requires a great deal of letter writing and telephoning and even then there is always somebody in a master control at one of the stations who did not get the word. As an additional safety measure, we have devised a light status system which indicates when a station is using its auxiliary antenna. This is accomplished by using a set of dry contacts from the various antenna transfer switches which then feed a panel near the tower light flasher system.

Despite the foregoing there is very good cooperation among the various tenants. The reaction to the notification regarding access to the higher levels of the tower was received with more interest than concern about the ability to inspect and measure at the tower top. So far we have not had any adverse reaction from any of the tenants.

The word 'radiation' has become a scare word, it would be well to be prepared to counter any adverse action being contemplated by a municipality or neighbor. Most people do not know the difference between the various kinds of radiation. It is imperative that you point out the distinction at the outset of any discussion. A simple rule of thumb is anything below visible light is non-ionizing and anything above visible light is ionizing. Most anyone knows that radio waves are below visible light.

Treat any question or complaint courteously, do not attempt to avoid or ignore inquiries. When dealing with a local government agency, be candid and offer any information requested. Show them your radiation study, but do not try to explain it in an overly technical manner as you will loose your audience. Convince any inquirer that you are aware of his concern and that you are trying to cooperate. When dealing with a neighborhood association, ask the officers to visit your site. Show them that you have nothing to hide. Evasion or obfuscation is most always counterproductive.

Most areas of the country are accepting the FCC ANSI standard and will adopt local ordinances to comply with these standards. There are a few exceptions to this, notably Moultnomah County, Oregon and the Commonwealth of Massachusetts. Other regulations are being proposed in other parts of the country which are more or less restrictive than the FCC ANSI 1982-levels.

In the future I think we may well assume that the standards will become more restrictive. For example, NIOSH, The National Institute for Occupational Safety and Health, has recently issued, for comment, a draft criteria document for RF and microwave radiation. After completion of the document it will be offered to OSHA which will quite probably use it as a basis for a more restrictive occupational standard for RF and microwave radiation. The NIOSH document suggests a radiation standard which is 1/2 the permissible limit of the 1982 ANSI standard for the frequency range 0.3 to 300 megahertz. And with the exception of the UHF television channels, this constitutes the entire commercial broadcast field, AM, FM, and TV!

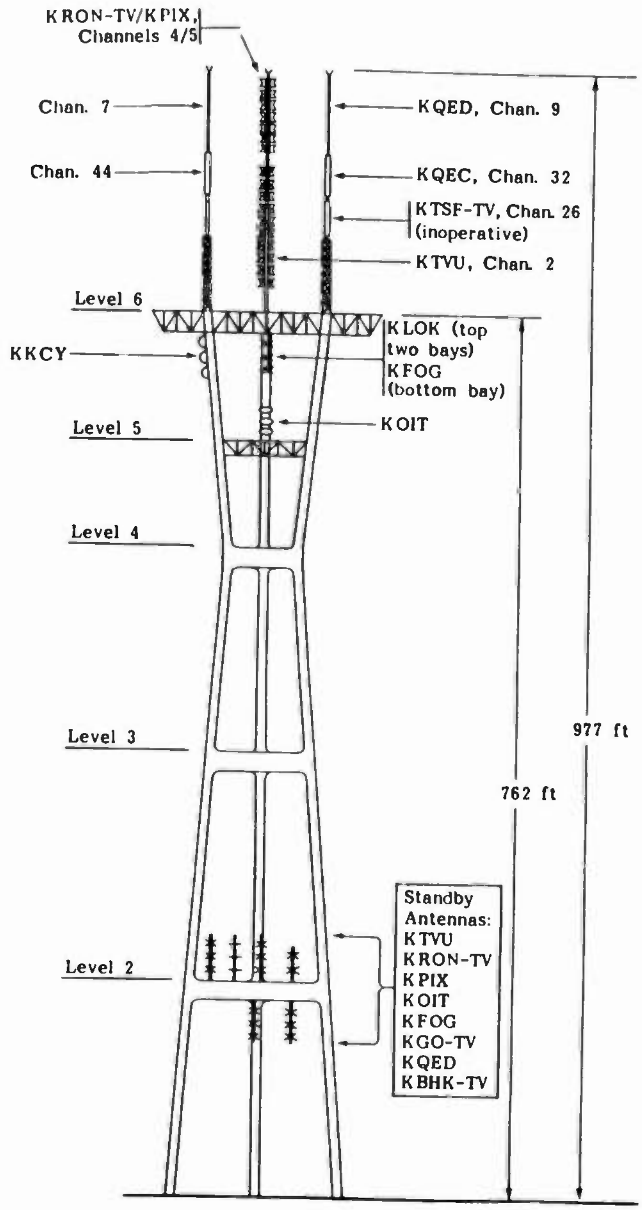
Any standard adopted should be carefully considered as to the affect upon the industry worker as well as the public. Too many rules, in many areas, have been adopted on the basis of what might happen rather than on provable effects and dangers. The present FCC adopted standards appear to favor the side of conservatism. Safety is always a major consideration, but in light of no provable harmful effect, why change a standard which has been in force and working?

Although I am not an advocate of greater government interference or control, I do feel that certain areas, particularly those concerning health and safety, should have some sort of federal control. Along with this control there should be a degree of reasonableness which has not always been manifest in the federal bureaucracy. Industry and the public should have input to any rules or regulations adopted. Professional societies such as SBE, NAB, NRBA, and other interested groups such as EEPA should offer comments.

In conclusion, I feel that even if we don't like it, we can live with the new standards. Many industry groups have had input into the recently adopted rules. The time to cry foul is not after the adoption of a rule or regulation, but before its adoption. If you don't like it, try to legislate a change. We all agree that there are some rulings which seem short sighted or foolish. There is usually a reason behind them. Very few regulations are enacted capriciously. Make your ideas known. Work through your industry associations. Present alternative views.

Since it is with us, we must live with ANSI C94.1-1982. It is vital that your own people, management and technical workers know about these standards and that you are bound to comply with the required constraints.

Like it or not, it is here and we have little choice but to comply.



TOWER ELEVATION
VIEW LOOKING WEST

SUTRO TOWER INC
SAN FRANCISCO CALIFORNIA

ANTENNA SIDELOBE CONTROL TO REDUCE RADIATION HAZARDS

G. W. Collins
Harris Corporation, Broadcast Group
Quincy, Illinois

ABSTRACT

Strategies for complying with the FCC Rules implementing the National Environmental Policy Act of 1969 regarding standards for the exposure of workers and the general public to non-ionizing radiation from broadcast stations rightly involves proper design of the antenna vertical radiation pattern. This paper identifies those areas of the pattern affecting exposure levels that are under the antenna designers control, the factors that affect the radiated level in the sidelobe region of the pattern, and the results of using specific techniques on the power density exposure level and antenna gain. A computer program useful for predicting the exposure level and graphically displaying the results is also described.

INTRODUCTION

The purpose of this paper is to discuss techniques for complying with the FCC guidelines for non-ionizing radiation exposure to workers and the general public at broadcasting transmission facilities from the antenna design point of view. Following a brief description of the new problems faced by the broadcaster, I will define the scope of the problem as it relates to the antenna vertical radiation pattern characteristics. This will necessitate a discussion of the antenna near field and far field regions and the significance of each. I will then address the parameters affecting sidelobe in the far field regions and the factors affecting these levels and location. Following this will be a brief discussion of the numerical method used to calculate exposure levels and graphically displaying the results. Finally, a few examples will be presented to illustrate the results one can expect from applying the various sidelobe control techniques.

You will find that I have not presented any new or startling theory relating to arrays or aperture antenna. Rather a straight forward application of well known principles is the basis for this paper.

STATEMENT OF THE PROBLEM

The broadcaster is now faced with the possibility of showing compliance with FCC specified exposure levels. These exposure levels have been widely publicized, but in the interest of clarity, I have repeated them here. In the frequency range of VHF TV and FM radio exposure levels must be below 1 mw/cm^2. For UHF the standard requires exposure levels of less than 1.58 mw/cm^2 at Channel 14 increasing to 2.68 mw/cm^2 at Channel 69. These levels represent total RF exposure, so, if you have a circularly polarized antenna the power in both polarizations must be considered. Similarly, if more than one transmitter operates into a single antenna, the total power density from all sources is the quantity of interest. Some local standards may require exposure levels as low as 0.1 mw/cm^2 at certain frequencies.

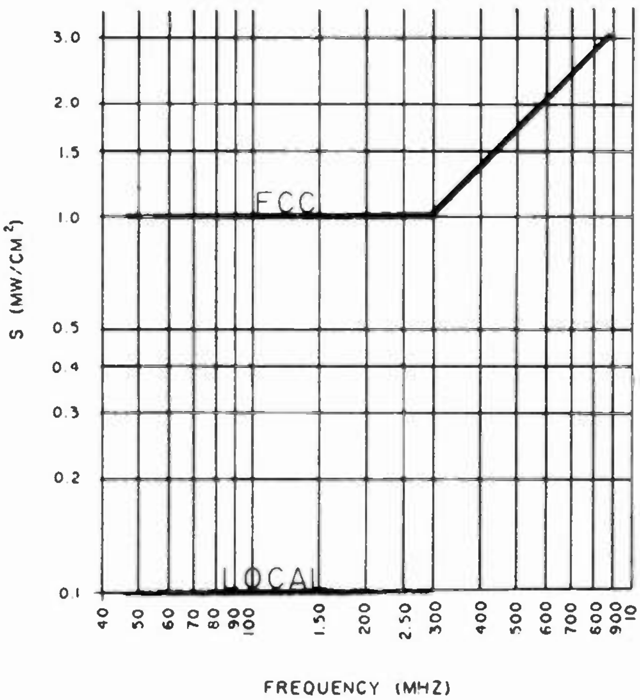


FIGURE 1

RF EXPOSURE STANDARDS

There are many approaches to controlling exposure including site selection, increased tower height and controlled access. Another approach that should not be overlooked is that of antenna design. This can be especially effective in controlling exposure to the general public and can be an important element in controlling occupational exposure. For example, if your antenna is mounted on a short tower located on a building top or hill that is accessible to the public, control of the antenna pattern sidelobe region can prevent exposure of the public. Occupational exposure will also be reduced since your personnel will be able to perform maintenance tasks at the tower base without over-exposure. Obviously, sidelobe control will not prevent over-exposure while working on certain locations on the tower nearer the antenna.

NEAR AND FAR FIELD REGIONS

In considering the near field and far field regions of typical TV and FM broadcast antennas, we may apply the same theory of apertures as is commonly used for reflector antennas. While this may come as a surprise to some, a moments reflection will convince you that the summation of element currents used to calculate the vertical pattern of an array is just a special case of the continuous summation or integral used to calculate the patterns of continuous aperture antennas. Thus, the criteria for establishing near and far field regions are essentially the same. The near field or Fresnel region of a broadcast array extends out to a distance R[1] of about

$$R = \frac{L^2}{N\lambda} \qquad (1)$$

where N is approximately 4, L is the length of the array and λ is the wavelength.

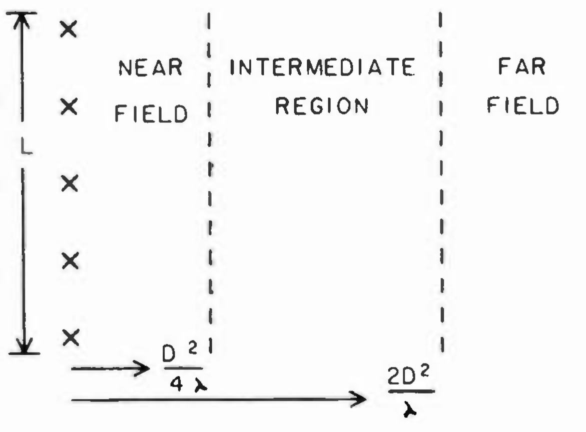


FIGURE 2

FAR FIELD/NEAR FIELD REGIONS

The far field, or Fraunhofer region is defined as the region beyond

$$R = \frac{ML^2}{\lambda} \qquad (2)$$

where M ranges from 0.6 to 2,[2] depending on who is writing the definitions. Between the near field and far field is a transition or radiating near field region. For the purposes of this paper, I will consider only the far field region, since it is in this region that the sidelobes and null structures are completely defined and readily calculated. Similar calculations may be done in the near field and transition regions, but with significantly more complexity. In addition, the region of concern for controlling exposure is often in the far field. For example, consider a two bay FM antenna with a radiation center 100 feet above ground level. the far field distance is (using M = .6)

$$R = \frac{.6(2\lambda)^2}{\lambda} = 9.6\lambda \simeq 96 \text{ Feet} \qquad (3)$$

Finally, it has been demonstrated[3] that, except for the null depth, the sidelobe regions for the near and far fields are often not of significantly different relative levels. If we consider the envelope of the pattern defined by the sidelobe peaks, a good estimate of the power density results using far field patterns.

Thus for exposures on the ground (or roof tops), it is often appropriate to consider only far field radiation.

PARAMETERS AFFECTING WIDE ANGLE RADIATION

The formula recommended by the EPA for calculating power density from FM and TV broadcast antennas is

$$S = \frac{2.56}{4\pi}\frac{EIRP}{R^2}\left[f(\theta)\right]^2 \qquad (4)$$

where EIRP is the effective isotropic radiated power from the antenna including both polarizations and f (θ) is the field pattern of the antenna. Thus for fixed geometry, power and polarization, the antenna pattern is found to control the spatial distribution of power. No surprises here!

In an array antenna, as typically used for broadcast applications, the elevation pattern may be written as a product of an array factor, A (θ) and an element function E (θ)

$$f(\theta) = A(\theta)\,E(\theta) \qquad (5)$$

Thus, the antenna designer may use either the array factor, the element function or both to control the radiated power distribution.

The effectiveness of controlling the element function is illustrated in Figure 3. I have plotted the elevation patterns of three typical element functions in polar coordinates and dB. The first of these is a constant function. This is the type of element function one would expect from a horizontally polarized dipole in free space. You will note that it radiates equally in all directions and does nothing to suppress radiation in the downward direction.

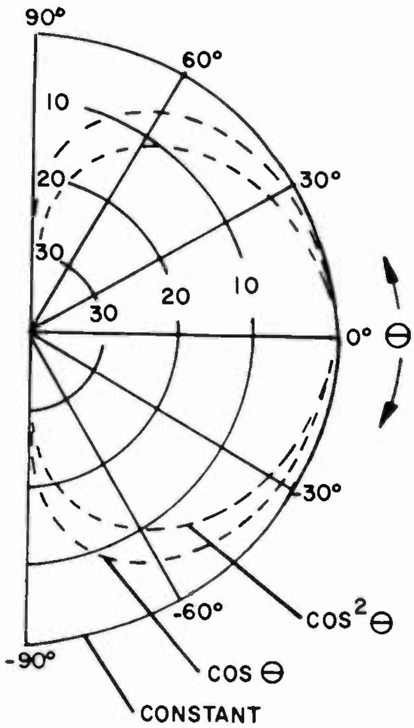


FIGURE 3

TYPICAL ELEMENT FUNCTIONS

The second element function is termed COS θ. This is the type of function one would expect from a vertically polarized short dipole in free space and some cavity antennas. Note that it provides peak radiation in the direction of the horizon and progressive lower levels as the depression angle increases. In fact, there is no radiation at all in the downward direction. Thus, this element function is quite useful in reducing wide angle radiation. Even more reductions may be obtained for the off axis angles by using the $\cos^2\theta$ element function. This element function is closely approximated by a 3/4 wavelength dipole and the larger cavity designs. Thus, the control of the element function is an effective tool for suppressing wide angle radiation.

To understand the effect of the array factor it is necessary to investigate the behavior of a rather complex looking equation

$$A(\theta) = \sum_{m=1}^{M} a_m \cos\left[\frac{(2m-1)}{2} Kd \cos\theta\right]$$

This is the array factor for an even number, M, of elements with uniform spacing, d, and non-uniform excitation coefficients, a_m. (A similar formula may be written for odd numbers of bays.) Actually, it is not as complicated as it appears. It merely tells us that the array factor depends on the number of array elements (bays), their currents and their separation and that all elements must be included to fully characterize the array. We may use this equation to determine the effects of each variable on the wide angle radiation of the array.

A common tradeoff that is made when selecting a transmission system is the number of bays versus transmitter power for a fixed ERP. The outcome of this decision also affects wide angle radiation levels. Figure 4 compares the array factors for 2 bay and 4 bay antennas for the case of uniform amplitude and one wavelength spacing. We see that there is no difference in the pattern level in the direction immediately below the antenna or at -30°, but a significant reduction in the region from about -7 to -22° and -40 to -62°. Increasing the number of bays is an effective means of reducing radiation in the sidelobe region of the pattern.

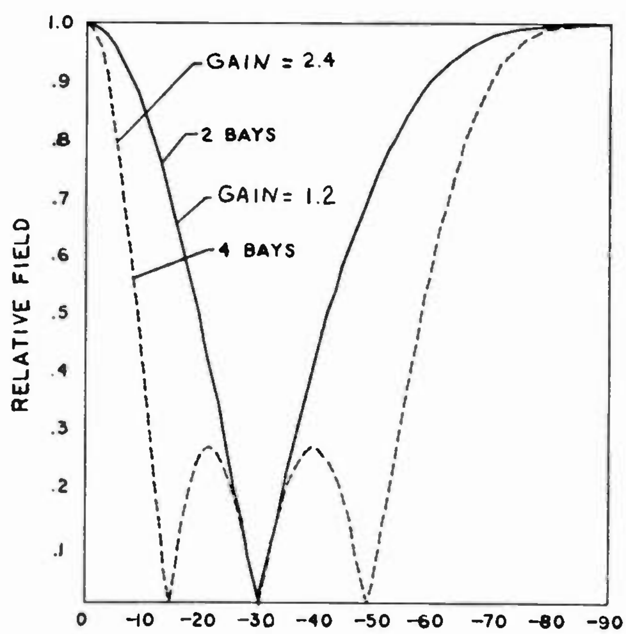


FIGURE 4

REDUCTION OF WIDE ANGLE RADIATION

BY INCREASING THE NUMBER OF BAYS

For reducing the radiation at the larger angles and directly below the antenna, the spacing may be decreased. While it is true that λ/2 spacing will reduce the downward radiation to zero for an even number of bays, other spacings can be used effectively. Figure 5 shows the effect of reducing the spacing of the four bay array to 0.9 λ. It is apparent that significant reductions are achieved for the angles between -55° and -90°. Even greater reductions in this region result from a spacing of 0.75λ. A null occurs directly below the antenna. It is significant for these reduced spacings that the width of the main beam and the gain are increased. These surprising and apparently conflicting results are due to the large decreases in wasted energy in the lobe at 90°. Thus, one can have his cake and eat it too. While reducing radiation exposure on the ground, near in coverage is improved and required transmitter power is decreased. Less tower space is required and small reductions in windload may be achieved.

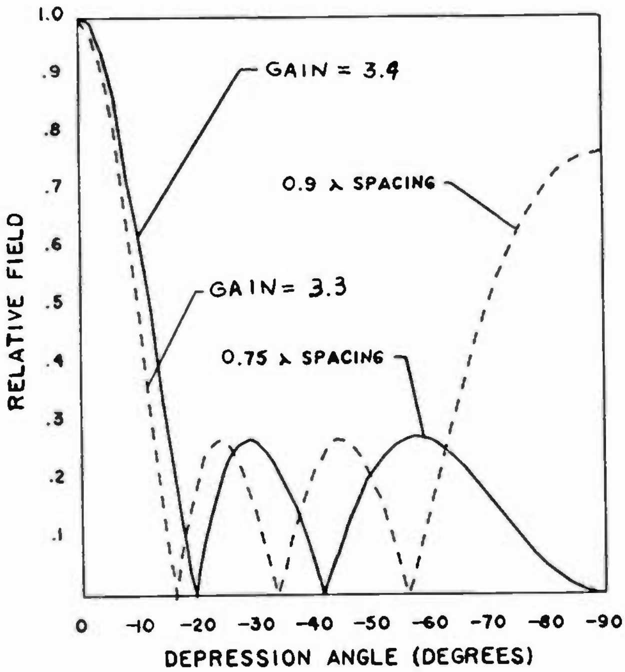


FIGURE 5

FOUR BAY ARRAYS WITH REDUCED SPACING

Implementation of reduced spacing has an additional affect of changing the mutual impedance and thus the driving point impedance of the array elements. While this often is not straight forward, there are methods for compensating for the impedance changes. The reduced spacings also complicate the phasing between elements, especially for shunt fed feed systems. However, it is not difficult to introduce lagging phase shift networks between bays to achieve the required phases. In branch type feed networks, the required phase shifts are readily achieved by adjusting feed line lengths.

Finally, it is possible to combine the array factor control with element function control to further reduce wide angle radiation. Figure 6 shows the vertical pattern of a four element array with one wavelength spacing and a COS θ element function.

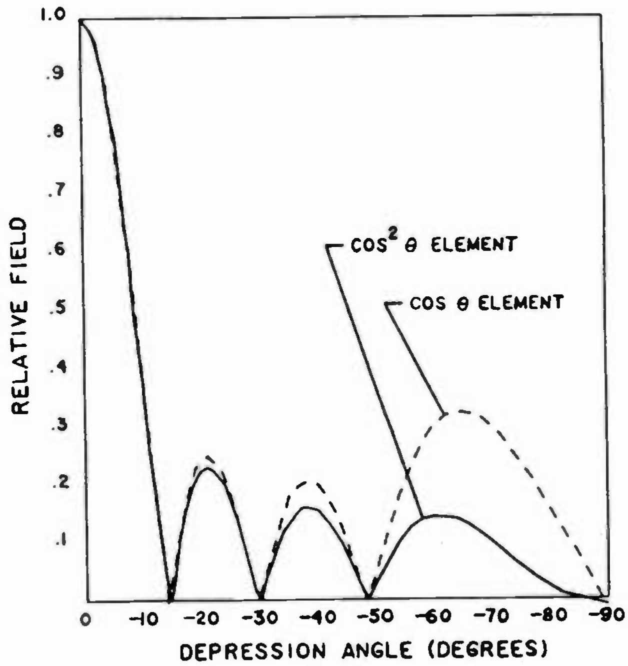


FIGURE 6

ARRAY PATTERN FOR 4 BAY WITH

1 WAVELENGTH SPACING AND

DIRECTIVE ELEMENT ANGLE (DEGREES)

Comparison with Figure 4 shows substantial reduction in radiation from -55° to -90° with no significant effect on the main beam width. Gain is increased due to the reduced level of the sidelobe near -90°. Further improvement in the sidelobe region and increased gain are achieved by using the $\cos^2 \theta$ element function.

COMPUTER PROGRAM

Computer programs have been written for the HP9816 that permit calculation of the power density, S, versus depression angle as given by equation (3). Two programs are utilized. The first of these is a far field elevation pattern program called ELEPAT that Harris has used for years to calculate vertical radiation patterns. The required inputs for this program are the number of elements, their amplitudes and phases, the element spacing, and the element function. The output of this program is the elevation pattern as a function of angle which is saved to a file for use in the power density calculation.

To calculate the power density the program FDEN is used. It is assumed that the area around the base of the antenna and tower is flat. Thus, the only inputs needed in addition to the pattern file are the ERP for horizontal polarization and the vertical height to the radiation center above ground. A factor of 2 is included in the program to account for circular polarization. The output is a graphical plot of the power density as a function of depression angle.

CALCULATED RESULTS

I will now present some examples that show the effectiveness of the various techniques in reducing potential exposure levels below a transmitting antenna. I have selected a single FM station radiating 20 KW ERP from a vertical height of 100 feet. I selected an FM station because the exposure standards are lowest in this band, typical antenna heights are low and the antennas used often exhibit high levels of downward radiation. However, the principle effects apply to TV stations as well.

Figure 7 shows the results for a single bay with a uniform element function. Note that for locations directly below the tower out to beyond -60° the radiation level is above 1 mw/cm^2. This corresponds to a distance of over 55 feet from the tower. Use of a COS θ element makes substantial reduction especially directly below the tower, but also at locations beyond the tower. Even greater reductions result from the COS^2 θ element.

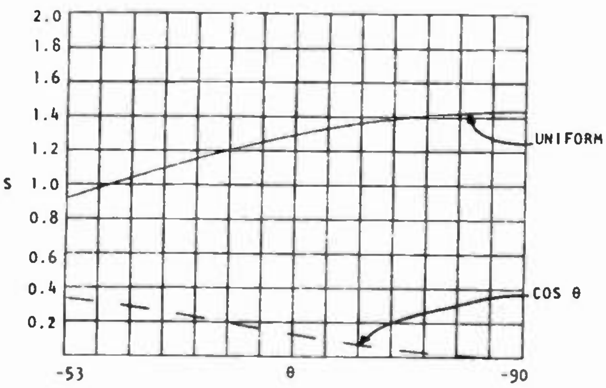


FIGURE 7

RADIATION LEVELS FOR SINGLE ELEMENT ANTENNAS

Using a larger number of bays and one wavelength spacing has the effect of reducing the radiation at the larger distances from the tower, as shown in Figure 8. For this (4 bays) the radiation level is below 1mw/cm^2 for distances beyond a -69° depression angle or about 31 feet. Thus, for stations with perimeter fences increasing the number of bays could be the answer. Note that there is no reduction directly below the antenna.

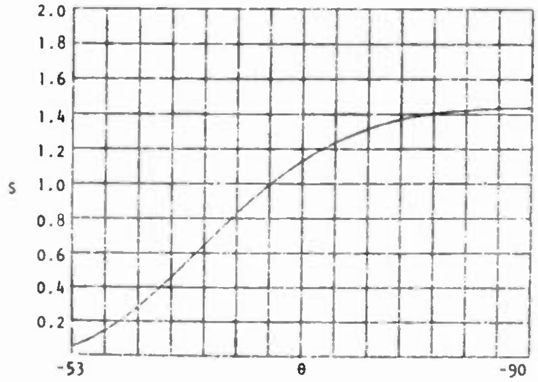


FIGURE 8

RADIATION LEVELS FOR 4 BAY UNIFORM ELEMENT WITH 1λ SPACING

Reductions directly below the tower may be effected by using less than 1λ spacing. The example in Figure 9 is a 4 bay antenna with .75λ spacing. The radiation directly below the tower is reduced to zero. Alternatively a directive element function may be used. Figure 9 also shows the effect of using a COS θ element function with the 4 bay array with 1λ spacing. Using a COS^2 θ element function would reduce the peak sidelobe levels even further.

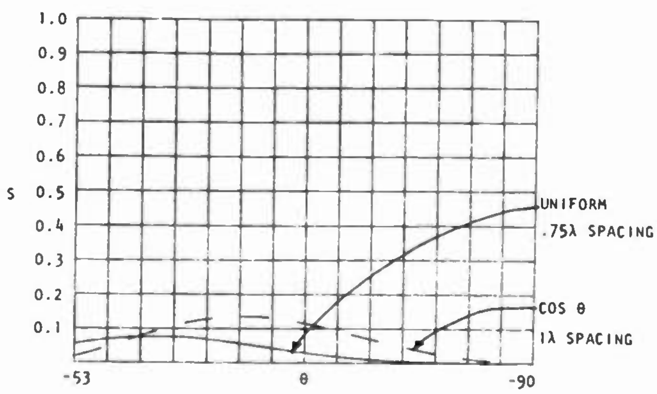


FIGURE 9

RADIATION LEVEL FOR 4 BAY UNIFORM ELEMENT ARRAY WITH .75λ SPACING AND COS θ ELEMENT WITH 1λ SPACING

As the antenna height is reduced, the ERP is increased or the number of stations at a given site is increased the techniques for power density reduction become even more important.

In addition, special care must be taken when several stations use a common antenna. In these cases, one is tempted to pick a midband frequency, add the ERP's at all frequencies and calculate the total power density. A more accurate approach is to calculate the power density for each frequency and ERP separately and add the results. This is due to the array factor changing rapidly as the frequency changes.

CONCLUSION

The antenna designer has at his disposal several tools for controlling exposure levels in the sidelobe region. These include the array factor, the element function and combinations thereof. By judicious use of these tools, wide angle exposure levels may be controlled without significant negative effect on the antenna gain and coverage pattern. In some cases, the gain and main beam shape may be improved while reducing wide angle sidelobes. Implementation of the techniques described is relative straight forward and would not be expected to greatly increase the complexity of an antenna.

---

[1]Evaluating Compliance with FCC Specified Guidelines for Human Exposure to RF Radiation, OST Bulletin No. 65, October 1985.

[2]Johnson RC and Jasik H, Antenna Engineering Handbook, McGraw Hill, 1984.

[3] Gailey, Paul C. and Richard A. Tell "An Engineering Assessment of the Potential Impact of Federal Radiation Protection Guidance the AM, FM and TV Broadcast Services." U.S. EPA Report No. EPA 520/6-85-011, April 1985.

National Association of Broadcasters