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PROCEEDINGS OF THE 15TH ANNUAL NAB ENGINEERING CONFERENCE

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UNITED STATES INFORMATION AGENCY
WASHINGTON

With the compliments of the Voice of America, attached is a copy of a technical paper entitled "The International Broadcasting System of the Voice of America" prepared by Edgar T. Martin and George Jacobs of the U. S. Information Agency. The paper was presented originally at the 1961 Convention of the Institute of Radio Engineers, and served also as the basis for a similar presentation at the Engineering Conference of the 39th Annual Convention of the National Association of Broadcasters, 1961.

The paper discusses the development of VOA's world-wide technical system from its war-time inception. Highlighted in the discussion are the problems encountered in the development of the system, the techniques designed to counteract these obstacles, and future plans for strengthening the signal of the Voice of America.

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THE INTERNATIONAL BROADCASTING SYSTEM

of

THE VOICE OF AMERICA

b y

George Jacobs, Chief
Frequency Division
Office of Engineering Manager
Broadcasting Service
U. S. Information Agency
Washington 25, D.C.

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Abstract

The Voice of America, the international broadcasting service of the U. S. Information Agency, speaks for America in thirty-five different languages to a worldwide audience. The technical facilities that make this possible literally encircle the globe. Thirty shortwave transmitters at seven locations in the continental United States range in power from 25 to 200 kilowatts. Overseas, the VOA has nine relay stations with forty-seven transmitters ranging in power from 35 to 1,000 kilowatts. This presentation discusses the development of VOA's technical system from its war-time inception. Highlighted in the discussion are the problems encountered in the development of the system, the techniques designed to counteract these obstacles, and future plans for strengthening the signal of the Voice of America.

Introduction

Within three months after the Japanese attack on Pearl Harbor, the Voice of America went on the air for the first time with the mission of combating enemy propaganda and explaining why the United States was in the war and what we were fighting for.

The first broadcast, on February 24, 1942, was in the German language. This broadcast heralded the beginning of a new era in the United States' foreign relations and established the pattern for the current world wide operations of the Voice of America, and its parent organization, the U. S. Information Agency. America's story is told overseas by the U.S.I.A. through radio, television, press, publications, motion pictures and other cultural activities.

Today, the Voice of America, speaking for the United States as the international radio service of the U. S. Information Agency, provides millions of listeners in many parts of the world with objective newscasts, up-to-the-minute facts about U.S. policies, and information concerning the life and culture of the American people. The Voice does this in thirty-five different languages, for a total program time of nearly a hundred hours a day.

Edward R. Murrow, recently appointed Director of the U. S. Information Agency, has reaffirmed that the creed established in that first Voice broadcast of nearly twenty years ago -- to tell the truth -- will continue to be the guiding principle of the Voice of America's operations.

This paper deals with the technical side of the Voice of America, and will discuss the development of the present far-flung network from its war-time inception. Highlighted in the discussion will be some of the problem encountered, how they were solved, and future plans for strengthening VOA's signal.

Before Pearl Harbor, the United States was far behind other major powers in the field of international broadcasting. By early 1942, the Axis was blaring forth its propaganda to the world from approximately seventy-five high power broadcast transmitters. In the United States, the international broadcasting effort consisted of about a dozen shortwave transmitters operated on a commercial basis by five privately owned broadcasting organizations. These transmitters formed the nucleus of VOA's technical network when it began broadcasting in 1942.

Since that time, and at a cost of approximately fifty-three million dollars, VOA's transmitting network has been developed into an integrated system that literally encircles the globe. Thirty shortwave transmitters, located at seven plants in the continental United States, range in power from 25 to 200 kilowatts. Overseas, VOA has nine transmitting plants with a total of forty-seven broadcasting transmitters ranging in power from 35 to 100 kilowatts shortwave and 50 to 1,000 kilowatts on medium and long wave.

Problems

The main technical problems that confront international broadcasting from the United States can be stated as follows:

1. The problem of overcoming the deteriorating affects on radio propagation encountered on the transmission paths from the United States passing through, or near, the northern auroral zone to the important target areas of eastern Europe and Asia. Figure 1 shows how the shielding effect of the auroral zone prevents direct transmission from the United States to many important areas of the world on the consistent basis necessary to attract and maintain a listening audience.

2. The problem of overcoming the vast distances between the United States and the target areas in order to reach listeners with competitively strong signals in the broadcast bands that are popular in the areas.

3. The problem of overcoming Communist jamming, which since 1948 has attempted to prevent reception of VOA broadcasts in the languages of the Soviet Union, its European satellites, and, more recently, China.

Development of the System

Operational experience gained during the war years clearly indicated that effective world-wide broadcasting requires a carefully developed integrated network or system of facilities, specifically designed to deliver a strong technically competitive broadcast to a listener in any selected area of the world on either the short-, medium- or long-wave broadcasting bands -- whichever are popular in the specific area and can be picked-up by most of the available receivers.

Long-range forward planning is essential in the development of such a system. It cannot be developed piecemeal, but must take into account all the interrelated elements of the system. In the case of international broadcasting, the system begins at the microphone and ends in the receiver of the listener. In the technical development of the VOA, the "systems concept" -- that of considering the performance of the system as a whole -- has been of paramount importance.

Relay Stations

The development of the VOA facilities system centers upon the use of overseas relay stations, at locations where it is possible to take maximum advantage of favorable radio propagation conditions, to overcome the problems facing direct short-wave broadcasting from the United States.

While the transmission paths passing through the auroral zones are heavily distorted and absorbed, paths that do not pass near the auroral zones are not affected by this phenomenon. In Figure 1, for example, the circuit from New York to Tangier, North Africa, does not pass near the auroral zones, and it is therefore possible to maintain a reliable program service from the United States to Tangier by short wave.

The effects of the auroral zone on circuits from Tangier are indicated in Figure 2. It can be seen, by comparison with Figure 1, that the very areas that are shielded from the United States can be reached without difficulty from Tangier. Therefore, programs transmitted from New York to Tangier can be simultaneously relayed from Tangier directly into European or Near and Middle Eastern target areas -- areas that cannot be reached effectively directly from the United States. By the use of strategically located relay stations, the auroral zone can be by-passed and technically effective transmissions can be delivered to target areas that are normally shielded from direct transmission from the United States.

Auroral zone by-passes to other areas of the world can be achieved by locating relay stations in, for example, Hawaii and the Philippine Islands. Both the fundamental problems of distance and auroral zone absorption can be solved by this relay station concept. Relay stations in such locations can receive short-wave transmissions directly from the United States with the least possible effects from auroral zone absorption. After receiving the transmissions, the relay station can boost them in strength and simultaneously relay them directly into selected target areas on the broadcast bands that are popular in the areas and lie within the range of most of the available receivers.

Based upon this concept, VOA relay stations have been established at various locations throughout the world. Each station is a complete self-contained installation with its own diesel power plant, small studio complement, receiving station for program reception, high-power short-, medium- and long-wave transmitting facilities, and point-to-point radio teletype communications facilities.

The relay stations are integrated into a single system so that they can be fed programs directly from the United States, or from another relay station.

The overseas relay system of the VOA consists of the following:

1. Tangier, Morocco: This station was designed primarily as VOA's main gateway to Europe, North Africa and the Near and Middle East. At Tangier, the major facilities consist of ten shortwave transmitters ranging in power from 35 to 100 kilowatts. Twenty-nine rhombic antennas are available for beaming programs to the various target areas. Figure 3 and 4 are interior and exterior shots of the Tangier Relay Station.

2. Munich, Germany: This location is close enough to the Central European target areas so that medium- and long-wave broadcast bands can be used, as well as shortwave. The station consists of four shortwave transmitters ranging in power from 75 to 100 kilowatts, and several lower power transmitters. A 300 kilowatt medium-wave transmitter operates on a frequency of 1,196 kc and a 1,000 kilowatt long-wave transmitter operates on a frequency of 173 kc. Twenty-six shortwave antennas are available for coverage of Europe, the Eurasian areas of the Soviet Union,

Near and Middle East, and parts of Africa. The medium-wave antenna is a 4-element array providing four separate patterns each beamed towards a desired European target area. This antenna system is designed for sky-wave radiation out to about 500 miles from Munich. The long-wave antenna consists of a single top-loaded tower over 900 feet high. It has been designed for omnidirectional radiation to provide Central European coverage.

3. Thessaloniki, Greece: This relay station was engineered to take advantage of its proximity to the Balkan target areas. The station consists of four 35 kilowatt shortwave transmitters, and a 50 kilowatt medium-wave transmitter operating on a frequency of 791 kc. Twelve shortwave antennas are available for coverage of the Balkans, the western Soviet Union, east Europe, the Near and Middle East and parts of Africa. The medium-wave antenna consists of a 2-element directional array providing a reversible cardioid pattern with one beam centered to provide sky-wave coverage of the Balkans and the other to provide coverage of Greece.

4. Rhodes, Greece: VOA's station at Rhodes is used primarily for covering adjacent areas of the eastern Mediterranean. A 150 kilowatt medium-wave transmitter beams broadcasts to this area for nine hours a day on a frequency of 1,259 kc. Two 35 kilowatt shortwave transmitters reinforce the medium-wave coverage. The Rhodes' station is rather unique in that the transmitting facilities are housed aboard a vessel, the U.S. Coast Guard's Courier. The Courier does not, however, broadcast from the high seas. The vessel operates as a fixed installation, either from an anchorage in Rhodes harbor, or from within the national waters of Greece, with the approval of the Greek Government.

5. Philippine Islands: VOA maintains transmitting facilities near Manila and San Fernando on the island of Luzon. These facilities consist of six shortwave transmitters ranging in power from 35 to 100 kilowatts, a 50 kilowatt medium-wave transmitter operating on 920 kc., and a 1,000 kilowatt medium-wave transmitter operating on 1140 kc. Twenty rhombic antennas are available for beaming shortwave broadcasts over an arc extending from Korea to India. The 50 kilowatt medium-wave transmitter uses a six-tower array for sky-wave coverage of the Philippines and adjacent areas of Southeast Asia, while the megawatt transmitter uses a four-tower array which produces three separate beams directed towards Southeast Asia, and parts of China. This antenna system increases the effective power of sky-wave radiation to 3,500 kilowatts in certain directions.

6. Okinawa: VOA's Okinawa installation completes Far Eastern coverage by beaming short and medium-wave broadcasts to northern and central Asiatic areas. This station consists of three shortwave transmitters ranging in power from 35 to 100 kilowatts, and a 1,000 kilowatt medium-wave transmitter operating on 1180 kc. Six rhombic antennas direct shortwave transmission to Siberia, the Far East, China and Central Asia. The medium-wave antenna consists of a six-element array producing two beams directed towards China, Manchuria, Korea, and the Soviet Far East.

7. Colombo, Ceylon: This installation, operated for VOA by Radio Ceylon in accordance with an agreement between the governments of the U.S. and Ceylon, is intended primarily for coverage of India and Pakistan. The station consists of three 35 kilowatt shortwave transmitters. A large number of curtain arrays are available for beaming broadcasts to India, Pakistan and adjacent areas.

8. Woofferton, England: Six 50 kilowatt shortwave transmitters, operated for VOA by the British Broadcasting Corporation, on a contractual basis, beam Voice broadcasts to Europe, Africa and the Near and Middle East. Twenty-six high-gain curtain antennas are available for directing these transmissions to their target areas.

9. Honolulu, Hawaii: This station, located in the nation's newest state, serves as an auroral by-pass to the Far East and Southeast Asia. It consists of two 100 kilowatt shortwave transmitters and seven rhombic transmitting antennas.

The overseas system of the VOA, consisting of forty-seven high-power transmitters, effectively by-passes the auroral zone and bridges the vast distances between the U.S. and the target areas, enabling VOA to reach listeners with competitively strong signals in the broadcast bands most popular in the areas.

"Feeder" Link

The overseas stations of the VOA have just been described. They are the links in the over-all system effort directed towards the selected target areas. The link from the United States to the overseas stations is referred to as the "feeder" link in the over-all system. It consists of thirty high-power shortwave transmitters located at seven plants in the continental United States. These high-power transmitters employ high-gain directive transmitting antennas for the dual purposes of feeding program transmissions from the studios of the VOA to the overseas relay stations for simultaneous relay into selected target areas, and also providing supplemental direct target area coverage during periods of favorable propagation conditions. The following facilities are used for this purpose:

1. Bound Brook, New Jersey: Six 50 kilowatt shortwave transmitters and seventeen high-gain antennas beamed towards Europe, North Africa and South America.

2. Brentwood, New York: Three 50 kilowatt shortwave transmitters and nineteen high-gain antennas beamed towards Europe and South America.

3. Schenectady, New York: Three shortwave transmitters ranging in power from 25 to 100 kilowatts and eight high-gain antennas beamed towards Europe and South America.

4. Wayne, New Jersey: Two 50 Kilowatt shortwave transmitters and four high-gain antennas beamed towards Europe.

5. Bethany, Ohio: Six shortwave transmitters capable of operation at powers between 50 and 140 kilowatts and 22 high-gain antennas beamed towards Europe, Africa, and South America.

6. Delano, California: Five shortwave transmitters ranging in power from 50 to 200 kilowatts and 22 high-gain antennas beamed towards Southeast Asia, the Far East, Siberia, and South America.

7. Dixon, California: Five shortwave transmitters ranging in power from 50 to 200 kilowatts and 20 high-gain antennas beamed towards Hawaii, Australia, Southeast Asia, the Far East, and South America.

Washington Headquarters

For the most part, VOA programs originate from its Washington, D.C. headquarters plant. The Washington facilities, which take up nearly 100,000 square feet in the Health, Education and Welfare Building on Independence Avenue, include eighteen studios, equipment to make forty different disc or tape recordings simultaneously, ten tape-editing booths, a recording control center, the Master Control, engineering offices, editorial offices, music and transcription libraries, and various other service units which are required to keep VOA in operation twenty-four hours a day.

VOA's Master Control is one of the largest and most flexible in the world. It feeds programs originating in VOA studios, through special telephone circuits, to the shortwave transmitters in the United States. The Control Console (see Figure 5) is capable of selecting program material from one hundred sources and of handling twenty-six programs simultaneously.

This rounds out the systems concept of the VOA world-wide international broadcasting network. VOA broadcasts originating in studios located in Washington, D.C., are fed through appropriate control equipment and landline circuits to any one of thirty feeder transmitters located at seven plants in the United States. These programs are then broadcast over the high-power shortwave "feeder" transmitters, employing high-gain directional-antenna systems, to any one of forty-seven high-power transmitters located at nine overseas relay points throughout the world. The circuits to the relay stations by-pass the auroral zone of exceptionally heavy r-f absorption. The relay stations, located at optimum distances from the selected target areas, boost the level of the signals received from the "feeder" transmitters and simultaneously relay the broadcasts directly into the target areas on either the short, medium-, or long-wave broadcasting bands, whichever are popular for broadcasting in the target areas. Often during periods of favorable propagation conditions, secondary target-area coverage is also obtained directly from the transmitters located in the continental USA.

Figure 6 shows pictorially how VOA broadcasts originating in the Washington, D. C., studios are transmitted to overseas listeners. Figure 7 shows the areas of the world that VOA broadcasts now reach.

Jamming

Communist jamming of VOA Russian-language broadcasts was first observed in February 1948. Since that time, jamming has continued and it is believed that approximately 2,000 radio transmitters are presently being used to jam Russian, European-satellite and Chinese-language transmissions of the VOA and other broadcasters.

Jamming consists mainly of irritating noises which sound like buzz saws, sirens, white noise, etc., placed on the same frequency as the VOA transmissions for the purpose of making reception of the program difficult, if not impossible. Although intentional interference of radio transmissions violates international radio agreements, these transgressions continue.

The VOA early realized that the most effective way to combat or nullify the effectiveness of jamming was to adopt a dynamic, versatile approach requiring a wide range of latitude in engineering, operating, and programming techniques. Such an approach is necessary because there is no single "magical" solution to this problem -- a technique that is successful today may be blotted out by increased jamming efforts tomorrow.

Concurrent with the development of the system itself, certain techniques have been devised in the form of electronic devices such as heterodyne filters, speech clippers, exalted carrier type receivers, etc., the use of high-power transmitters and high-gain antennas, the advantageous use of favorable propagation conditions when these exist, the transmitting of the same program simultaneously from various relay stations located at different geographical locations, broadcasting on an around-the clock basis, increasing the number of broadcasts in the English language, which are not jammed, as well as continuous study of the problem. These have permitted various degrees of, and in some cases complete, penetration of the jamming barrage.

That many broadcasts can be heard in spite of jamming is clear from reports of monitoring stations located on the rim of Communist territory, from systematic questioning of visitors to and escapees from the Soviet orbit, from letters written by Soviet bloc listeners, and from violent attacks on the Voice by Communist dignitaries and by the press and radio of the Soviet Union. Nevertheless, jamming is effective and represents a major problem for the Voice of America.

Future Plans

The growth and competition in the field of shortwave broadcasting continues at a dynamic pace. Shortwave broadcasting throughout the world increased 13% during 1960, with about 140 countries engaging in this medium of mass communication. VOA's greatest competition, from the standpoint of the number of hours devoted each day to shortwave programming, comes from Radio Moscow, Radio Peking and the UAR's "Voice of the Arabs"; each of these devotes more time than the VOA to shortwave programming.

Many newly emerging countries and developing nations began, or increased, shortwave broadcasting during the past year or two. For these countries, shortwave radio provides an effective, simple and relatively inexpensive means of mass communication. Even the Soviet Union depends to a great extent on shortwave radio for keeping its people in the hinterlands informed.

The increased availability of transistorized radio receivers at steadily lowering costs has also played an important part in the recent upsurge in the popularity of shortwave broadcasting. With receivers independent of power lines and capable of being operated for months on a few cheap batteries, radio can now penetrate into rural and underdeveloped areas, opening up vast new potential audiences, both for the Voice of America and its competitors.

VOA has developed a long-range facilities planning program for meeting the growing world competition in shortwave broadcasting. Basically, this plan calls for eliminating coverage deficiencies which currently exist, and for boosting signal strengths in the more important target areas where competition is greatest.

Congress has recently appropriated funds for two major steps in this program. The first of these is a new domestic plant now under construction in Greenville, N.C. This plant will provide VOA relay stations in Europe and the Mediterranean area more reliable and higher quality signals, and will also improve the capability for direct broadcasting to some areas of Europe, Africa and Latin America. The principal transmitters will number six 500 kilowatt shortwave, six 250 kilowatt shortwave, and six 50 kilowatt shortwave. This new installation, being built at a cost of nearly twenty-four million dollars, will be the world's most powerful shortwave broadcasting station when it comes on the air during early 1963 (see Figure 8). It will permit VOA to discontinue use of fourteen obsolete shortwave transmitters at other domestic plants, some of which have been in service for more than twenty-five years.

The other new technical facility approved by Congress is a relay station in Africa, now under construction near Monrovia, Liberia. This station, being built at a cost of approximately thirteen million dollars, will provide VOA, for the first time, with competitive shortwave coverage of the entire African continent. The six 250 kilowatt and two 50 kilowatt shortwave transmitters planned for the Liberian installation are expected to go into operation during mid-1963. The new station will partially fill the coverage gap that will result when VOA's Tangier station ceases operation on December 31, 1963, the termination date of the present agreement with the Moroccan Government. It will also improve VOA's coverage capability in parts of the Middle East and Europe during critical periods of low sunspot activity.

Science and Research

Research has played an important part in the development of the VOA broadcast system. The VOA has established, during the development of this system, a research program utilizing the services of leading research organizations at various colleges and universities, other government departments and agencies, and commercial research organizations having experience along the lines most important to the technical development of the VOA. In general, this research program has explored the broad field of electronics, communications, and radio propagation. VOA's research program played a very significant role in the early development of ionospheric scatter communications, advancement of the state of knowledge concerning auroral and other anomolous types of radio propagation, and development of high-power transmitters, high speed, self calibrating modulation monitors, peak audio clippers and other devices which have benefitted both the VOA and the communication field in general.

VOA is keenly aware of the necessity for keeping abreast of technical improvements in broadcasting and communications. To focus attention on scientific research and development, VOA has organized a Science Advisory Group drawn from a cross-section of the academic world, industry, and government. This group is chaired by Mr. Henry Loomis, VOA's Director. It serves both as a forum for review of technical plans and as a source of technical ideas and information. Through the Science Advisory Group, VOA has available to it for consultative purposes, some of America's engineering and scientific leaders in the field of communication.

VOA is actively participating in governmental long-range planning for space communications. It has urged that international radio and television broadcasting be considered as a high priority goal for this country's space communications program.

VOA also participates actively in the Inter-departmental Radio Advisory Committee (IRAC) and other government and international groups concerned with telecommunications planning.

Engineering Personnel

The Office of the Engineering Manager, VOA's engineering headquarters in Washington, is made up of approximately one hundred engineers, communication specialists, technicians and supporting clerical personnel. Of this number, about one-third hold degrees in the various fields of engineering or associated sciences, or are registered Professional Engineers. Overseas, VOA employs approximately six hundred and twenty-five communication specialists and technicians, eighty-six of whom are American (see Figure 9).

Effectiveness

The question may certainly be asked whether all this is effective; does the VOA actually reach its target areas, especially in those countries under Communist domination? To determine the technical effectiveness of the VOA world-wide broadcasting system, monitoring stations have been set up to act as "ears" for the VOA. At each monitoring stations all VOA language broadcasts to the particular areas are monitored under reception conditions that are typical for the average listener in the area. Reception information amassed at these technical monitoring stations during 1960, amounting to over a million individual monitoring observations. On languages that are not jammed, such as English, Arabic, Hindi, Urdu, etc., over 90% of all the programs monitored were reported as being received satisfactorily. On the Soviet and satellite VOA language transmissions, which are being jammed by the Communists, the percentage of satisfactory reception is, as one would expect, somewhat lower. Indications are, however, that fairly good reception of the VOA is possible over large areas under Communist domination.

Possibly one of the most tangible proofs that the Communists regard the VOA as a threat to their designs is the magnitude of the Soviet Union's effort to jam the broadcasts beamed to the Communist-dominated areas of the world.

Scientific surveys, letters from listeners, efforts by the Communist press and radio to discredit the broadcasts, and reports from correspondents and travelers, all provide convincing evidence that the VOA's world-wide international broadcasting system has been successful in overcoming the natural and man-made obstacles and is getting through, to an appreciable degree, with its message from America.

The Voice of America, broadcasting through its technical facilities, seeks only to be the radio mirror, without distortion, of America and the American people.

The Voice of America's Washington studios are located in Health, Education and Welfare Building, on Independence Avenue. Free public tours are conducted at 11 A.M. and 3 P.M., Monday through Friday, and visitors are cordially invited.

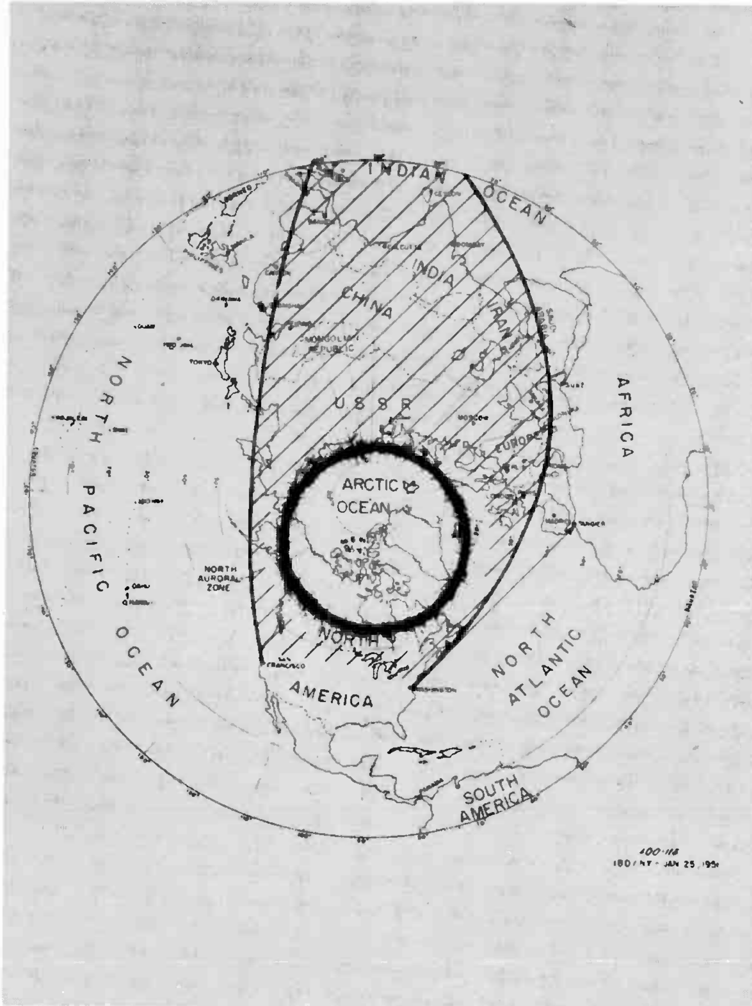

Figure 1: An arctic projection indicating the approximate location of the northern auroral zone. Cross-hatched area shows parts of the world that cannot be reached effectively from shortwave transmitters in the United States due to the shielding effect of the auroral zone. Note, however, that circuits from New York to Tangier and from San Francisco to Manila are not shielded by this zone.

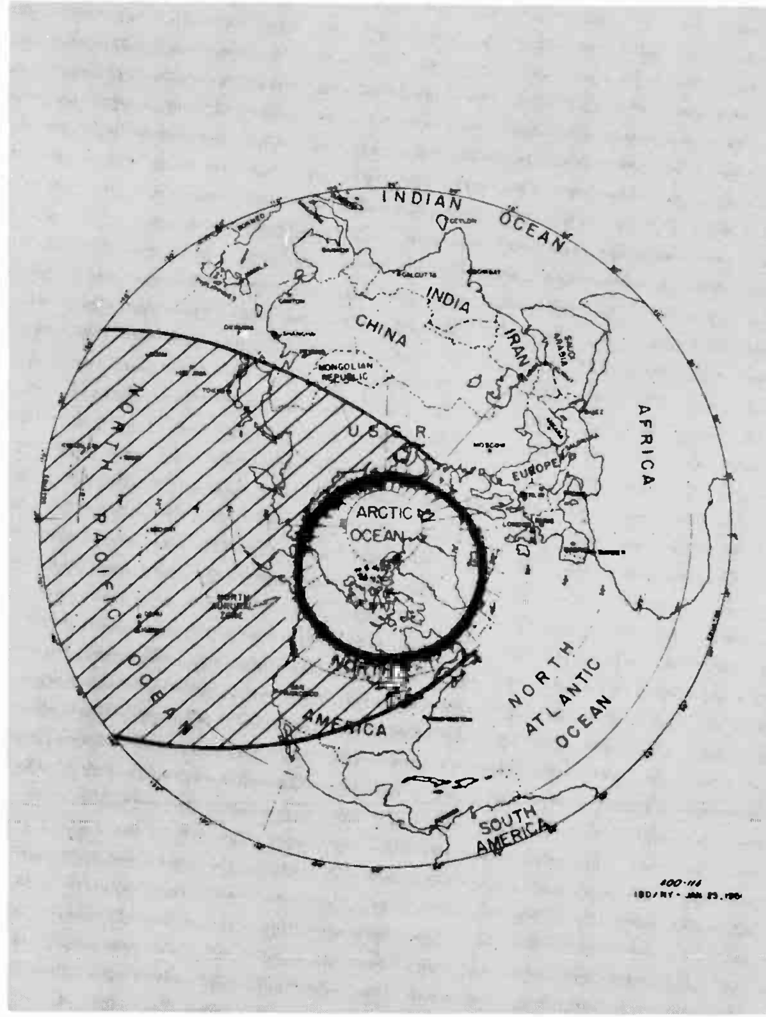

Figure 2: The same map projection as Figure 1 with the cross-hatched area indicating the auroral zone shielding effect upon shortwave transmission from Tangier. Note that Asiatic and European areas shielded from direct coverage from the United States (see Figure 1) can be covered from Tangier.

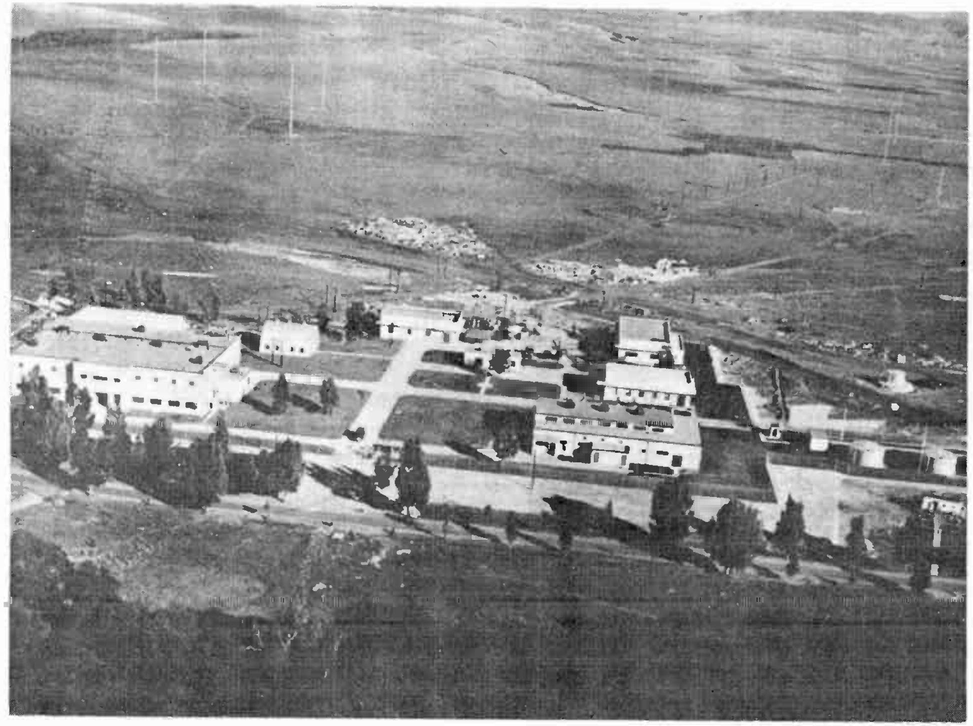

Figure 3: Aerial view of VOA's Tangier relay station. Transmitter buildings on left house ten shortwave transmitters. Self-contained diesel-generating plant is contained in buildings on right. Antennas in background beam VOA broadcasts to Europe, North Africa and the Near and Middle East.

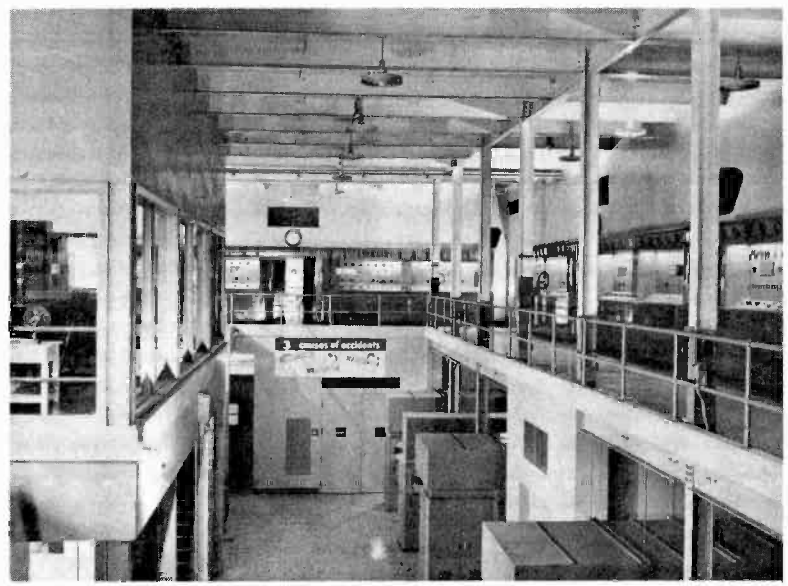

Figure 4: Interior view of VOA's Tangier relay station showing 100 kilowatt transmitters (upper level) and 35 kilowatt transmitters (lower level).

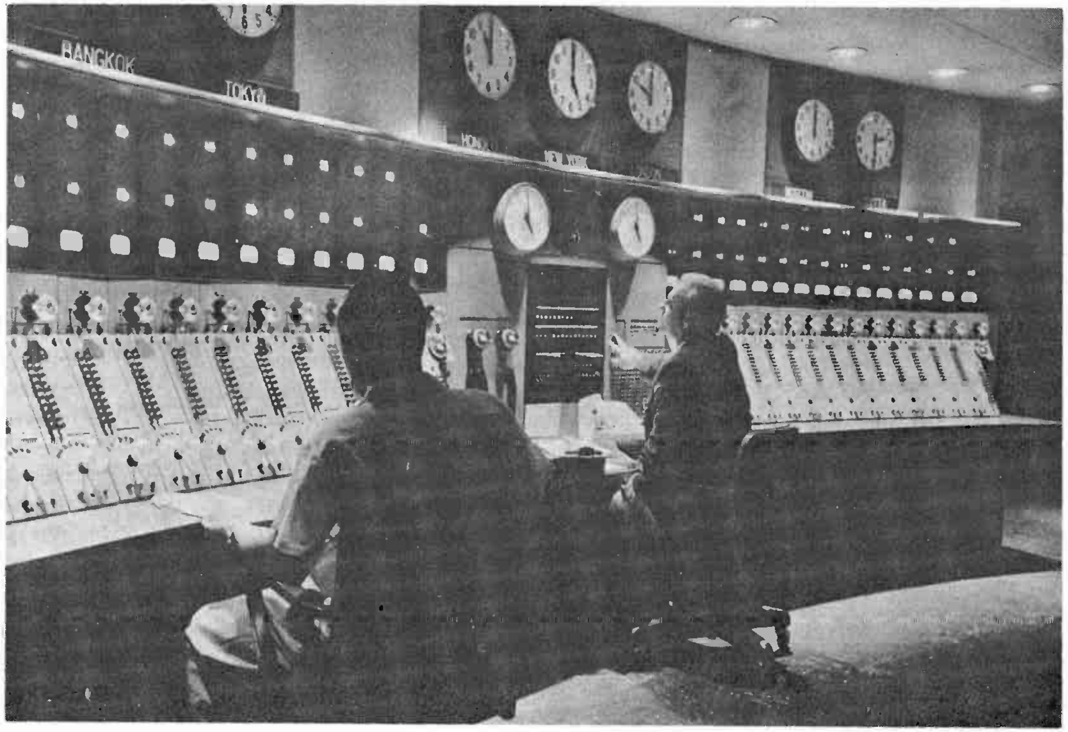

Figure 5: The Voice of America's master control console is largest and most flexible in the world. Especially designed and built for the Voice facilities in Washington, D.C., it can select programs from 100 different sources and transmit 26 programs simultaneously.

Master control is manned at all times by two radio technicians who pre-set the board in advance for each 15-minute program change. Here two technicians check the volume control while monitoring the programs which are being transmitted.

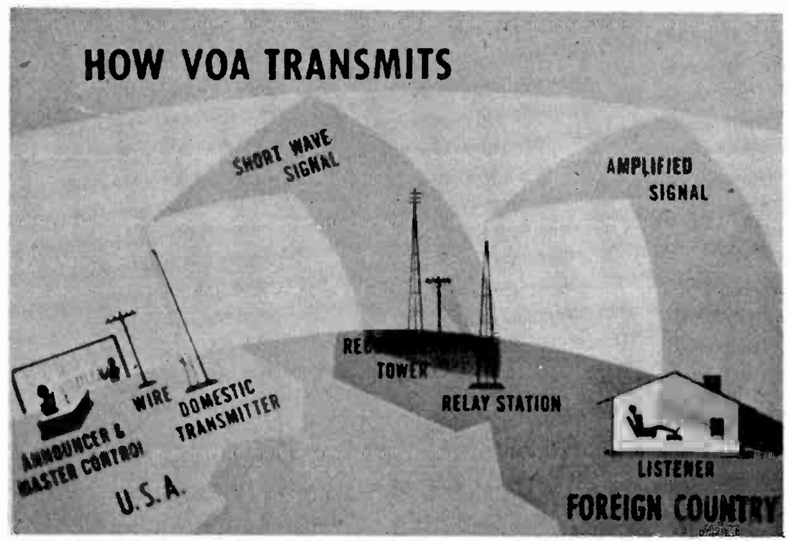

Figure 6: Programs in thirty-five languages originate in VOA's Washington studios, and are carried by landline to high-power shortwave transmitters located on the east and west coasts of the United States. Overseas relay stations pick up the broadcasts and strengthen the signal, transmitting the program to the intended audiences on long, medium and shortwave.

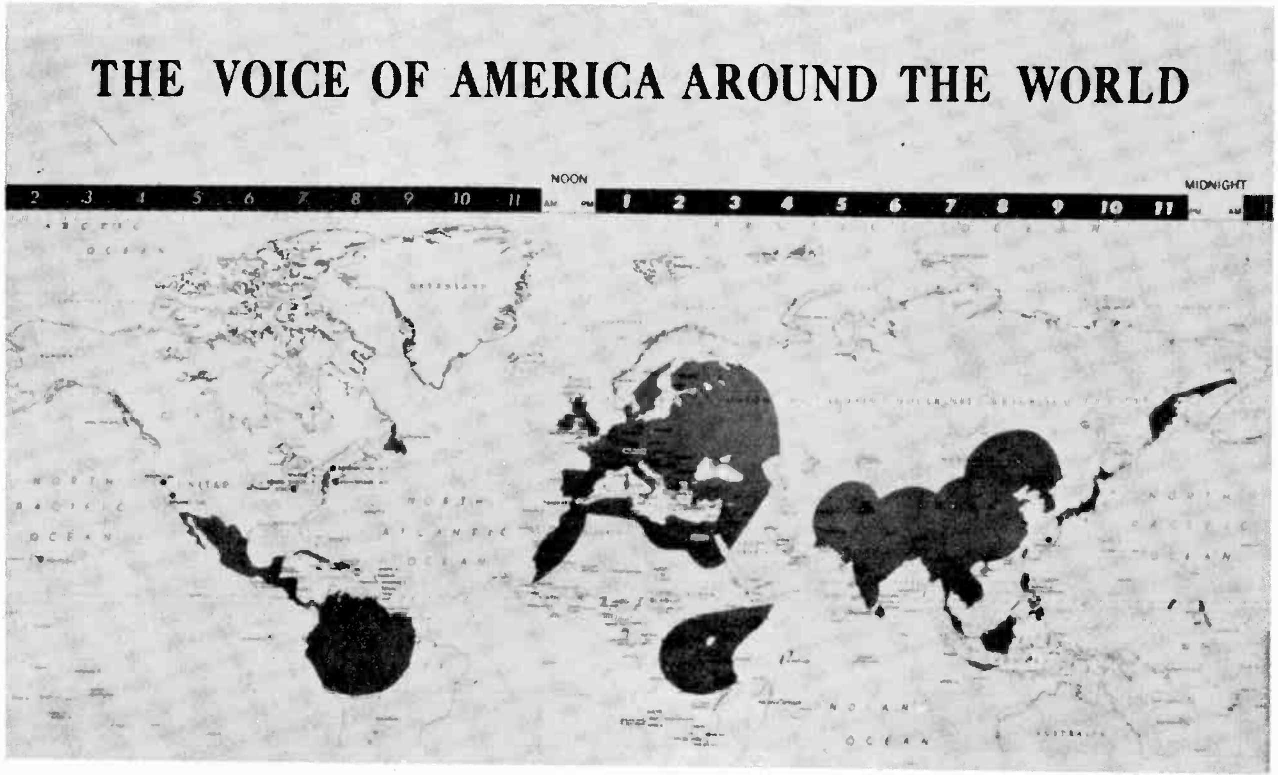

Figure 7: The Voice of America, broadcasting around the clock, beams programs to a potential audience of more than 500 million people. VOA's present coverage areas are shown shaded in the above map.

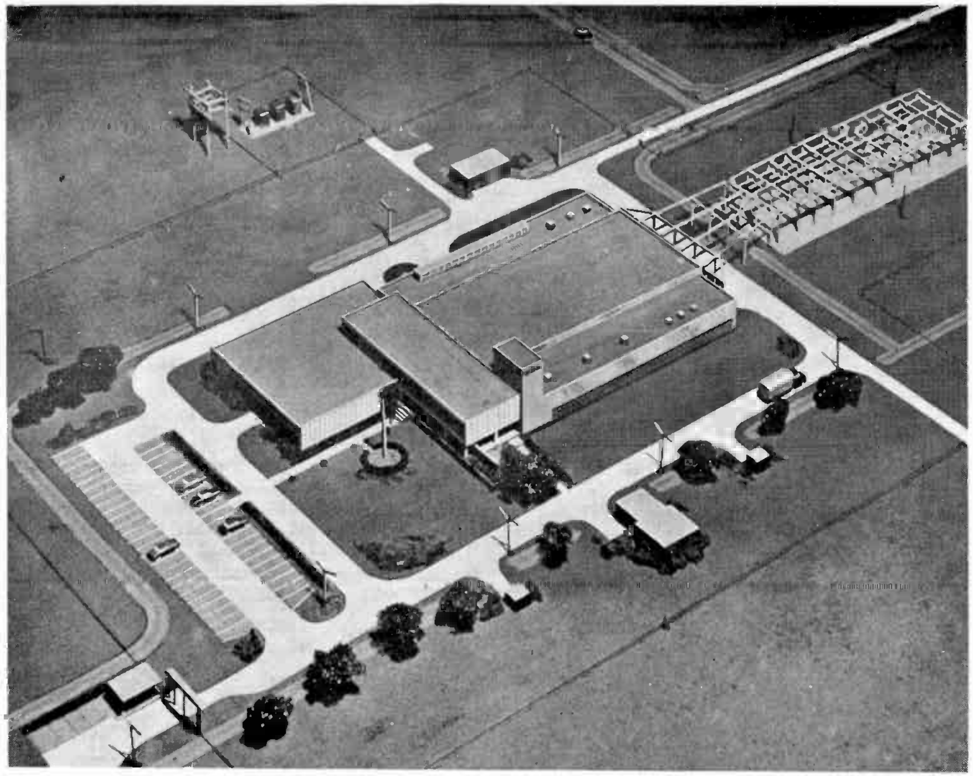

Figure 8: Plan model of one of the transmitting plants now under construction for VOA near Greenville, N.C. The 24 million dollar project will include two such transmitting plants and a receiving center. When completed, during early 1963, the installation is expected to be the largest broadcasting station in the world.

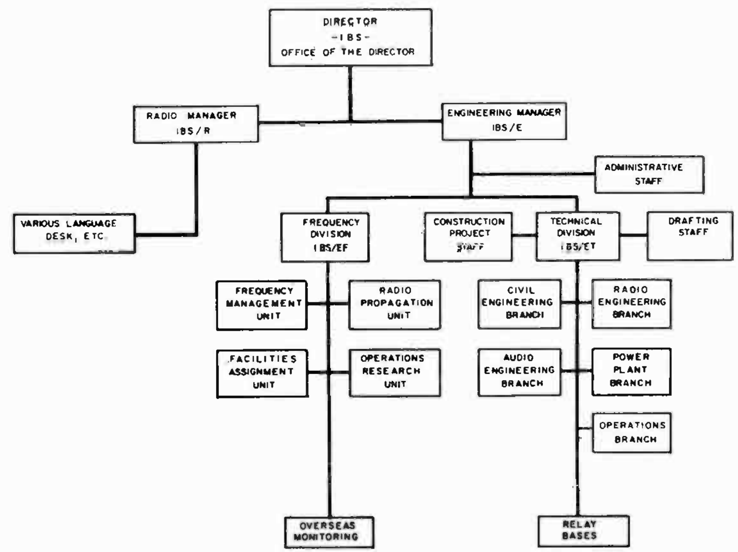

Figure 9: Headquarters for VOA's engineering staff is in Washington, D.C. The organization chart shown above illustrates the many functions performed by the 100-man engineering staff.

MERCURY RECTIFIER REPLACEMENT WITH HIGH VOLTAGE SEMICONDUCTOR DIODES

Robert M. Morris

American Broadcasting Company

With increased interest in remote control of broadcast transmitters has come an increased emphasis on and need for trouble-free transmitter operation. Even without this stimulus, the need for reliable and failure-free transmitters in radio and television service has been evident for a long time. Studies of transmitter trouble reports from several sources has shown that probably the largest single source of outages has been mercury rectifier arc backs which have averaged 35 to 40 per cent of total outages. The recent development of high voltage semiconductor rectifiers offers a means of eliminating this source of transmitter trouble and at the same time reducing tube replacement costs. Thus, while the cost of semiconductor rectifiers is higher by a factor of 3 to 10 times that of the mercury rectifiers they replace, the improved reliability and reduced tube costs make their use in existing transmitters, as well as new ones, quite advantageous.

The replacement of mercury rectifiers by silicon units has been facilitated by the recent development of modular units with the same base and cap connections as the mercury tubes they are designed to replace. In some circuits these modules can be used as direct replacements for existing 866A, 8008 or 872 type rectifiers with no circuit changes required. In circuits operating near the upper limit of current or peak inverse voltage of the tubes or in circuits of higher plate power using 869 or 857 type rectifiers, some special protective measures will usually be required.

Silicon rectifier units, as with most rectifiers, have two basic limiting characteristics. These are peak inverse voltage rating and current ratings. Inverse voltage rating is a function of the materials of which the junction is formed and usually remains constant, other things being the same, throughout the life of the junction. Peak inverse voltage ratings of 400 to 600 volts per unit are commonly supplied.

In this respect it is interesting to note that ratings which three or four years ago would be approximately the value of the zener or avalanche voltage of the diode are now being set at approximately two-thirds of this value by many manufacturers. Some diodes rated at 600 volts PIV have an avalanche voltage of 900 to 1,000 volts. A word of caution is in order in the testing of diodes for PIV rating. It is advisable in such tests not to apply potentials appreciably greater than the peak inverse rating since some of the higher voltage junctions have been developed to the point of having avalanche ratings in excess of the non-reversible breakdown voltage of the junction. A test to the point of showing reverse current might in such cases permanently damage the junction.

The current carrying capacity of a junction is a function of the heating of the junction due to the flow of current and of the ability of the junction and of the mounting of the unit to carry and dissipate heat. The current rating of a silicon diode is thus a function of time, temperature and of the mounting and cooling of the diode. It is customary to give a short term rating, usually 0.1 sec., and a continuous duty rating given as a function of ambient temperature and cooling.

The short term rating is important since it is the maximum current which should be permitted to flow during a fault or short circuit before fuses or breakers open the circuit. The continuous rating, of course, is the primary consideration in the selection of a type of diode and its mounting for a particular rectifier circuit arrangement and direct current output.

In high voltage rectifier units it is, of course, necessary to use several silicon diodes in series to achieve the necessary peak inverse voltage rating. Such modules of series connected diodes are now available from several manufacturers. In these modules voltage equalizing capacitors and resistors are connected across each of the series diodes to compensate for differing capacity and resistance as a function of voltage. These capacitors are usually from 0.003 mf to 0.01 mf and the resistors from 30K to 100K ohms.

The foregoing will probably suggest that by reference to a table of factors for the particular rectifier circuit under consideration and thus determining the operating PIV and average current per rectifier section it should be possible to select a silicon rectifier module and use it satisfactorily providing a suitably high factor of safety is applied. This approach can be quite expensive; directly so if too high a factor is used, and totally so if too low a factor is chosen. There are several circuit factors which must be considered if this factor of safety and cost is to be reduced with assurance of successful performance.

First there is the factor of maximum surge or fault current. In smaller power supplies this is not a primary consideration for at least two reasons. First, the surge to continuous rating ratio is greater proportionately in the smaller diodes, (a 500 milliampere diode has a surge rating of 10 amperes); and second, the resistance of the filter choke, the transformer and other parts of the circuit is usually higher. In high power supplies such as for the final stage of a 50KW radio or TV transmitter it is necessary to consider and to control this factor.

In this, and in discussion of other factors, it will be considered that a conventional choke input filter and vacuum tube amplifier constitute the load circuit on the rectifier. The large filter condenser shunted across the rectifier output constitutes a potential cause of high transient starting currents, the effect of which is reduced by the input choke. The starting transient can also be reduced by a resistance in series with the condensor, the value of which resistance is not in excess of the reactance of the condenser at the fundamental frequency of the rectifier output (120 cycles for single phase and 180 cycles or 360 cycles for 3 phase). The starting current surge can be essentially eliminated by a charging resistance in series with the filter condenser equal to or greater than the load resistance and arranged to be shorted out by a time delay relay set for approximately one second.

A more important consideration in the matter of protection against current surges is that of protection against excessive currents due to short circuits or faults in the load circuit. Since the rectifier current rating is a function of time and current, this requires a knowledge of the protection characteristic of fuses or breakers in the supply circuit to the rectifier. Breakers for large power supplies are usually provided with data as to their current time characteristic for operation. If the characteristic of breaker protection is not known, it would be well to consider augmenting the normal over-current protection with some form of silver-sand fuse such as the Amp-trap. These, used at a value of 1.5 to 2.0 times the normal load current, will provide excellent protection against short time currents 8 to 10 times normal without danger of failure at customary overload values.

Some stations have unusually "stiff" regulation of the main power supply with a stepdown transformer bank at or near the station. In such cases the regulation of the line should be determined with respect to the load of the main rectifier plate supply. This can be done by reading the AC line voltage with plate power on and off.

$$\text{Regulation} = \frac{(E_{off} - E_{on})\ 100}{E_{off}}$$

Regulation of less than four per cent, while excellent from the standpoint of transmitter performance, means the possibility of excessive transient fault currents. In such case it is recommended that additional regulation to the extent of 3% to 5% in the form of current limiting reactors be provided. These reactors, available from manufacturers of heavy electric switch gear, are air core inductors (to avoid saturation) and should be connected in the primary circuit of the plate transformer.

In the matter of control of voltage transients in the rectifier circuit other factors must be considered and other measures taken. There are two conditions under which transient voltages can be created in a rectifier power supply; application of power and shut-off of power. Both can cause unusually high values of voltage. Starting transients can create potentials up to approximately twice normal peak voltage depending upon the time of circuit closure relative to the voltage cycle. Shut-off transients can be even greater in value depending upon the load circuit, the Q of the filter reactor, and the type of circuit contactor or breaker used. Vacuum type switches may cause substantially higher transients as compared to older air break contactors. Both types of transients can be effectively controlled by lowering the impedance of the filter reactor at high frequencies such as exist in the steep wavefront of a transient pulse or by lowering the impedance at voltages in excess of some normal value. This latter is believed in general to be the best method of surge protection and is easily and relatively inexpensively accomplished by the use of Thyrite varistors. These units made of processed silicon carbide have a negative coefficient of resistance as a function of voltage. This means that at an impressed potential across the varistor considered normal, the resistance may be several hundred thousand ohms and thus cause a negligible effect on the circuit across which it is connected. This resistance may, however, drop 1,000 to 1 with a potential such as might be created by a voltage transient with the result that the energy of the transient (usually stored in the transformer or reactor) is dissipated automatically in the thyrite varistor.

A typical unit such as has been used in ABC transmitter modifications has a resistance at 1,500 volts of 1.5 megohms. A voltage of 6,000 volts, however, reduces the resistance of this unit to 900 ohms. This unit connected directly across the filter reactor of a 7KV, 3 phase double Y rectifier supply effectively limits transient potentials to approximately 6KV, a value well within safe values of the associated rectifiers. It is interesting to note that while this varistor may be called upon to absorb transient energy at crest values of approximately 70KW, its normal operating dissipation is less than 2 watts.

In single phase supplies the use of thyrite is not quite as easy nor as advantageous as with 3 phase supplies due to the higher value of alternating component across the reactor relative to the average or DC output voltage. It requires a more precise selection of thyrite characteristic and usually requires greater normal dissipation in the thyrite to obtain satisfactory limiting of surge potentials. An alternative method is the use of a series connected resistance and condenser instead of the thyrite across the filter reactor. The condenser should have an AC rating approximately equal to the DC output voltage value and a capacity of 0.05 to 0.1 mfd. The resistance should be approximately half the value of the load resistance and have a dissipation rating of at least 100 watts for supplies of 2 to 3 thousand volts. Either of these methods will effectively control transient voltages in rectifier circuits although the thyrite method is believed the more effective and usually the less expensive of the two.

In order to get the most rectifier for the cost involved it will be necessary to consider the matter of cooling. Most manufacturers clearly indicate that the current rating of a silicon rectifier unit is a function both of ambient temperature and the amount or type of cooling provided. In most transmitters rectifiers are or can be mounted in a cubicle with a certain amount of forced ventilation and an ambient temperature of 35 degrees C or less. In such cases it may be both expedient and economical to mount rectifier modules designed for convection cooling with no special or additional provisions for cooling the rectifiers. This is especially true in medium power supplies or where sealed plug-in replacement units are used.

In higher power units it will probably be desirable to consider the use of modules with a moderate amount of forced cooling. Even a small amount of air circulation through a module will substantially increase the continuous current rating. It should be borne in mind, however, that this does not increase the short time current rating of the unit. A satisfactory value for both current ratings is necessary for safe trouble-free operation. One manufacturer is providing an insulating mounting for 3 modules (suitable for 3 phase supplies) and arranged with self-contained blowers and an air flow microswitch to be connected in the interlock circuit to guard against cooling failure. This housing provides approximately 150 cfm of air or 50 cfm per module.

The life of silicon rectifier units under normal conditions is believed to be essentially unlimited. There is as a practical matter, however, one factor which apparently is difficult to control which can result in early failure. This is the matter of sealing the junction against the action of moist air or water vapor. An imperfect hermetic seal can result in a junction which deteriorates rapidly, especially under conditions of high humidity. This deterioration can occur whether the unit is in operation or on the shelf and is believed to explain the mysterious failure of rectifiers stored as spares. If a rectifier has a defective seal it will probably become evident within six months or a year of manufacture. A guarantee by the manufacturer against such failure is believed necessary and appropriate.

The foregoing problem brings up the matter of testing of semiconductor rectifiers. Several rather sophisticated methods have been described in which both forward and inverse voltage as function of current can be determined using an alternating potential applied to the unit under test. It is believed that the most important characteristic and the one which suffers if seal leakage exists is that of reverse current at rated inverse voltage. This can be easily determined by the use of a small DC supply delivering the desired inverse voltage (400v to 500v usually) with a milliammeter of appropriate scale (10-20 ma) protected against short circuit by a current limiting resistance of 20 to 50 thousand ohms.

Each cell is separately checked by this test unit and a reading of inverse current is obtained. Inverse currents on 500 ma units should not exceed approximately 100 microamps. Currents on 5 to 10 ampere units should not exceed approximately 1 milliampere. If voltage distributing resistors are connected across each cell of a module, the current through this resistor must be taken into account in making the test. If cells are found to have inverse currents higher than an allowed value they should, of course, be replaced to maintain the full peak inverse voltage rating of the module. It will probably be found unnecessary to make cell tests more often than once or twice a year after the first year of operation of a rectifier.

In summary, the steps in replacement of mercury rectifiers with silicon diode units are as follows:

1. Determine the average voltage and current, the RMS and peak inverse voltage and the AC ripple voltage for the power supply under consideration.

2. Select a rectifier module or assembly with a peak inverse voltage rating twice that value determined above, with a short term (0.1 sec.) rating at least 10 times the value of average current and with an average current rating satisfactory for the load current with appropriate cooling. (A safety factor of 50 to 100 per cent in current rating is recommended).

3. Select and connect to the filter reactor a thyrite varistor or other surge protecting unit appropriate to the ripple voltage of the rectifier circuit.

4. Determine the need for an apply any necessary current limiting reactors, surge limiting resistors, fast-blow fuses, etc., for protection against excessive short duration currents.

5. Determine the need for and apply any necessary cooling to the rectifier modules or assemblies.

With these precautions it should be possible to fully modernize the power supplies of any radio or television transmitter and substantially reduce those sudden and unpredictable outages due to mercury rectifiers.

APPENDIX

Useful and available data relating to application of Silicon rectifiers:

"International Rectifier Corporation Engineering Handbook"

International Rectifier Corporation
El Segundo, California

"Semiconductor Rectifier Components Guide"

General Electric Company
Application Engineering Center
Rectifier Components Department
Auburn, New York

"High Voltage Silicon Rectifier Technical Data 54-261" and "Rectifier Handbook 90-000"

Westinghouse Electric Corporation
Semi-Conductor Department
Youngwood, Pennsylvania

"Silicon Rectifier Handbook"

Sarkes Tarzian, Inc.
Semi-Conductor Division
Bloomington, Indiana

"Silicon Rectifier Selection Guide"

Transitron Electronic Corporation
Wakefield, Melrose
Boston, Massachusetts

"Brochure Thyrite Varistors"

General Electric Company
Magnetic Materials Division
Edmore, Michigan

"Current Limiting Reactors Descriptive Bulletin 45-455"

Westinghouse Electric Corporation
Transformer Division
Sharon, Pennsylvania

39TH ANNUAL CONVENTION NAB
Washington, D. C. May 7-10
1961
Engineering Session

REMARKS BY GEORGE P. HIXENBAUGH
Chief Engineer The WMT Stations

)BLEMS INVOLVED IN COMMUNICATING OPERATIONAL & MAINTENANCE INFORMATION TO & FROM TECHNICAL STAFF

- -

How many times, as a technician, have you arrived on duty at 6:00 AM find a hastily scribbled note stuck to the "ON BUTTON" saying, "this and that been done, plus a new amplifier installed, and it should work okay - but if doesn't phone me at home." When you, the chief, run down a failure discovered, rly everyone except you and the supervisors knew this could happen - - but the hnician just failed to pass on the information.

With increased service in years on the job, the chief engineer may ume all men know the plant equally well. However the younger men are lost. lan should be worked out to keep older men alert - younger men eager to learn - management informed - - as well as management keeping all technicians informed to equipment and operational duties.

The solution - -conferences take up too much time, and impractical to all men at the same time. Memo's - seldom read and, if read, may be misunder-od. Personal supervision - too costly. For many years at the radio trans-ter, a daily operational log was kept in which all happenings were written all transmitter men could read what had happened on their days off, and er shifts.

With the advent of TV, this type of log was used at the TV trans-

er. Plus a maintenance log used on the all-night maintenance shifts. The

- - the sign-on man began the daily operational log, listed happenings,

ures, corrections, etc. Middle shift the same, and sign-off shift the same....

man coming on duty reads the logs, and after his days off the previous two,

ing himself up-to-date. This worked fine at the transmitter. The super-

or could make work assignments by writing them on the log, and then their

pletion noted on the log.

If this worked for transmitters - why not make it work for studios.

was done: A clipboard with a log form for that location was placed at

gram sources; namely - the sound stage, projection room, video tape master

trol, auxiliary transmitter at studio, plus maintenance assignments.

The WMT Stations have no job classifications - - a man may have

eral assignments including maintenance during his work day. He begins his

st assignment by signing the appropriate log form. He then reads the log or

vious logs in case of days off. Any failures while he is on duty are written

- including symptoms and corrections. All technicians use the same procedure.

uld supervisors wish to make an additional assignment at a certain location, s written up and addressed to the technician. Upon completion, the assigned nician writes it up. Possible faults are noted, items required, and so forth, listed.

The supervisors check all forms when coming on duty, and transfers 8th report to the file. This permits seven days of forms to accumulate for iew by everyone. They are filed with equipment service manuals for future erence. Maintenance and new construction assignments are made on a separate m - which is used in non-emergency cases.

The advantage of this system is that everyone knows what is going on the time and, equally advantageous, is that technicians are doing the municating with little supervision.

This is what we have learned from the practice of using these logs: en times better technicians do not write legibly. In that printing would be time consuming - the typewriter is the solution, even though the "hunt & ek" method must be used. With a failure corrected, the technician writing up at happened, and how he corrected it, he will remember it a long time - just cause he wrote it. He also will be sure of what he has said and that it is chnically correct; otherwise, he is in for some kidding (usually this being some good-natured research).

asionally younger technicians are afraid to write up a story - fearing they ld be wrong. However, they soon learn from reading as to what others have done. s is fundamental - the experienced teaching the non-experienced.

The fault we have discovered, is the failure to write up an ident. Reason - forgotten. Seldom does a failure occur without someone ing or hearing it, and if it is not on the log - a lot of explaining is essary by the one forgetting. Neglecting to make a comment on the log occurs, t times, near the end of a work day when there might not be time to write it . We urge them to make their comments on the log - even if it takes 15-minutes overtime.

Any major failure with complete explanation is available for supersors, the chief engineer, and to management, immediately. Should a major ilure occur, complete details can be on the sales manager and manager's desk the beginning of business the following day, thus you have paid for your ouble in setting up this system.

To conclude - we have slides of nine operational forms picked at ndom. (Show slides 1 thru 9).

Comments.....

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FCC BROADCAST STATION RENEWAL INSPECTIONS

GEO. S. TURNER, CHIEF

FIELD ENGINEERING AND MONITORING BUREAU

F.C.C.

NAB ENGINEERING CONFERENCE

May 8, 1961

Washington, D. C.

FCC BROADCAST STATION RENEWAL INSPECTIONS

I. Early Equipment - Technical Limitations

In the 1920's and early 1930's broadcast transmitters consisted of basic components without technical refinements. Many transmitters had a single modulated oscillator stage, without crystal control, coupled directly into the antenna. The only method of maintaining frequency was by beating the carrier against a non-temperature controlled crystal oscillator. In view of the ease with which these transmitters could change frequency certain stations located on the coast and Great Lakes area were required to maintain a listening watch on the marine distress frequency of 500 kc. and sign off in the case of distress. With such crude equipment in the early days, close supervision was necessary and the Commission maintained a special early morning monitoring schedule to observe operations of standard broadcast stations. I recall one instance where a station was found to be exactly on the measured frequency, but unfortunately when he identified it was discovered that he was operating on the next channel, 10 kcs. away. In another case the station split the difference and compromised by settling on a frequency just half way to the next channel. The frequency tolerance at that time was 500 cycles.

Safety measures in the early days were practically nonexistent and high voltage was in easy reach of the careless operator. A number of operators were painfully burned and severely scarred; others in not insignificant numbers lost their lives. Stations were oftentimes composite and constructed by the station's chief operator. In consequence he was the only one who knew the idiosyncrasies of the equipment and in his absence unexpected technical problems would develop.

II. Extensive Maintenance and Need for Frequent Inspections

Since most equipment was individually constructed with little uniformity in circuits or component parts, extensive and constant supervision by first class operators was necessary even to keep the equipment in operation, much less in compliance with the Department's rules. Frequency inspections by the field force of the Department of Commerce Radio Division and subsequently Federal Radio Commission were necessary to prevent serious interference both to other stations within the standard broadcast band and other services on both lower and higher frequencies. The problem of inspection was, however, much simpler in those days, that is, around 1924 when I signed up with the Department of Commerce as a Radio Inspector. There were less than 600 standard broadcast stations in operation in those early days and FM and TV problems were in the future.

In the very beginning of broadcasting, as many oldtimers will remember, operation was limited to 360 meters for music and like matter, and 485 meters for weather reports. It might be of interest for me to review with you a very enlightening observation contained in a very delightful book entitled "Microphone Memoirs" written by Credo Fitch Harris, the first General Manager of broadcast station WHAS in Louisville, Kentucky. Mr. Harris writes as follows:

"In the beginning when 360 meters had been assigned to all stations, happily there were only a few and those widely scattered. For, although we did not become aware of it until later, it was impossible to tune those clumsy little transmitters with any reasonable degree of accuracy, and, because of that, their mutual interference was negligible to the listener.

"The way a transmitter was complacently assumed to be kept on its required 360 meters in those days would be amusing now, or horrifying. A government inspector arrived every four or five months to 'measure' us. He carried a little black box with a meter in it -- and perhaps other things, but I never looked. He discouraged looking, so the mystery surrounding it remained profound. He usually placed that box on a chair about eight feet from our transmitter while the apparatus was operating --- a distance which was considered safe from the standpoint of interference that might readily be caused by the proximity of a human body.

"In front of the main panel was a large aluminum disk with a center knob, devised by the manufacturer to vary its emitted frequency -- similar to a peg for the tuning of a fiddle string which, by turning it one way or the other, raises or lowers the pitch. The supervisor would gravely and thoughtfully turn that knob back and forth, watching his meter betimes.

"During this process his breathing always became labored, his brow puckered, -- which may have been an individual characteristic or a desire to impress us. He would then take a pencil and make a thin mark on the disk's circumference, announcing solemnly: '360.' Another mark: '485 for the weather.' Without further ado he left, his manner indicating an unexpressed admonition: 'Take care!' If those pencil strokes escaped being rubbed off by an over-zealous janitor some early morning, we probably retained an accuracy of five or ten meters, above or under par. Or if they remained long enough for the supervisor's next visit, it was interesting to observe that he invariably rubbed them out himself and put on new ones."

I particularly wanted to give you this story from one of radio's well known pioneers and have you contrast it with the principal subject matter of my talk relating to broadcast station inspections as currently carried out. In so doing, however, we both must keep in mind that not only has life become more complex, but most certainly broadcast equipment operation and regulation has become much more involved also.

III. Three Decades Later

As of the end of the fiscal year 1960 there were approximately 3600 standard broadcast stations and 7500 in FM, TV and miscellaneous broadcast services. The problem of enforcement is obvious since there has been only a modest increase in personnel assigned to broadcast work in the field subsequent to 1930, while the total number of broadcast transmitters of all descriptions has increased nearly twenty fold. This is why up until recently, instead of making inspections every four to five months apart as Mr. Harris indicated, we were doing well to make inspections of even the principal transmitters in many instances not more often than three to five years apart.

Progress in equipment design has greatly reduced early technical enforcement problems such as development of precision frequency control and standardization by use of manufactured equipment which is reliable under normal service conditions. On the other hand, although many technical problems of the early days have been eliminated, new problems have taken their place. These include such technical developments as complex directional arrays, the use of remote control for many installations and, I would be less than candid if I failed to mention the employment of the non-technical operator or what is oftentimes equally as bad, if not worse, the disc-jockey/announcer type operator.

If I may digress for the moment, I believe we will find it interesting to compare the results of our inspection and measurements of the technical characteristics of TV and AM broadcast stations. Although the equipment at a typical TV broadcast station is far more complex than AM broadcast equipment, we find that general violations of the technical standards are somewhat less common than for AM broadcast stations. For example, on a recent trip of one of the Commission's TV Enforcement Units into the southeastern states, measurements and inspections were made on 23 TV stations. These were very detailed inspections involving measurements of carrier frequencies, bandwidth and modulation level, the characteristics of the synchronizing pulses and other composite video components, and, where color transmissions were being made, measurements of the characteristics of the color signal. Even so, only six of the 23 stations were issued violation notices for technical deficiencies. I believe this is a demonstration of the excellence of the engineering staffs at many of the TV stations, and I feel that many of the AM stations could benefit by the conscientious preventive maintenance commonly performed at TV stations.

Because of this letdown or lack of technical or other supervision by all hands, or because of other reasons less obvious, anyhow, it became apparent to the Commission in the latter part of 1959 from a review of inspection and citation records by the Field Engineering and Monitoring Bureau that there was a growing disregard for engineering rules, operator requirements, and equipment performance standards on the part of many broadcast licensees particularly in the standard AM broadcast service. These deficiencies were formally called to the attention of the Commission and as a result broadcast licensees were informed of the deteriorating technical compliance by means of a public notice dated April 29, 1960. At the same time disclosures of "rigged" programs and action by Congress alerted the Commission to the need for increased activity in non-technical phases of broadcast enforcement.

IV. Joint Action by Field Engineering and Monitoring and Broadcast Bureaus

In recognition of their joint responsibility, the Field Engineering and Monitoring Bureau and the Broadcast Bureau have developed a coordinated enforcement program, the salient points of which are: (1) renewal inspections in depth during the last 18 months of the license term consisting of (a) program recording in advance of the station inspections, (b) technical inspection including antenna, transmission lines, ground system, performance of transmitters as well as studio equipment and compliance with the Commission's technical rules, and, (c) inquiry into non-technical areas including sponsorship, identification, hidden ownership, payola, etc., using recorded material for comparison of actual performance against station records; (2) Growing out of renewal inspections performed by the field engineer or as a result of complaints or other information received by the Commission from outside sources, the Broadcast Bureau may send an investigative team to a specific station for detailed analysis of the station's non-technical operation. Additional participation by the field engineer is also available for the purpose of covering current technical performance as required; (3) Supplementary to the foregoing, prompt submission of technical deficiencies or questionable practices in non-technical areas with recordings are made to the Broadcast Bureau by the Field Engineering and Monitoring Bureau for consideration in renewal license processing or for specific enforcement action.

V. Renewal Inspection Technique

The Field Engineering and Monitoring Bureau in the making of renewal inspections is giving particular attention to the technical performance of AM broadcast stations and more especially in many instances to radiation patterns of directional stations, proof of performance measurements and antenna resistance and monitoring point measurements.

AM Broadcast Station Directional Antenna Monitoring Points are checked by our Field Engineers as a part of the renewal inspection of the station to determine whether or not the prescribed radiation pattern is being maintained. In the period immediately following World War II when hundreds of new stations went on the air with directional antennas, it was not uncommon to find a majority of these stations operating with field patterns which did not conform to the terms of their grants. In one "horrible example" which I recall, the station's pattern was so poorly adjusted that the field strength at one of the monitoring points was 800% of the specified limit.

Although there has been some improvement over the years in this respect, a considerable number of stations still apparently do not take the monitoring point measurements seriously and thus find themselves the recipients of a violation notice for excessive monitoring point field strengths. In the course of a recent survey of four month's duration, 24 stations were so cited.

Obviously, improper antenna patterns are of concern to all co-channel stations whose own coverage depends in a considerable measure on protection from excessive radiation from other occupants of the channel; and of course in some cases an improperly oriented pattern may actually reduce coverage in areas which the station is licensed to serve. In enforcing the pattern limitations, our field engineers have been taught to be sympathetic to the problems of the licensee and to adopt a cooperative attitude in correcting unsatisfactory conditions which exist. In all our enforcement activities, our prime purpose is to help the licensee to help himself to provide the best possible service for the benefit of the public.

Proof of Performance Measurements are also frequently made as a part of our renewal inspection program. A considerable number of AM stations apparently experience difficulty in maintaining compliance with the transmitter performance provisions of the Rules especially with regard to audio frequency response and audio distortion. Surprisingly enough, this difficulty seldom shows up in the station's records which habitually indicate that the frequency response, distortion, and carrier hum are well within the limitations; in fact, it sometimes appears that the station's Chief Engineer has "switched transmitters" since the same measurements made by the Commission's engineer often indicate considerably inferior operating characteristics compared with those on file. Since July 1960 our engineers have made equipment performance measurements at 22 standard broadcast stations. Deficiencies of a sufficiently serious nature were disclosed as a result of these measurements to justify issuance of one or more violation notices to 16 of these 22 stations. An example of the deficiencies encountered involve a midwestern station in which the audio frequency response varied over a range from plus 6 to minus 4.2 db from the 1000 cps pattern. Wide variations extended throughout the audio range. This same station was also found to have audio distortion as high as 13% at normal modulation levels and the carrier shift likewise exceeded the specified limit. Obviously this station was not providing the quality of service that the public had a right to expect.

Field Strength Measurements to Determine Coverage were made at two stations in a western town, both operating with 250 watts power in the same area and in the same general portion of the AM band. Measurements showed that one of the stations was consistently much stronger than the other at the same distance from the antenna even though they should have been approximately equal in strength. The average difference was of the order of two-to-one. The licensee of the station with the poorer coverage expressed great concern and indicated he would take immediate steps to have a consulting engineer check the antenna system to determine the reason for its low radiation effectiveness.

It has been our experience that a significant number of the AM broadcast stations operating with non-directional antennas are providing less coverage than was contemplated by the Commission's Rules or terms of the license. This condition is often due to a deteriorated ground system or to other deficiencies in the radiating system. Of 115 AM stations checked since last September, 18 stations had field strengths which were more than 20% below the expected value, and at four stations the field was less than 50% of the expected value. Obviously such conditions as these result not only in reduced service to the public, but in less value received per dollar expended insofar as the program sponsors are concerned, and indirectly in reduced income to the broadcast station. At times, where the Commission engineer has reason to suspect that lower than expected field strength may be due to the use of the improper value of antenna resistance in arriving at the power output, the actual resistance is checked by the Commission engineer. In such cases it is not uncommon to find that the resistance has changed significantly. In one instance this change in antenna resistance was found to be due to changes in tower lighting circuitry after the antenna resistance measurement had been made. Therefore, it would seem that it would behoove the licensee to have antenna resistance measurements checked periodically and especially after changes have been made in the antenna or associated circuitry. I know this must be apparent to most of you, however, it might be desirable to remember that if the transmitter requires, as for example, 1500 watts input to the final to achieve the specified antenna current, and at some later date only 1200 watts is required for the same antenna current, it should be generally quite obvious that some change has taken place in the overall antenna system and that such a change requires investigation.

"The FCC Inspectors Have Just Moved In and All Hell Is Breaking Loose" is a paragraph heading by an unidentified member of a state broadcast association which very fortuitously but nonetheless unintentionally, I am sure, came to our attention. This was a title used to introduce a very well thought out notice to his membership in regard to the renewal inspection program which had just gotten underway in his state. Those of you who may not have seen this release might be interested in the next four lines of the text:

> "THIS IS AN UNASHAMED ALARM! NEVER IN THE HISTORY OF BROADCASTING HAS THERE BEEN SUCH A THOROUGH-GOING AND UNRELENTING EXAMINATION."

One thing is certain, this is an eye-catcher and I have put it in at this point in my talk as a "waker-upper." Frankly, the information contained in this association paper is very valuable and in fact, I find that this or similar information outlining in considerable detail the nature of our inspection program is being presented before other state broadcast associations. Before this release came to my notice, it was my intention to do the same thing as the unidentified broadcast association author has done, i.e., cover in detail the various items which our field engineer specifically covers in the course of his renewal inspections of a broadcast station. However, I do not feel that this is now necessary, and because my paper is already growing unnecessarily long, I simply incorporate his remarks by reference as a part of my advice and recommendations to your membership but with one additional observation -- the main points our unknown friend cautions you to look out for are surprisingly enough, in the final analysis, no more nor less than existing rules which have been in the Book of Rules, lo these many years!

Admittedly, it is true, as I have previously said: our men are giving broadcast stations a thorough goingover. It isn't quite accurate, however, to say as our unknown friend has said in his release that "this is a white glove inspection." Those of you who have been in the Navy as I have know what a white glove inspection is. We are not looking for dirt as such. All that we intend to do is to check for compliance with the Rules and with the terms of your license; also, to report on performance as we find it.

Areas of Coverage Involving Non-technical Items are quite well known to broadcasters inasmuch as broadcast station inspections have long included such matters. These are specifically set forth in the Rules under the heading "Other Operating Requirements" and begin with Rule 3.111 and include such items as logs, station identification, mechanical reproductions, broadcasts by candidates for public office, rebroadcasting, and lotteries.

In addition, as special matters come to the field inspector's attention, notes are made thereof for referral to the Broadcast Bureau for such further action as may be indicated. The following is an example of such a non-technical item:

> On the basis of recordings made by field offices and monitoring stations, a careful anlysis in depth of program practices of a number of broadcast stations indicates several instances where program material and station logs do not agree with material filed with the Commission.

<u>How to Make Friends and Still Be An Inspector</u> isn't easy. Probably nobody really likes to be inspected. I know when I have gone down to have my car inspected, don't quite make it, and as a result drive out with a red sticker, which means that they have found something wrong, I don't particularly feel like congratulating the officer for being so efficient. On the other hand, on occasion the inspection can turn up a part failure or mechanical deficiency which is so consequential that I cannot help but feel that the inspector has done me a personal favor. To know about this may not only save me a more costly repair bill, but could make it possible for me to have avoided a serious accident. Taking our cue from this, in carrying out our inspection work, we also like very much to be able to be of service. In fact, there are many occasions when the type of inspection that we are now performing can be as beneficial to the licensee as a thoroughgoing survey by a consulting engineer. I hasten to add for the benefit of consulting engineers in the audience that we are not attempting to compete, but rather to join forces with them in raising the overall standards of performance within the Broadcast service.

Examples of the kind of inspections from which I feel the broadcaster benefited are as follows:

(1) Inspection of this station disclosed that there were nine violation items including important technical irregularities such as operating power more than 10% below licensed power, frequency and modulation monitors defective, no proof of performance measurements, remote meters had not been calibrated, base current ratios were beyond tolerance, phase monitor readings abnormal and the field intensity at three of the check points were well beyond authorized values. It is evident that correction of these deficiencies was in the best interest of the licensee since he was not providing coverage authorized by the Commission and was obviously, through lack of proper control, unable to insure that emission was of satisfactory broadcast quality.

(2) Eight discrepancies were noted in this inspection including bypassing of interlocks which exposed high plate voltage, no equipment performance measurements, excessive audio frequency distortion and audio frequency characteristics deviating well beyond authorized tolerance. This equipment was not only dangerous to operating personnel but failed to meet the minimum requirements of the rules as to audio capability.

(3) The inspection of another station disclosed that the antenna resistance had decreased from <u>66 ohms to 52.1 ohms</u>. Therefore, the power output of the transmitter had decreased 21% which meant that the <u>service area</u> of the station had been similarly reduced. The licensee in this case was anxious to take corrective action since the strength of his received signal was increased thereby.

(4) In the next case the importance of <u>audio performance</u> measurements and the need for making thorough technical inspections was most obvious. The <u>audio distortion and frequency response were well beyond</u> the authorized tolerances. In addition, the <u>directional pattern was out of adjustment</u> with three check points exceeding the authorized licensed value by from 35% to 200%. Likewise, the authorized base current and loop current ratios were exceeded by as much as 8.0% and the modulation monitor was defective.

(5) A recent inspection of another station disclosed that there were 26 violations of the Commission's rules and four items of non-compliance with the terms of the station authorization. These include citations for inoperative control system, defective high voltage interlocks, wiring was not in accordance with good engineering practice, output power was excessive, phase monitor was inaccurate and field strength measurements at check points were greatly in excess of authorized tolerance.

<u>Friends We Were When We Entered and Friends We Were When We Departed</u>. We have a handful of letters to prove it. Excerpts from just a few of these letters follow:

(1) "Your department can be very proud of your field inspector. Needless to say, Mr. ________ is a veteran in the field and in my many years in the broadcasting industry, I had heard a great many things about him. I had heard that he was tough and a stickler for perfection. I found Mr. ________ to be of great assistance to me and the other stations under my direction. He found fault with our technical operation, and also criticized our programming department. He substantiated each criticism with direct reference to the FCC rules and regulations. He was extremely helpful regarding improvements to be made as well as providing my engineers on duty with a better understanding of their responsibilities.

"As long as the Government has men like Mr. _______ in its employ, we need never fear of a letdown in the rigid standards required to be maintained by the broadcasters."

(2) "I, for one, hope the Congress will authorize enough funds to the FCC in order that more frequent inspections might be made. I think this will be helpful to the stations who are anxious to operate a good station and in accordance with the Rules and Regulations. Our

station was last inspected in 1958 and many amendments and changes to the Rules have been made since that time. A more frequent inspection would have helped in the proper interpretation of those changes."

(3) "I have always prided myself in trying to give credit where credit is due. This gentleman was extremely kind, courteous, and helpful to me, and I would like for you to know that he is a credit to your agency."

(4) "We are anxious to correct our deficiencies and every effort will be made to do so. We welcome inspections and wish that they could come annually. Negligence in several areas is not an immediate thing but can creep in gradually over a period of many years. We feel that it is to our benefit to be made aware of these violations. That to do so is to the benefit of ourselves, the industry, and to the people of this area."

(5) The following has already been quoted in a state broadcast meeting; however, I think it deserves to receive top level billing such as this meeting affords. Therefore, I am giving it to you as follows: "Some of you perhaps, have had an inspector in your station in recent weeks. I had the pleasure - - and I am sincere - - in having a fine gentleman visit me last Saturday afternoon and to say it was a tonic was putting it mildly. It was a routine inspection like we normally have during our renewal year. Let me suggest, if you have not already had your inspection, a friendly attitude on the part of your personnel and yourself. In fact, you can carry this thing a little too far! At one station near Crossett when the inspector introduced himself and said he was there to inspect the station, the very charming receptionist said . . . 'Do you want to inspect me first!"

This year we are making inspections in depth. However, we do have to draw the line somewhere. Gentlemen, it has been a pleasure to be with you, and I hope in closing we part as good friends.

*"THE NEWLY ADOPTED FM STEREOPHONIC BROADCASTING SYSTEM - HOW IT WORKS"

BY: William H. Beaubien, Manager
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Utica, New York

The standards for FM stereophonic broadcasting announced by the Federal Communications Commission on April 19, 1961 will usher in a new era in broadcasting and home entertainment. High fidelity sterophonic sound, compatible monophonic programming, and simultaneous storecasting capabilities assure dynamic growth for this new service. A discussion of key technological features such as the AM subcarrier, subcarrier suppression, the subharmonic pilot carrier and sidebands nesting as well as some consideration of efforts required to meet the rules and regulations will be offered to help clarify the system's technological characteristics.

*Presented at the National Convention of the National Association of Broadcasters in Washington, D.C. on May 9, 1961.

"THE NEWLY ADOPTED FM STEREOPHONIC BROADCASTING SYSTEM - HOW IT WORKS"

The standards for FM stereophonic broadcasting announced by the Federal Communications Commission on April 19, 1961 will usher in a new era in broadcasting and home entertainment. Dynamic growth for this new service is assured by its multiple abilities to meet the requirements of 3 major areas of interest to the broadcaster, namely; monophonic compatability, hi-fidelity stereophonic sound, and maintenance of revenues from SCA operations. In this introductory paper for the newly adopted FM stereophonic standards a brief appraisal will be made of the broad system capabilities. This will be followed by a detailed technological description of the system. Finally some initial considerations will be discussed relative to equipment needed and techniques required for "getting on the air".

SYSTEM CAPABILITIES

The system is capable of producing hi-fidelity stereophonic sound fully separated at frequencies from 50 to 15,000 cycles. Actually transmitters will be required to meet Commission performance specifications of 29.7 db stereophonic separation over this frequency band, thus enabling stereophonic FM radio to compare favorably with stereophonic reproduction from phonograph records.

Since distortion and frequency response standards for stereophonic transmissions have been set equal to those prevailing for existing FM monophonic broadcasting the new system will maintain FM's reputation for serving as the broadcasting outlet of the hi-fidelity world.

In addition, today's FM listener, who decides not to convert to stereo, will be able to continue to enjoy monophonic sound unaffected by stereophonic broadcasts. There are 14,000,000 to 16,000,000 estimated owners of FM radios today. These listeners will receive a fully balanced program with an imperceptible signal to noise change.

For stereophonic listeners field tests have shown that the new service will be capable of providing satisfactory signal to noise performance even in fringe areas. However, there will be some loss of station coverage area as shown by this table taken from the FCC's "Report and Order", establishing Stereophonic Standards issued on April 20, 1961.

		EXPECTED SERVICE RANGE (MILES)	
		TUNER NO. 1	TUNER NO. 2
Monophonic Transmission		90	46
Stereophonic Transmission	Monophonic Reception	88	44
Stereophonic Transmission	Stereophonic Reception	61	23

Since most stereophonic receiving equipment will probably incorporate "stereo-monophonic" switches the listener will be able to tune in distant stations if he is willing to sacrifice receiving the signal stereophonically.

We can also predict "local distance" controls where some portion of the stereophonic effect is traded for range.

Also, since the table shows that range is dependent on the quality of the receiver, as well as the type of signal being transmitted, we can anticipate a trend towards better tuners and radios for FM stereophonic listening in remote areas.

One significant feature of the new system is its ability to provide for storecasting under the FCC's Subsidiary Communications Authorizations (SCA) simultaneously with stereophonic broadcasting. This should be good news for the large number of FM stations currently engaged in this activity.

A technological description will now be undertaken to reveal the manner in which the multiple abilities of the new system are realized.

TECHNOLOGICAL SYSTEM DESCRIPTION

The newly adopted FM Stereophonic Broadcasting system features sum and difference matrixing with the sum transmitted as main carrier frequency modulation and the difference signal transmitted as suppressed carrier amplitude modulation of an ultra-sonic subcarrier. Provision for recovery of the carrier at the receiver is made by transmission of a pilot signal at half subcarrier frequency.

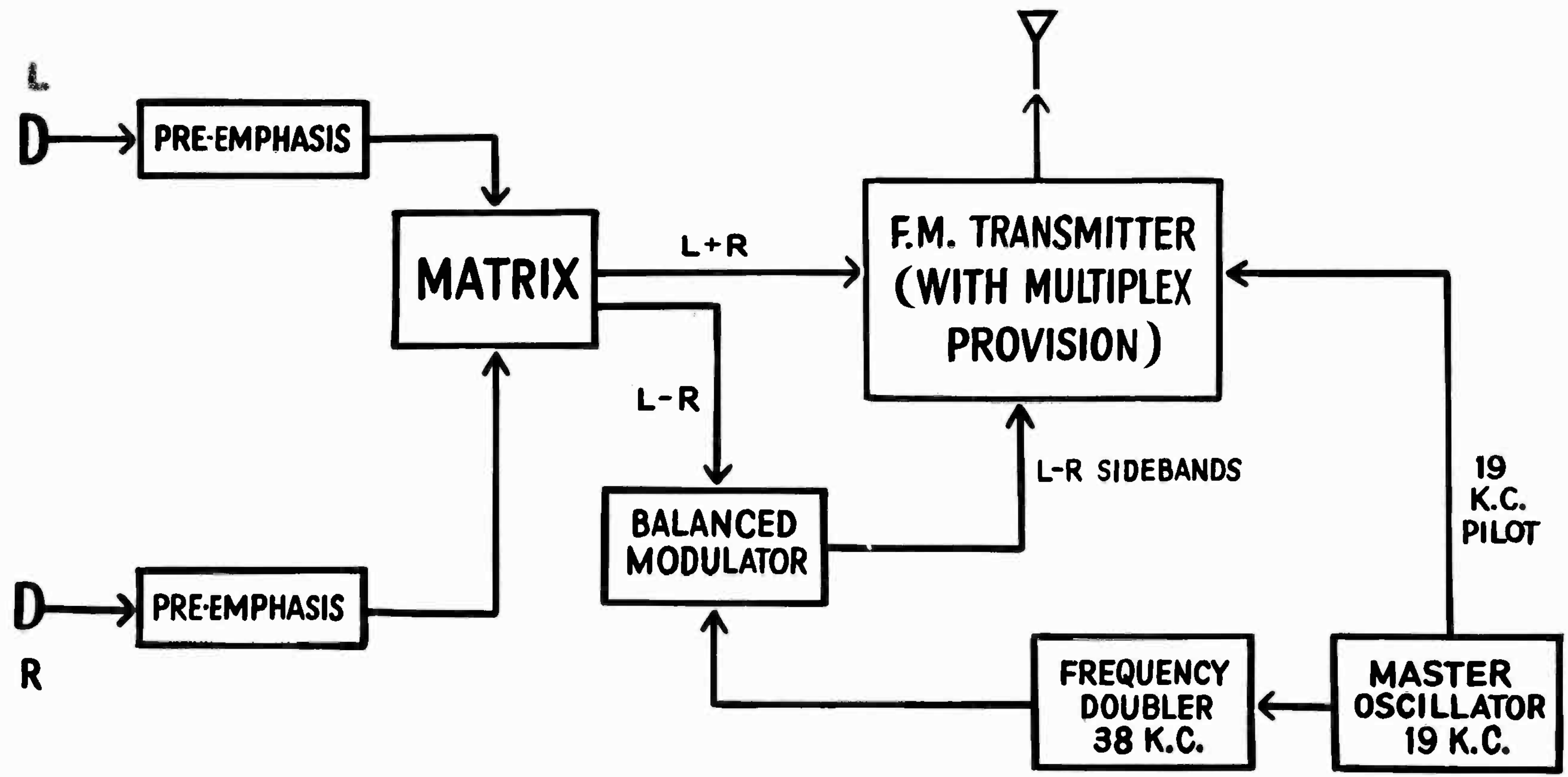
TRANSMITTER BLOCK DIAGRAM The transmitter operates generally as shown in the simplified block diagram Fig. 1. The left (L) and right (R) stereophonic signals are developed conventionally and then preemphasized separately before being fed to the matrix where the sum (L+R)and difference (L-R) are produced. The L+R signal is fed into the FM modulator in the normal manner. However, the L-R signal is fed to a balanced modulator where proportional sidebands are generated above and below the subcarrier frequency of 38 kilocycles. The carrier is automatically suppressed. Note that the carrier input to the balance modulator comes from doubling the output of a 19 kilocycle oscillator. A parallel output from this same 19 kilocycle oscillator goes into the FM modulator to act as the pilot subcarrier.

RECEIVER BLOCK DIAGRAM The receiver operates generally as depicted in the block diagram Fig. 2.

The receiver is conventional to the discriminator output which is, however, taken ahead of any deemphasizing networks. The L+R signal in an existing monophonic receiver would produce a compatible aural program, but in the stereophonic receiver it is fed directly to a matrix. The L-R

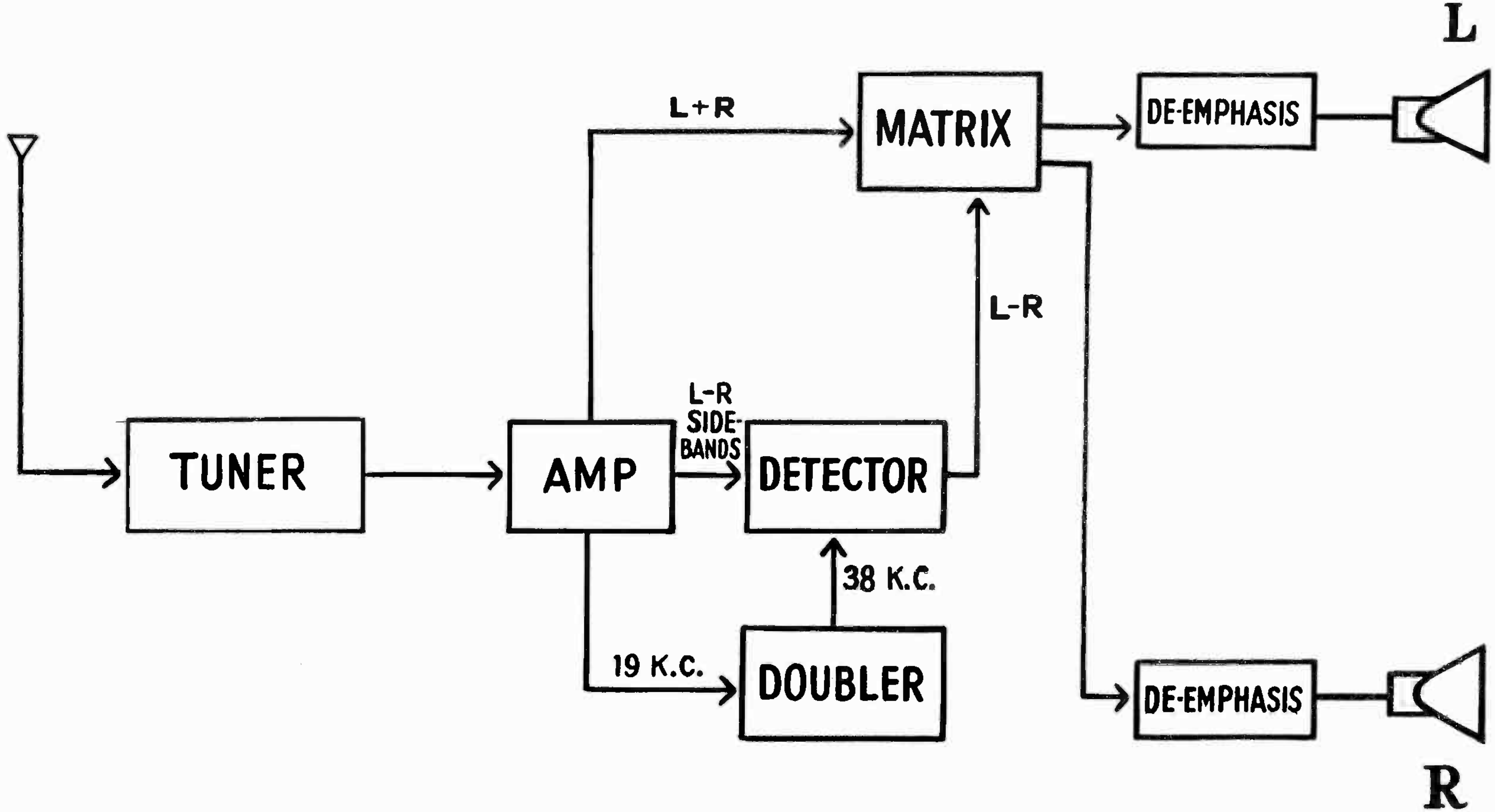
STEREO TRANSMITTER UNIT FOR F.M. MULTIPLEXING

BLOCK DIAGRAM



STEREO F.M. RECEIVER

BLOCK DIAGRAM



sidebands and pilot signal which are above the range of normal hearing would not be heard in the monophonic receiver, however, in the stereophonic receiver they must be decoded to produce the L-R signal. This takes place as the 19 kilocycle pilot signal is filtered and doubled to recover the 38 kilocycle carrier which is in turn mixed with the filtered sidebands to form a normal AM modulated signal. This is detected to produce L-R signals for the matrix.

The matrix outputs after passing through separate deemphasis networks are then the original left and right stereophonic signals.

DISCRIMINATOR SPECTRUM A study of the spectrum for the signals appearing in a discriminator output will help to provide for a better understanding of the system.

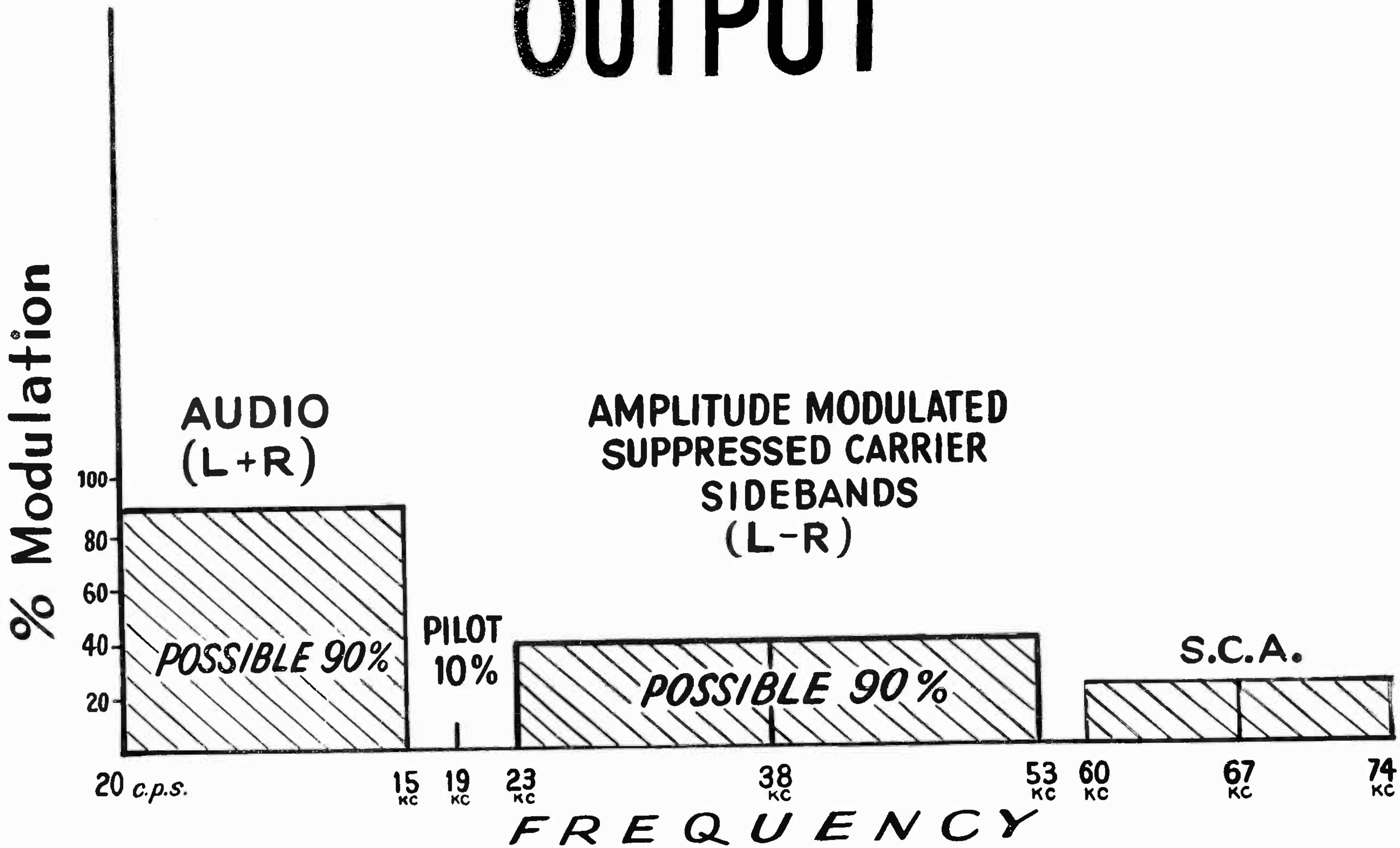
Such a spectrum is shown in Fig. 3 . The left hand block shows the monophonic or what would normally be the 50 to 15,000 cycle audio program. Also shown is an SCA signal with a carrier at 67 kilocycles deviated ± 6 kilocycles by the SCA program. (The new rules permit simultaneous SCA from 53 to 75 kilocycles.)

The stereophonic signal is just above the monophonic signal. This is made up of a lower sideband from 23 to 38 kilocycles and an upper sideboard of 38 to 53 kilocycles.

Note the abscense of the 38 kilocycle carrier itself and the presence of a 19 kilocycle pilot carrier at reduced amplitude.

There are important advantages for supressing the carrier and transmitting a subharmonic pilot. One of these that will be explained later, results from an interleaving affect which permits 90% of maximum deviation on the main channel, as well as 90% on the subchannel, with the other 10% in each case being reserved for the pilot carrier.

DISCRIMINATOR OUTPUT



Another advantage can be best explained at this time. Note that the 19 kilocycle pilot falls in a clear channel portion of the discriminator output, with the L+R audio 4 kilocycles below and the L-R lower sideband 4 kilocycles above. It will be recognized that this affords the use of relatively simple filter circuits in the receiver for isolating the pilot signal so that it may be doubled to recover the subcarrier. THIS IS A MOST IMPORTANT FEATURE OF THIS SYSTEM AND IS ONE OF THE PRIMARY REASONS THAT A SIMPLE ONE TUBE ADAPTOR IS POSSIBLE.

SIGNIFICANT SYSTEM SPECIFICATIONS At this point it might be well to tabulate some of the important system specifications prior to presenting a discussion of the technological factors leading to their choice.

Main channel	L+R Main Carrier FM modulation
	50 - 15000 cycle audio band
	90% max. main carrier deviation
SUB channel	38 kilocycle suppressed carrier AM subcarrier (FM modulating main carrier)
	50 - 15000 cycle audio band
	90% max. main carrier deviation
	19 kilocycle pilot carrier (FM modulating main carrier)
	10% max. main carrier deviation
S.C.A. (Storecasting)	67 kilocycles (In the frequency band from 53 to 75 kilocycles)

USE OF AN SUBCARRIER There are very strong justifications for the AM subcarrier, namely, the hi-fidelity fully separated 50 - 15000 cycle stereophonic sound and the simple one tube adaptor.

With an FM subcarrier 50- 15000 cycle sterophonic bandwidth could not have been obtained without compromising some aspect of the system. Signal to noise ratios on the monophonic receivers would have been deteriorated, the subcarrier carrier was prone to distortion, or if a different set of parameters were chosen each of these difficulties could have been minimized at the expense of system signal to noise ratios.

Second detectors for FM subcarriers have many associated problems which would have required quite complex and expensive circuity to overcome.

An AM subcarrier also permits storecasting with no compromise in the system except a slight signal to noise degradation which is always experienced anyway with monophonic standard FM programming in the presence of storecasting.

SUM AND DIFFERENCE MATRIXING The use of sum and difference matrixing provides the monophonic listener with a compatible balanced aural program. It also is more stable and less sensitive to system amplitude and phase errors than a sum signal transmitted with an "L only" or an "R only" in place of the difference signal.

In addition the noise levels are equal at both speakers which seems to avoid annoyances noted with systems where all of the sub channel noise comes from just one of the speakers.

INTERLEAVING Perhaps one of the most interesting and important aspects of this system is the interleaving affect of the L+R main channel signal and the L-R generated sidebands on the subchannel.

Because of this effect 90% of normal deviation can be used on the main channel and also the subchannel because one is producing peak main carrier deviation while the other is zero, and vice versa. Thus the monophonic listener experiences a signal to noise loss of less than 1 db.

The interleaving affect arises from the fact that the sum of 2 variables (L+R) is high when their difference is low (L-R) and vise versa. Since the sidebands envelope produced by the L-R signal is directly proportional to L-R, this relationship between a sum of 2 variables and their difference is maintained and the main and subchannel will interleave.

Perhaps a reference to Figure 4 will help in developing an understanding of this phenomena. The (a) signal represents an L input. The (b) signal is an imaginary square wave pulse on R used for illustrative purposes only.

The (c) line shows, L+R (the L sine wave plus the R pulses) and the (d) line, L-R (the L sine wave minus the R pulses).

The (e) line shows the L-R subcarrier sidebands.

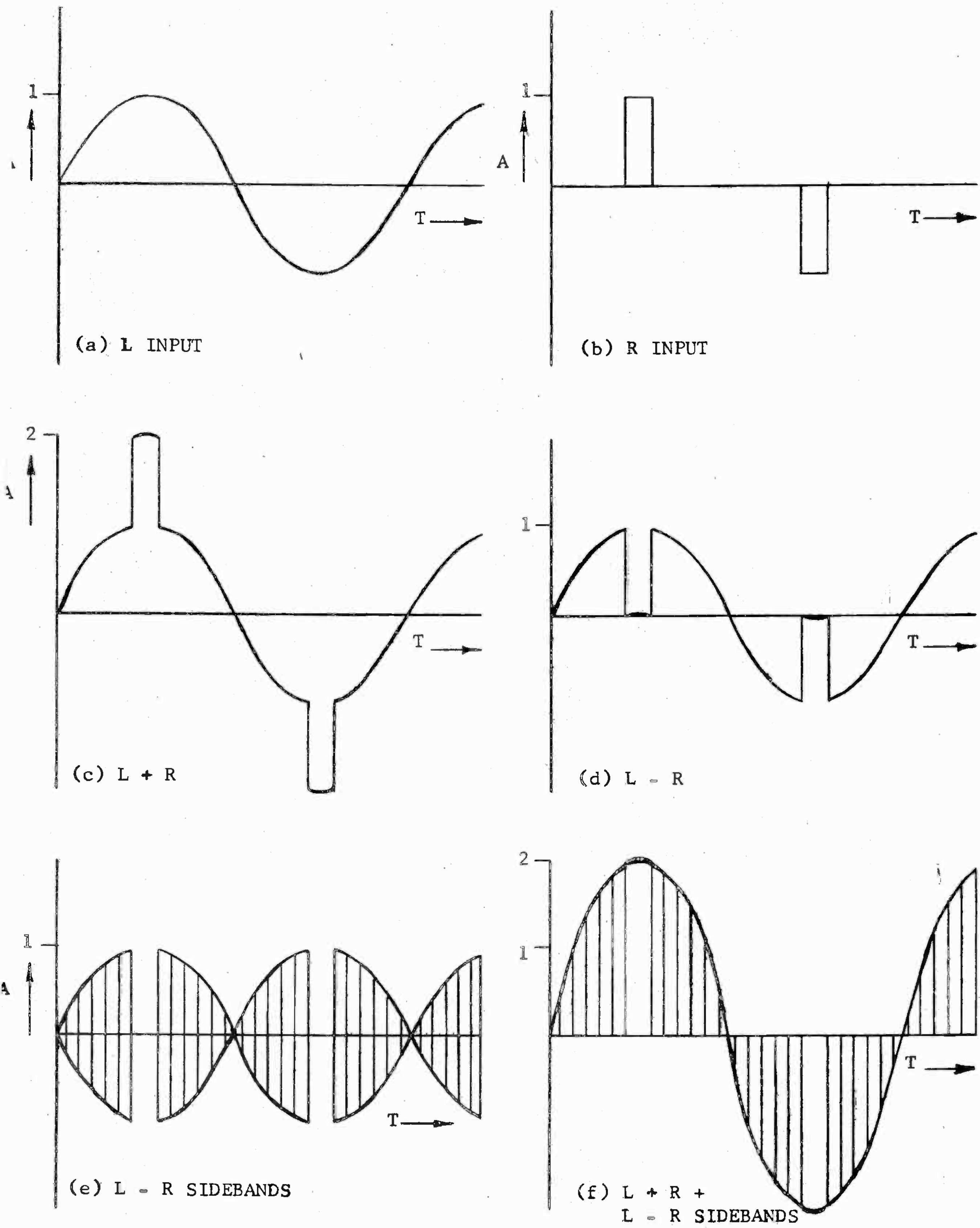
The (f) line shows the composite signal (minus the pilot for illustrative purposes) consisting of L+R and the L-R sidebands and would be the signal fed to the FM modulator. Note that its peak amplitude is equal to the peak amplitude of L+R or the L-R sidebands. Also observe that there is a depression (caused by -R, the pulse) in the L-R sidebands, while there is a simultaneous peak (caused by +R, the pulse) on the L+R signal. When they add to form the composite, the L+R peak fills the L-R sideband depression.

Figures 5 to 7 form another illustration of this important effect. The scope on Figure 5 shows an L+R signal where L and R are equal sine waves of differing frequencies. Note the peak to peak amplitude of approximately 4½ divisions.

Figure 6 shows the L-R sidebands. The peak to peak divisions again total 4½.

Figure 7 shows the composite signal that would feed an FM modulator (minus the pilot for illustrative purposes) namely, L+R plus the L-R sidebands. Observe that the peak to peak divisions still total 4½.

FIGURE 4.


1
A
T
(a) L INPUT
1
A
T
(b) R INPUT
2
A
T
(c) L + R
1
T
(d) L - R
1
A
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(e) L - R SIDEBANDS
2
1
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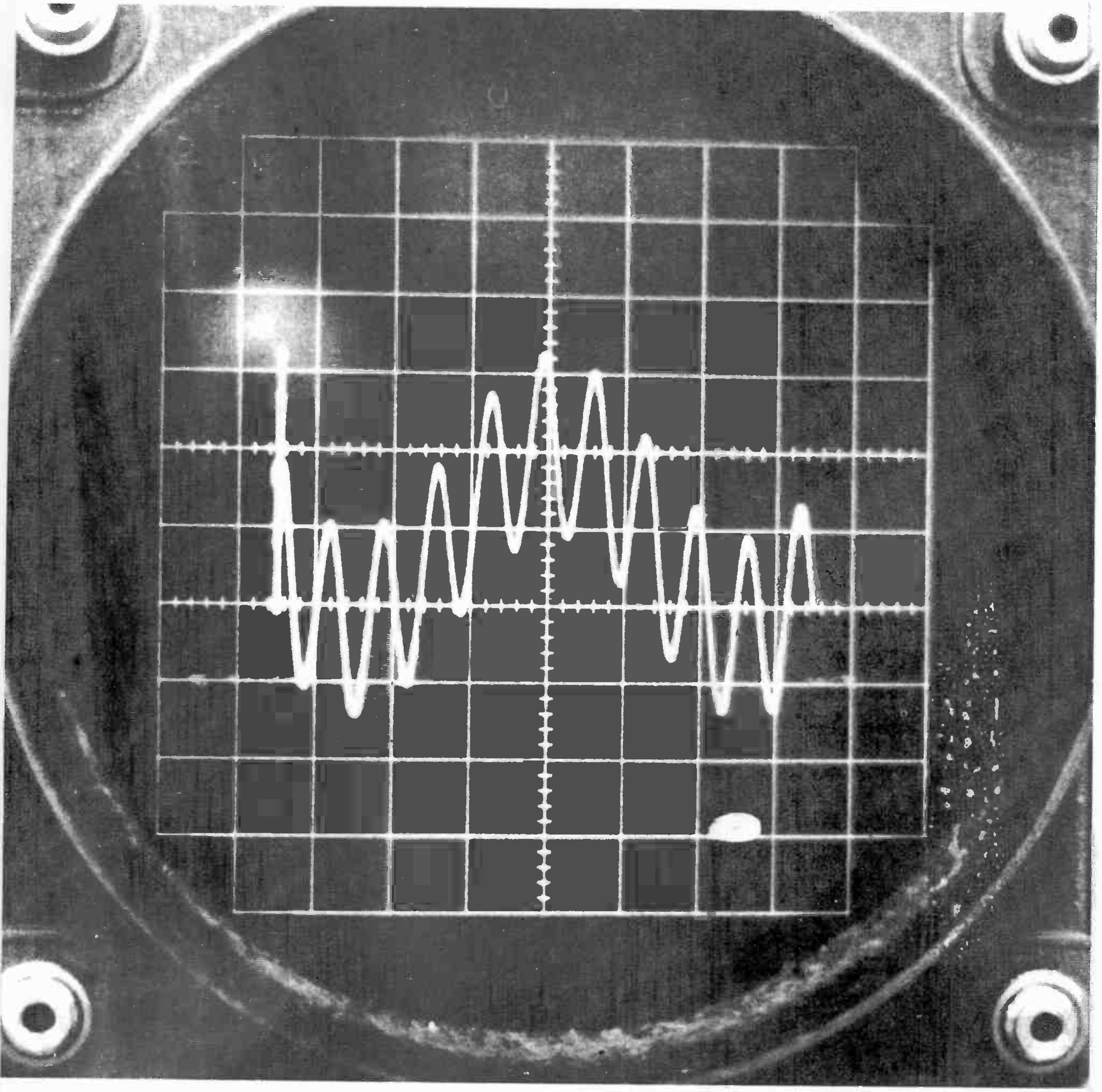
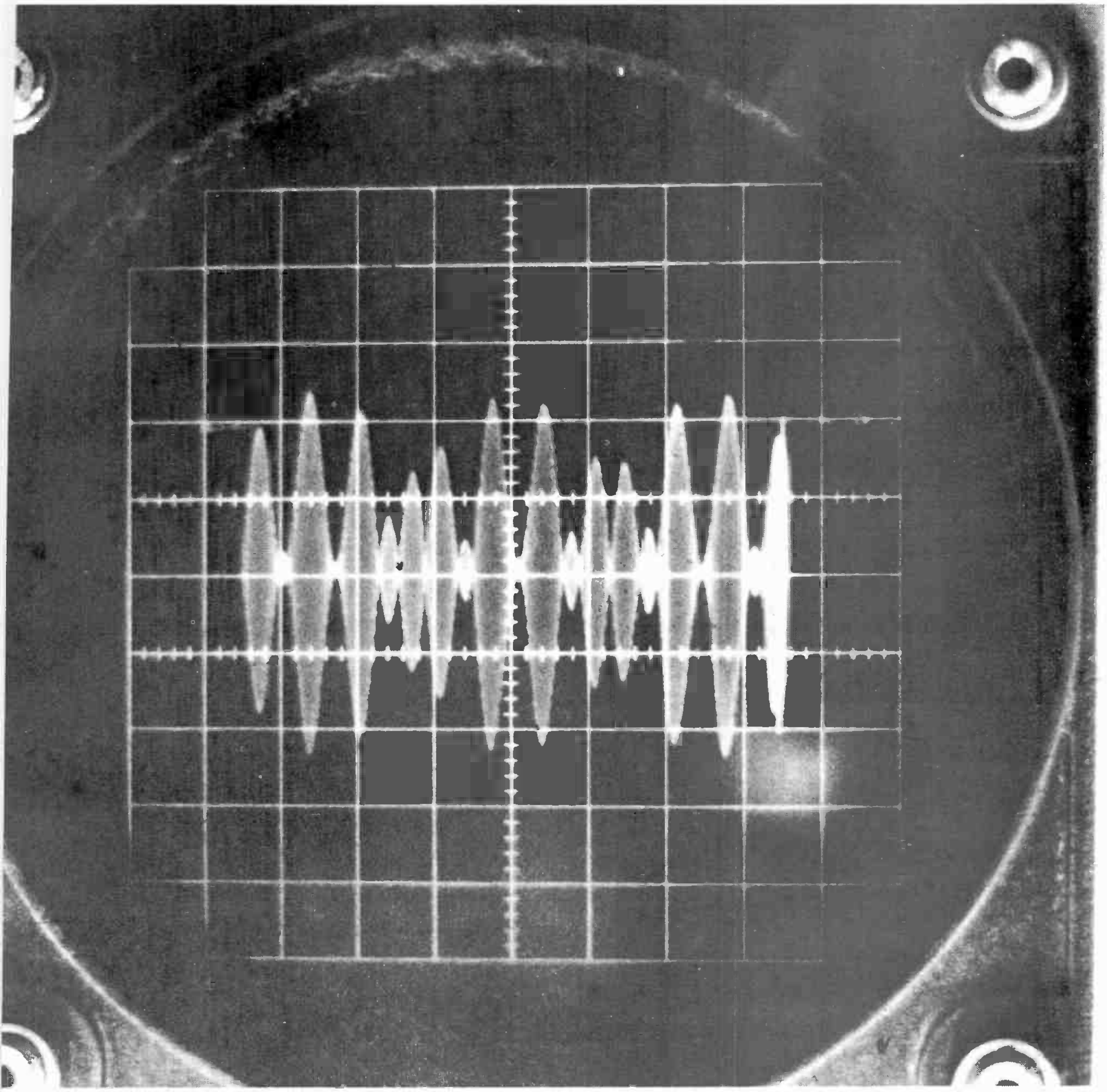
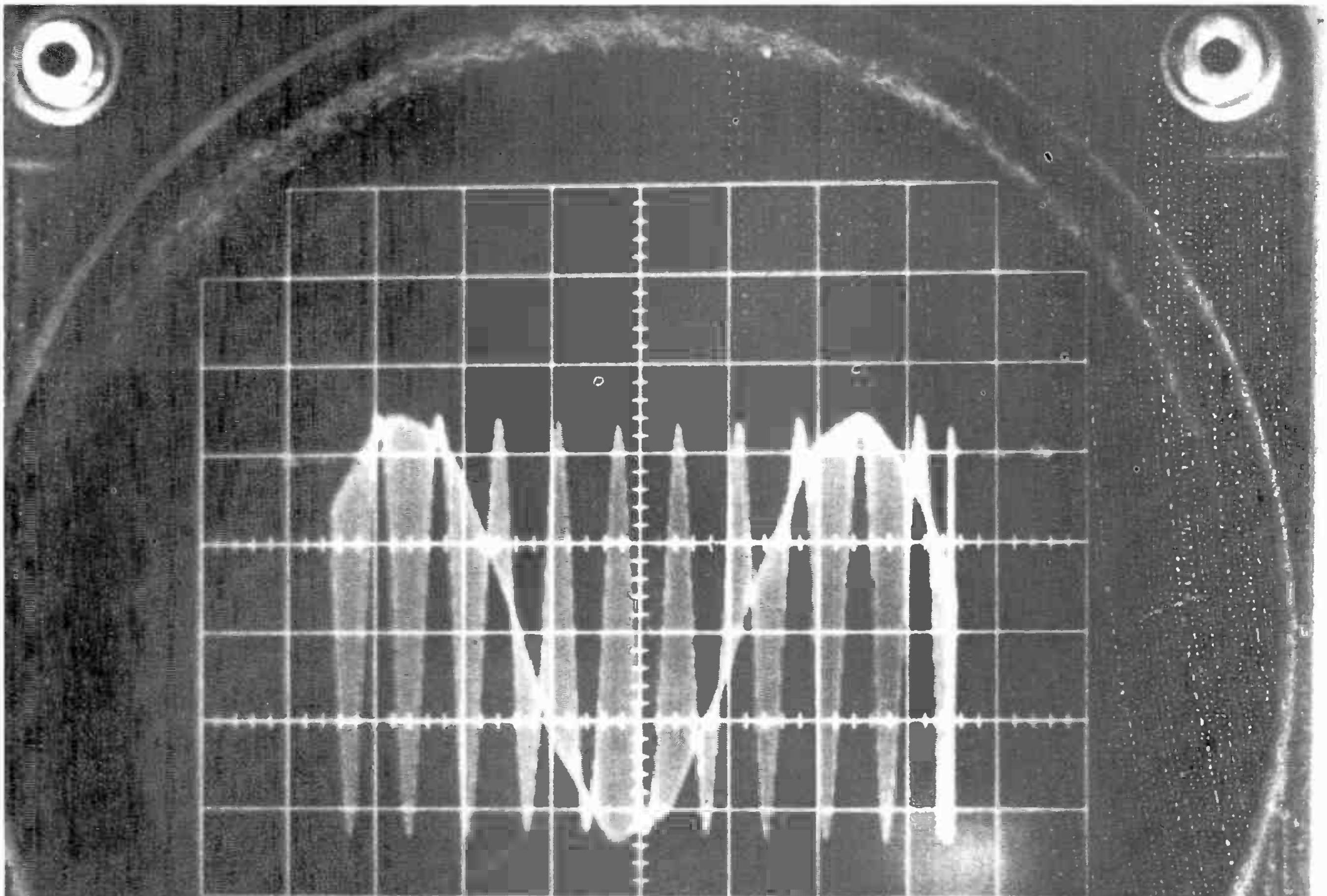
(f) L + R +
L - R SIDEBANDS







If the subcarrier is suppressed, the main and subchannels can have peak FM deviations limited only by the necessity to provide for the pilot subcarrier.

Another advantage of suppressing the carrier is that it can be restored at a higher level in the receiver (exalted) so that the effective subcarrier modulation level is less in the receiver than the transmitter leading to more linear and more stable and efficient AM detection.

STANDARD PREEMPHASIS ON SUBCHANNEL The use of the standard 75MS preemphasis is necessary to prevent overmodulation at higher frequencies which might have occurred with a higher value.

In addition, the stereophonic separation is more easily obtained when the same preemphasis is used on the main and subchannel because difficulties of trying to match differing phase shift and amplitude functions of frequency are avoided.

Perhaps of the greatest importance is the ability to perform preemphasis and deemphasis in the audio channels that comes with the use of equal main and subchannel preemphasis values. This avoids many phase shift and amplitude variations from main to subchannel that would effect separation adversely.

SYSTEM ADVANTAGES Figure 8 shows the simple one tube adapter. It should be realized that actual adapters that will be offered for sale can have almost any number of tubes and associated circuit complexity. This will be dependent on the type of equipment with which the adapter must work and also on the special features that the manufacturer will offer. None the less, it is worth noting that this particular 1 tube adapter performed very creditably in the field test and does represent minimum equipment necessary to receive stereophonic sound from a monophonic tuner in the present state of the art.

Figure 9 shows the transmitter gear. The panel at the base of the rack represents the equipment necessary to add to a system already equipped for multiplexing.

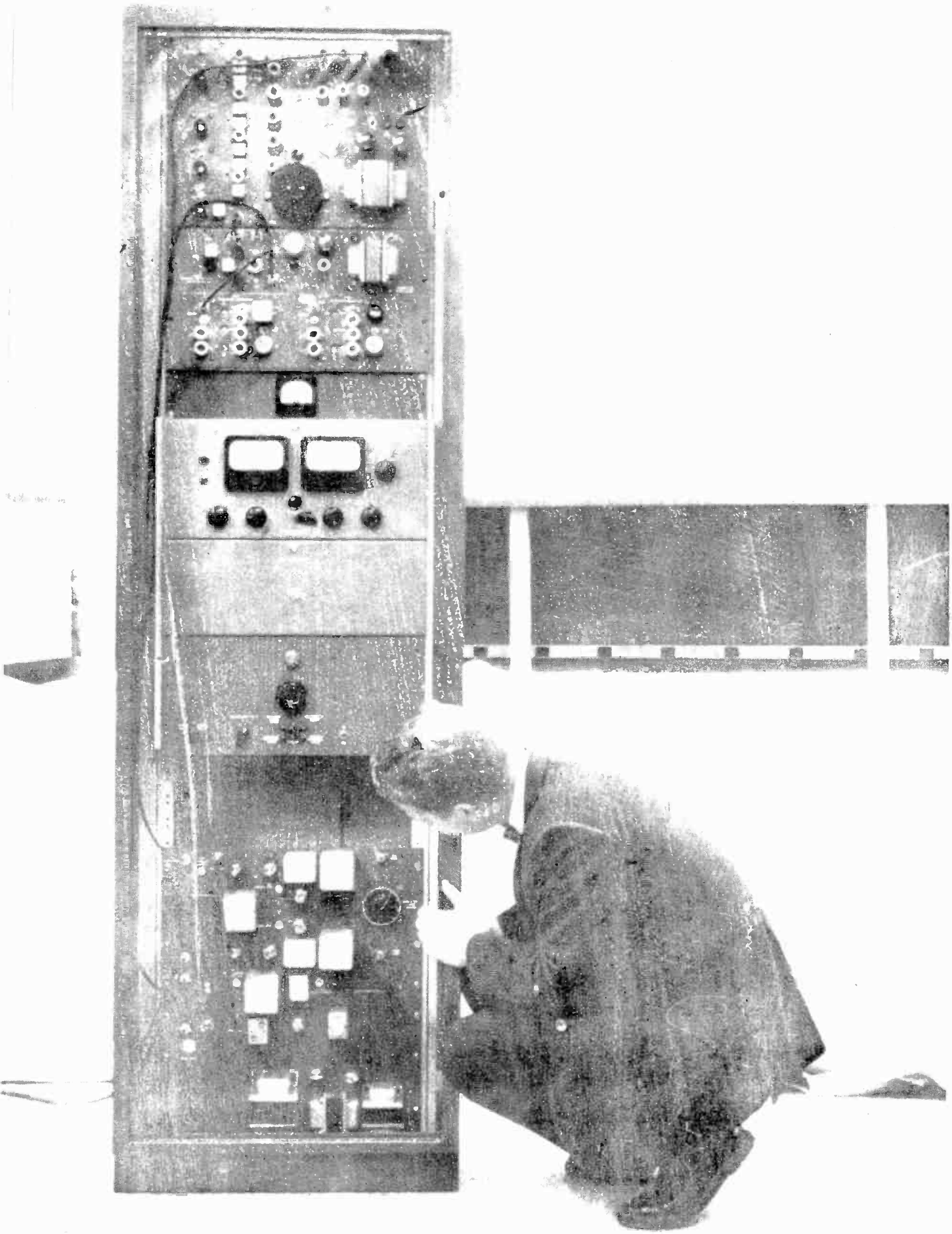
Tabulated are the advantages for the new system:

For monophonic listeners	0.9db decrease in signal level, fully compatible program,
For stereophonic listeners	1 tube adapter, hi-fidelity stereo (separation 50-15,000 cycles)
For multiplex operators (240 stations in 1960)	Simultaneous S.C.A. at 67,000 cycles.

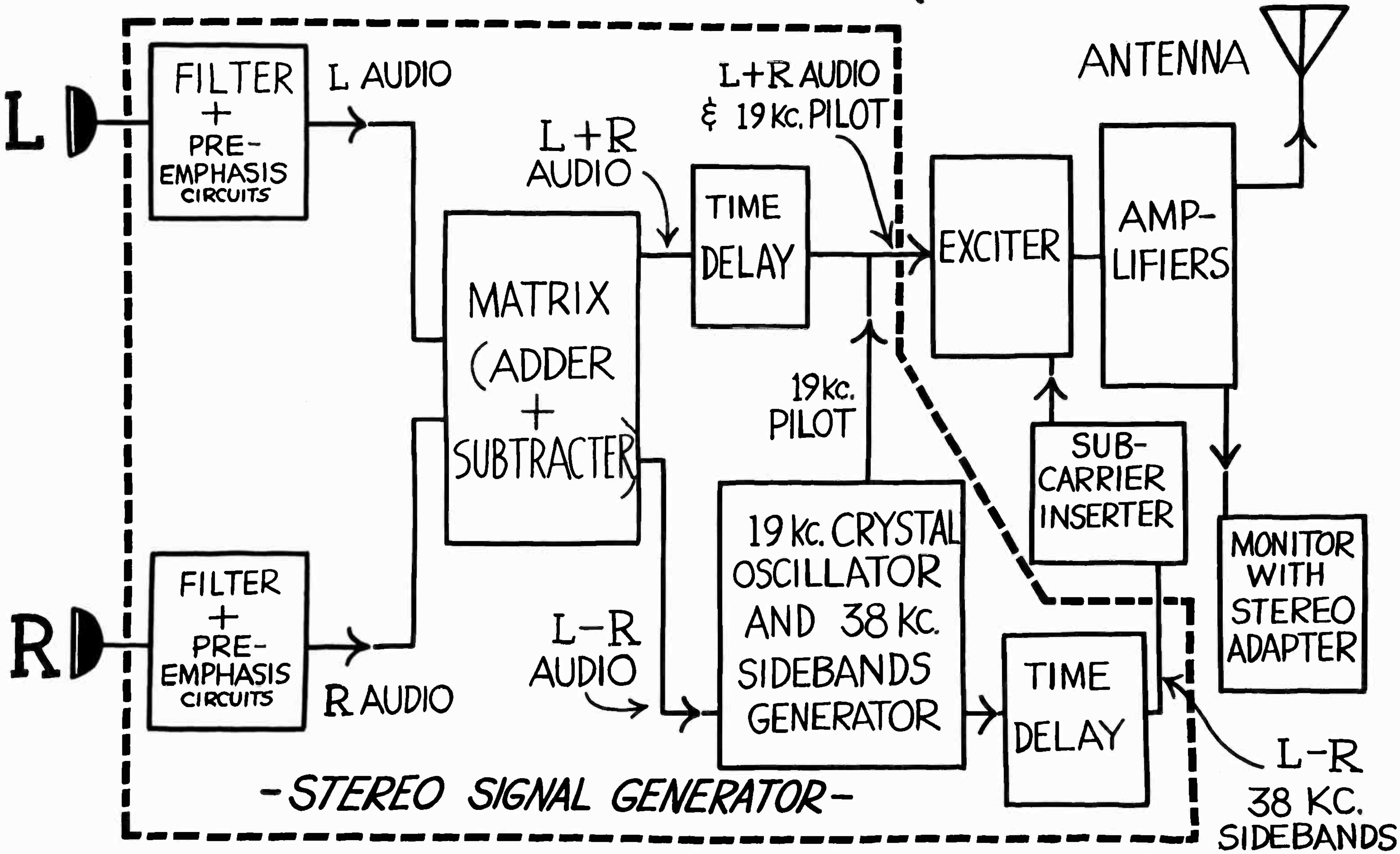
Plus these other technological features:

straightforward engineering
stable matrixing
receiver subcarrier exaltation
clear channel pilot signal
simple pilot carrier recovery
standard 75 microseconds preemphasis
preemphasis in audio channels

It will now be possible to refer briefly to equipment and techniques required to participate in the new FM stereophonic broadcast service.



TRANSMITTING EQUIPMENT



GETTING ON THE AIR

The scope of this paper will only permit a brief glance at general equipment requirements for broadcasting the new FM stereophonic signal. However, this should be of some help in initial planning considerations for stations interested in early participation in FM stereo.

Figure 10 shows a block diagram of the type of equipment necessary. Stations already engaged in S.C.A. multiplexing should only be required to obtain the stereo signal generator and the adapter for the monitor receiver. The signal generator will develop L+R audio, L-R subcarrier sidebands and the 19 kilocycle pilot carrier. It will probably be necessary to modify the subcarrier inserter to accept this stereophonic signal because of the higher deviation levels associated with the L-R 38 kilocycle sidebands.

Any station that has not participated in S.C.A. will require the subcarrier inserter and an exciter designed or modified to work with the inserter. This equipment should be specified as capable of accepting the stereophonic signals from the signal generator.

Sophisticated monitoring equipment is not yet available, nor has the FCC specified the particular monitoring requirements as yet. However, initial compliance with the stereophonic Rules and Regulations can probably be realized with; an electronic voltmeter and low-pass filter to periodically check stereo separation, a distortion meter to check system distortion and an oscilloscope to check pilot carrier, subcarrier and sideband phase correlations.

Particular note should be taken of the importance of maintaining proper phase and amplitude correspondence between the main channel and subchannel or between the sum (L+R) and the difference (L-R) signals anywhere in the equipment line up. A non-compensated time delay larger than ½ of a microsecond at 15,000 cycles or a relative amplitude change of 3.5% will preclude compliance with the Commission's Rules and Regulations.

This means transmission of the composite signal over a telephone line or UHF studio to transmitter link is ruled out. It will probably be necessary to provide for separate studio to transmitter links for L and R with matrixing and stereophonic composite signal generation accomplished at the transmitter location.

CONCLUSION

We have shown that the capabilities of the new FM stereophonic broadcasting standards include compatible monophonic programming, hi-fidelity stereophonic sound and simultaneous SCA. Technological features of the system include sum and difference matrixing with the sum transmitted as main carrier FM modulation and the difference transmitted as AM suppressed carrier subcarrier modulation. A subharmonic pilot carrier is transmitted for subcarrier restoration at the receiver. Equipment required for broadcasting will be minimized if a station is already equipped for SCA. Phase and amplitude correlation requirements for L+R and L-R will probably necessitate separate L and R studio to transmitter links with matrixing and composite signal generation taking place at the transmitter.

The Effect of SWR on Cross - Modulation of FM Multiplexed Signals

by

A. H. Bott

Transmitter Engineering

Radio Corporation of America

Broadcast and Television Equipment

Camden New Jersey

The Effect of SWR on Cross-Modulation on FM Multiplexed Signals

by

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Broadcast Transmitter Eng.

Summary

An FM multiplex system was set up, which included a transmitter consisting of a 10 watt RCA BTE-10B Exciter, a BTX-1A Subcarrier Generator and a HP206A Audio Generator. The exciter was fed to a single bay antenna over 950 feet of 3-1/8" transmission line. The receiving end utilized a dipole antenna about 100 feet away from the transmitting antenna, an FM monitor and special equipment for the detection of the subchannel.

It was established that the multiplex crosstalk increased with increasing antenna and transmission line mismatch. On the other hand, realignment of the receiving equipment could reduce crosstalk to a value only slightly worse than that obtained under conditions of optimum match. Yet compensation will become more critical and difficult to achieve with increasing VSWR. It appears that emphasis should be placed not only on a low VSWR but also on the stability of the VSWR.

Curves and numerical data will be given to corroborate the above conclusions.

Crosstalk performance of FM transmitters has been investigated. However, little is known about the contribution of the antenna-transmission line system to crosstalk. This paper should provide some helpful information in this respect.

We are concerned with crosstalk that appears on the subchannel as a result of the modulation of the main carrier with audio material. Cross-modulation from the subchannel into the main channel is not of interest here since it is negligible for all practical purposes. Crosstalk in an FM multiplex system is due to certain imperfections in the transfer characteristics of the system. If the transfer characteristics were such as to provide a uniform amplitude response and a linear phase response over a certain band of frequencies, no crosstalk would be generated. Any practical system, however, will depart from this ideal in a manner indicated in Fig. 1. The black curves represent the ideal network, while the red lines correspond to a practical network. The amount of crosstalk will depend on the kind and the degree of departure from the ideal. In an FM or PM system the effect of amplitude variation is relatively small compared to the effect of the variation of phase versus frequency.

A practical network which departs from the ideal will have three main effects. First, while the FM carrier is frequency modulated it will create amplitude modulation. Second, the FM signal will suffer harmonic and intermodulation distortion and center frequency shift. Third, it will cause crosstalk.

Crosstalk is phase modulation of the subcarrier at the rate of the main channel modulation waveform. This phase modulation is a modulation component which is added to the subcarrier modulation. It could be compensated for by modulating the subcarrier by the same waveform with opposite polarity. This is the same as saying that phase nonlinearity in one part of the system can be compensated by suitable networks in another part of the system, provided the unwanted waveform is of the opposite polarity in the two parts of the system.

The imperfections in the transfer characteristic are almost exclusively caused by tuned circuits, and circuits which are equivalent to tuned circuits, for instance, the antenna. Vacuum tubes will only affect the transfer characteristic if they affect tuning of the tube circuit, for instance, in an IF amplifier or limiter where a tube, loading a tuned circuit, may vary its capacity with the limiting voltage. Otherwise, tubes will not cause crosstalk by themselves. This is an over-simplification which would only apply in a system linear with respect to amplitude. A class A amplifier or an ideal mixer are such linear systems. Limiters in receivers and class C amplifiers in transmitters are amplitude-nonlinear systems.

Several measures can be taken in the tuned circuits to more closely approximate the ideal transfer characteristic. One would be to lower the Q of the tuned circuit. Another method would be to use double-, triple-, or stagger-tuned circuits. Both methods have advantages and disadvantages. A method used is to lower the "Q" as far as possible. This has the advantage of a very simple tuning procedure.

Cross modulation introduced by tuned circuits of identical "Q" will be more pronounced with lower main carrier frequencies. The rate of change of the main carrier due to the subchannel modulation does not change. Differently stated the percentage of the carrier to sideband separation will increase with lower carrier frequencies.

It is to be expected that a receiver IF amplifier at a frequency of 10.7 mc will be more critical with regard to crosstalk than a circuit operating at a carrier frequency of 100 mc, such as the r-f portion of the same receiver. It is therefore desirable to have the subcarrier in a transmitter modulated on the main carrier at the highest possible frequency.

The fact that phase nonlinearity in an FM system can be compensated at different places in the system has caused a great deal of confusion, since one can never point with certainty to a specific part of the system as the faulty part. If one assumes a great amount of phase nonlinearity in a poor transmitter and an equal but opposite amount of phase nonlinearity in the receiver, the over-all system may work quite satisfactorily as long as this phase relationship remains constant. If one would, however, replace the poor transmitter with a good transmitter, it would upset the amount of compensation and would make the whole system appear worse. This creates a very difficult situation for the operator, especially since crosstalk-measuring equipment is rarely available. Of course, it is desirable to keep the phase distortion in all parts of the system to a minimum.

A further uncertainty arises due to the difference of approximately 10 to 20 db in crosstalk performance in the transmitter and the receiver. The receiver is operated under widely varying conditions of field intensity, interference, and antenna locations which all will affect crosstalk and make it difficult to pinpoint trouble. (One may get the impression that FM transmitting and receiving equipment is quite vulnerable to cross-modulation, at least relative to other imperfections. This is misleading. A system can tolerate -40 db of harmonic distortion or intermodulation products, but the same amount of crosstalk would be objectionable. If one would, for example, increase the requirement for <u>system</u> harmonic distortion to -60 db (which corresponds to 0.1%) the difficulties would be <u>exactly</u> the same as the ones encountered in FM multiplex.)

Fig. 2 shows the measuring system used to determine antenna and transmission line crosstalk. The transmitting part consists of a 10 watt BTE-10B exciter, a BTX-1A subcarrier generator and suitable audio generators. The exciter is fed into 950 feet of 3-1/8" coaxial line. This line is terminated in a single section BFA antenna, mounted in a clear area. The receiving portion consisted of a dipole tuned to the exciter frequency, 100 feet of RG58A/U transmission line, a suitable FM monitor, a subcarrier demodulator, distortion analyzer and oscilloscope. I wish to emphasize at this point that it is very important to always observe the waveform at the output of the distortion analyzer and make sure that unwanted waveforms do not mask whatever waveform is being measured. In the receiving portion a commercial multiplex receiver could be substituted for the FM monitor and subcarrier demodulator.

The transmitting antenna was fed by the 950 feet transmission line for two reasons. First, it would more closely approximate a practical system and second, the measurements of crosstalk would include all possible reflections created or caused by the mismatch of the antenna which might be reflected again at the exciter and reradiated with a time delay. However, the signal thus reradiated is of fairly small magnitude; furthermore, the receiver performance would enter at this point since the capture ratio undoubtedly will have an effect in discriminating against the delayed signal which is only a fraction of the magnitude of the directly radiated signal. We feel that the inclusion of the transmission line did alter the results of the measurements, but only to a slight degree.

The system capability from the exciter to the FM monitor and the distortion analyzer, <u>excluding</u> the transmission line and the antenna, permitted crosstalk measurements at a level of approximately -70 to -75 db.

The system was operated under the following general conditions:

The carrier frequency was 101 mc, a frequency chosen as having no local interference. The subcarrier was modulated by a 400 cps tone and deviated ±7 1/2 kc which represented 100% modulation of the subcarrier.

The main carrier was modulated 30% (approximately ±22.5 kc) by a subcarrier frequency of 67 kc. In addition, the main carrier is modulated 70% by either 400 cps or 4 kc tones.

Cross-modulation is a phase-modulation process, adding deviation to the modulation already present. It is expected, as in phase modulation, that the modulation index is proportional to frequency. An increase of 2 to 3 db per octave has been confirmed experimentally.

Cross-modulation will therefore increase proportional to the main channel modulating frequency. Most multiplex receivers use low pass filters in the subchannel demodulator to eliminate noise above approximately 8 kc. This filter will also eliminate cross-modulation components above 8 kc. For this reason a high-modulation frequency of 4000 cps was chosen to represent the highest amount of crosstalk within the audio range.

The 400 cps was chosen to represent a condition causing a small amount of crosstalk relative to the 4 kc level. The 400 cps frequency is still high enough to allow effective removal of masking 60 and 120 cps hum.

Our system used a 10 kc low pass at the subchannel output.

The signal-to-noise ratio of the subchannel is -76 db using the FM monitor and admitting a bandwidth from 100 cps to 10 kc. Using a commercial receiver the signal-to-noise ratio is -62 db in a frequency band from 200 cps to 8 kc.

Crosstalk system capability using the FM monitor is better than -76 db at 50 cps, decreasing to -64 db at 4 kc. Both readings are relative to 100% (±7.5 kc deviation) modulation of the subcarrier.

The receiver measurements were somewhat complicated by the lack of shielding of the receiver which resulted in a strong signal pickup even with the antenna disconnected. The first r-f amplifier tube in the receiver had to be removed to bring the limiter voltage down to a normal value.

Before proceeding with the crosstalk measurements the antenna and antenna plus transmission line VSWR was measured. This is shown in Fig. 3. Without the transmission line the VSWR is not greater than 2 within a range of ±1 mc of the carrier. With the transmission line a VSWR of 1.6 is not exceeded within the same frequency range.

The FM monitor used for the measurement can be considered a precision FM receiver. It was tunable over a wide frequency range and employs 4 i-f stages at 10.7 mc which are all single-tuned and have low "Q" circuits. A Foster-Seeley discriminator using crystal diodes follows the i-f amplifier. The output of the discriminator is fed into a cathode follower which is followed by a three stage a-f amplifier. The monitor had to be used with deemphasis switched off to recover a sufficient amount of subcarrier voltage. The monitor has two indicating meters. One will indicate modulation percentage of the carrier, the other will indicate center frequency. The monitor was tuned so that the center frequency meter is in the 0 position.

The first set of measurements was made on 101 mc. The results are shown in Fig. 4. Crosstalk at 400 cps was -70 db, at 4 kc -64 db.

Next, the tuning strap in the antenna was changed. The antenna was swept and the point of optimum match was found to be 100.75 mc. The VSWR is shown in red in Fig. 4. With the FM monitor left untouched the crosstalk read -65 db at 400 cps, and -59 db at 4 kc. However, when the monitor was detuned approximately 10 to 15 kc, crosstalk could be reduced at 400 cps to -77.5 db and at 4 kc to -61 db. Next, the strap of the antenna was changed further to provide an optimum match at 100.25 mc. The crosstalk now was -56 db at 400 cps and -44 db at 4 kc. Further retuning of the monitor reduced crosstalk to -66 db and -54 db, respectively. The same procedure was followed at frequencies of 102 and 103 mc. In each case the antenna straps and the VSWR curves are shown at the top of Fig. 4. It is evident from this data that tuning the monitor will greatly reduce crosstalk. Retuning of the monitor will shift the departure from linear phase in a way to compensate for non-linear phase elsewhere in the system.

The distortion could be in the antenna, the transmitter, or in the receiving portion. Tuning the monitor to minimum crosstalk does represent a practical condition, since whenever a receiver is installed in the field this receiver will have to be adjusted for minimum crosstalk by tuning the discriminator alone or perhaps the discriminator in conjunction with several i-f stages. A receiver <u>cannot</u> be set in the factory for minimum crosstalk. Furthermore, in a receiver crosstalk will depend greatly on the intensity of the input signal. This means that a receiver which is tuned for minimum crosstalk at a 1 mv input level will have to be retuned if that signal is changed by any substantial amount, e.g., ± 3 db.

It is evident from Fig. 4 that crosstalk, even under most adverse conditions but with monitor retuning, is always at a very low level. It is better than -60 db over most of the audio spectrum. It is also evident that a receiver with a very limited high-frequency response will, due to this fact, provide a better crosstalk figure than a receiver with a good high frequency response. If there is a treble control in the receiver, conditions of severe crosstalk can be partially corrected by adjusting the control to reject high frequency components.

Finally, measurements were made using a commercial multiplex receiver. The results are shown in Fig. 5, which shows that the level of crosstalk has shifted up approximately 10 to 15 db. The variation of crosstalk is less pronounced in the receiver as compared to the measurements made with the monitor. The receiver was not retuned so that the values given in Fig. 5 represent a condition of widely varying antenna tuning.

The following conclusions can be drawn from the results of the measurements outlined above:

Fairly high ratios of VSWR can be compensated for by tuning the receivers. Since the receiver has to be tuned anyway, it appears that high ratios of VSWR can be tolerated. The higher the VSWR, however, the more difficult it becomes to obtain and maintain proper compensation.

It is our belief that small changes in the antenna will have a more detrimental effect in a system using a great amount of compensation (high VSWR in the antenna-transmission line system) as compared to a system requiring only moderate amounts of compensation (low VSWR in the antenna-transmission line system).

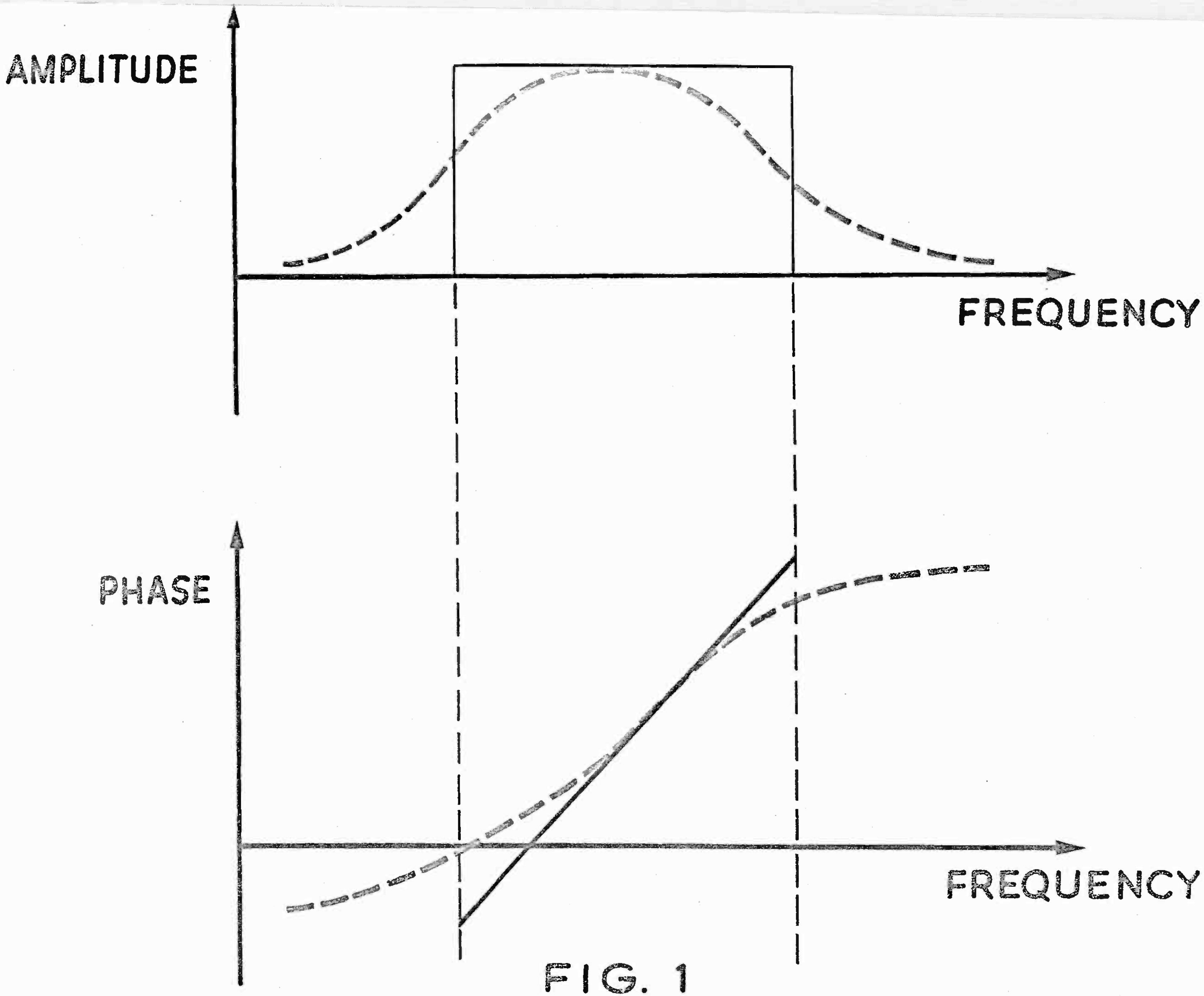


FIG. 1

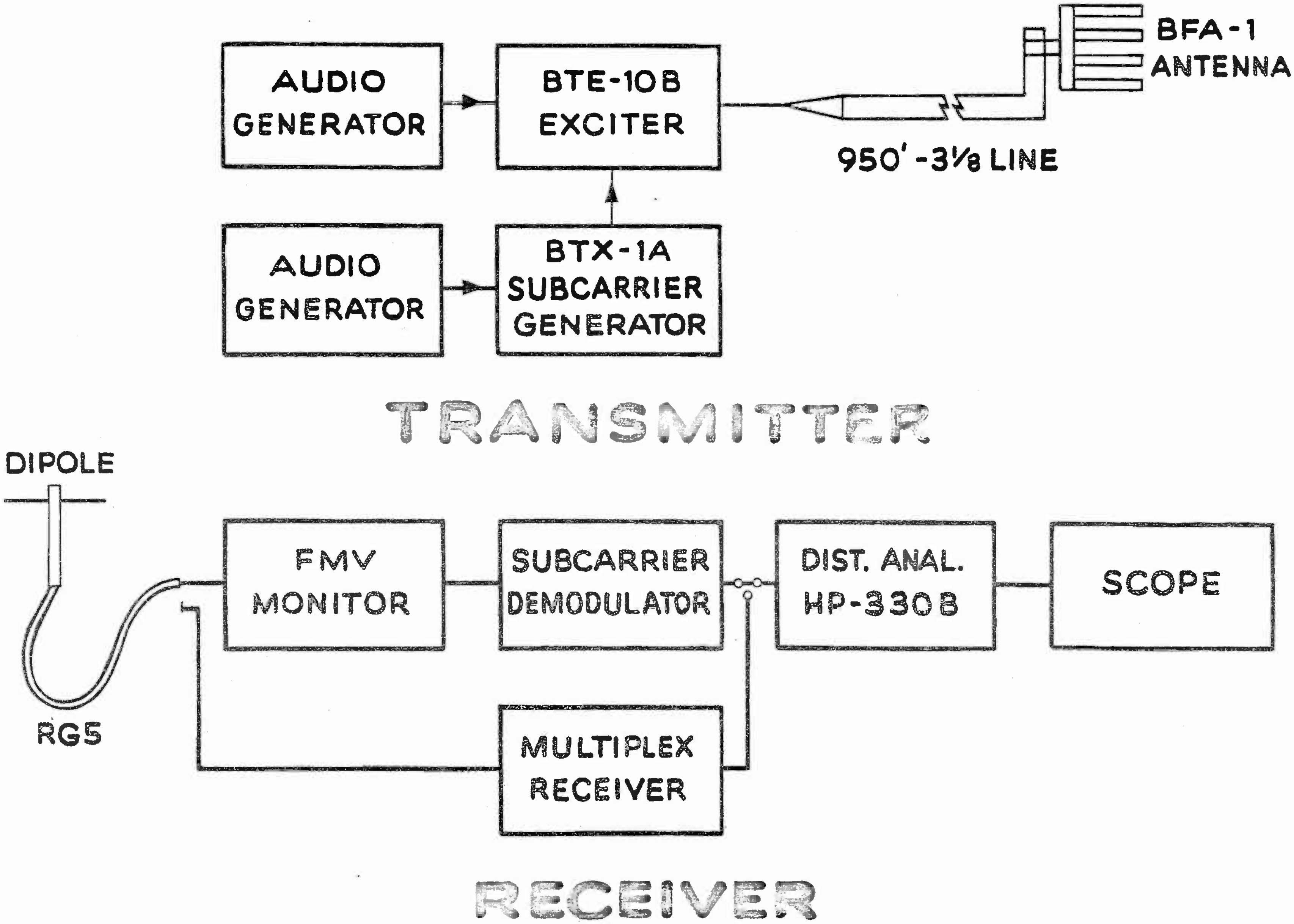

AUDIO GENERATOR
BTE-10B EXCITER
BFA-1 ANTENNA
950' -3⅛ LINE
AUDIO GENERATOR
BTX-1A SUBCARRIER GENERATOR
TRANSMITTER
DIPOLE
RG5
FMV MONITOR
SUBCARRIER DEMODULATOR
DIST. ANAL. HP-330B
SCOPE
MULTIPLEX RECEIVER
RECEIVER

FIG. 2

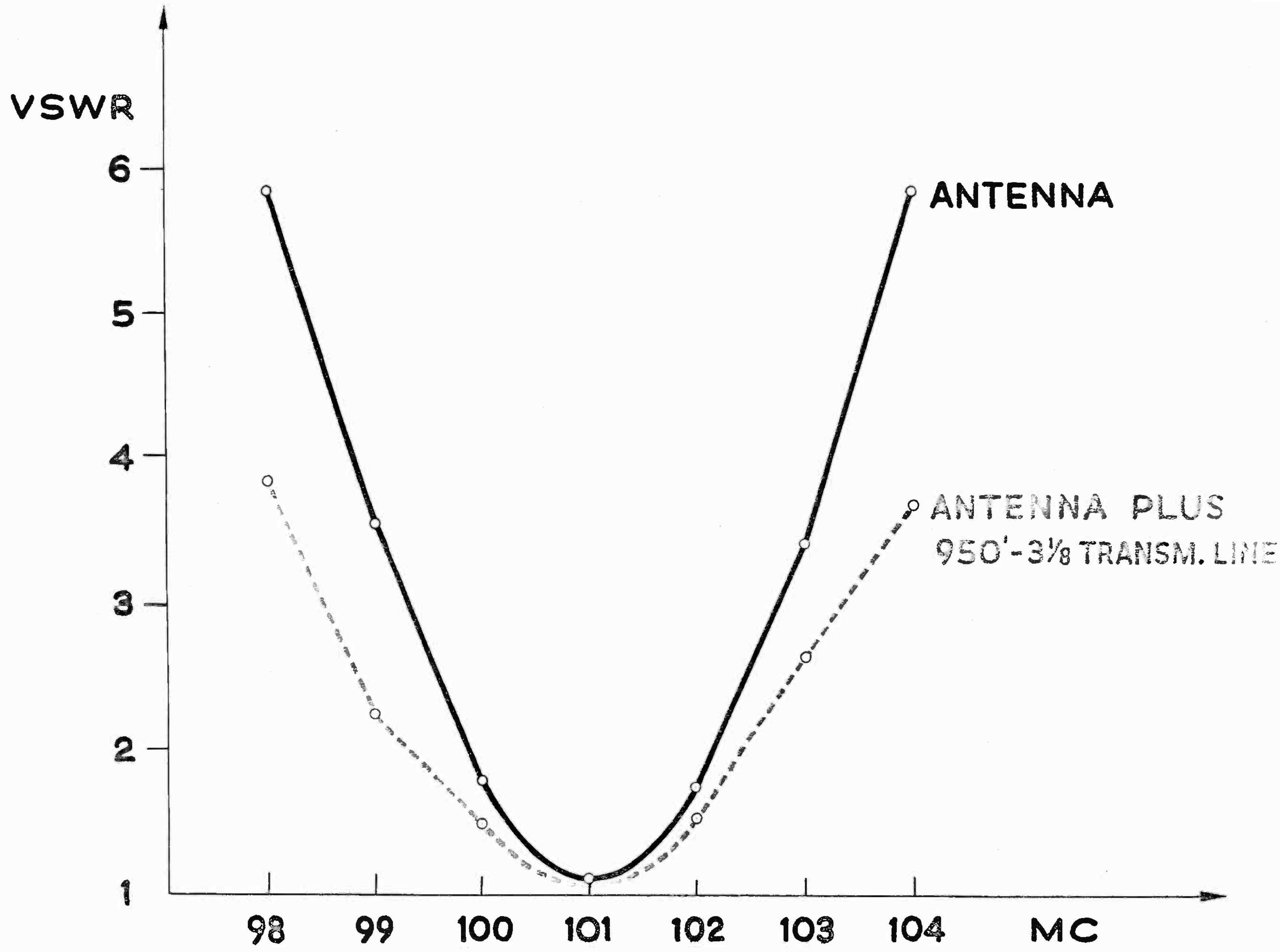
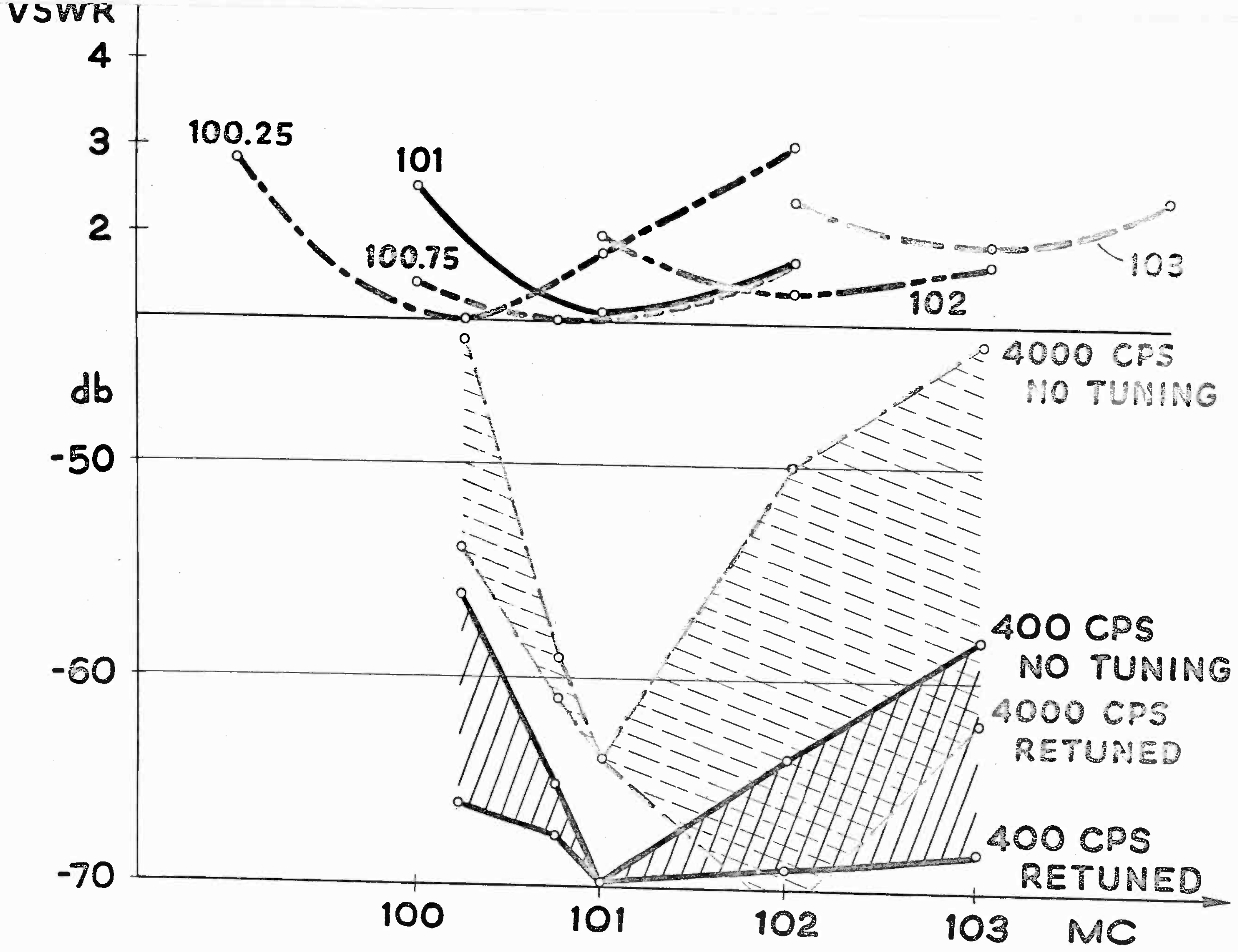

VSWR
6
5
4
3
2
1
ANTENNA
ANTENNA PLUS
950'-3⅛ TRANSM. LINE
98
99
100
101
102
103
104
MC

FIG. 3



VSWR
4
3
2
100.25
101
100.75
102
103
db
-50
-60
-70
4000 CPS
NO TUNING
400 CPS
NO TUNING
4000 CPS
RETUNED
400 CPS
RETUNED
100
101
102
103
MC

FIG. 4

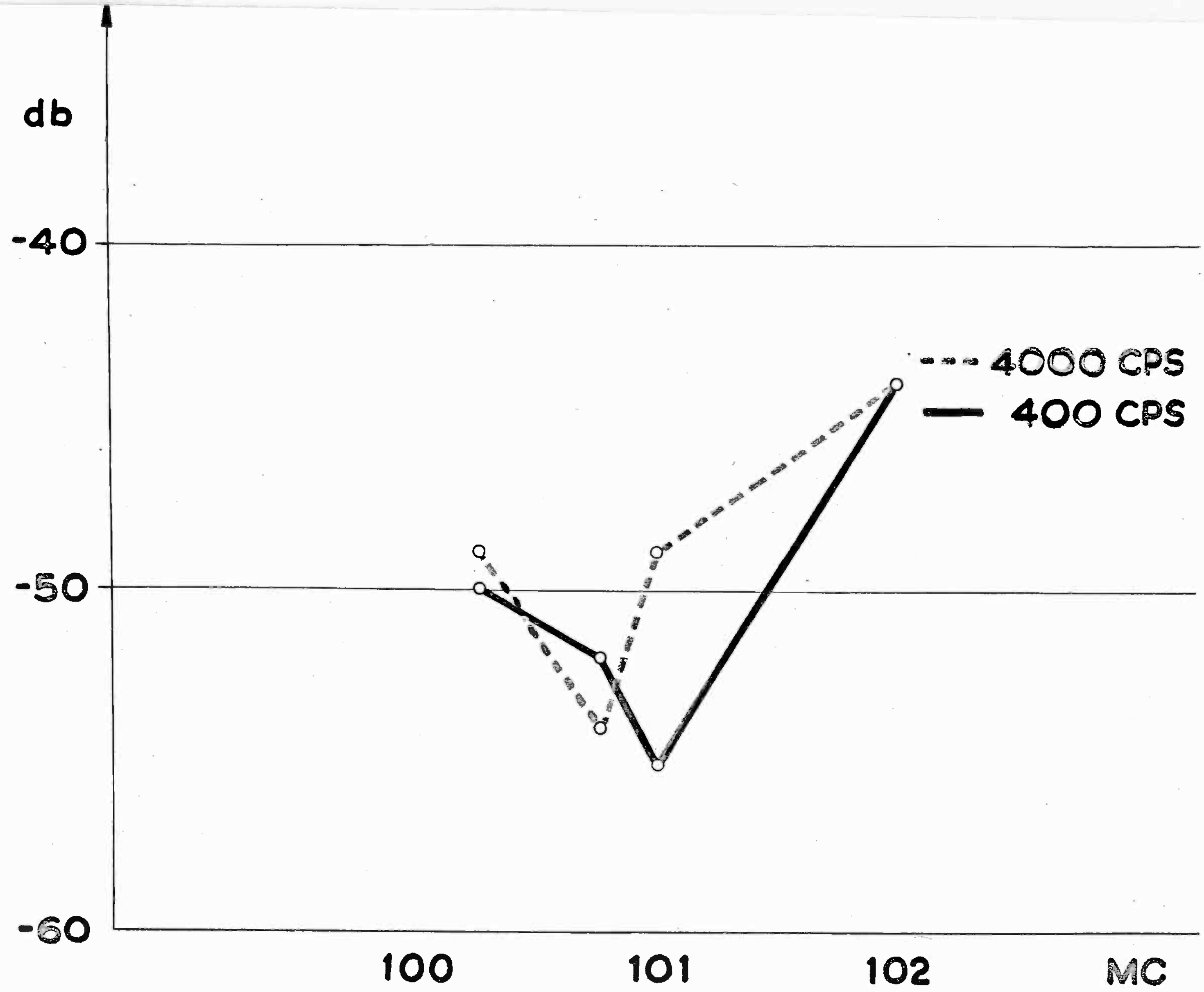


FIG. 5

8

Power Dividers For Directional Antenna Systems

By: R. S. Bush, Phasing System Engineer, Gates Radio Company

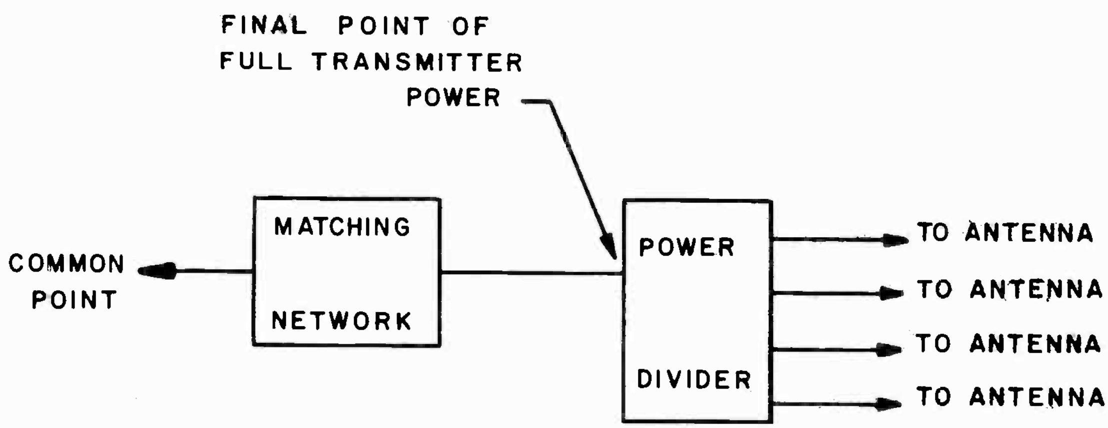
TRODUCTION

Many engineers have often expressed a long felt need for better understanding of power divider systems, particularly as they are in use today. Available literature is very limited, and a survey of the problems encountered in power divider design and adjustment indicates that there are many areas where a more comprehensive understanding of present day power divider devices would lead to more economical designs and easier, more efficient adjustments.

It is the purpose of this paper, therefore, to examine power divider systems and illustrate those factors which are of prime consideration. In this way, it is believed, that many designs can provide a somewhat more realistic approach, easier adjustments and a better contribution to more economical phasing systems.

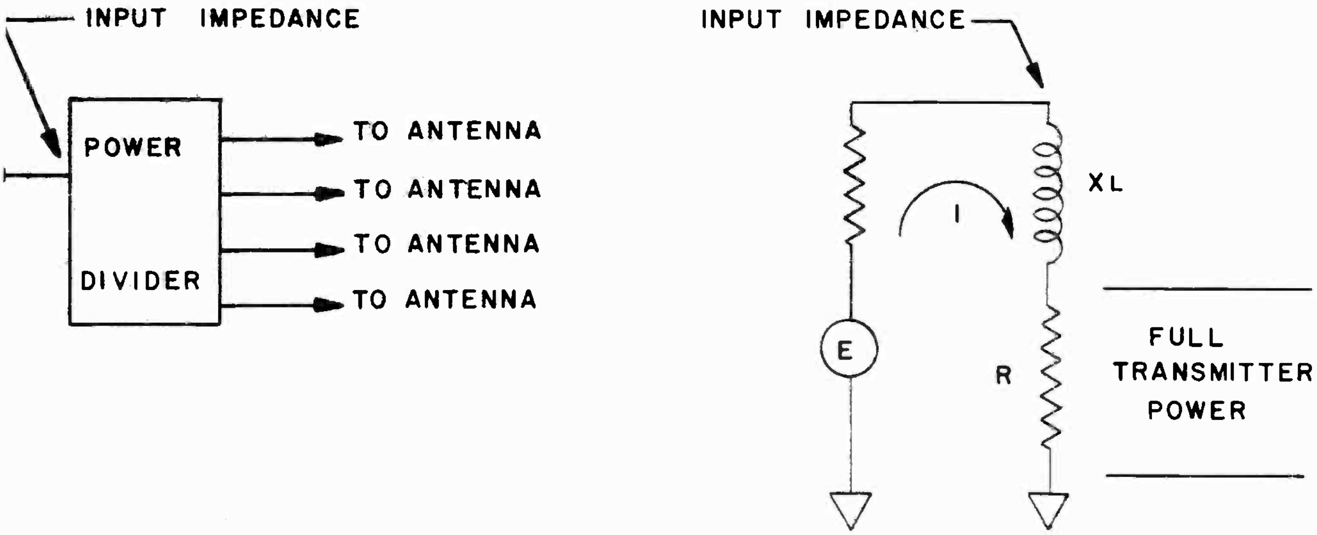
HE GENERAL POWER DIVIDER

The power divider section of a directional antenna phasing system is, in reality, two separate and distinct devices as shown in Figure I. Specifically, there is the power divider proper and a device for matching the impedance of the divider to the desired common point resistance. The point of separation between the two devices is always that point at which the full transmitter power exists for the last time.



BLOCK DIAGRAM
GENERAL POWER DIVIDER

FIGURE I.



GENERAL POWER DIVIDER
AND ITS
EQUIVALENT CIRCUIT
FIGURE 2.

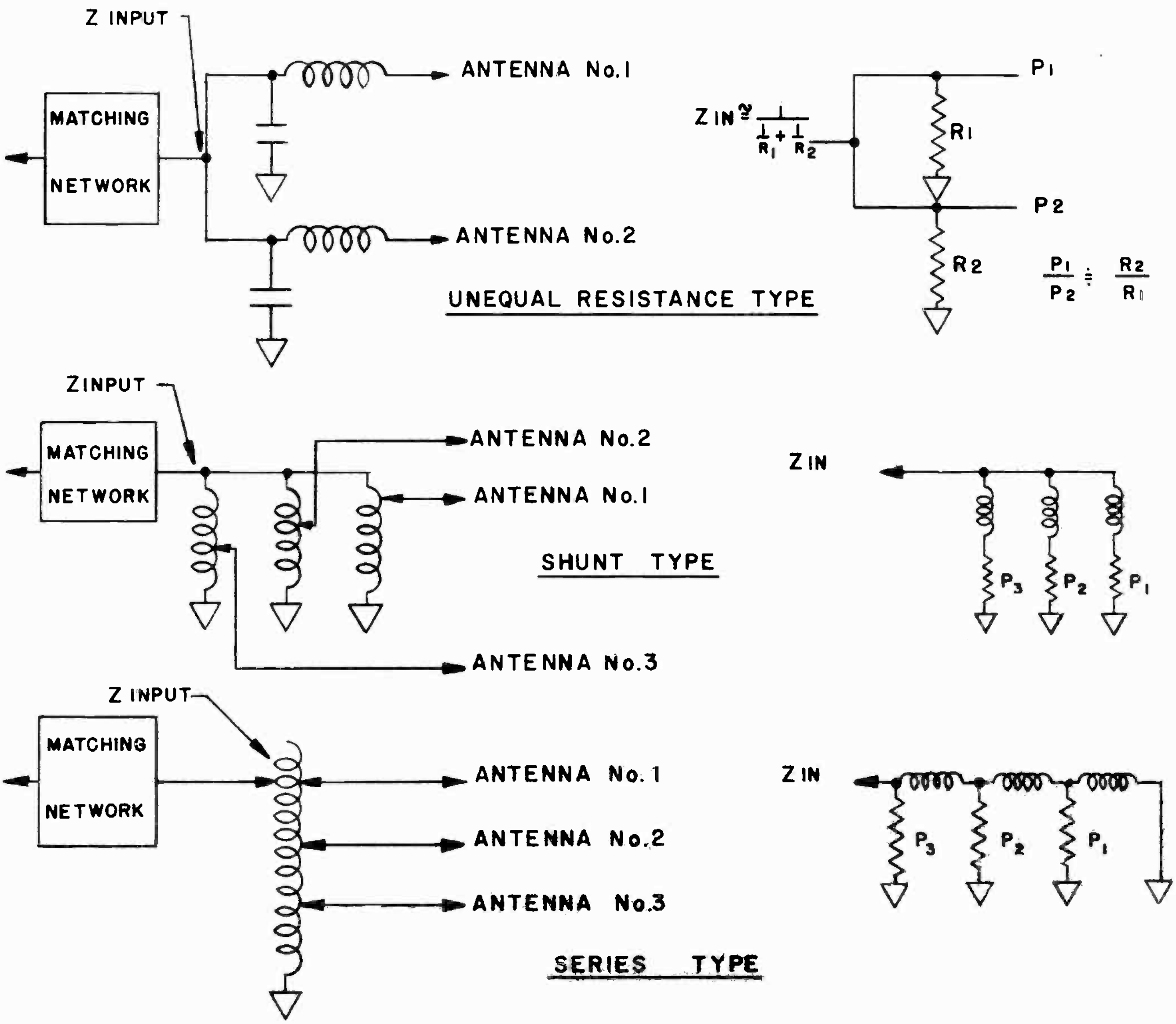
IN FIGURE 2, A THEVENIN EQUIVALENT CIRCUIT HAS REPLACED THE POWER DIVIDER PROPER. THE IMPEDANCE OF THE DIVIDER IS SHOWN CONSISTING OF A REAL, OR RESISTANCE PART, AND AN IMAGINARY, OR REACTIVE PART. EXCEPT IN RARE INSTANCES, THIS REACTANCE WILL ALWAYS BE INDUCTIVE. THE RESISTANCE SHOWN HERE IS THE REAL LOAD FOR THE TRANSMITTER AND IF THE FULL TRANSMITTER POWER IS TO BE SUPPLIED TO THE ANTENNA SYSTEM, THE FULL TRANSMITTER POWER MUST BE DISSIPATED IN THIS RESISTANCE. FOR THIS REASON, THE VALUE OF THIS RESISTANCE IS THE ALL IMPORTANT PARAMETER IN THE DESIGN AND ADJUSTMENT OF ANY POWER DIVIDER. IT COMPLETELY DETERMINES THE CURRENT FLOW IN THE CIRCUIT.

POWER DIVIDERS MUST FIRST OF ALL BE CAPABLE OF DIVIDING POWER AND THIS POWER DIVISION MUST BE EASILY ADJUSTABLE. HOWEVER, IN THE FINAL ANALYSIS, THEY MUST ALSO OPERATE EFFICIENTLY AND REQUIRE AS INEXPENSIVE COMPONENTS AS IS CONSISTENT WITH GOOD ENGINEERING PRACTICE. AND, SINCE EFFICENCY AND ECONOMY ARE A FUNCTION OF THE CURRENTS FLOWING IN THE POWER DIVIDING SYSTEM, IT CAN READILY BE SEEN THAT THE HIGHER THIS INPUT RESISTANCE CAN BE MADE, THE MORE EFFICIENT AND ECONOMICAL WILL BE THE DIVIDER.

THIS RESISTANCE ALSO DETERMINES THE REQUIREMENTS OF THE MATCHING NETWORK; FOR, AS WILL BE SHOWN LATER, IT IS THIS RESISTANCE THAT MUST BE MATCHED TO THE DESIRED COMMON POINT.

Currently, there are three basic types of power dividing circuits in use. For lack of better names, they have been called an "Unequal Resistance Type", a "Shunt Type", and a "Series Type". They are shown in Figure 3, together with their equivalent circuits.

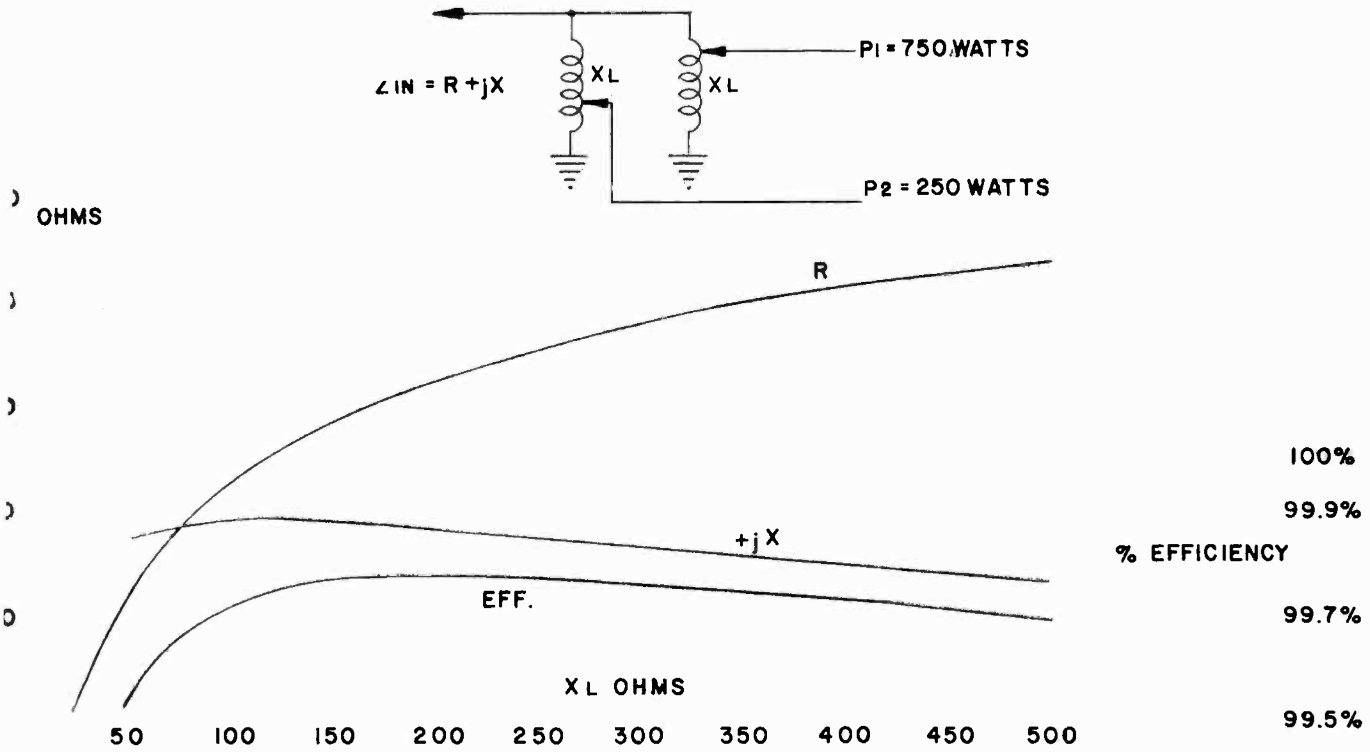
FIGURE 3



E "UNEQUAL RESISTANCE TYPE"

The "Unequal Resistance Type", consists essentially of two "L" networks connected back to back, and power division is accomplished by making their input resistances inversely proportional to the two powers. It is not too easily adjusted, because it requires an adjustment of both the series inductances and the shunt capacities to effect the desired power division, and, every adjustment is always accompanied by a rather large change in phase shift added to the two lines. This type of power divider is not used very often and is not practical at all except for two tower arrays.

FIGURE 4
SHUNT POWER DIVIDER
ZIN VS SHUNT INDUCTANCES
P1 = 750 WATTS P2 = 250 WATTS



E SHUNT POWER DIVIDER

The "Shunt Type" of power divider consists of a separate coil shunted to ground for each antenna feed. Full and complete control of the power division is possible if all but one of the shunt coils is made variable. Placing the tap for the highest power output from this divider at the top of one of the coils, always produces the highest possible input resistance for any given power division.

In Figure 4, the variation of the input resistance and reactance of this type of divider is shown as a function of the reactance of the two shunt coils. The example is based on the assumption that the input to each of the transmission lines is 50 ohms. From these curves, it is readily seen that the input resistance of the divider increases as the reactance of these coils increase. However, the efficency curve definitely shows an optimum size for them -- in this case, approximately 3 to 4 times the transmission line impedances. This is an important consideration in the design and adjustment of this type of divider.

FIGURE 5

SHUNT POWER DIVIDER

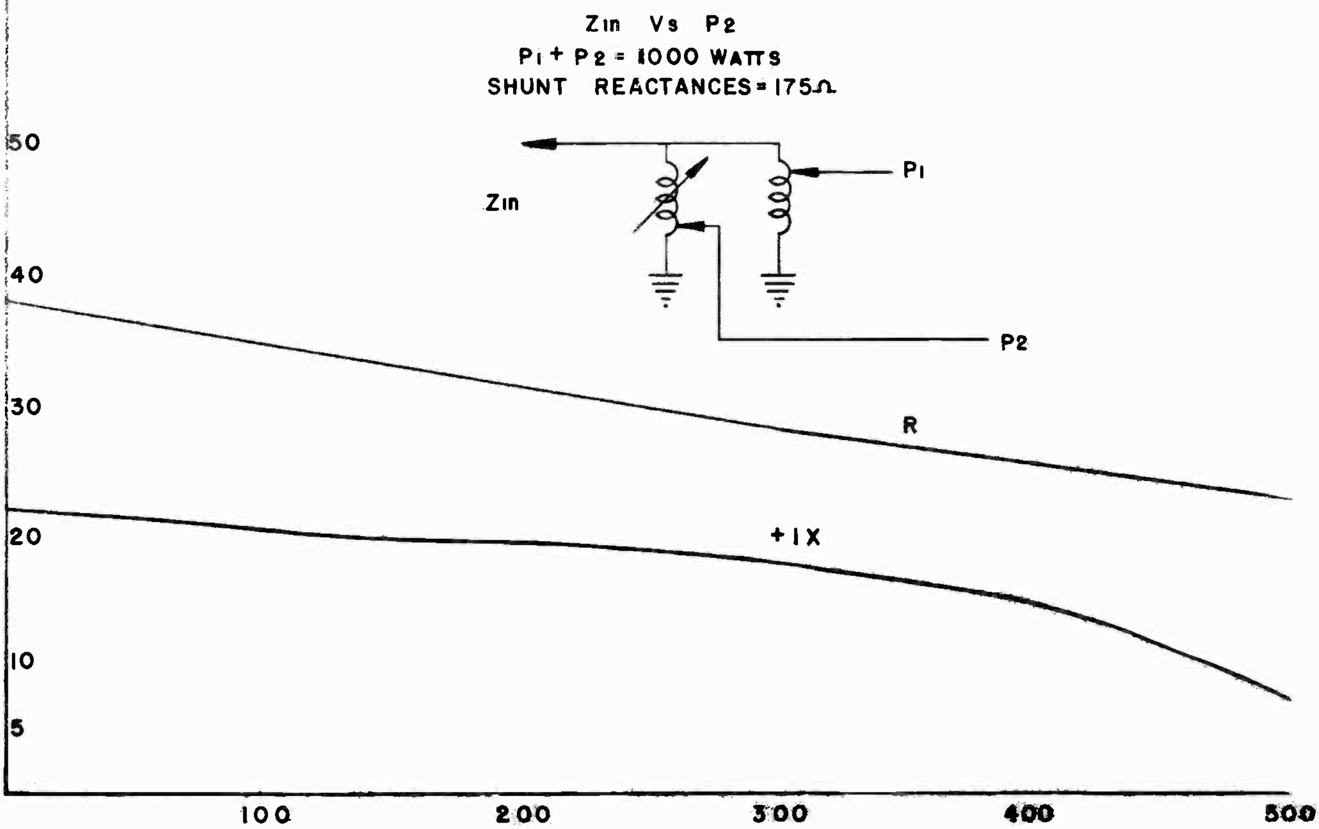


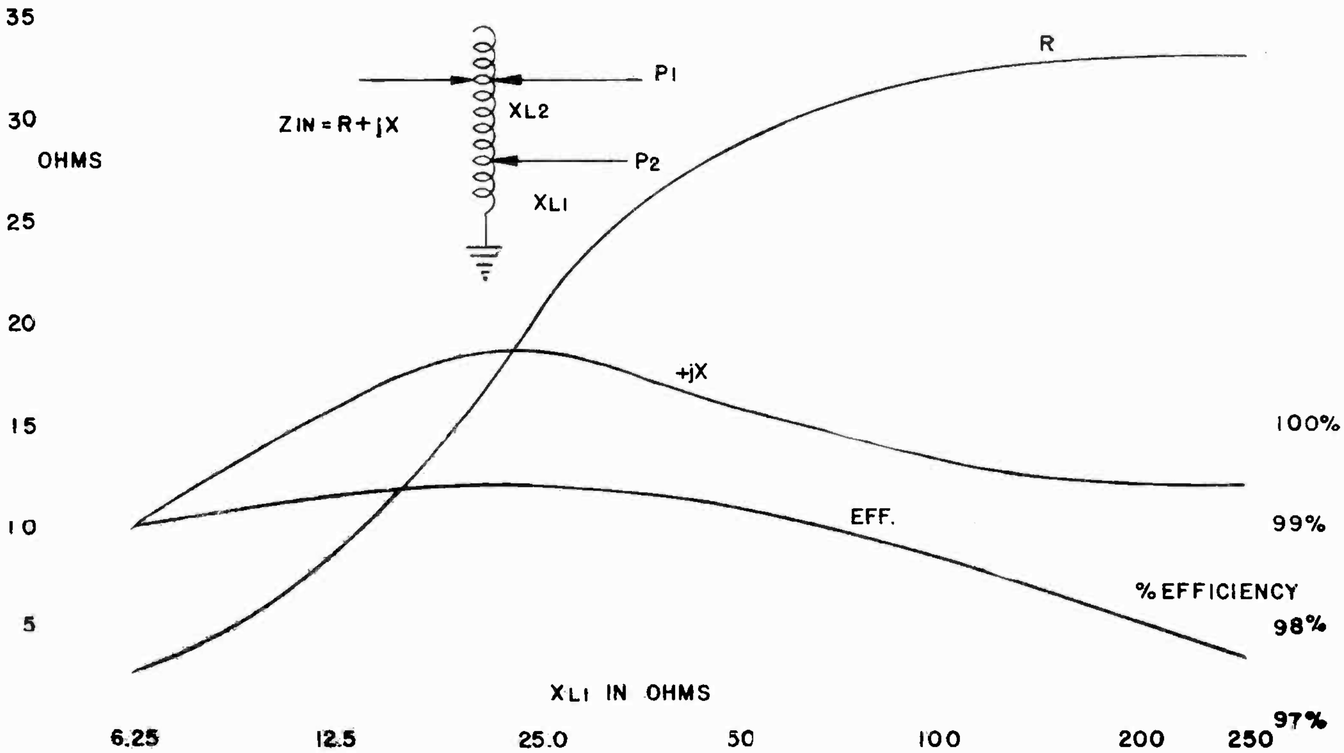
FIGURE 5 ILLUSTRATES THE VARIATION OF THE INPUT IMPEDANCE AS A FUNCTION OF THE POWER FED TO THE LOWEST POWER TOWER, WITH THE TRANSMITTER POWER REMAINING CONSTANT AT 1000 WATTS. THE RESISTANCE CURVE, IN THIS FIGURE, IS ESPECIALLY SIGNIFICANT IN THAT IT SHOWS ONLY A SMALL VARIATION AS THE POWER DIVISION IS ADJUSTED FROM ZERO TO EQUAL POWERS IN BOTH TOWERS. THIS FACT IS INDICATIVE OF THE RELATIVE EASE OF ADJUSTMENT OF THIS TYPE OF POWER DIVIDER OVER A VERY WIDE RANGE OF POWER DIVISION. THIS IS, DEFINITELY, THE MAIN ADVANTAGE OF THIS TYPE.

THE PRIMARY DISADVANTAGE FOR THIS DIVIDER LIES IN THE FACT THAT AS MORE ANTENNAS ARE ADDED, ADDITIONAL IMPEDANCES ARE CONNECTED IN PARALLEL ACROSS THE INPUT OF THIS DIVIDER. CONSEQUENTLY, FROM A PRACTICAL VIEWPOINT, IF MORE THAN THREE TOWERS ARE SERVED WITH THIS TYPE, THE INPUT RESISTANCE BECOMES VERY LOW AND THE RESULTING HIGH CURRENTS MAKE THE SHUNT DIVIDER VERY INEFFICIENT AND COSTLY.

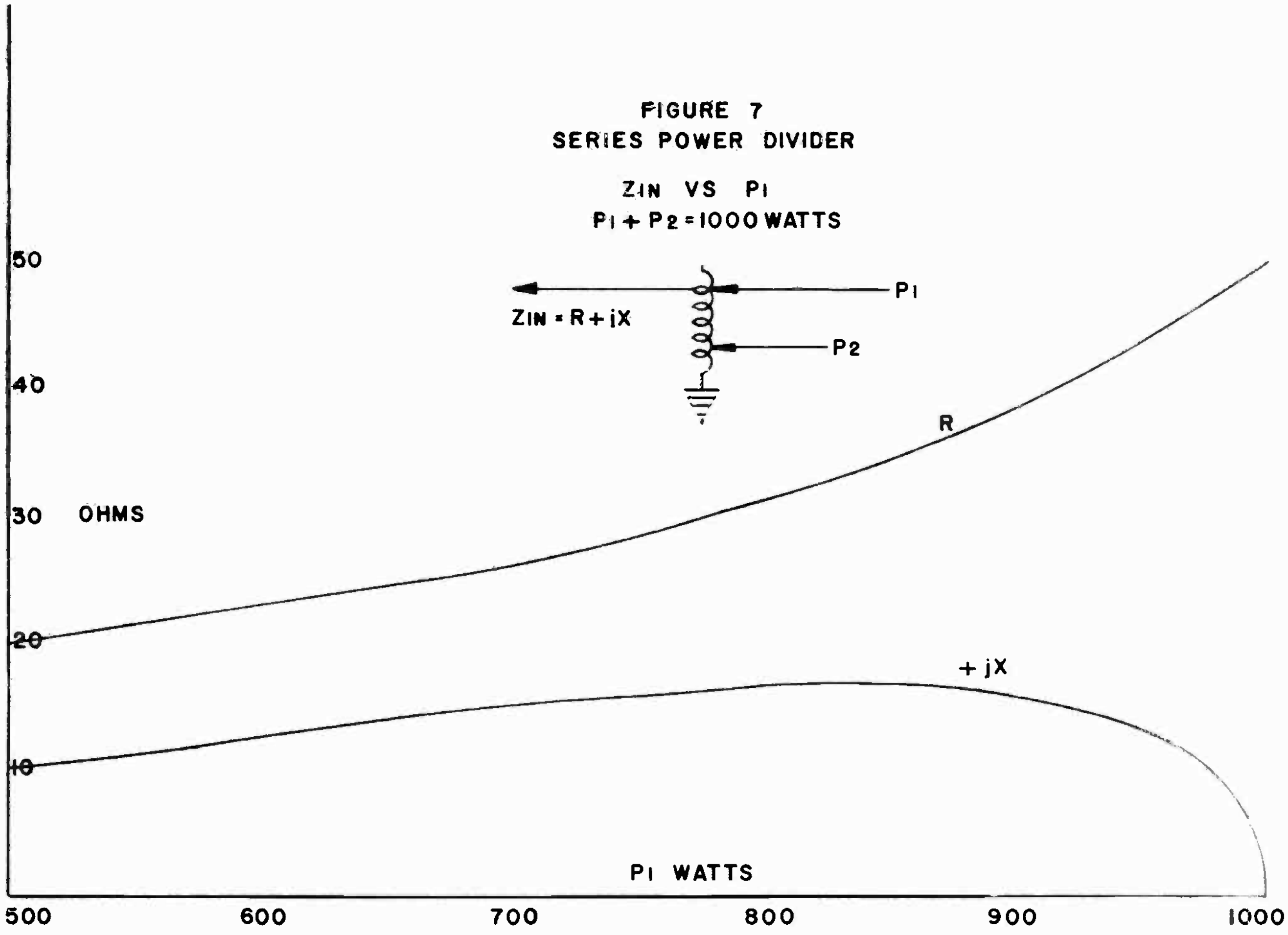
SERIES POWER DIVIDER

The series divider consists of a single coil on which the various antenna feeds are tapped. Practical adjustment of this divider is usually begun by locating the tap for the most power well up on the coil, and then adjusting the lower power feeds, as required, for the desired power division. The input of this divider always occurs at the position of the highest power tap.

FIGURE 6
SERIES POWER DIVIDER
ZIN VS XL1
P1 = 750 WATTS P2 = 250 WATTS



For design purposes, however, it is more convenient to fix the lowest tap and adjust those for higher powers. So, in Figure 6, is shown the variation of the input resistance and reactance of this type of divider as the lowest tap is placed higher and higher on the coil. Here, again, an optimum position is indicated as far as efficiency is concerned, although it is not critical as long as this lowest tap is above a certain minimum value.



In figure 7, the lowest tap is set at a point where the reactance of the coil below the tap is equal to the input to the transmission line feeding from it. The highest tap is then moved further and further up the coil to provide more power to the number one tower. Note the rather sizeable change in input resistance as the power division is changed. Obviously from this curve, this type of divider is a little more difficult to adjust than the shunt type. However, in general, the input resistance can be made higher. Also, as additional antennas are served with this type, the input resistance is not directly shunted by the additional impedances, so that the series divider can always provide a higher input resistance with a large number of towers that can the shunt divider. This fact gives this type of divider a decided advantage over the shunt type for greater than three towers or for systems involving high powers.

One of the most common errors made in power divider design occurs in the practice of making the assumption that the input impedance to the transmission lines is a pure resistance. This is done to simplify the mathematics. However, the design is often concluded with this assumption being considered as a statement of fact.

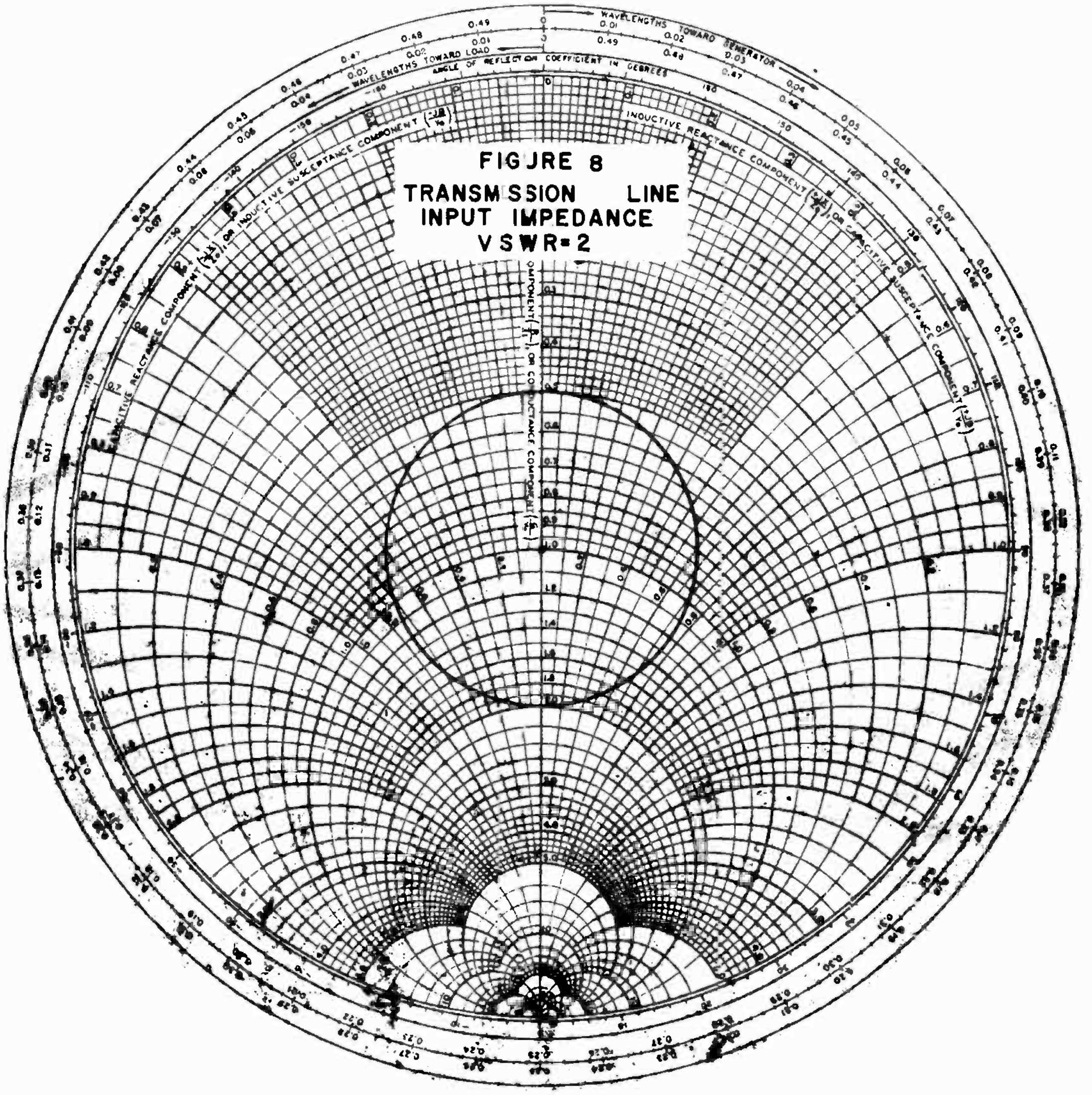
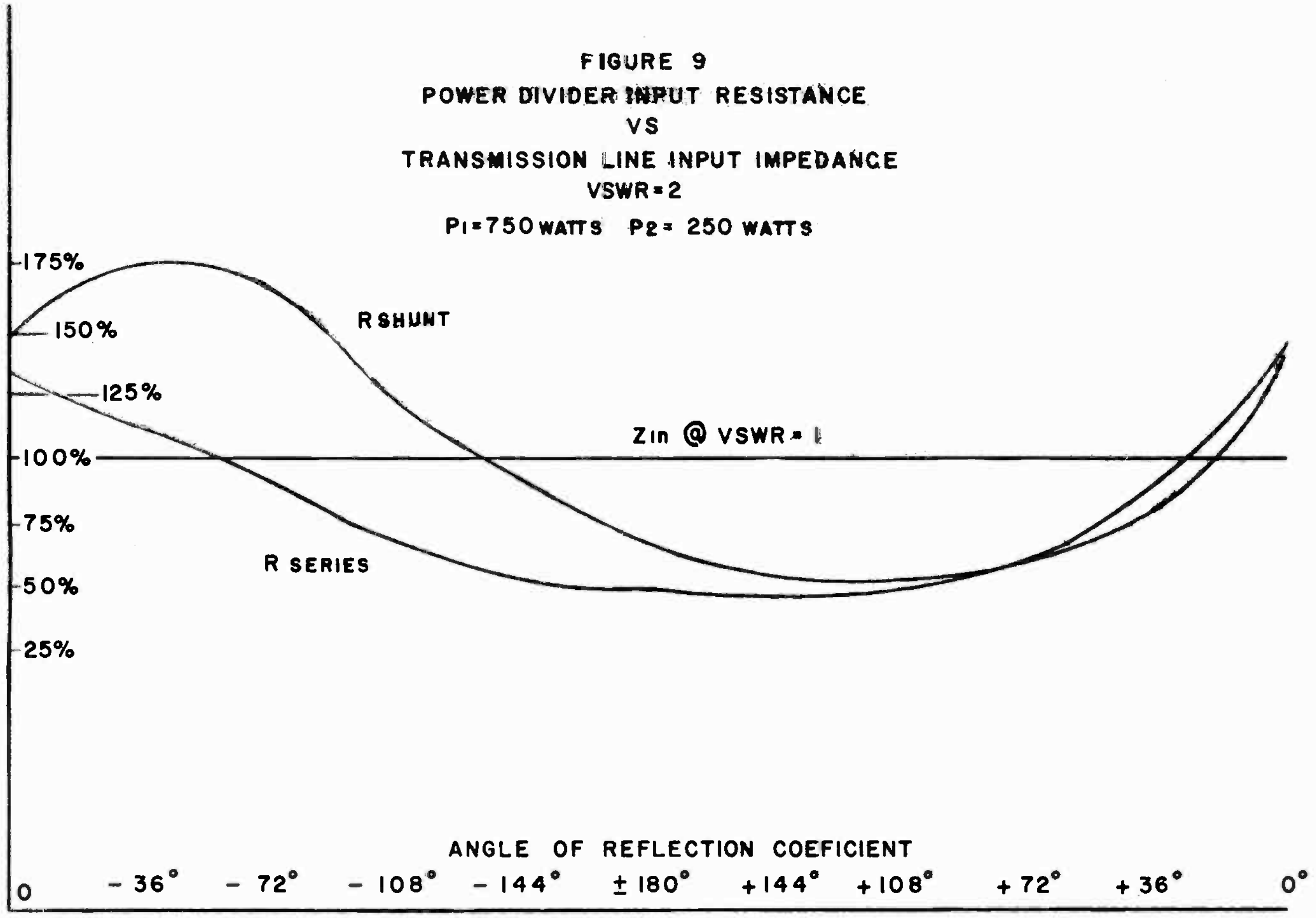


FIGURE 8
TRANSMISSION LINE
INPUT IMPEDANCE
VSWR=2

NOW IT IS A WELL KNOWN FACT, THAT, IN MOST DIRECTIONAL ANTENNA SYSTEMS, THE TRANSMISSION LINES WILL BE SOMEWHAT MISMATCHED IN THE FINAL ADJUSTMENT. THIS MISMATCH MATERIALLY AFFECTS THE OPERATION OF THE POWER DIVIDER, SINCE THE LINES PROVIDE THE LOAD FOR THE DIVIDER. TO ILLUSTRATE THIS, A SPECIFICATION HAS BEEN CHOSEN THAT THE LINES WILL HAVE AN INPUT VSWR OF 2 TO I, AND THE SMITH CHART IN FIGURE 8 GIVES THE RANGE OF INPUT IMPEDANCE THAT THE LINES MAY HAVE IF THEY FALL WITHIN THIS SPECIFICATION.



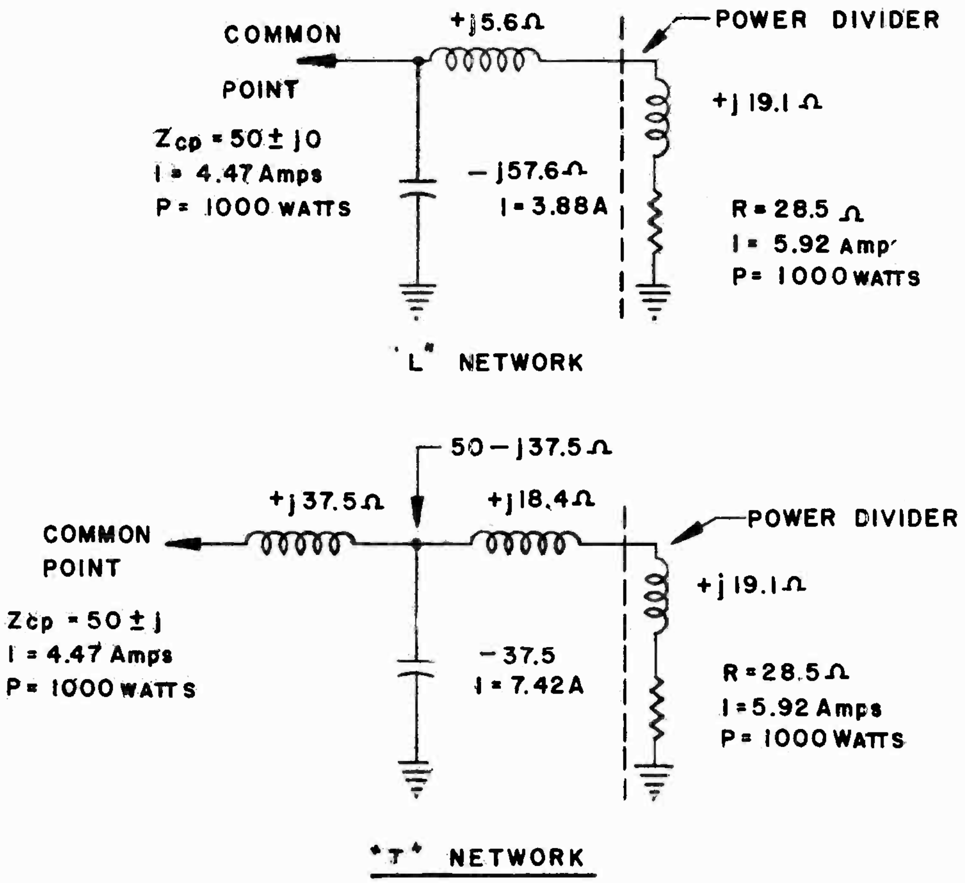
In Figure 9, both the shunt and the series type of divider have been adjusted for the power division shown and so that they will have equal input resistances when the transmission line inputs show a VSWR of unity. This input resistance is represented by the horizontal line in the center of the figure. Now, by induction the maximum effect of the transmission line mismatch occurs when both transmission lines are mismatched an equal amount in the same direction. The two resistance curves represent the variation in the input resistance of each type of divider as the input to the lines varies around the VSWR circle of Figure 8.

Evidently, there can be a considerable variation of the divider input depending upon the extent of the transmission line mismatch. Hence, no power divider design can ever be considered complete unless that design has been computed over a considerable range. It is likewise an important point that no power divider design should ever be submitted unless accompanied with a full and complete statement as to the extent of the range over which the power divider design has been considered. The range would be impossible to predict from a simple list of components, and the adjusting engineer could not possibly know within what limits the system was capable of satisfactory performance.

MATCHING NETWORK

Probably more variation occurs from one system to another in the matching network that in any other portion of phasing system design. However, as will be shown, all methods are basically the same and aside from requiring more or less components, all perform equally well.

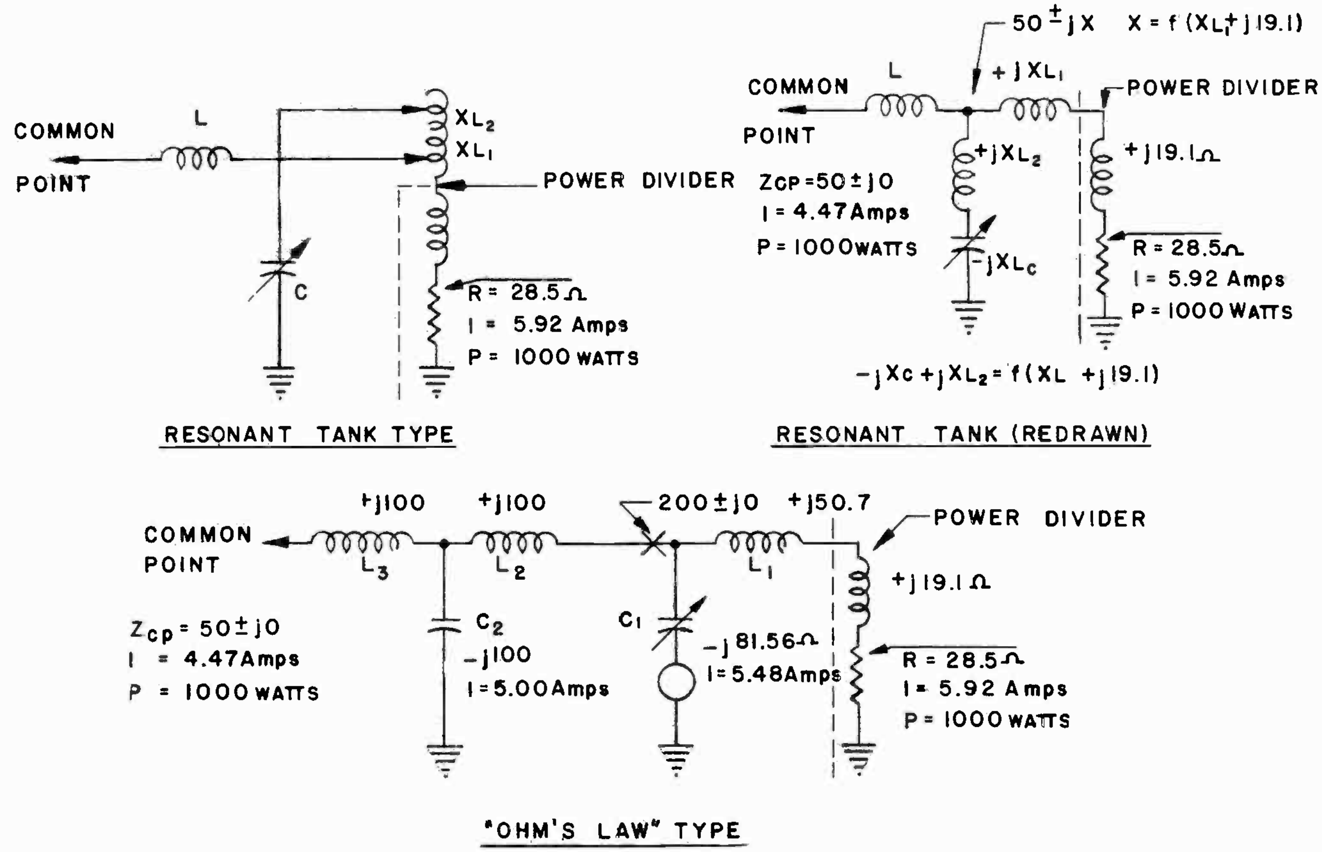
FIGURE 10
MATCHING NETWORK



In Figure 10, an "L" network is shown designed to match the given power divider input resistance to the common point. This is the simplest and most econo mical method, and, if designed with sufficient range, it is the easiest to adjust, since ther are only two elements to adjust. Matching devices, no matter how elaborate, serve only the single purpose of matching the divider input to the common point, Consequently, the more simple this network can be made, the more efficient and economical will this portion of the system be. The "L" network will always suffice for this purpose if power is to be supplied to more than one tower; for with this stipulation, the input resistance of the power divider can never exceed the common point resistance.

"T" network, shown in Figure 10, is nothing more than an "L" network with an tional reactance to aid in tuning out a reactance which appears at the junction he capacitor and the series coils. The "T" network, therefore, provides a ht advantage in adjustment facility at the sacrifice of adding an additional ment to adjust.

FIGURE 11
MATCHING NETWORKS



Probably the most common type of matching system used today is the resonant tank circuit type shown in Figure 11. Here the capacity "C" is tuned to resonance with an additional inductance added to that already supplied by the input impedance of the power divider. The actual operation of this type, however, is best illustrated in the re-arranged version shown at the right. Here it is easily seen that this type of network is really nothing more than the "T" type shown in Figure 10.

The fourth matching network, chosen for this discussion, is one that has come into frequent use in recent years. C is tuned to resonance with the power divider input and L, so that a pure resistance of some value higher than the common point appears at point X. This high resistance is then matched down to the desired common point value by an additional "T" network. A parallel resonant circuit with resistance in the inductive branch is exactly equivalent to an "L" network matching the resistance in the inductive branch to the higher resistance appearing across the capacitor. In the illustration shown here, exactly the same component values and the same currents and voltages are computed regardless of whether this circuit is designed as a resonant tank circuit on the basis of circuit "Q", or whether it is designed as an "L" network to match the 28.5 ohms to the 200 ohms. From this, then it follows, that in this type of matching network, we have nothing more than an "L" network preceded by a "T" network to perform exactly the same function as was performed by the simple "L" network shown in the first illustration.

Occasionally the term "bandwidth" has been used in connection with power divider systems and their associated matching networks. Bandwidth of any phasing systems is a function of the system as a whole. It is effected by the antennas, by the system parameters, and by the adjustment of the complete phasing system from transmitter to antennas. Generally, the greater the ratio of the dissipated energy in any part of the system to the stored energy, the broader will the bandwidth be. In connection with the power divider, the higher the input resistance of the divider the broader the bandwidth. When considering only the matching networks, however, no significant difference could be found from one type to another when all of the above types were considered on an equal basis.

CONCLUSION

It has been shown that two devices are involved in every power divider design– the divider and a matching network. Of the two most generally used, the shunt type is easiest to adjust and most suitable for two or three tower systems, especially for lower powers. For more than three towers or for high power, the series divider is better suited because of its higher input resistance.

The necessity for designing power dividers over a wide range and for specifically stating over what range the design was considered, has been demonstrated as important, because of the wide variation the input resistance may assume with varying adjustment conditions.

And finally, the matching network should be as simple as possible, consistent with the ability to match the common point resistance over the full expected range of the power divider input.

Obviously, the subject of power dividers has been barely touched upon in this discussion. It is believed, however, that sufficient information has been given to stimulate further investigation and in this way much can be done to provide power dividing networks that are easier to adjust, more efficient to operate and contribute to more economical phasing systems.

Collins

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PROBLEMS ENCOUNTERED IN MOUNTING FM ANTENNAS ON VARIOUS TYPES OF SUPPORTING STRUCTURES

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COLLINS RADIO COMPANY

RDP-153

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PROBLEMS ENCOUNTERED IN MOUNTING FM ANTENNAS ON VARIOUS TYPES OF SUPPORTING STRUCTURES

INTRODUCTION

In the years shortly after World War II, there was a considerable increase of interest in FM broadcasting. Towers to support multiple element FM antennas were expensive to the average broadcaster, and it was at this time that Collins Radio Company began installing FM arrays mounted on the side of existing AM structures. Competitors quickly followed this new technique, and soon FM antennas were mounted on all types of structures, varying a great deal in structural design and size.

Recently, there has been renewed interest in the FM broadcasting field with more and more broadcasters exploring the possibilities of additional revenue from multiplexing services. As a result, the design requirements of the FM antenna are becoming more stringent, particularly with regard to the impedance and radiation properties.

It is the purpose of this paper to indicate some of the existing problems regarding structural interference to the desired radiation pattern of an FM antenna. The experimental data that follows is based on measurements from a single element FM antenna. Unfortunately, time prevented measurements on multiple element FM antennas. However, it is known that the performance of an array may vary considerably from that indicated by the single element performance.

MEASURED DATA

Radiation pattern measurements were made with a single element FM antenna at 100 megacycles. The FM antenna, except in two cases where a "V" antenna was substituted, consisted of a single, capacitively loaded loop, approximately 15 inches in diameter. Free space radiation properties of this type are omnidirectional within 1 db. A Blaw Knox tower having a uniform 7-foot square cross section was employed as the supporting structure with the exception of two conditions in which the radiation properties were determined in the presence of a triangular tower. All data is presented in terms of relative voltage plots.

In figure 1 the antenna is mounted on the corner of the tower where the diagonal braces of the tower are joined to the leg. The resulting pattern has rather pronounced deviations from the omnidirectional characteristics of the FM loop antenna in free space. The nulls are approximately 8 db down from the major lobes for this condition.

Movement of the antenna to a distance half way between the diagonal braces on the corner of the tower gives a noticeable improvement in results. This is illustrated in figure 2.

In mounting a multielement antenna on a tower of this type, each element most likely will be located, depending on frequency, at varying distances from where the diagonal braces of the tower join the corner leg. The resulting array pattern undoubtedly would be different and determination of its properties cannot be completely predicted from the single element results. Also, this data results from measurements taken at 100 mc and an additional variation with frequency over the FM band of 88 and 108 mc could be expected because of the varying electrical properties of the tower. These points are mentioned here to indicate the great number of variables caused solely by the supporting structure which, in many instances, are not at the complete control of the antenna engineer.

In figure 3, the 100-mc antenna has been moved around to the flat side or face of the structure at the point where the diagonal braces intersect. Deviation from omnidirectional properties, for this case, are approximately ±5 db.

As experienced with the corner mounting locations, there also is quite pronounced variation with position along the side of the tower. This is evident in figure 4 where the antenna is located at a point midway between the crossover points of the diagonal braces.

In addition to the above indicated variations between side and face mounted locations, there are several mechanical aspects to be considered:

(1) Corner mounting usually positions the antenna or the coaxial line at a point where it interferes with guy wires and causes difficulty in obtaining a rigid mechanical installation. This vertical alignment problem of the antenna discourages the use of the corner leg mount.

(2) The face mount, as shown in figures 3 and 4, offers the installer a chance to achieve a rigid mechanical job free of guy wire interference, and this, apparently, is the type of mounting more widely used than any other.

Although not usually recommended, in some installations the antenna has been mounted within the tower. This is illustrated in figure 5 where the antenna is located inside the tower 15 inches from the corner of the diagonal or X-bracing cross. Figure 6 illustrates a similar condition except the antenna was placed midway between the bracing.

Mounting the antenna inside the supporting structure has some mechanical advantages, such as the problem of reducing interference with the guy wire system. Also, in some cases, the wind loading is reduced. As mentioned before, this type of mounting generally is not recommended.

Figures 7 and 8 show the results of varying the positions of the antenna within the structure but with the antenna located symmetrically with respect to the tower. The position indicated in figure 7 results in the least variation from the desired pattern (omnidirectional within ±2.5 db). It probably is safe to assume that if each element in a multielement arrangement arrived at identical places throughout the structure with relation to cross bracing, a pattern of this type would result.

The installation of an array within a supporting structure of this type is difficult because the interior of the tower generally is used for ladders, cross bracing, elevators, etc. No attempt was made to determine what degradation might result from such items.

In all the measurements discussed previously, the supporting structure was large in terms of wavelengths. Actually, the cross-sectional dimensions are greater than one-half wavelength at 100 mc. The result is structural members of resonant length causing, in some cases, severe degradation of the radiation pattern. This effect is reduced considerably for the following two conditions.

Illustrated in figure 9 is the pattern from a single loop FM antenna mounted approximately 8 inches off a small triangular tower. Because of the smaller cross section, there is less reflection and scattering by the supporting structure. For this case, the FM antenna width is larger than the cross section of the supporting structure. The improvement from previous results is quite evident.

In figure 10 the radiation pattern of a single element "V" antenna mounted on the triangular tower is shown, and while the results are not as good as those of the ring antenna, it clearly demonstrates that the smaller supporting structure gives improved performance.

In figure 11 the measured pattern of an FM antenna inside a smaller supporting structure of square cross section is shown, and in figure 12 the same arrangement of internal mounting is employed but with a variation in the relationship of the antenna to the diagonal bracing. There could be no doubt that this type of mounting is detrimental to the performance of the antenna and should be avoided.

In figures 13 and 14 additional patterns resulting from mounting the 100-mc FM loop antenna asymmetrically inside the Blaw Knox tower of 7-foot cross section are illustrated. For both cases, the antenna is 46 inches from the corner, but in figure 14, the relationship is changed with regard to the cross bracing structure.

Although it is beyond the scope of this paper, recent field measurements indicate that, in the case of guyed structures, interference from the guying system may affect the radiation pattern seriously. As a result, it may be necessary, for some installations, to "break up" the guy wires by proper insulating techniques in the near vicinity of the antenna.

Also, because of the close coupling between the supporting structure and the antenna, the impedance properties of the array may be adversely affected. This is particularly true when the supporting structure is larger in cross section than the FM antenna. Experience has shown that it usually is necessary to retune the antenna to secure a low vswr after the installation has been completed. The radiation pattern will not be affected, of course, by this tuning procedure unless the current distribution on the antenna is changed appreciably.

CONCLUSIONS

The data presented here definitely shows that in mounting an FM antenna on the supporting structure the placement of the antenna on, or in, the structure can have effects which greatly impair the performance of the FM antenna. Unfortunately, no formula is available which would enable a broadcaster to predict with reasonable accuracy the pattern that might be expected from installations on a particular type of structure. The best approach is to use a supporting structure of small cross section, which should keep the pattern interference at a minimum. A type of structure that fulfills this requirement is the steel tubular column. Complete actual field strength measurements of the majority of FM installations now broadcasting are not available, therefore hindering the evaluation of existing systems.

It must be realized that the patterns presented here represent an exploratory investigation of this problem. It indicates that a great deal more patterns should be taken before accurate recommendations can be made concerning the mounting of FM antennas. The success of the FM installation will depend largely on how well the antenna is installed and on the environment under which it operates.

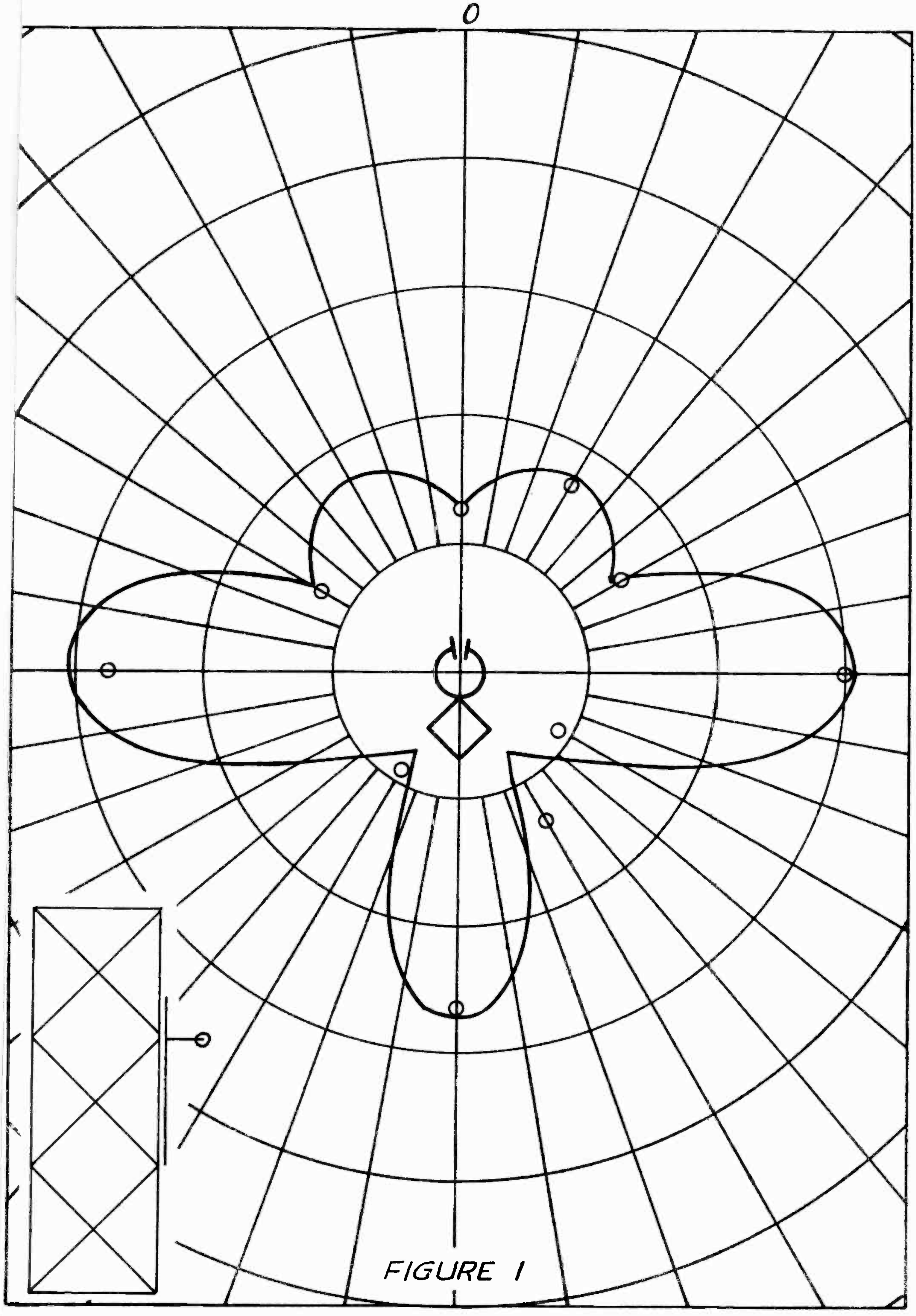


FIGURE 1

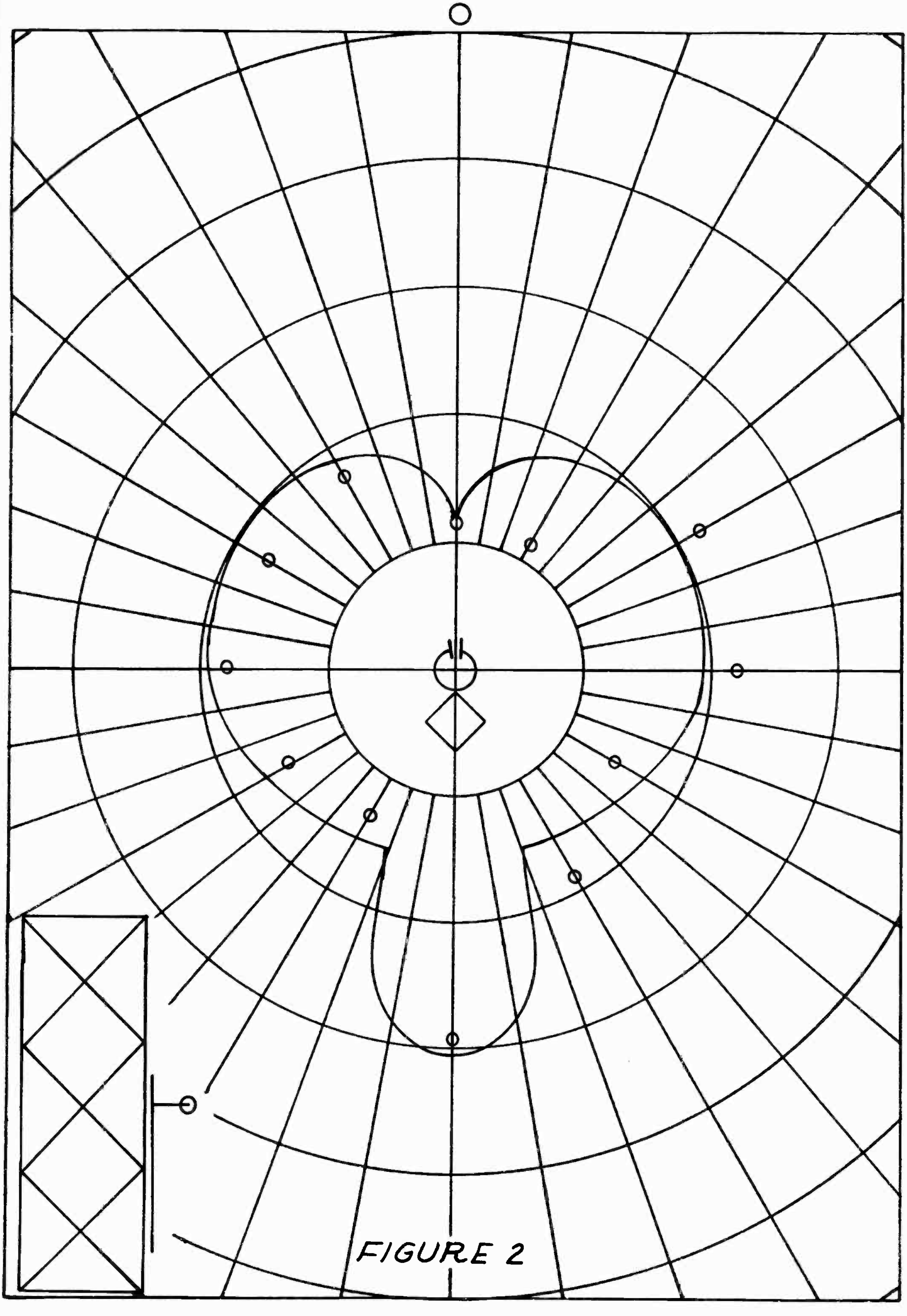


FIGURE 2

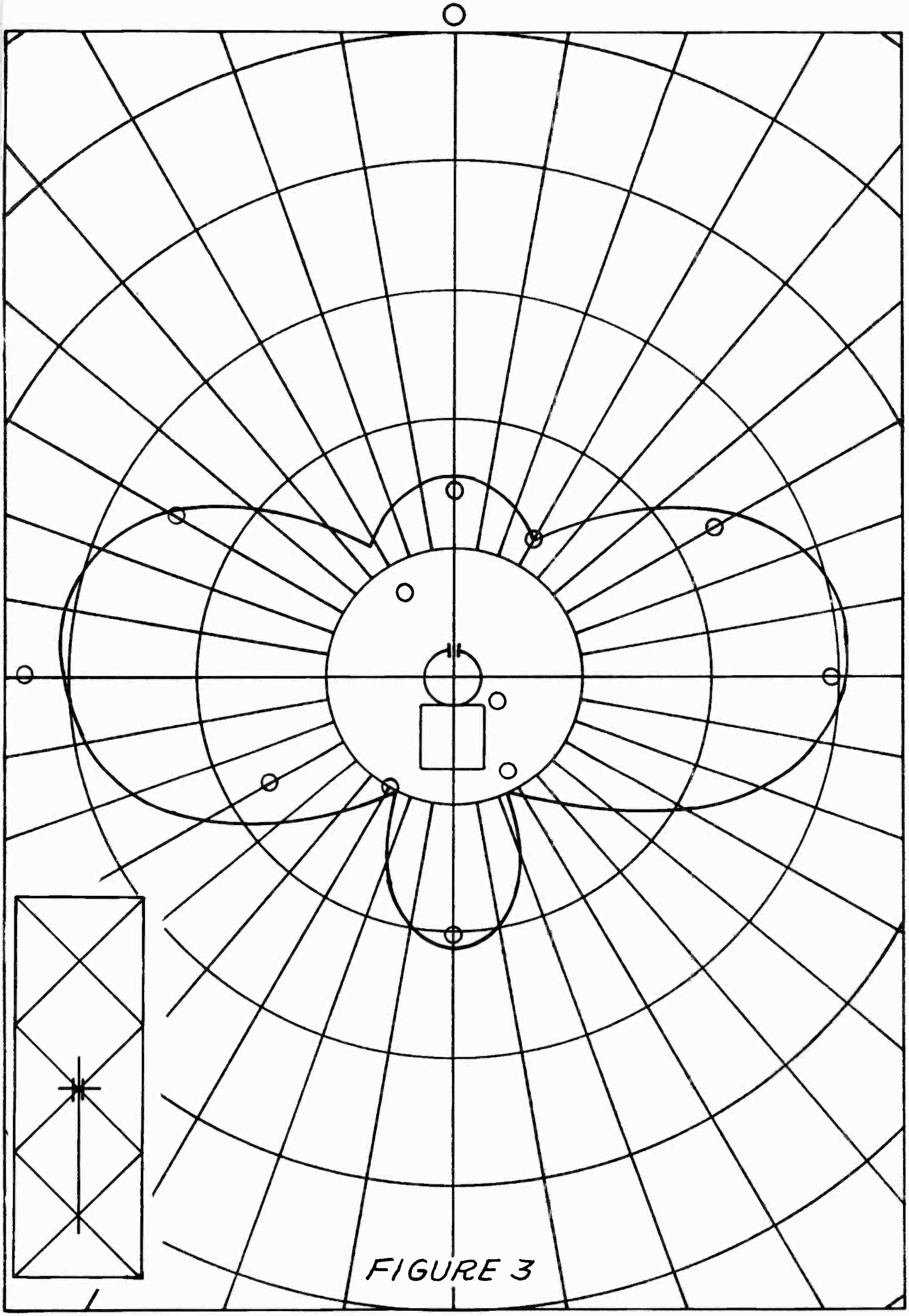


FIGURE 3

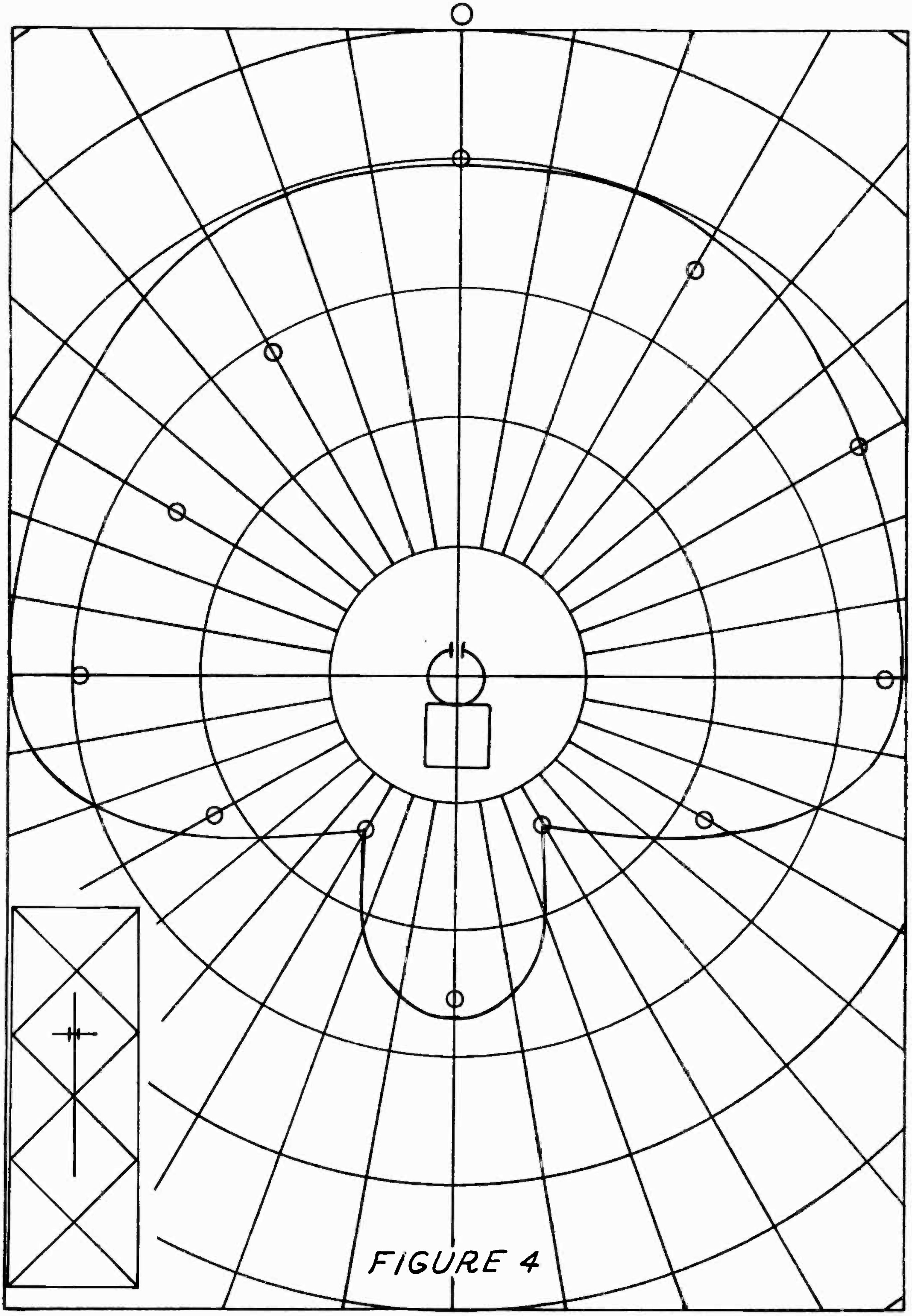


FIGURE 4

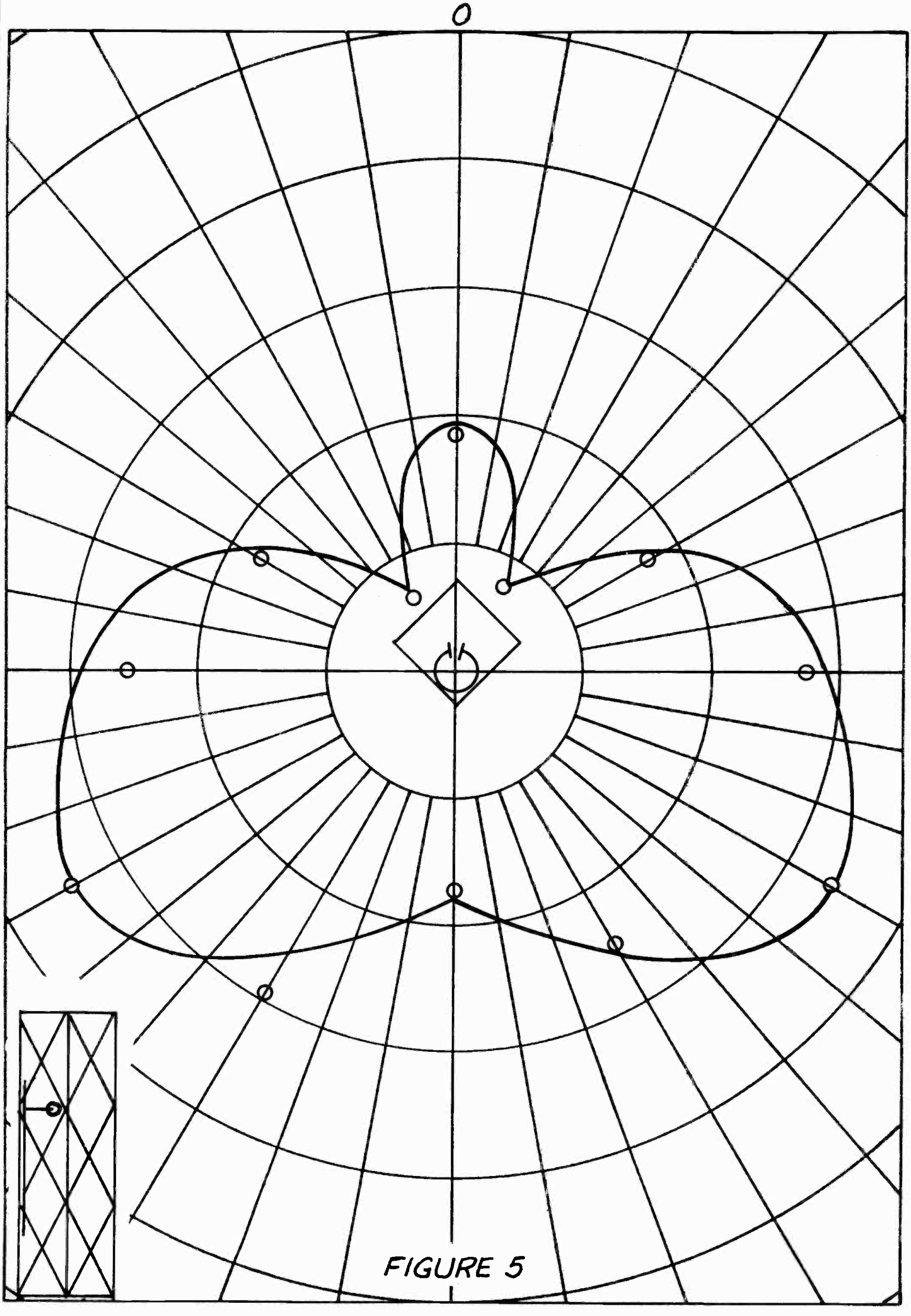


FIGURE 5

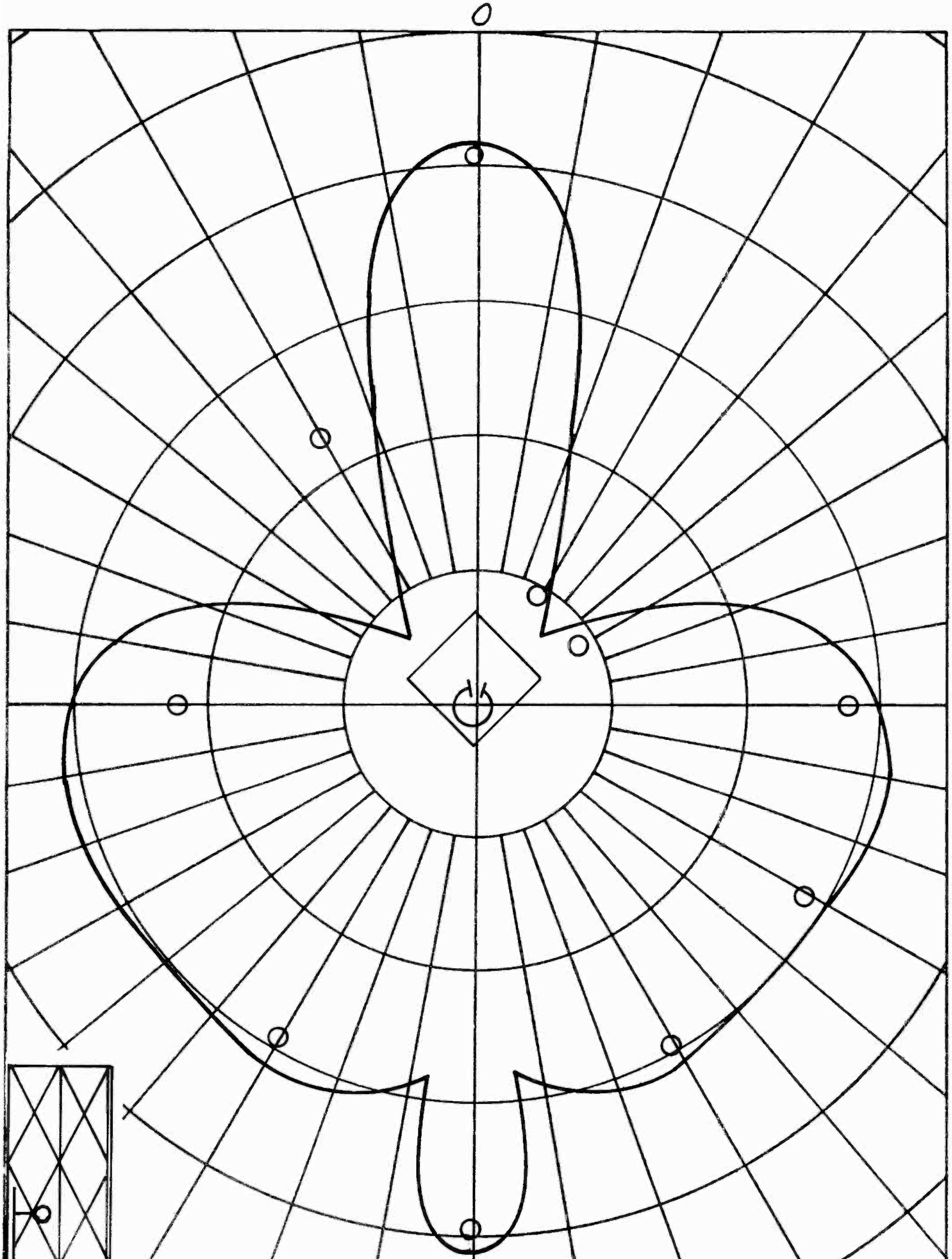


FIGURE 6

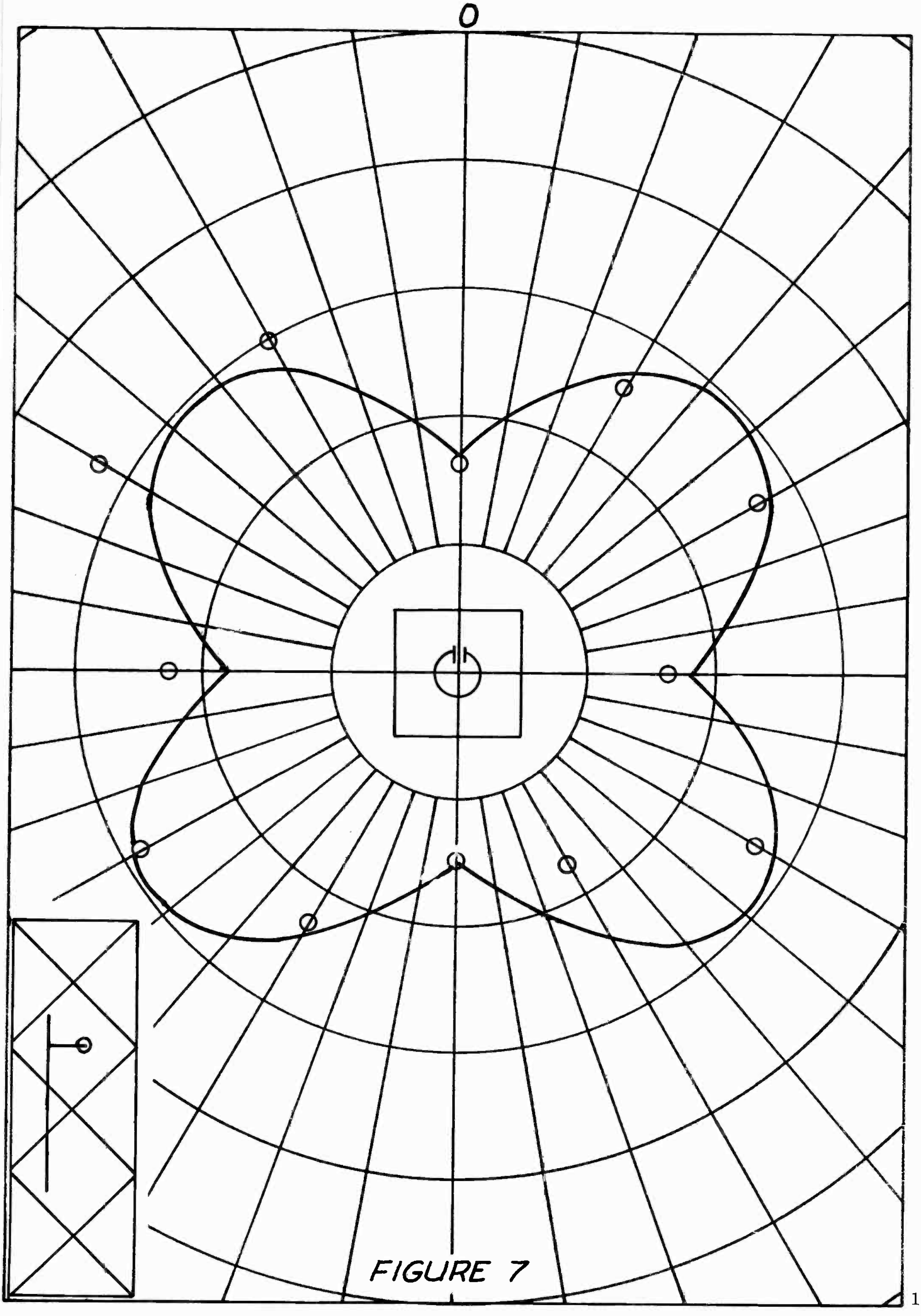


FIGURE 7

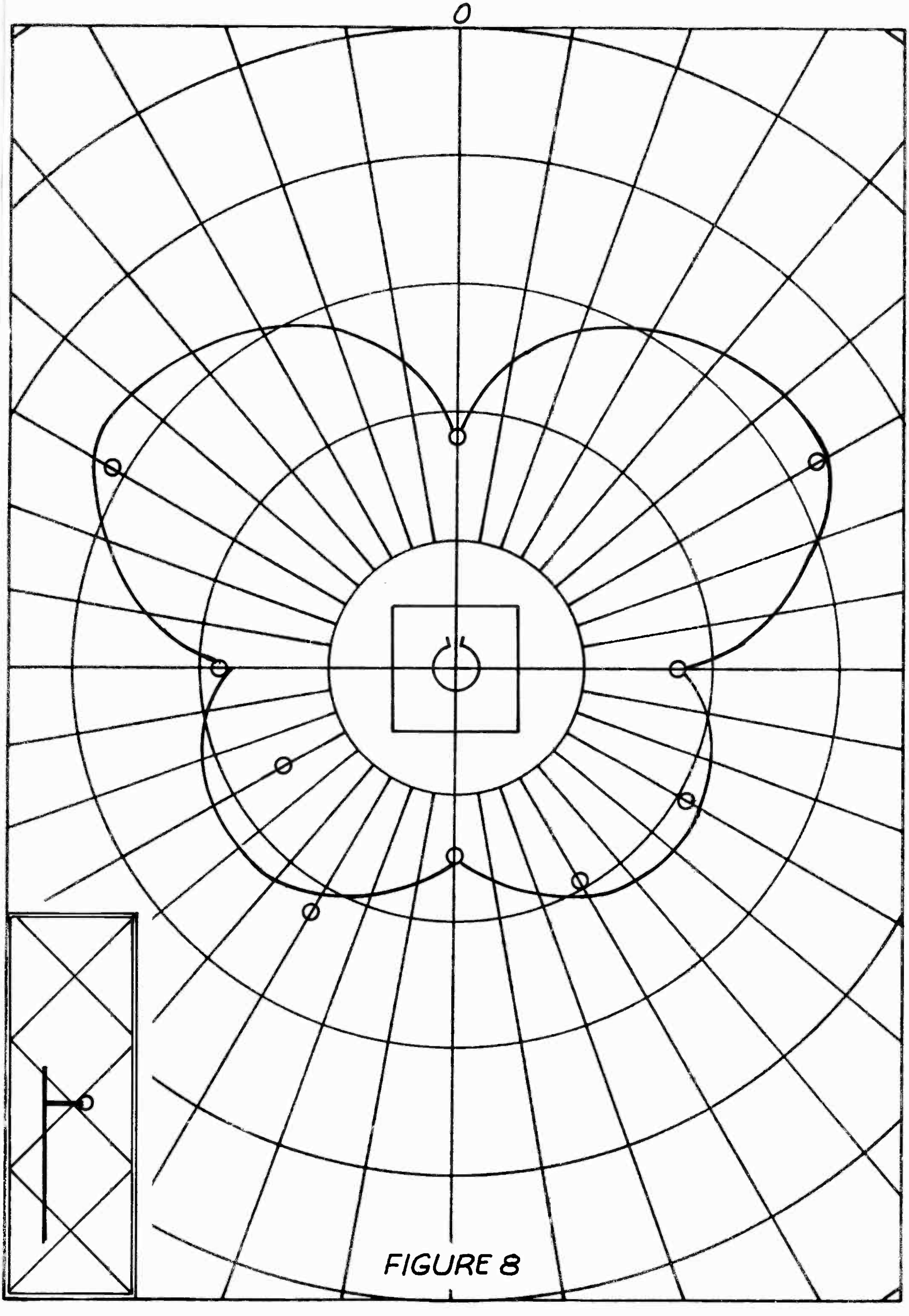


FIGURE 8

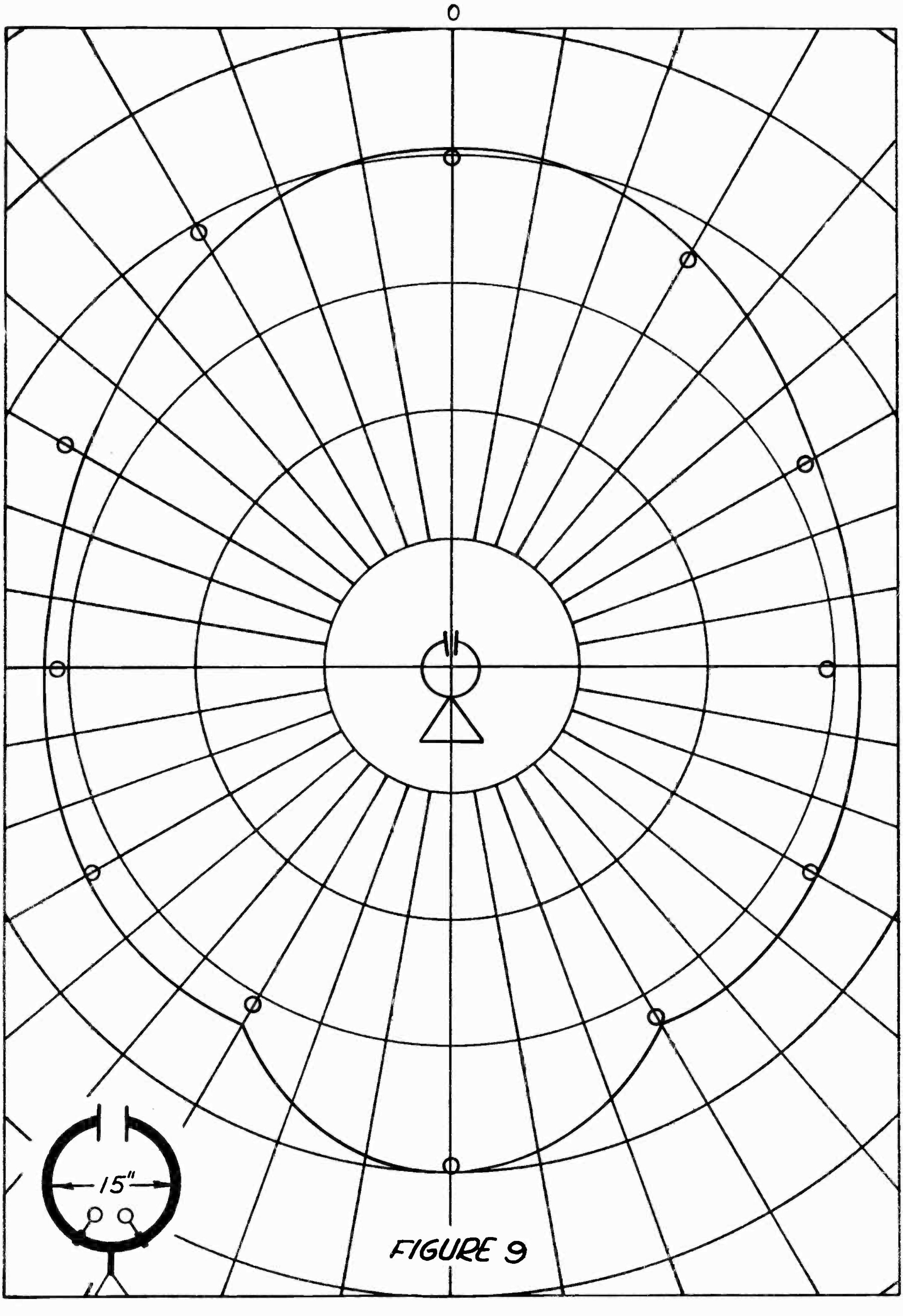


FIGURE 9

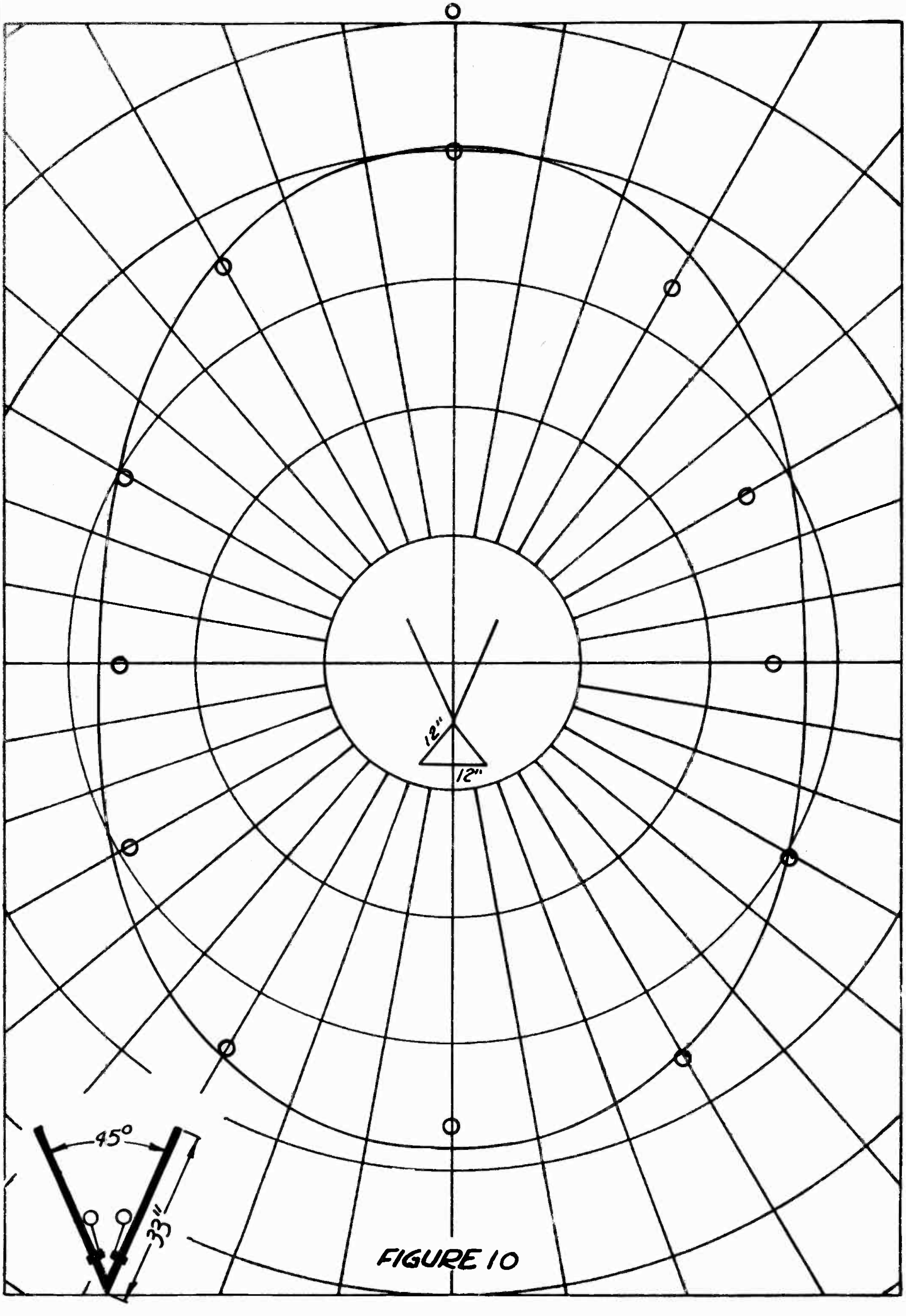


FIGURE 10

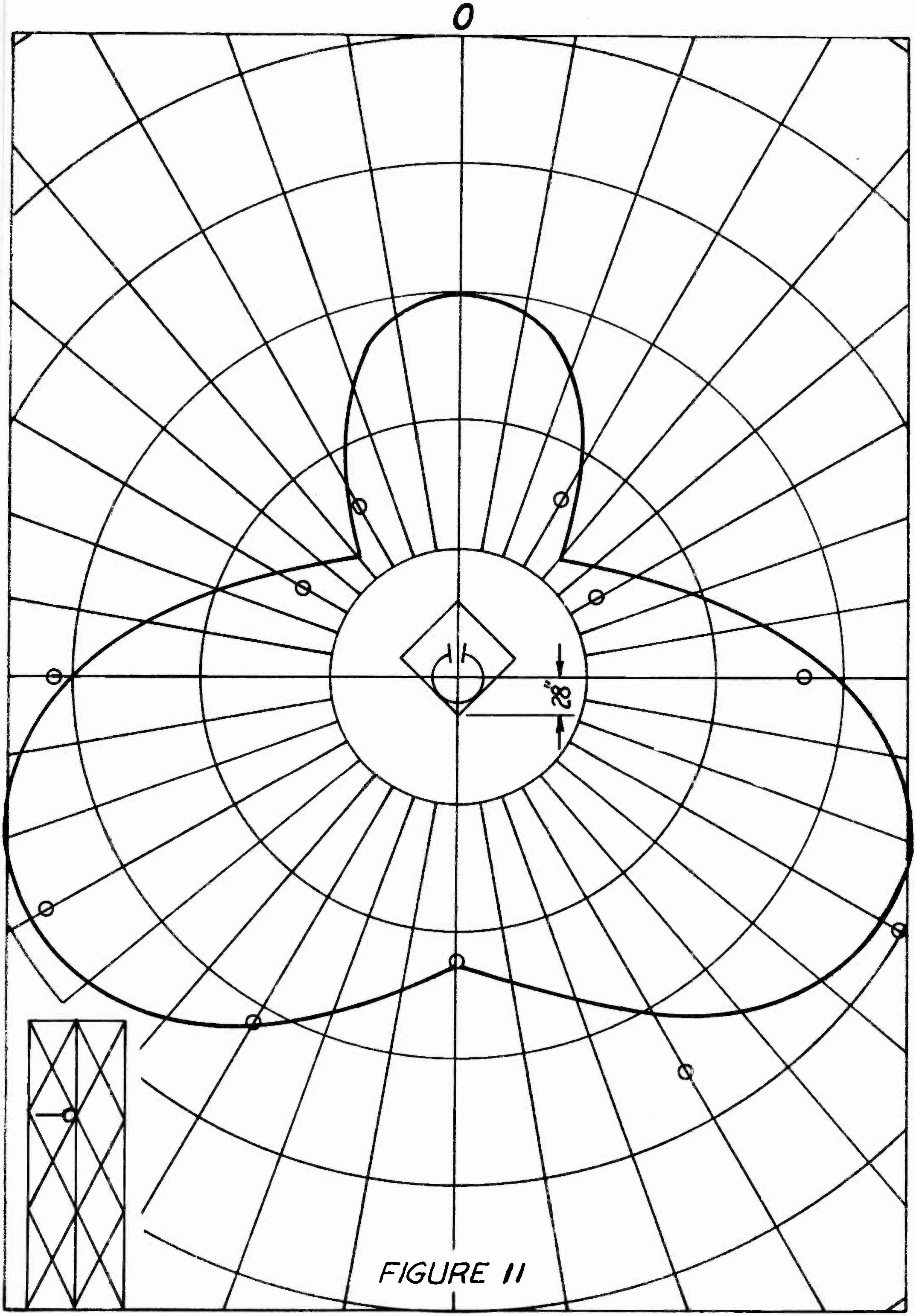


FIGURE 11

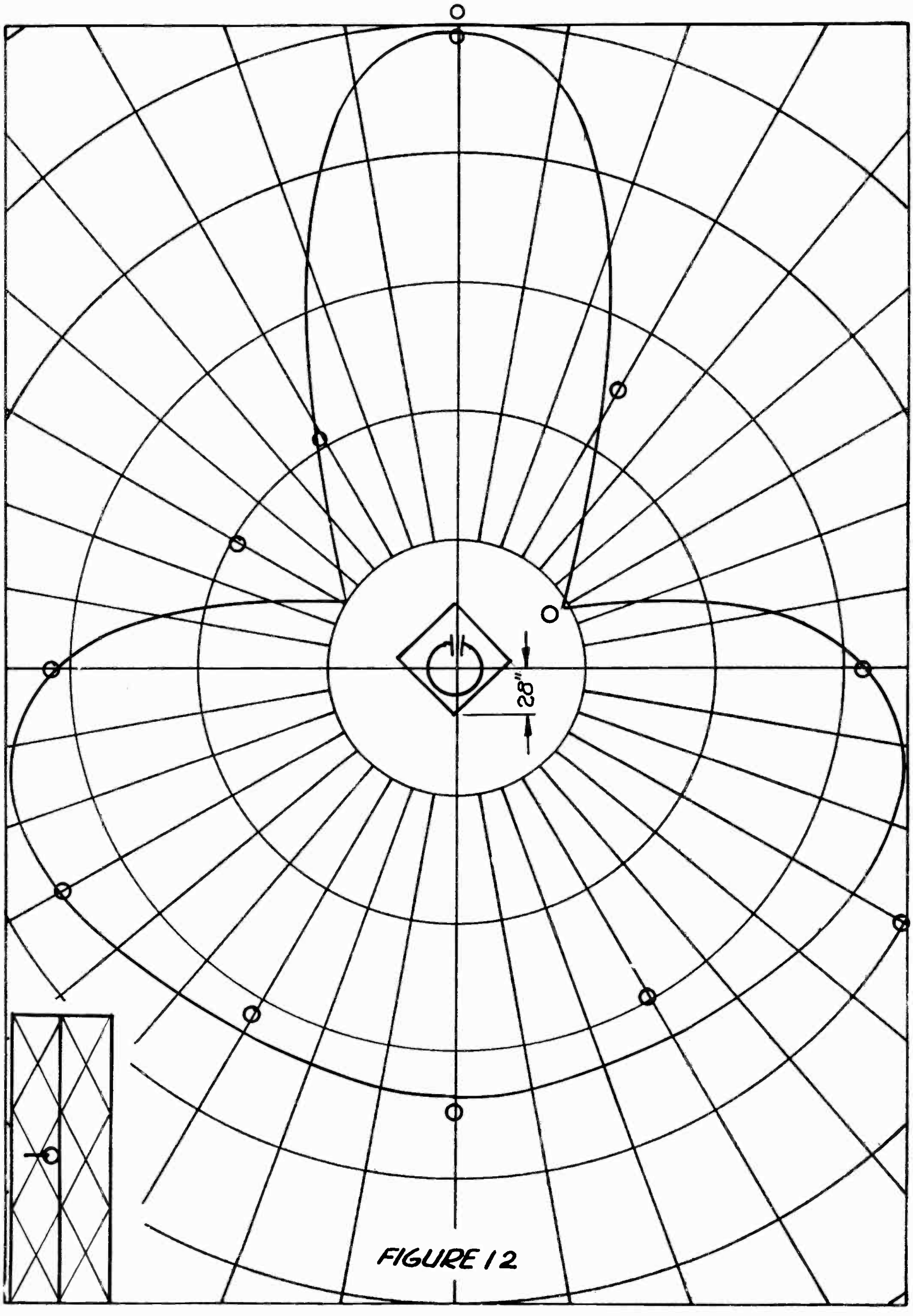


FIGURE 12

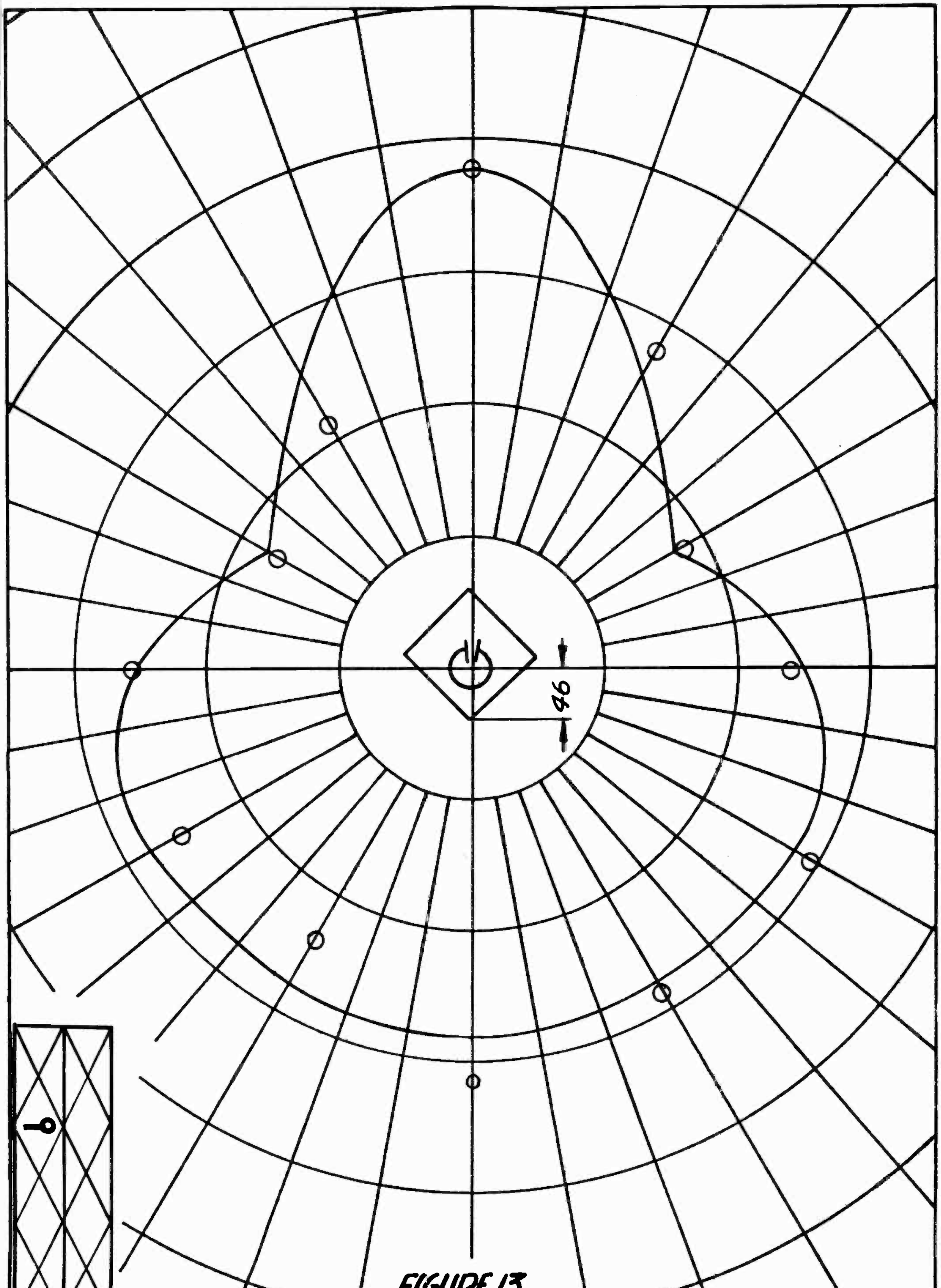


FIGURE 13

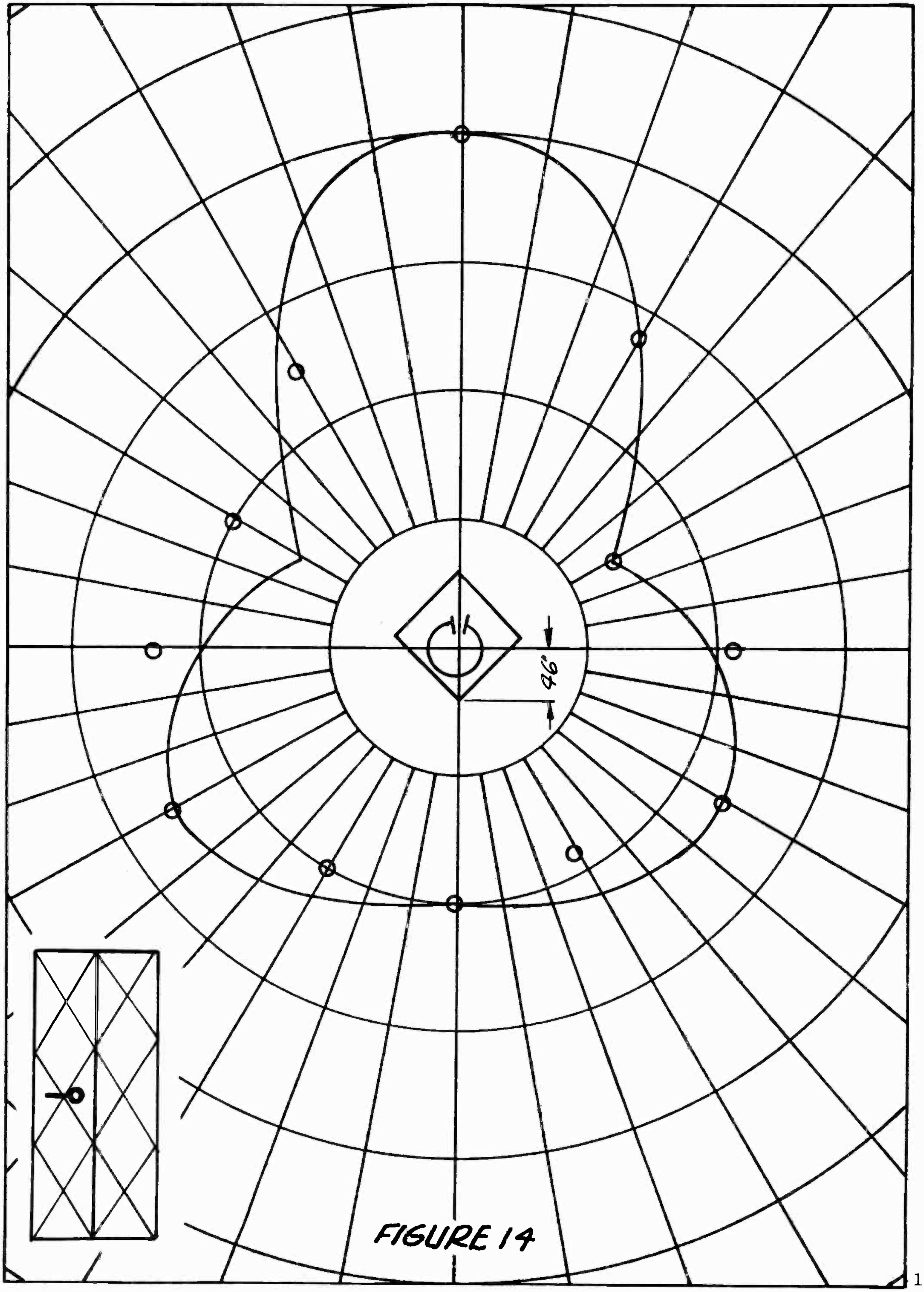


FIGURE 14

COLLINS

COLLINS RADIO COMPANY

"CREATIVE LEADER IN ELECTRONICS"

11

P R A C T I C A L   F M   E N G I N E E R I N G

Presented by

BERNARD WISE

President
of
ITA ELECTRONICS CORPORATION

NAB CONVENTION
May 1961

Within the near future, there is a very good possibility that station management of existing broadcast facilities will approach their technical people with the request to initiate plans either for a new FM installation, or for an expansion of their existing facilities.

During the past four years, ITA has shipped approximately 400 FM transmitters. Since we include installation supervision within our equipment price, we have had intimate contact with the practical problems associated with FM installations. We hope that the summary which follows can be considered as "Practical FM Engineering" and can assist you with your station's FM plans.

SELECTION OF FREQUENCY

The first phase in the determination of the FM facility is the selection of a frequency. The rules of the FCC prevent interference to co-channels and adjacent channels. For the sake of brevity it shall not be repeated at this time. However, given the choice of selecting a number of frequencies the following thoughts should be considered.

1. Analyze the TV signals in your area, giving special consideration to TV channels 8 to 13 inclusive. Although new FM transmitters have harmonic attenuations in excess of 80 db, areas that are being served by fringe TV signals will definitely be affected by a second harmonic from a strong local FM station which corresponds to the frequency of the fringe TV signal.

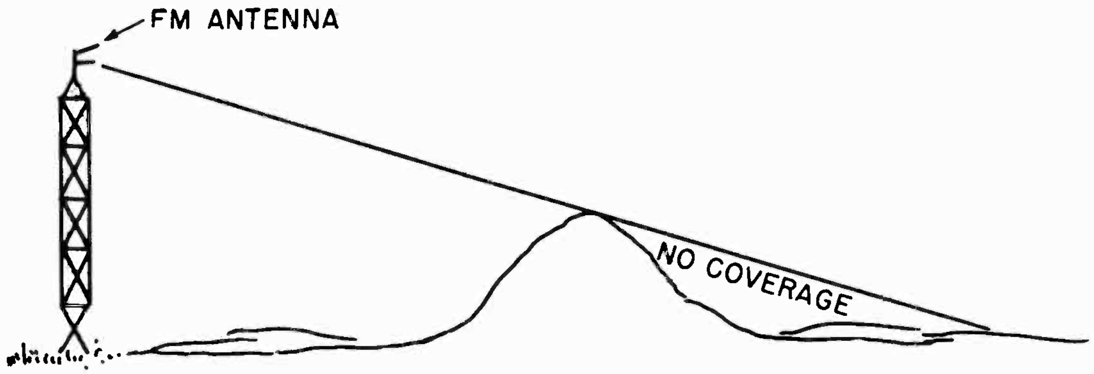
2. In selecting an FM frequency, it is also desirable that this frequency is not separated from an existing service by one of the standard IF frequencies; namely, 4.5 mc, 10.7 mc, or 21 mc. These services include aircraft, government, and broadcast services. This precaution is to circumvent the obvious problem of having two RF signals mix in the receiver front end and produce an IF frequency. We know of several instances where this has occurred.

3. A third area that requires frequency consideration is in the unique condition where an FM installation is placed in a market which depends on a fringe channel 6 for TV coverage. The high gain TV receiving installation will very easily accept a low frequency FM signal and interfere with TV reception. An obvious solution in this case is to select an FM channel about 100 mc. It may seem unfair that the FM broadcaster must go to such extremes to protect competing mediums. Nevertheless, to be oblivious may result in extremely poor public relations.

DETERMINATION OF ERP

FM broadcast frequencies, 88 to 108 mc are probagated in free space with very little refraction and reflection. Thus, like in TV, we must depend on line of sight for coverage as exemplified in Figure #1.

Figure #1



FM COVERAGE REQUIRES LINE OF SIGHT BETWEEN TRANSMITTING & RECEIVING ANTENNA

It is, therefore, essential that one selects the point of highest elevation above average terrain for the location of his FM antenna. Consistent with good economics this may be a short tower on a tall building, an existing AM or TV tower, or a special FM tower. However, in every case line of sight to all points must be assured.

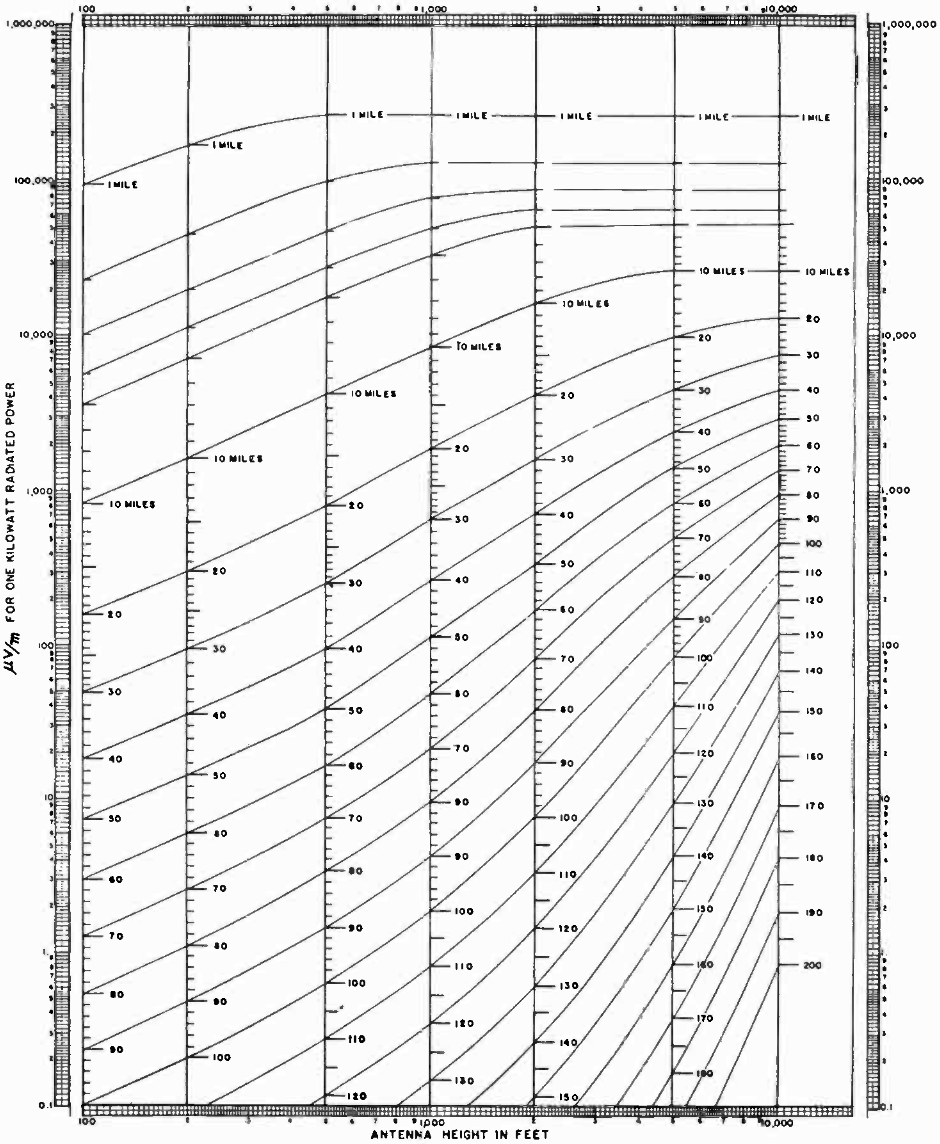
After the practical decision of elevation of the antenna has been made, consideration must be given to providing adequate field strength in the area to be serviced. In order to conform with FCC rules, a station must provide a field strength of 1 millivolt/meter in urban areas and 50 millivolt/meter in rural sections. In practice, each station should strive for a minimum field strength of 1 millivolt/meter in the prime market.

Having determined the proposed elevation of the antenna, the engineer must now determine the required effective rated power necessary to achieve the desired field strength in the area to be covered.

The term "ERP" is an expression which describes the product of transmitter power, antenna gain and transmission line efficiency.

Referring to Figure #2, which is a copy of the standard FCC probagation charts, the station engineer should select a point on the abscissa which corresponds to his proposed antenna elevation and proceed upward along this line until it intersects with a mileage curve which agrees with his most distant prime market. Where this intersection occurs, draw a horizontal line to determine the ordinate of this point. This ordinate represents the field strength in millivolt/meter at the desired distance and antenna elevation but with an ERP of only 1KW. Squaring the ratio of this field strength with the desired level at this mileage will determine the necessary ERP. For example, from an elevation of 1000 ft. above average terrain, and assuming line of sight exists between the radiating and receiving points, a field strength of 5 millivolts/meter is desired 25 miles distant. It can be seen that 1KW provides only 1 millivolt/meter under these conditions. In order to obtain the desired level the ERP must be increased by a factor of this ratio squared or essentially 25KW ERP is necessary.

Figure #2



GROUND WAVE SIGNAL RANGE FOR F M BROADCASTING

SELECTION OF PROPER TRANSMITTER AND ANTENNA COMBINATION

We have just described the method of determining the required ERP. The next step is to determine the proper combination of transmitter power and antenna gain to obtain this ERP. Occasions will arise where the wind loading to the supporting structure is such that it is not practical to consider an antenna of gains greater than a particular value. However, assuming there are no restrictions along these lines, in general, selection of a combination will be made that represents the minimum dollar investment consistent with good engineering.

Figure #3 describes two approaches for representative ERP's with the associated selling price of the equipments. This chart is extremely interesting in that it indicates the comparatively attractive pricing of higher priced transmitters for it can be seen that the combination of high power transmitter and low gain antenna is comparable to the high gain antenna-low power transmitter approach. Of course it should be noted that the higher the power of the transmitter, the more the operating expense with regards to power consumption and tube replacement. However, by the same token you will find that your signal is much more solid in the immediate market, a point which will be discussed in detail when we describe the selection of the FM antenna.

Figure #3

ERP**	TRANSMITTER	ANTENNA	EQUIPMENT* COST
1KW	250W	4	5,100
	1KW	1	5,400
5KW	250	20	13,100
	1KW	5	7,400
20KW	1KW	20	14,900
	5KW	4	13,000
50KW	5KW	10	16,000
	10KW	5	15,500
	5	20	21,000
100KW	10KW	10	18,500

* ANTENNA COST AROUND $500/BAY

** ASSUME 0 LINE LOSS

EQUIPMENT COST VS. TRANSMITTER COMBINATION

SELECTING THE FM BROADCAST TRANSMITTER

In analyzing the various features of the FM broadcast transmitters available, it is extremely important that the final selection have the following characteristics:

1. The final PA tube should be of the modern ceramic type. At FM frequencies it is extremely important that low loss materials such as ceramics be used rather than the outmoded glass envelopes.

2. The plate dissipation of these tubes should be equal to at least half of the total output power required from the equipment. Essentially, I am saying that a practical plate circuit efficiency in the FM band is 66%.

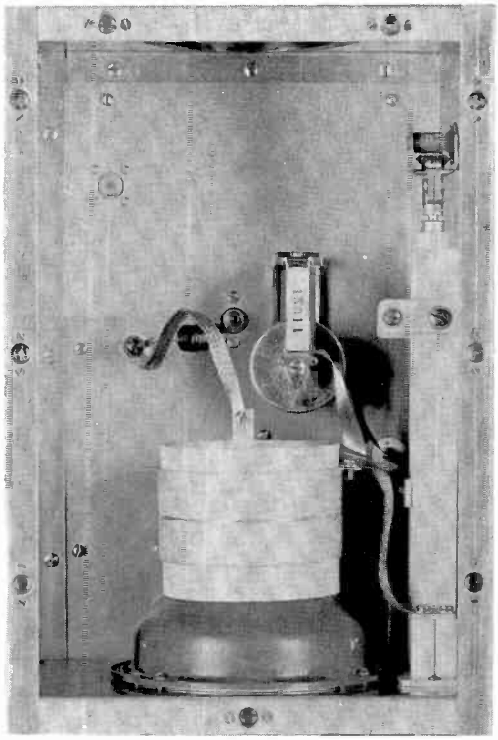
3. Careful consideration should be given to the recent FM stereo rules. These require that the equipment selected must be capable of providing crosstalk free multiplex operation. All manufacturers are going to claim that their equipment will be crosstalk free, and I am sure that all of them are correct for specific conditions. However, we have found that the selection of tubes that do not require any variable neutralization controls to achieve stability reduces considerably the problems of crosstalk. When a transmitter utilizes an approach that requires neutralization controls, we find that all this does is add to the complexity of adjusting the transmitter for minimum crosstalk and, furthermore, we find that these controls require readjustment as the tubes age.

In order to achieve this non-neutralization requirement, we at ITA, as well as some other equipment manufacturers, select tubes that do not have high inductance internal structures and have, in addition, increased the stability of the circuits by operating these tubes in grounded grid. Although operation in grounded grid reduces the overall sensitivity of the stage, it guarantees the operator freedom from problems of crosstalk, neutralization, or instability.

Pictured in Figure #4 is the 4CX1000A that is used in our 1KW transmitter that is operated grounded grid.

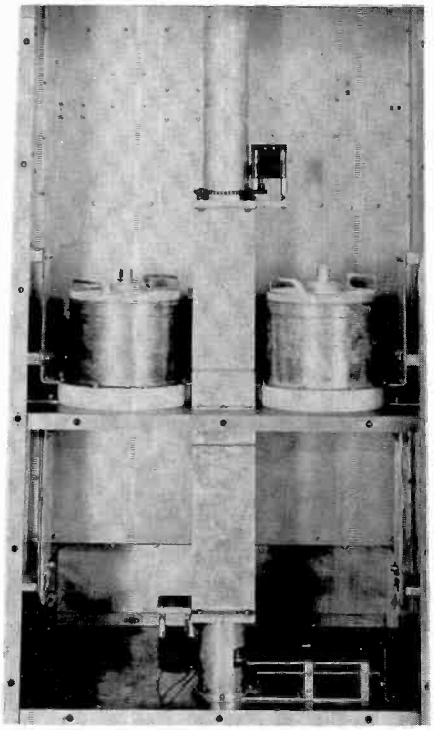
In Figure #5 are two 3CX10,000A7 triodes that are operated grounded grid in our 35KW transmitter.

Figure #4



PHOTOGRAPH OF 4CX1000A OPERATED GROUNDED GRID IN PA. OF ITA-FM-1000 C. 1KW TRANSMITTER

Figure #5



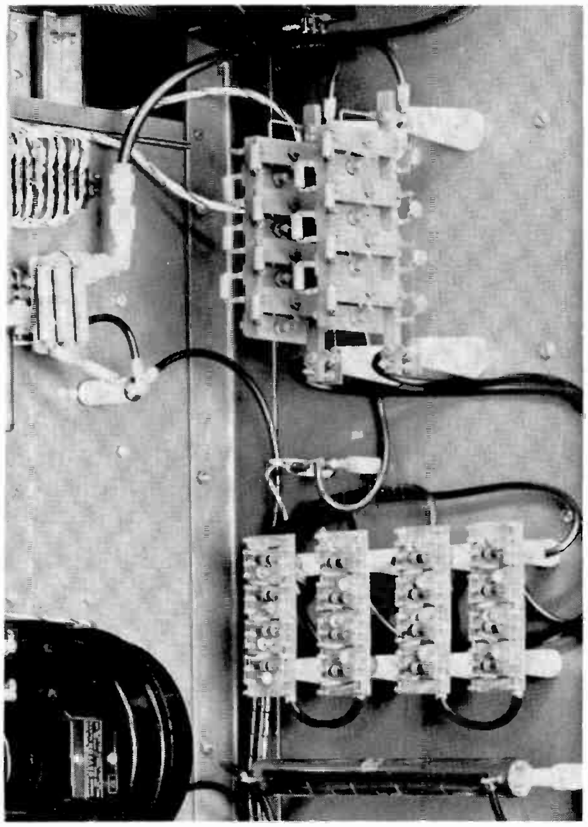
PHOTOGRAPH OF TWO 3CX10,000A7 OPERATED GROUNDED GRID IN ITA 35 KW FM POWER AMPLIFIER

POWER SUPPLIES

Available today are field proven, trouble free, infinite life, silicon rectifiers. To select a transmitter which does not incorporate these components is similar to purchasing an automobile that does not have turn signals. Prior to this past year, we at ITA were somewhat hesitant regarding the use of silicons, but during this year we have concentrated our investigation of these units and are convinced that the selection of silicons with adequate peak inverse voltage safety factors, the utilization of fast acting relays, the installation of surge protection resistors, the utilization of silicons with sufficient current rating so that they can sustain a fault until overload and/or circuit breakers operate, will guarantee absolute protection and infinite life for silicon rectifiers. The obvious advantage of these units, from the operator's view, is that they can be operated without any preheating, that they can be operated in any ambient temperature condition, that they contribute a negligible amount to the cabinet heat, and finally, that they occupy very little volume and thus provide more space for air circulation.

Typical silicon arrangements, as used in ITA FM transmitters, are pictured in Figure #6.

Figure #6

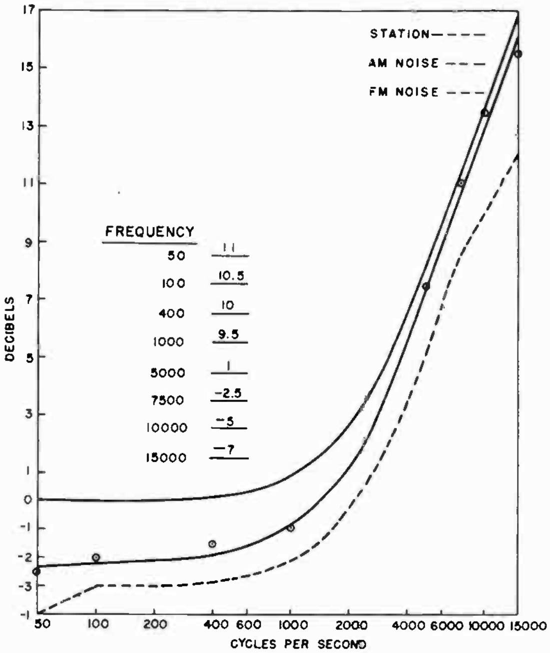


SILICON SUPPLY IN
ITA I KW FM TRANSMITTER

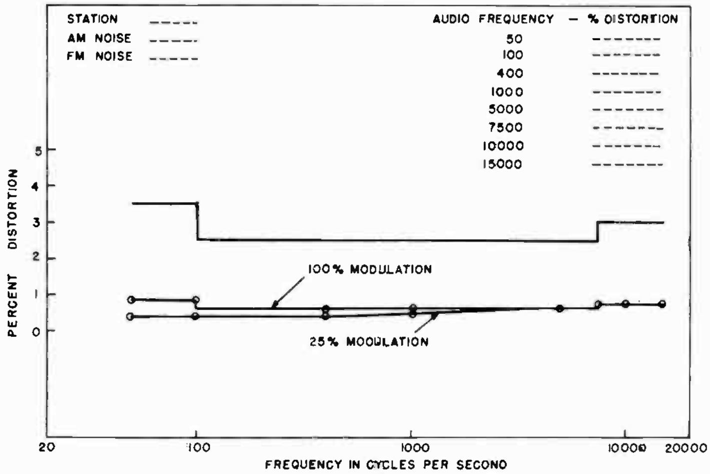
FM EXCITERS

One last phase to consider in evaluating a transmitter is to analyze the exciter that is being used to generate the FM signal. All equipment suppliers today, save one, offer a phase modulated exciter. If the majority of manufacturers think the way we do, they have selected the phase modulated exciter because of its simplicity, reliability, and ability to achieve low distortion and excellent frequency response. Pictured in Figure #7 are typical frequency responses and noise distortions obtained from our exciters.

Figure #7



FREQUENCY RESPONSE DATA

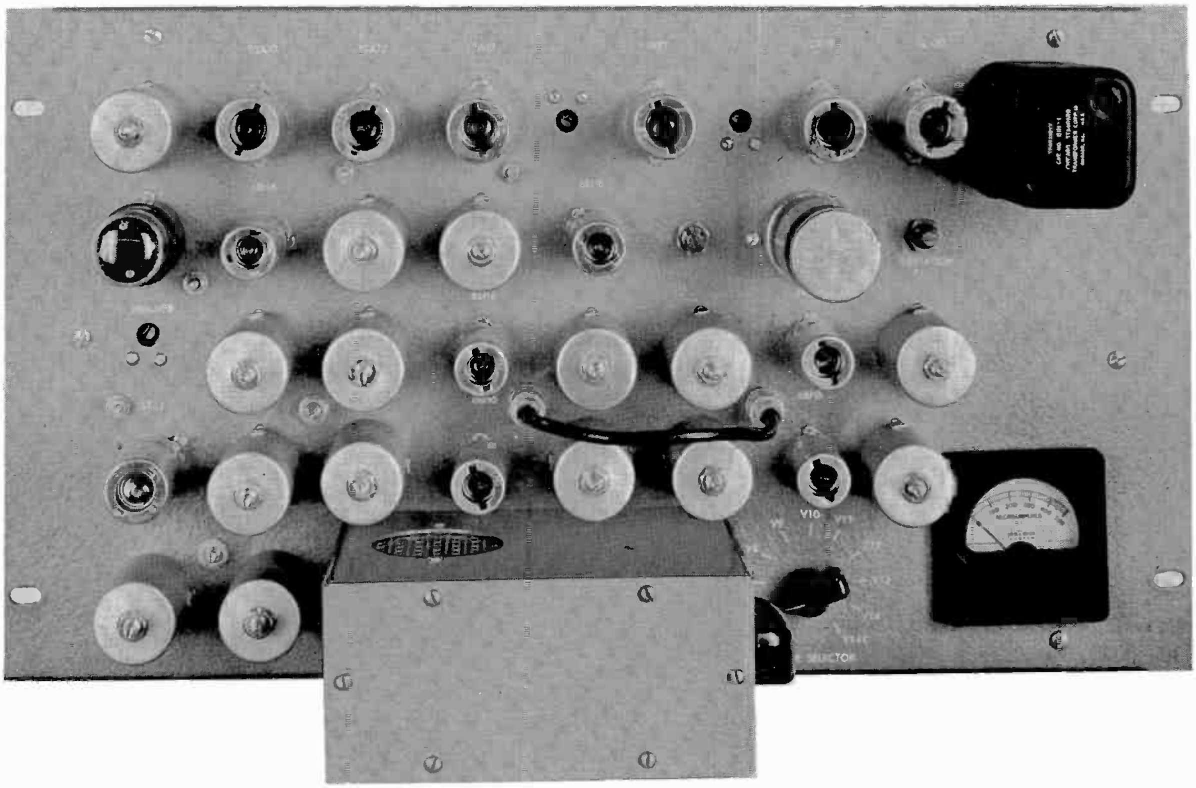


DISTORTION CURVE

ACTUAL DATA OBTAINED FROM MEASURING ITA
PHASE MODULATED EXCITERS

Pictured in Figure #8 is the front view of the ITA FM exciter. It can be seen that by simply adjusting the coils for a maximum indication on the lower right hand meter, the complete exciter can be tuned from the front panel. You will also note that two jacks exist on this panel to which the sub-carrier generators can be connected for stereo or multiplex operation. At these points of injection are phase modulated circuits which combine the sub-carriers with the program channel.

Figure #8

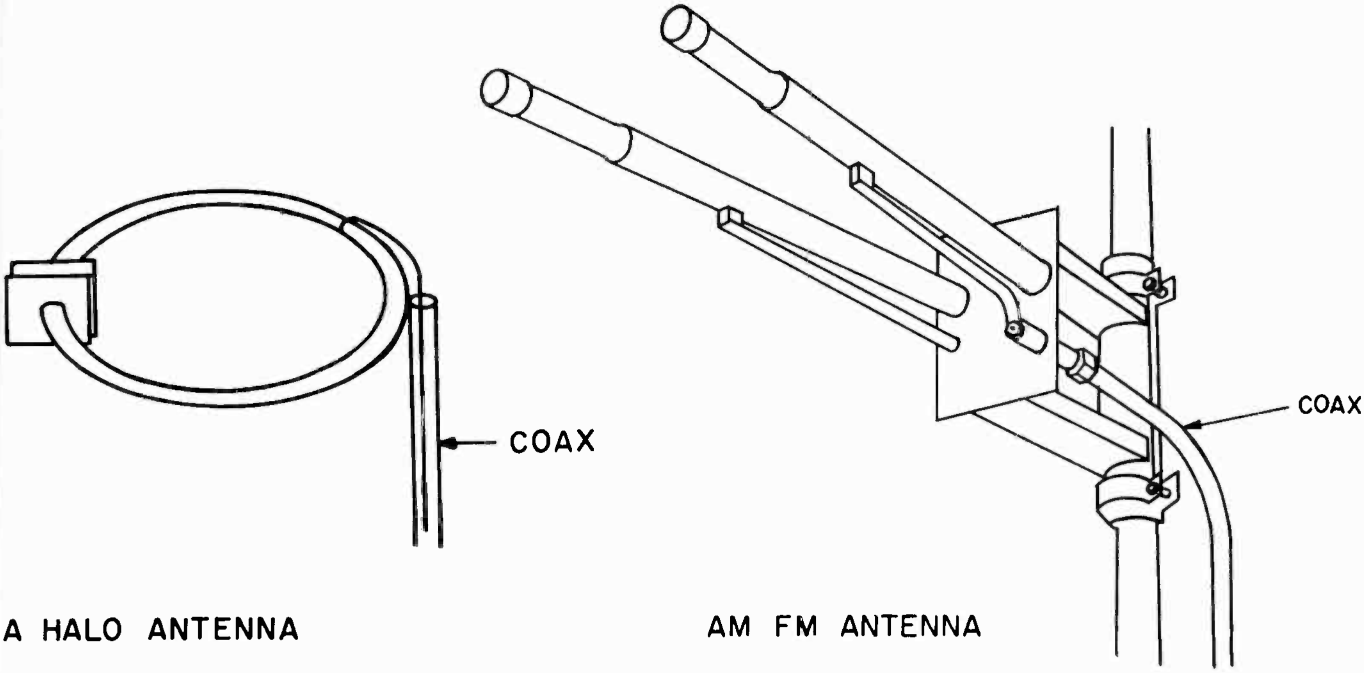


SELECTING AN FM ANTENNA

The FM antennas of today are available in two general form factors. One type is the "V" antenna and is offered by Jampro and Andrew. The other is the "Halo" antenna. Both types are pictured in F igure #9. Each form factor has specific advantages over the other and for your application this may influence your choice. The "Halo" antennas have approximately unity gain per element and offer somewhat lower wind loading to a supporting structure. One major weakness of this form factor is that the high voltage point in this system occurs at the end of the unit. This results in an extremely large voltage gradient and there have been a number of field reports associated with arc-over at this point. Because of the general configuration, this point is also very susceptible for accumulating ice under foul weather conditions.

The "V" antenna has a gain of approximately 10% less than the "Halo" element. It also offers more wind loading to the supporting structure. Its form factor is such that the gradient across the high voltage points is fairly low and obviously no problems occur relating to arc-overs at these points. In addition, it is less likely to accumulate precipitation than the "Halo" form factor.

Figure #9



A HALO ANTENNA

AM FM ANTENNA

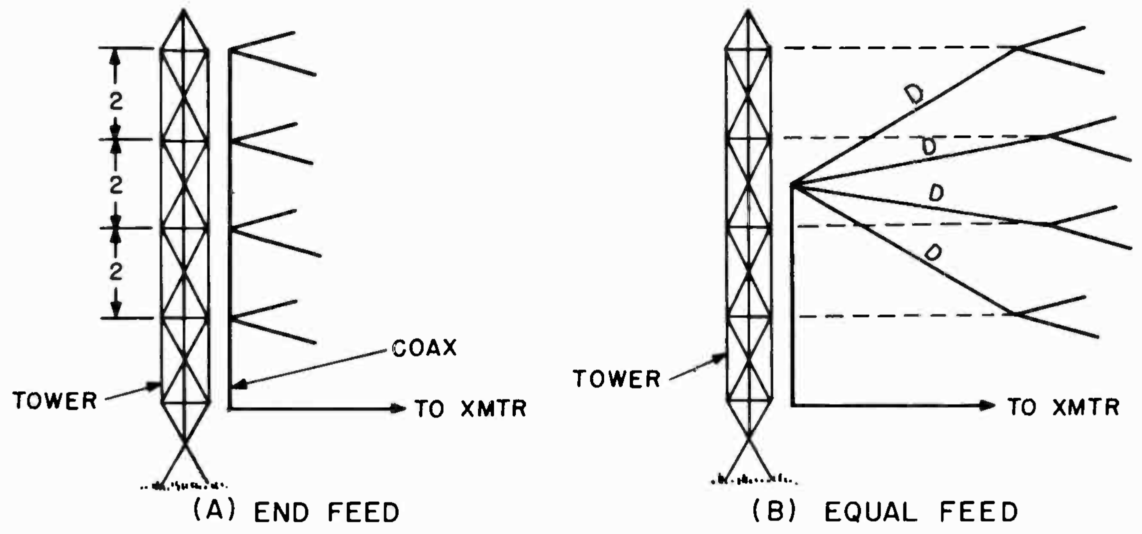
The present FM antennas are fed, in general, by two methods. These are described in Figure #10. In the (a) version you see the antennas are end fed. In this method, all the elements are assumed to be 360° apart and are fed with equal phase and amplitude. A second approach is to feed each of the elements from a center distribution point with equal lenths of transmission line. This latter approach of feeding each element through the same length of transmission line assures equal phase feed.

Whether one uses the "Halo" or the "V" antenna, it is extremely important that the following information be reviewed before selecting an antenna:

1. Radiation in the vertical plane. Assuming no interference from the supporting structure, the vertical pattern of an FM antenna array will be a function of its gain.

Figure #11 refers to the location of the first null from a uniformly illuminated aperture for various gains. This null is not a zero. It represents that the signal level is down approximately 20 to 1 in power from the signal that exists in the main lobe. By simply setting up a drawing similar to that described in Figure 11b, it should be very easy to determine the location of this null in your far field pattern. This is an extremely important point to cover because we know of many instances where stations have sizeable powers and do not cover markets that they predict in their coverage area. For example, we know of a station thirteen miles from a major market with 130KW that does not cover that market. They happen to have a 16 bay antenna and from their elevation their first null occurs thirteen miles away.

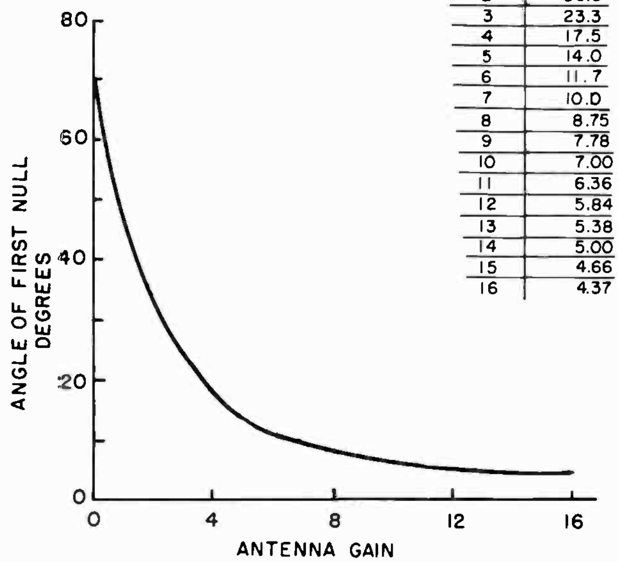
Figure #10

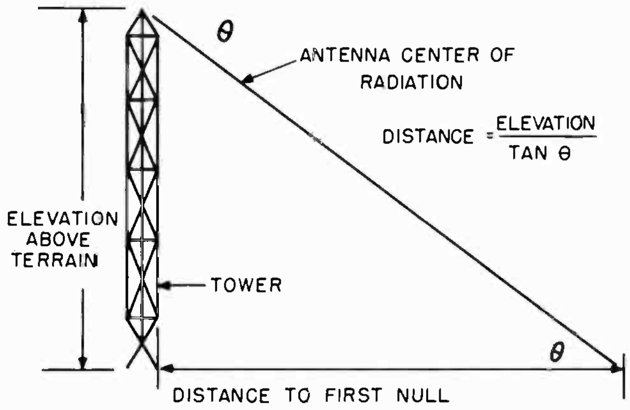


TWO METHODS OF FEEDING FM ANTENNAS

Figure #11

GAIN	ANGLE
1	70.0
2	35.0
3	23.3
4	17.5
5	14.0
6	11.7
7	10.0
8	8.75
9	7.78
10	7.00
11	6.36
12	5.84
13	5.38
14	5.00
15	4.66
16	4.37





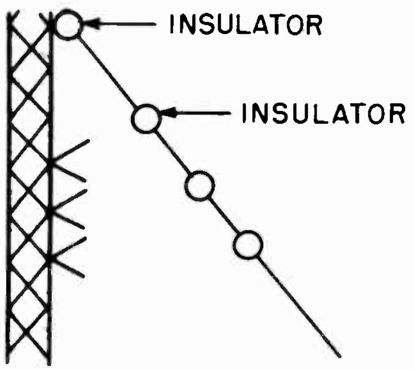
METHOD OF DETERMINING DISTANCE FROM FM ANTENNA TO FM ANTENNA 1ST NULL

INTERFERENCE OF SUPPORTING STRUCTURE TO PATTERN

The supporting structure of an FM antenna, if not considered, will seriously affect its pattern. When ordering an antenna it is extremely important to advise the supplier of the tower dimensions and the type of tower used. If guy wires are used to support the tower, it is very important that they be insulated from the tower and be broken up every two feet within a vicinity of three feet of the radiating elements.

Figure #12 describes this arrangement. Again we have found a number of instances where people have forgotten to break up their guy wires, and disastrous results have occurred.

Figure #12



METHOD OF BREAKING UP GUY WIRES IN VICINITY OF FM ANTENNAS

POWER HANDLING CAPABILITY

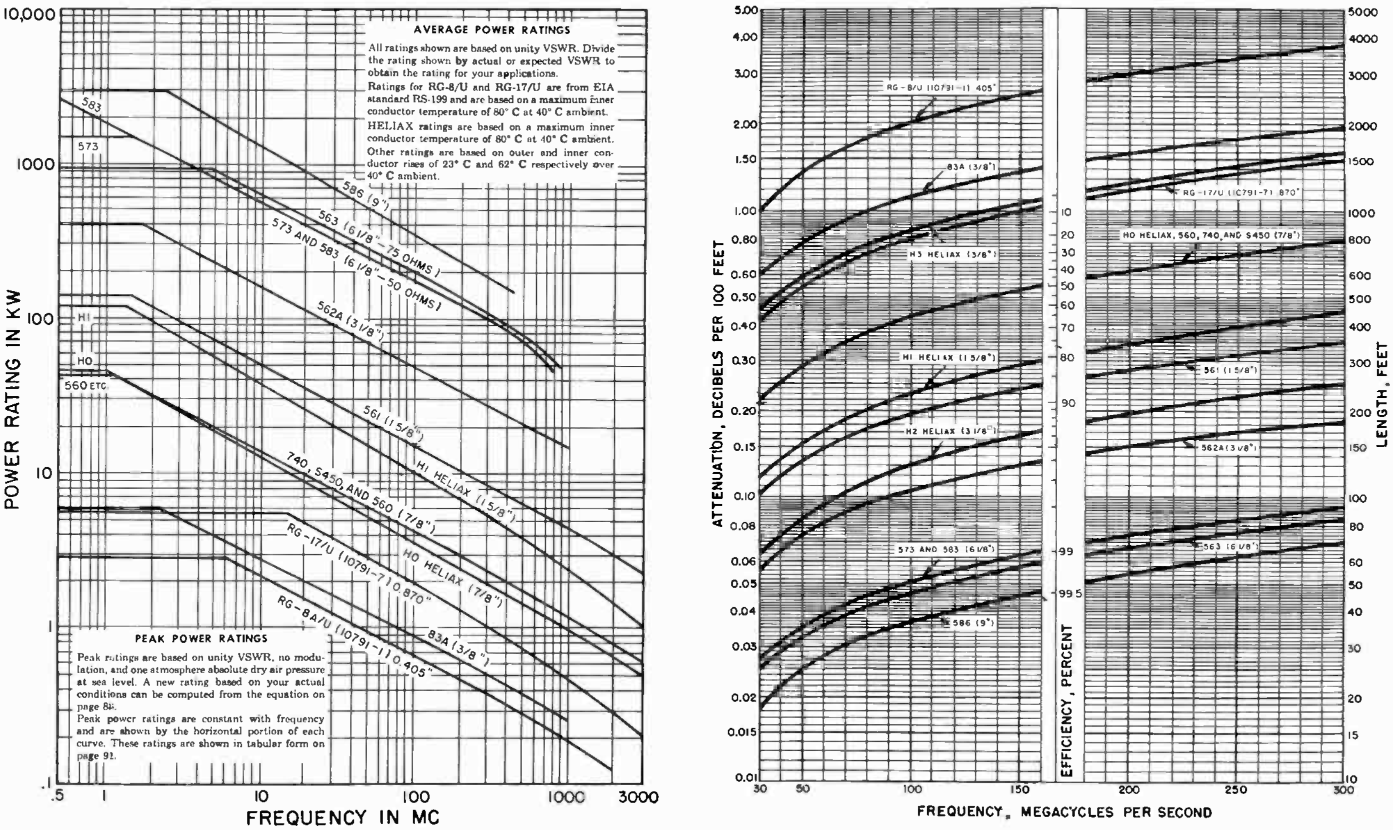
The average FM antenna element is capable of handling a nominal power of 3KW. If you contemplate utilizing an array of elements such that each element would require a handling capacity greater than this nominal value, it is extremely important to point this out to your procurement source.

SELECTION OF TRANSMISSION LINE

Figure #13 describes the attenuation and the power handling capacity of standard RF transmission lines. It should be noted that 7/8" transmission line can safely handle 1KW. Greater than this value and including 10KW, 1-5/8" line is applicable. Above 10KW, 3-1/8" line is imperative. The rating limitations on these transmission lines are not due to voltage breakdown characteristics, but rather to the current handling capacity and the heat generated therein of the center conductor. Accordingly, it is permissable to utilize for runs of less than 10 feet, transmission lines of smaller diameters in order to achieve installation convenience, providing the termination of the short run is with larger copper areas that could transfer the generated heat.

Two general types of transmission line are used in FM - rigid copper line and semi-flexible line. The former has a somewhat higher power handling capability but requires much more installation expense. The multiple flanges in a fixed transmission line run represent a problem with regards to keeping the transmission line gassed. In addition, if many elbows are used, the expense of this type of installation is much more than utilizing a continuous run of semi-flexible line with fittings required only at the transmitter and antenna ends.

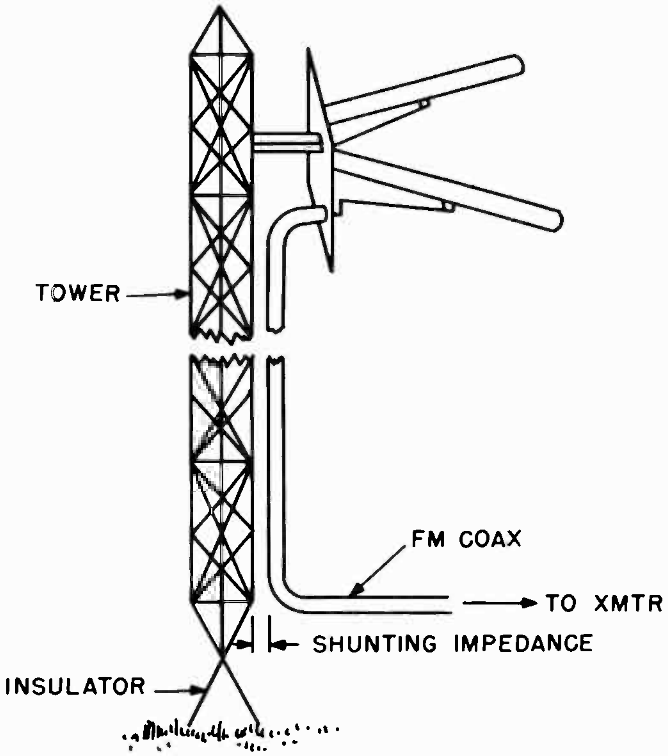
Figure #13



ANTENNA INSTALLATION ON AM TOWERS

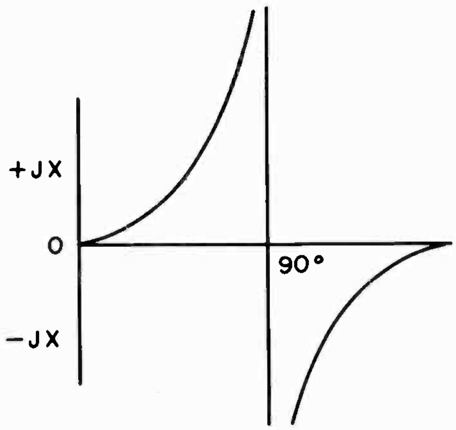
As you will note in Figure #14a, the installation of an antenna on the tower results in an open wire transmission line being formed between the outside conductor of the FM coax and the tower itself. This resultant transmission line will represent a reactance across the base insulator of the tower of a magnitude dependent on the tower's height.

Figure #14a



(A)

Figure #14b



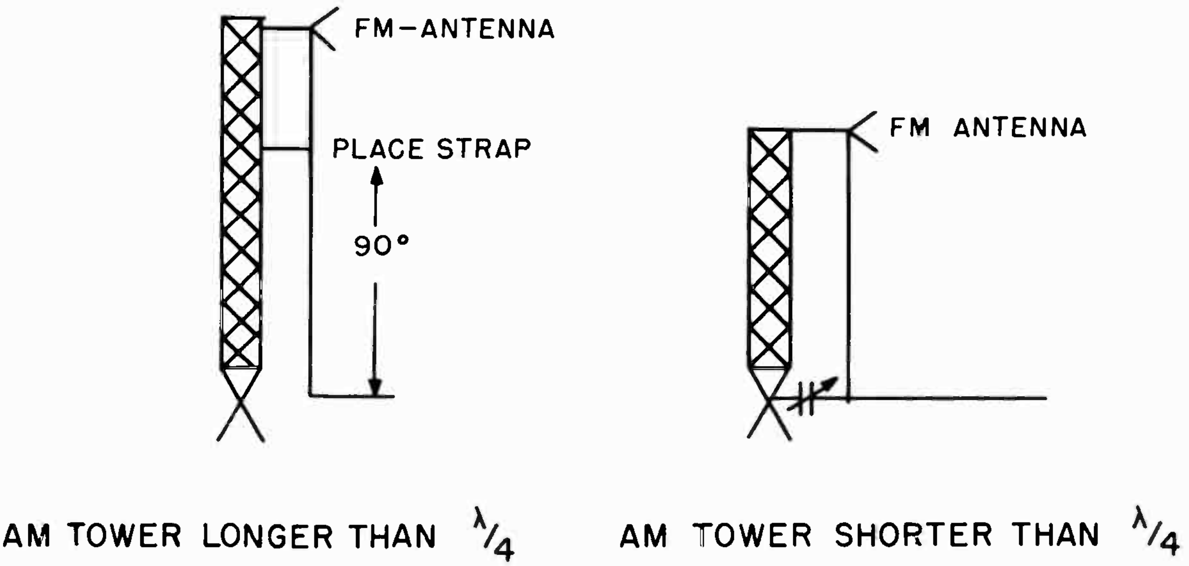
(B)

RESULTANT TRANSMISSION LINE
BETWEEN TOWER & FM COAX

Figure 14b describes the characteristics of this impedance. It should be noted that when the electrical length of this transmission line is 1/4 wave length at the AM frequency, the impedance is theoretically infinite, and thus represents no shunting effect to the normal AM tower impedance.

Figure #15 describes the method whereby you can achieve this 90° of electrical length under two conditions: (a) where the tower is longer than 1/4 wave length and (b) where the tower is shorter than 1/4 wave length. In both conditions the feed point of the antenna is mounted directly to the tower. The remaining transmission line is supported by insulated hangers. In the case of the longer tower, a shunting strap is placed between the outer conductor of the FM transmission line and the tower at a point approximately 1/5 of a wave length at the AM frequency from the base of the tower. This distance, combined with the shunting capacity of the insulated hangers, will achieve approximately 90° of electrical length. In case (b) where the tower is shorter than 1/4 wave length, a variable vacuum capacitor is placed from the outer coax to the top of the base insulator and is adjusted to tune the section of line to achieve a resonance at the AM frequency. Obviously, both methods must be checked by conventional AM bridge methods to be sure that proper isolation of the FM transmission line from the AM tower has been achieved. Failure to take these isolation precautions could result in the detuning of your AM transmitter, reduction in AM transmitter output power, and in the case of a multi-tower installation, serious degradation of your AM pattern.

Figure #15



INSULATION AT FM COAX FROM AM TOWER

STUDIO PRECAUTIONS

The majority of program equipments are adequately filtered, but unique conditions may occur where FM interference will arise. It will be manifested by problems such as buzz getting into the tape recorders and consoles. In anticipation of this, the transmitter frame should be connected to the station ground. Special RF filters can be placed in series with the AC power input to all of the critical units that manifest this FM buzz problem. These filters should take the form of .01 disc capacitors to ground, shunting the AC power line with series elements of sufficient capacity to handle the line current but with resonances in the FM band. A typical choke could be formed by 22 turns of #16 wire around a 1/2" form.

ACCESSORY EQUIPMENT REQUIRED FOR FM PROGRAMMING

The FM receivers of today are extremely sensitive and serve as the source of high fidelity audio systems. Quality standards accepted in other broadcast media may not be tolerated by some FM listeners. It should also be noted that severe overmodulation will cause distortion of the FM program channel, and in the case of stereo, will contribute considerably to crosstalk.

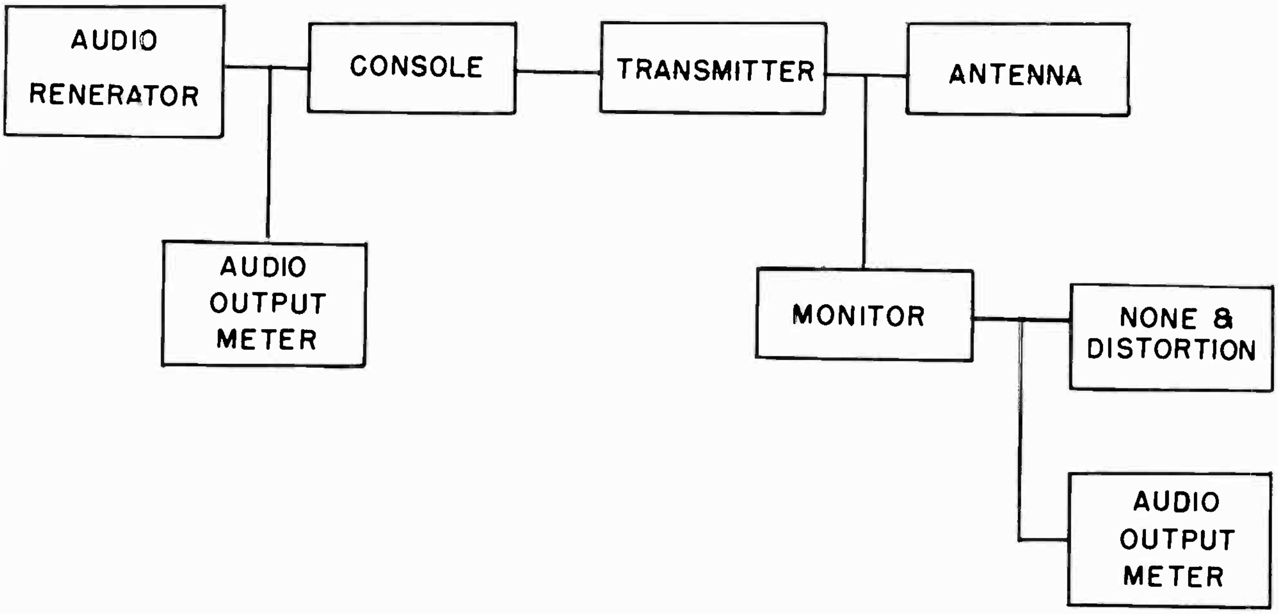
In order to reduce the anxiety of your operators, it is extremely important that some type of limiting amplifier be utilized in the program sources for FM equipment. This approach eliminates the human error and can assure you of freedom from distortion due to overmodulation.

FM PROOF OF PERFORMANCE

In order to obtain a station license, one must submit a proof of performance. This requires that the broadcaster analyze the operation of his complete system from console through the transmitter with respect to audio frequency response, noise and distortion. Figure #16 presents a typical arrangement of equipment for providing this series of measurements. Here it should be seen that the audio level required to achieve 100%, 50% and 25% modulation at the audio frequencies of 50, 100, 400, 1000, 5000, 7500, 10,000 and 15,000 cycles are noted and recorded. The noise and distortion measured at the output of the frequency monitor for these various levels and frequencies are also recorded.

Figure #17 describes the FCC limits for this data.

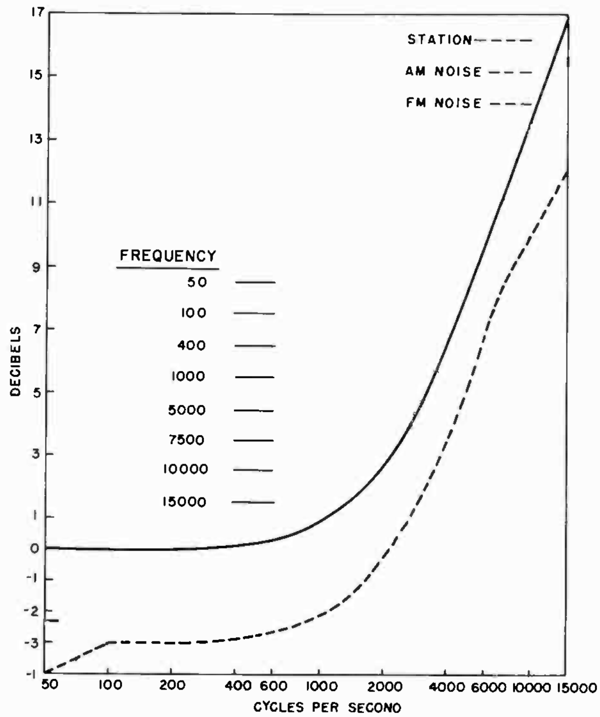
Figure #16



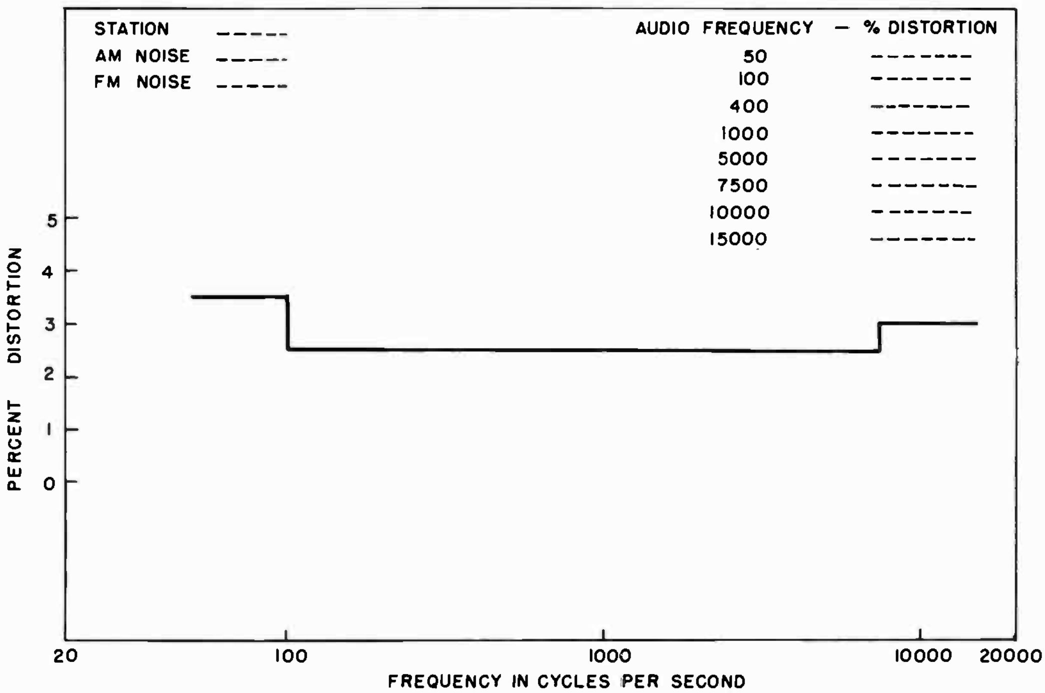
AUDIO FREQ.	V_1 100% MOD.	50%	25%	DISTORTION 100%	50%	25%
50						
400						
1000						
5000						
7500						
10000						
15000						

BLOCK DIAGRAM OF EQUIPMENT ARRANGEMENT FOR FCC PROOF

Figure #17



FREQUENCY RESPONSE DATA



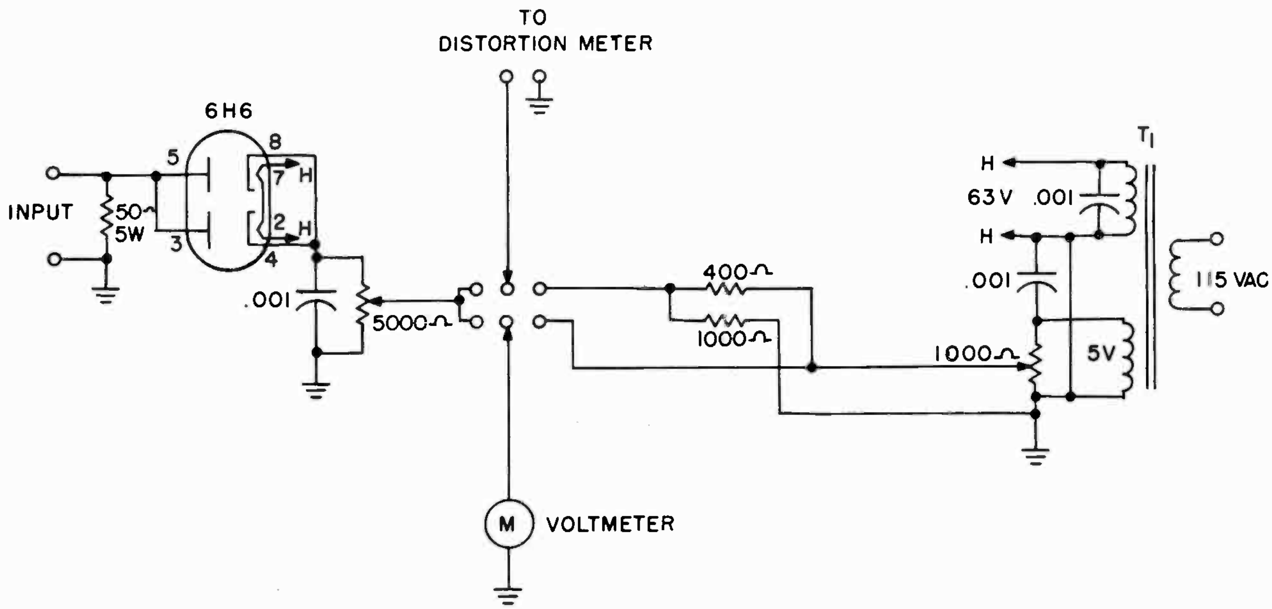
DISTORTION CURVE

It may be worthwhile at this point to refer to Figure #17 which describes the 75 microsecond pre-emphasis curve. By referring to this curve it should be noted that it requires 17 db less audio signal at 15KC to produce the same 100% modulation of the carrier than was necessary at 400 cycles. Thus when the engineer completes his proof of performance, he should not be alarmed to find that less signal is required at higher frequencies than that which is required at the lower frequencies to achieve the same modulation. This pre-emphasis of the high frequencies has been incorporated as an FCC standard in FM broadcast systems to increase the signal to noise ratio in the transmission of higher frequencies, since it is felt that the average program represents an extremely low level of high frequency information. At the receiving end of an FM system the converse is true and a de-emphasis circuit exists which returns the program material to its original proportions.

Two other items are required to complete the FM proof of performance. One is the determination of FM hum, while the other is the determination of the AM hum. The former is achieved by modulating the carrier at 100% at 400 cycles and measuring the audio output from the monitor terminals. This intelligence is then removed and the ratio of the remaining signal to the original 400 cycles is the FM noise. The FCC insists that this ratio be at least 60 db.

The AM noise is determined either by utilizing the technique described in the instruction book associated with your particular FM broadcast monitor, or by utilizing the circuit described in Figure #18. In any event, this measurement is a comparison of the AM modulation of the carrier with the RMS value of the carrier itself. The FCC requirement is that this ratio be at least 50 db.

Figure #18



AM NOISE DETECTOR

MODULATION MONITORS

For the past three years those in the FM broadcast industry utilizing subsidiary services have worked under a severe handicap. They have not been able to have any standard against which they could compare the performance of their multiplex channels. Recently equipments have been made available to provide this analysis. This is due to the fact that the more popular program monitors were of a counter type and did not have the IF frequency bandwidth to reproduce the sub-carrier frequencies.

The ITA FMM-1A which we are offering for the first time this year, together with the G.E. Monitor, are the only two program units that I know which can, in addition to providing information relating to the program channel, produce the sub-carrier for analysis. With the recent FCC ruling on stereo, it is extremely important that those people considering this have some standard by which they can determine their complete operation.

As you can readily see, it is very difficult for anyone to cover all the facts of FM station engineering in such a brief time. I hope this presentation has not been too confusing. I appreciate this opportunity of being permitted to express our FM recommendations.

Final Report

THE USE OF COLOR FIELD REDUNDANCY
FOR THE SIMPLIFICATION AND COST REDUCTION OF
COLOR TELEVISION TRANSMISSION SYSTEMS

By

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Department of Electrical Engineering

November, 1960

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ENGINEERING
EXPERIMENT
STATION

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of Science and Technology / Ames, Iowa

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THE USE OF COLOR FIELD REDUNDANCY FOR THE SIMPLIFICATION AND COST REDUCTION OF COLOR TELEVISION TRANSMISSION SYSTEMS

by

Wm. L. Hughes

INTRODUCTION

Color television systems have many possible uses. The first and most obvious use is for commercial television broadcasting. The second, which ultimately may become much more important than the first, is for educational purposes. The third use of color television has possibilities that have not yet been developed. These include all the special purpose uses of color television, such as scientific research, observation of dangerous processes, and medical applications.

ECONOMIC PROBLEMS

In commercial broadcasting, advertisers would like to see their products in color, and the viewers would certainly like to see their favorite television shows in color. However, the advertiser cannot pay the tremendous increase in production costs over black and white, and the public will not pay $350 to $500 for a color set unless a great many programs are in color. It has been fairly well proved that network programming alone will not result in the widespread use of color television that had been hoped for. If television broadcasting is to become primarily color television broadcasting, almost all stations must be able to originate programs in color. Networks alone cannot do the job. However, the equipment and economic problems of the average television broadcasting station are radically different from those of a large network. The average television station cannot invest several hundred thousand dollars in color equipment unless it has a large number of potential color viewers in its area. The station also has the problem of hiring more technicians of higher quality to do color programming equivalent to what is now being done in black and white. If color telecasting is used widely for commercial broadcasting, the economic picture and technical characteristics of transmission equipment must both be quite different than they are now.

Black and white television has already made considerable inroads in the educational field. Much experimentation has indicated that for some purposes television can be used effectively as an educational medium. Although the use of color television for education purposes has not been explored with anywhere near the same degree of intensity, there is reason to believe that it would be very effective if it could be made economically practical. The difficulty is that even with black and white systems, many educational television teaching programs have their budgets strained to the breaking point on equipment and operation costs now. Only for quite special uses, such as in medical schools, is it practical to multiply this budget by the factor of two or three required to do an adequate job in color. In educational television, and particularly in closed circuit educational television, the cost of the receiver may be only a small part of the economic problem. There is real question as to whether or not the receiver economics is the only significant problem in color television commercial broadcasting, but in education television operations, the receiver problem is perhaps the least important.

REQUIREMENTS OF COLOR TELEVISION

The requirements of a general purpose color television transmission system for use in commercial broadcasting, in educational television, and in special applications are as follows:

1. Any new color television transmission system must be completely compatible with current color television standards. In other words, any color television receiver made according to the standards established by the Second N.T.S.C. must play perfectly satisfactorily when receiving a signal from the new transmission system.
2. The new color television system should require a much smaller capital investment than that now required for color television systems.
3. The quality of technicians required to maintain and operate the new color system should be no higher than required for black and white systems.
4. Much of the black and white equipment currently in use should be usable in the new color system or be economically convertible to

the new color system. This includes not only transmitters, but also microwave links, studio switching systems, and hopefully, even black and white cameras.

5. The quality of the color television picture that comes from such a system must be excellent.
6. The principles of operation of the new system should be applicable to film, video tape recording, live camera pickup, and any new type of recording devices that may be developed, such as thermoplastic film recording.

A SIMPLIFIED COLOR TELEVISION SYSTEM

For several years, the Engineering Experiment Station at the Iowa State University has had a project which has been concerned with the simplification of color television systems. Over these years, a system has evolved which appears to satisfy the aforementioned requirements.

BASIC SCHEME

REVIEW OF CONVENTIONAL APPROACH

Three pickup signals, red, green and blue, are used in conventional color television pickup devices for live camera pickup, or pickup from a film system (Figure 1). Each of these three pickup signals is amplified and gamma corrected and ultimately sent to a standard N.T.S.C. encoder. The output of the encoder is a standard color signal. All three color pickups must be wideband, because a luminance signal is not formed until the separate signals reach the N.T.S.C. encoder.

A MODIFIED CONVENTIONAL APPROACH

In a modification of the conventional approach one of the pickups is so arranged that it produces a luminance signal rather than one of the color signals, although theoretically there are many other possibilities (Figure 2). The three color signals go to amplifiers and gamma correctors and then to an N.T.S.C. encoder to produce the standard signal. The manner in which gamma correction is shown is not correct theoretically, but a small elaboration in this system will correct this. Subjectively it has been found to be unimportant, and so it is generally ignored.[3] An advantage of the modified system (Figure 2) is that the red and blue channels can be narrow band, thus easing pickup registration problems. Basically, the advantages of the modified system are not very great, and excellent color television pictures can be obtained from either system. Of importance is that if a luminance-red-blue pickup system can produce an excellent color picture, major simplifications and cost reduction can be made in much of color television pickup equipment using the Iowa State University approach.

THE IOWA STATE SYSTEM

A special color television camera is required for the modified system (Figure 3). In this camera the image is focused on the Y pickup and the chroma pickup through the use of a lens and beamsplitter arrangement. The Y filter, together with the Y pickup, have a total light spectral response of the luminosity function $\bar{y}$. This luminance signal goes to the N.T.S.C. encoder without modification except for amplification and gamma correction. This signal carries full video band width. The image on the chroma pickup is modified by the color filters in the color filter wheel. The chroma pickup is really a field sequential pickup, except that the field sequence is simply red, blue, red, blue, and so on. The color filter wheel is driven by a motor which is controlled by the vertical synchronizing pulse. Thus, at any one time, a luminance signal and one piece of color information, either red or blue, results. (Now comes the part which one has to see if he is to believe that it works, and it does work very nicely.) Each color field is delayed approximately 1/60 of a second. Then the result at any one time is a luminance signal, a red (or blue) signal, and a blue (or red) signal that is 1/60 of a second old. The three signals are sufficient to make a full three-color picture in the standard manner and they can be fed to an N.T.S.C. encoder as from three camera tubes.

Immediately three questions crop up: (1) What about color fringing as in a field sequential system? (2) Is this camera supposed to be simpler than a three image orthicon camera is now, and how does this idea simplify the whole complex of color equipment? (3) How does one go about building a delay line 1/60 of a second long with a band width adequate to handle chroma information? The whole argument stands or falls with these questions.

It would seem that fringing would not be as bad as in the pure red-green-blue field sequential system for reasons which should be obvious from the examination of the C.I.E. color chart (Figure 4). To color televise satisfactorily the fast motion of a white object on a black background is probably the most difficult problem one can imagine. In a red-green-blue field sequential system the gamut around the color chart is as shown in the large triangle connecting the primaries. Successive fields obviously have the maximum possible chrominance variation. Further, in a field sequential system, there is a severe luminance variation from field to field. Now let us return to the type of camera of Figure 3. Further, let us suppose that a white object is moving so fast that there would be complete color breakup rather than simple fringing. For example, suppose a ping pong game with a white luminescent ball were being televised in an otherwise dark room. During the field with a red signal and a luminance signal but a delayed blue signal, the white ball would appear on a color monitor as at point A on Figure 4. The blue signal would contribute essentially nothing. The red and luminance signals would combine in the matrix of the encoder to give an orange-yellow ball. During the next field, if we follow a similar reasoning process, we would get a cyan ball. A significant point is that there is very little luminance variation between the cyan ball and the orange-yellow ball. Now superimpose Figure 4 on a chart of Judd's Ellipses of Noticeable Difference (Figure 5). It is apparent that in a field sequential system about sixteen 100 J.N.D. Ellipses with wide luminance differences must pass field to field. With the camera of Figure 3 two 100 J.N.D. Ellipses must pass through with negligible luminance variation. In short, color fringing should be no serious problem, and experiments with the completed operating system have indicated that this is true.

Equipment Simplification. The new television camera (Figure 3) is simpler in some respects than current three pickup cameras because the optical system is much simpler, and only two camera tubes are required instead of three. One of these camera tubes is wide band, and the other is narrow band. This allows much broader tolerances in optical adjustment. However, it might seem that the new camera may involve an equal or greater total of electronics than that of the current television cameras. The major point here is that most of the electronics need not be an inherent part of every camera. Rather, most of it may be common to an entire studio system. To show how this is possible, consider the simplified camera of Figure 6. This camera operates exactly as the other except that the 1/60 second delay line and electronic switching system are left out. These two provide most of the electronic complication of the first camera (Figure 3). These devices are not necessary at the camera if some simple signal is added to identify vertical fields. Alternatively this may not be necessary, because once a camera is started properly, the synchronizing generator keeps it in the proper sequencing order. The alternate fields of color information can now be put on a suppressed lower sideband subcarrier system, with the carrier probably at 3.58 megacycles. The lower sideband cannot be utilized fully because we would not have the advantages of frequency interlace until N.T.S.C. encoding took place later. The entire composite signal can be transmitted over current studio switching systems without modification. This is true because no stringent differential phase requirements are at the upper end of the video pass band.

ADVANTAGES OF THIS TYPE OF SYSTEM

The simplified camera is a fairly simple device as a color television camera, and the modified composite signal at its output has a number of advantages:

1. Its picture can be sent essentially intact over circuits in the studio or over microwave cross-country links which have much broader tolerances on differential phase, differential gain, and envelope delay than are allowable with a composite N.T.S.C. color signal.
2. It could be monitored (in color) en route with a fairly simple low brightness color monitor without the 1/60 second delay system.
3. It could be put on a black and white video tape recorder without any concern for preserving colorburst phase information. This means that the expensive color attachment for a black and white video tape recorder is unnecessary.
4. The only place at which the 1/60 second delay and switching system is necessary is where N.T.S.C. encoding and final transmission occurs.
5. It provides the possibility that all color pickup and recording devices, including film, video tape, and live cameras, may be considerably simplified throughout the studio. Only one delay, switching, and encoding system is required. This entire operation takes about 1½ standard six foot racks. Actually, two such delay, switching, and encoding systems may be desirable so that one picture source may be monitored in high brightness color while the other is on the air.

6. Another advantage to this approach of color signal generation is not immediately obvious. This system inherently provides the possibility of automatic color balance, which reduces color drift correction from three adjustments to one adjustment. This is because both chrominance signals, red and blue, drift up and down together instead of independently. To correct color balance during system drift, either the luminance or the chrominance gains need to be touched up, but generally not both. If the system is color balanced at the start of operations, one adjustment will generally bring it back into balance. After the signal goes through the delay system and the electronic switch, it is again three signals rather than two. However, it has been found quite feasible in the electronic switch to detect unbalance in the switch and automatically correct for it. This is possible due to the nature of the switching system itself. Thus, right up to the final N.T.S.C. encoder the television transmitter or microwave link, color drift is under close and easy control.. For example, with the experimental film system, a stable, color balanced picture is easily obtainable three or four minutes after a cold start. The picture stays well balanced for hours thereafter.

An entire studio color operation can be greatly simplified (Figure 7). The simple color cameras, the video tape recorder and the simplified film chains all feed into the master switcher which can send any position to the cueing monitor or to the transmitter link. Most television stations have such a master switcher already installed. The color cameras may actually be conversions of the black and white cameras. The video tape recorder could be an ordinary black and white video tape recorder with no color conversion. (Some of the earlier models would probably require an increase in F. M. carrier frequency.) The simplified film chains can be much simpler than even the black and white 16mm film chains. The applicability of developments in thermoplastic recording are obvious. What has been said here, or course, encompasses a great deal of technical information. Though no equipment of the type discussed has ever been manufactured, such equipment would be much lower in cost (Figure 7), as well as much simpler than that now in use.

EXPERIMENTAL WORK ON
INDIVIDUAL PICTURE GENERATION SYSTEMS

Extensive work has been done on the simplified film chain and a working model has been built. An optical film camera for direct pickup of color which uses black and white film has been built and has been operated successfully. A simplified live pickup color camera has also been built and has been operated successfully.

FILM SYSTEM

The film system is basically a three channel flying spot scanner (Figure 8). The film moves continuously through a gate, and the vertical scanning for the color picture is obtained from this movement. The output of the cathode ray tube is for practical purposes considered a straight horizontal line, although in practice it is usually a raster compressed to a height of about 20 lines. Two columns of images are shown on the film. The left hand column of images represents the luminance information and is recorded field by field. The fields are compressed to slightly over half normal height to reduce consumption of film. For kinescope recordings, this reduction represents no loss in vertical resolution if the film transport mechanism is reasonably good. For live pictures recorded on a mechanical camera, the capabilities of films and optical systems are such that the vertical resolution is still limited by the standard television system itself.

The right-hand column of images represents alternate red and blue fields of chrominance information (Figure 8). As can be seen, photomultiplier 1 continuously feeds fields of luminance information. Its output is fed directly to the Y channel of the color television system. Photomultiplier 2 reads red information for one field, blue information for the next field, red information for the third field, and continues alternately. Photomultiplier 3 reads blue for one field, red for the next field, blue for the third field, and continues in a manner that alternates field by field with the information read by photomultiplier 2. The outputs of these two photomultipliers are fed to an electronic switch which is operated by a synchronizing pulse once each field during vertical blanking. Thus, three outputs, luminance, red, and blue, are fed continuously if the travel of the film is synchronized with the vertical scanning. rate.

If the film is started correctly in the experimental model, field recognizing marks are not necessary if everything else is controlled by the synchronizing generator (Figure 8). Standard 35mm film is used, and no field marks are required. They might be required in a commercial model, but they would be very inexpensive to install if commercial use over a period of months showed them to be necessary. Their major advantage in a commercial system would be that film splicing errors could be corrected automatically.

The primaries chosen are not red, green and blue but are red, blue and luminance. Initially, it was thought desirable to make one channel contain complete luminance information for three reasons. First, if there were any registration errors in any channel, it would be primarily a chrominance error. Thus, there would be less of a tendency for color picture smearing. Second, if the electronic switch were to become unbalanced or the gain in either channel prior to the switch were to shift, the flicker would primarily be a chrominance flicker. Third, any errors in registration would not appear as a smear in the luminance channel, and the compatible black and white picture on an ordinary television set would not be noticeably degraded. After initial construction of the system and much testing, it was found that balancing the chroma channels was very easy, and the second reason for the choice of the stright luminance channel was essentially groundless. Of all the problems in operating the system, the flicker problem was probably the easiest to overcome.

As the experimental work continued, an automatic balancing system was built before the electronic switch. This balancing system simply examined the chroma channel for any thirty cycle square wave and automatically adjusted the gains of the chroma channels to eliminate it. The automatic balancing system was first built to keep the gains of the two chroma channels identical. It did this job very well, but the electronic switching system was so stable that the balancing system was not needed. It was left in the system, however, because it turned out to have a much greater advantage than the purpose for which it was originally built. That advantage is that it automatically corrects for any drift in the photosensitive pickup devices. This simply means that the two chroma channels are forced to drift together, and color balance drift over a period of hours is radically reduced because the three pickup devices no longer drift independently in a way that degrades the color picture.

THE EXPERIMENTAL FILM SYSTEM

A block diagram of the first experimental film system shows it as an ordinary standard flying spot scanner tube with a raster of ordinary width but extremely narrow height (Figure 9). A beam current in the neighborhood of 25 to 30 microamperes was used with a type 5AUP24 scanner tube. The life of the scanner tube is more than 2,000 hours if a blast of air is blown onto the tube face. The face of the scanner tube is focused, through a beam splitting optical system, on the continuously moving film. The photomultipliers are so placed behind the film that each photomultiplier gathers light from the proper film area. The output of each photomultiplier is fed to an appropriate channel amplifier. The Y channel goes directly to the N.T.S.C. encoder. The chroma channels go to the electronic switch which, in effect, sorts them out and sends them to the N.T.S.C. encoder. The output of the encoder is a standard signal. No gamma correctors are used in the system because gamma correcting is easily done directly in the film processing.

The optical system on the scanner tube side of the film transport mechanism has three lenses, each of which is adjustable in two directions lateral to its axis as well as adjustable in the direction of focus (Figure 10). The thumb screws for lateral adjustment for each lens are shown. Behind the three lenses are three rhomboid prisms which displace the images from the central axes of the lenses to the proper positions on the film. Inside the photomultipler pickup mechanism are three more rhomboid prisms and three condensing lens systems (Figure 11). The complexity of the optical system could be reduced in a commercial system because only two pickups would be needed. The film transport motor drive is directly beneath the film gate. A small Bodine synchronous motor with a specially machined fly wheel, a commercial grade reducer and a precision Simplex film sprocket moves the film with adequate stability. The motors above and below the film transport mechanism serve merely to keep a large film loop into and out of the gate so that the drag of the film reel and the uneven tug of the film takeup do not appear as torques on the motor pulling the film through the gate.

THE FILM

A typical film used in this system is a test pattern with black and white resolution wedges and a series of color bars (Figure 12). The images in one of the columns are all the same. This is the luminance information. The other column in which alternate images are identical but adjacent images are different represents the red-blue, red-blue sequence of chroma information. The patches between columns are for test purposes, but this would normally be the space for a sound track.

This film, as well as many scenes of live action, were taken with a modified Bell and Howell Hodel K Eyemo camera (Figure 13). The mechanism was modified to pull down one sprocket hole instead of four each time the claw operated. The film gate was fitted with a mask to handle the small double image. A special optical system, which is an anamorphic front lens system, a beam splitter, two spherical lenses and two rhomboid prisms was attached. A color wheel was also attached to the film pulldown mechanism so that one of the images was exposed through a blue filter for one field and a red filter for the next field. The other image was continually exposed through a Wratten filter chosen to match the film spectral characteristic to the luminosity function. In every way, this camera operated as an ordinary black and white pickup camera. It used, for the most part, standard Eastman black and white Plus X film. The only dif ference was that it was necessary to process the film at a gamma somewhat lower than normal for black and white film. This was done to eliminate electronic gamma correctors. This was not difficult once the film processor was aware of the problem. A commercial processing laboratory was used for long film runs, and a gamma controlled test strip was provided with each film run. At current prices, film costs run one-half to one-third of the cost of 16mm color film for the same length program.

The film system was operated under a variety of conditions and with many strips of test film (Figure 14). It was capable of providing excellent color pictures from black and white film in a very economical manner.

FURTHER SIMPLIFICATION

The film system described can be greatly simplified when it is designed to work into an over-all system (Figure 7). For example, consider the system in which there is a scanner tube as before, a very simple optical system which merely has to set two images side by side, two photomultipliers, and two amplifiers (Figure 15). A mixer and special subcarrier generator send the signal to the central switcher. The only difference between this system and that detailed previously (Figures 6, 7) is that the images have been stored on black and white film first, and since gamma correction is done directly on the film, no gamma correctors are required. The cost of such a film chain for color should be far less than the cost of black and white film chains. The application of these techniques to thermoplastic kinescope recording is quite obvious.

LIVE CAMERA SYSTEM

In the operation of a live camera using the Iowa State system one camera tube plus associated optical filters together have the spectral characteristics of the luminosity function (Figure 3). The signal from this camera tube is amplified and gamma corrected and sent directly to an N.T.S.C. encoder. The other camera tube looks through a color wheel with alternate red and blue filters. Each filter passes in front of the camera tube in the time of one field. Actually, the filter wheel is so designed that the electron beam is always directly behind the border line between two filters. This is in accordance with Goldmark's system.[1, 2] The signal is amplified and gamma corrected and sent to two places. It goes both to the electronic field switch and to the delay system. The delay system is 262 television lines long so that one field will lay directly on top of the next field with only one line displacement. This one line displacement is well within the tolerance of color registration, as long as the luminance signal is packaged in a separate channel. The output of the delay system is also sent to the electronic field switch. The electronic field switch thus has at any one time an input of both blue and red signals as well as a Y signal. It thus has complete information for a standard color television signal and its output is a standard N.T.S.C. signal.

LIVE CAMERA USING TWO IMAGE ORTHICONS

A two image orthicon camera was built and operated using the Iowa State system. No details are given for the image orthicon circuitry because it was conventional in all respects. As a matter of fact, the actual camera was a conversion of one of the two original RCA color cameras used in the 1950 Washington hearings. This camera was originally a three-image orthicon camera. It was donated to Iowa State by the RCA Princeton Laboratories for the purposes of this research. One image orthicon was removed, the dichroic mirrors were changed because the spectral requirements were different. The color wheel was, of course, added to one of the image orthicons. Beyond these things, only trivial changes were made in the camera circuitry itself. Necessary facilities for registering the images were already built into the camera. Figure 11 shows the two image orthicon camera closed up and ready for operation. The close-up open shot of the camera (Figure 17) shows the details of the color wheel mounting, its drive motor, and the optical assembly including dichroic beam splitter, lenses and mirror. The camera control unit and its power supplies were rack mounted rather than in a console to facilitate laboratory work (Figure 18).

This camera gave excellent pictures when the incident flat light level on the scene was around 150 lumens per square foot, and the camera tubes were 5820 image orthicons. Two high sensitivity GL7629 image orthicons were donated by General Electric to the project and color pictures of high quality were easily obtained at incident flat light levels of 20 lumens per square foot.

IMAGE ORTHICON-VIDICON CAMERA

A standard Dumont studio camera was converted to a camera in which the luminance channel used an image orthicon and the field switched chroma channel used a vidicon (Figure 19). A regular vidicon camera was mounted along side the image orthicon camera. The sweeps of the vidicon camera were tapped directly off the sweeps of the image orthicon camera in such a way that a fraction of the orthicon yoke current passed through the vidicon yoke for both horizontal and vertical sweeps. Independent linearity adjustments and registration were provided (Figure 20). A special color wheel was placed in front of the vidicon. The optical system with the special lens and motor mountings was fairly simple. A beam splitting cube was placed directly in front of the image orthicon and the lens turret arrangement of the image orthicon was unchanged. It was necessary to change the lens mountings so that the optical center of the objective lens was moved back. This was necessary because the image orthicon had to be rolled back to allow the insertion of the beam splitting cube. The image orthicon carriage was locked in place, and focusing was done with the focusing mount of the front lens itself. The side image from the beam splitting cube went to a field lens which was mounted directly on an optical block. The image at the position of the field lens was focused on the vidicon through a two inch lens directly in front of the vidicon. A right angle prism was used so that the vidicon and orthicon cameras could be mounted side by side (Figure 21). A special vidicon control unit was built to mount side by side with the orthicon unit (Figure 22). The circuitry of the vidicon control unit was conventional in every way.

Little difficulty was encountered in registering the two images. The camera was not used, however, because it required far too much light to be practical. It would have taken at least 600 or 800 foot candles to get a usable color picture.

It is perfectly feasible, technically to convert a standard black and white studio camera to color. If some of the newer, light sensitivity vidicons had been available, the light requirement for this camera probably could have been reduced somewhat, however, there is probably a better way. It would seem feasible to develop a one inch camera tube operating on the image orthicon principle. This camera tube need only have 75 or 100 lines resolution capability. If it had a good light sensitivity characteristic then very low light levels could be used with the converted black and white studio camera as before. Camera equipment manufacturers might well consider the development of a conversion kit for their 3 inch and 4½ inch image orthicon cameras. Such a conversion kit would allow black and white television stations to go into color at moderate cost. Further, their camera equipment could be used for either black and white or color as the schedule demanded. The cost of such a kit should be less than half of the $25,000 figure given for the simple color cameras of Figure 7.

STICKING CORRECTION

If newly developed camera tubes have a sticking characteristic, this might not be too serious. At least two methods may be used to correct sticking. The first is an approximate one (Figure 23). Suppose that the camera tube had a residual or sticking characteristic such that its signal output could be represented as in Equation 1. In this Equation B_0 is the signal component due to the present scanning field, and in this case is shown to be a blue signal. R_1 is the residual signal from one field back, which was a red field. It is multiplied by a constant k which represents the one field back sticking characteristic. k is obviously some number between 0 and 1. The output obviously has remnants of previous fields also. For example, there is a term k^2B_2 which is the remnant of the second blue field back, it has a term k^3R_3 which is the remnant of the third red field back and so on. This assigns idealized decay characteristics to the camera tube, which are not exact but hopefully are not too much in error.

$$\text{Camera Signal Output} = B_o + kR_1 + k^2B_2 + k^3R_3 + k^4B_4 + \ldots \qquad (1)$$

For the moment, let us assume that a delay line output at this field is as shown in Equation 2.

$$\text{Delay Line Output} = R_1 + k^2R_3 + k^4R_5 \qquad (2)$$

In this equation R_1 is the red first field back, R_3 is the red third field back and is multiplied by k^2, R_5 is the red fifth field back and multiplied by k^4, etc. Having made this assumption we shall now show that this really is the delay line output. Note that the delay line output in Figure 23 is fed back to the input of the delay line along with the output of the camera tube. The delay line output is subtracted from the camera signal and is fed into the delay line input. Note, however, that the delay line output feedback loop has a gain adjustment which can be set to the number k between 0 and 1. The k is an inherent characteristic of the camera tube.

Under these conditions the delay line input signal is as shown in Equation 3.

$$\begin{aligned}\text{Delay Line Input} &= B_o + kR_1 + k^2B_2 + k^3R_3 + k^4B_4 + k^5R_5 + \dots \\ &\quad - kR_1 - k^3R_3 - k^5R_5 \\ &= B_o + k^2B_2 + k^4B_4 + \dots \end{aligned} \qquad (3)$$

All that survives at the input is the present blue signal, B_o, plus k^2B_2 which is the blue second field back signal, plus k^4B_4 etc. However, if one field has occurred, by exactly the same reasoning, a delay line input signal identical to the one assumed for the output would have resulted. The delay line output signal of Equation 2, therefore, is correct. The blue fields have no red contamination and the red fields have no blue field contamination. Further, the first contaminating signal for a blue field is a blue signal and is multiplied at least by k^2. A similar thing can be said for the red signal. In field sequential systems it has been shown that back field contamination as high as 10 percent can be tolerated with negligible effect on the final picture. Assuming that at least this much can be tolerated since there is no contamination from other colors as would be true in a conventional field sequential system, the first residual field back may be as high as 30 percent or more with no ill effects. Whatever contamination there is has only a second order effect on luminance.

If this contamination is still too high, an alternative method is available which uses a delay line system and the back field signals are completely cancelled (Figure 24). In this method the camera tube output and the output of the 262 line delay system are both fed to a subtractor. The output of the delay system is subtracted from the camera tube output. In effect, this gives the camera tube output minus the stuck fields. This is a more effective system than the first one but it has a major disadvantage. It requires the additional delay system since the output of the subtractor must now be fed to still another delay system before it can be used in the prescribed manner. Practical economics would have to dictate which system would be used if it was found that either system was necessary.

At first it may seem that noise would be a major problem in both systems. However, noise in camera tubes is primarily above 1 megacycle, and the chroma information is primarily below 1 megacycle. Therefore, with appropriate band pass filters the noise problem should not be significant. If one had a low noise camera tube which had a bad residual characteristic but in all other respects was a very good camera tube, the problem of residual fields can be eliminated. This has possible application in many plaoes, as well as in color television systems of the type described. One use, for example, is in black and white vidicon cameras for either film or live pickup.

SPECIAL ELECTRONIC CIRCUITRY AND DEVICES

In this work on color television systems several new devices were needed. These devices included a suitable electronic switching system, a method for delaying the chroma video signal for 262 lines, a suitable system for driving the film transport and camera color wheels, a method for running vidicon sweeps from an image orthicon camera, a suitable matrix to change the output of the signals from the Iowa State system to a form that could be used by a standard N.T.S.C. encoder and some specialized color monitoring equipment. Many techniques which are peculiar to both color television and conventional black and white television were used. Little attention is given to these devices and techniques here simply because they are easily available elsewhere. Included in this category are color encoders, color decoding circuitry, conventional sweep circuitry, conventional monitoring devices etc.

ELECTRONIC SWITCHING SYSTEM FOR BOTH FILM SYSTEM AND LIVE CAMERA

The electronic switching system takes two input video signals and sends them to two separate outputs; but during the vertical blanking interval each output circuit must be switched to a different input circuit. The electronic switching system might be compared with a large double pole, double throw cross connected switch (Figure 25). When the switch is in the left hand position the upper video input is connected to the upper video output and the lower video input is connected to the lower video output. When the switch is in the right hand position the upper video input is connected to the lower video output and the lower video input is connected to the upper video output. During each vertical blanking period the switch must be thrown to the opposite position.

Vertical intervals occur roughtly sixty times a second, and since band width, switching time, balancing characteristics and stability requirements are all rather severe, a somewhat more refined device was developed. Obviously, the band width of the electronic switching system must be at least that of the chroma signal. In the experimental system the electronic switching system was built with a full six megacycles band width and band width limiting was done elsewhere, because it was not certain at first that band width should be limited before the electronic switching took place. But upper frequency band width limiting can occur as far back as the camera tube if necessary with no detriment to the picture. In the film system it is desirable to do phosphor correcting after the electronic switching process. The reason for this was that phosphor correction is primarily a low frequency correction process. This means that if the switch channels were not exactly balanced a chroma flicker could occur. Upper frequency band width limiting can occur before the electronic switch in the film system also, simply because phosphor correction has little effect at those frequencies. Although it would seem that switching time is of no consequence because the full vertical interval is available, this did not turn out to be the case. A severe switching transient problem developed which could not be handled by the keyed clamp circuits until the switching time was made very rapid. The final form of the electronic switch was therefore designed to switch on the trailing edge of the vertical driving pulse in a time of less than one-half microsecond. It was necessary that no thirty cycle square wave be in the video output of the electronic switch. Therefore, d-c balance controls were built into the device. It was also necessary that the dynamic gain of each switching channel be identical with that of the other channel. Dynamic gain controls were therefore built into each switching channel. In addition, an automatic balancing device which held the dynamic gains of the two switching channels exactly identical was built. This automatic balancing device makes the Iowa State system much more stable than many other color systems.

The basic circuit of the electronic switching system evolved after several attempts at a suitable switching device (Figure 26). The circuit is about as stable as an electronic device using vacuum tubes can be. It is highly successful in all respects and is suitable for direct copying. Even in experimental work it would run for weeks at a time with no adjustment. When adjustments were needed, they could be made in a few seconds with no special equipment other than a waveform oscilloscope.

The two input video signals of the electronic switching system are brought in on 75 ohm coaxial lines at a one-half volt level. These two inputs have alternate color fields so the upper input is indicated as an RB input, and the lower input is indicated as a BR input to indicate that the same color is never brought into both inputs at the same time. The two inputs are connected through a single pole, single throw switch which is closed for adjustment purposes but is normally open during operation. The gain of each input may be adjusted. The inputs then go into conventional video amplifiers, V_1 and V_2. The outputs of the first video amplifiers in each channel go to a second set of video amplifiers V_4 and V_5. In the second video amplifiers, vacuum tubes of the type 6AS6 are used. This type of tube is used because when the device is being used with automatic balance the suppressor grids can be used to control transconductance. Thus when SW1 is switched to manual balance, the 6AS6's operate as purely video amplifiers. When SW1 is thrown to automatic balance gain adjustment signals are continually applied to the suppressors. These gain adjustment signals come in on terminal strip number one from the automatic balance unit. The outputs of the second video amplifiers are fed to two beam switching double plate vacuum tubes of the ADLER type. These are tubes of type 6AR8, V9 and V10. Conventional balanced keyed clamping circuits are placed in the control grids of both Adler tubes. The tubes in the balanced clamping circuits are V6, V7 and V8. The d-c returns of the clamping circuits are established by two 10,000 ohm potentiometers. The plate currents of both 6AR8 Adler tubes are made equal, and d-c balance is established. The switching plates (pins 1 and 2 of the Adler tubes) are controlled by a 30 cycle square wave derived from a multivibrator V11. The multivibrator is, in turn, controlled by the trailing edge of the vertical driving pulse. The switching phase can be reversed by SW3. If the electronic switching system is used as a two channel amplifier (and it sometimes is for adjustment purposes), this can be accomplished with SW2. The output of the 6AR8 Adler tubes is again clamped with conventional balanced keyed clamping circuits through the use of V12, V13 and V14. This removes any residual 30 cycle square wave due to slight d-c unbalance. The signals then go to 75 ohm coaxial outputs through amplifiers V15 and V17.

V16 is a double triode which samples both video outputs. The high frequency response of the two amplifiers of V16 is deliberately spoiled. The output of this amplifier goes to terminal strip number two and provides automatic balancing information (Figure 27). Here the video output signals are again filtered and are sent to conventional narrow band amplifying and filtering circuits which pass only frequencies very close to 30 cycles. The outputs of these circuits are fed to conventional phase discriminators which compare them with the phase of the switching miltivibrator and the electronic switch. The outputs of the phase discriminators provide d-c voltages which are applied to the suppressors of the 6AS6's in the electronic switch V4 and V5. Thus when there is any 30 cycle component in the output of the electronic switch, it is automatically removed. Since the 30 cycle output is a result of dynamic gain differences in the two channels, these gain differences are automatically corrected for. The 30 cycle square wave output has two possible sources. One source comes from the slight d-c unbalance of the 6AR8's which is always present except immediately after adjustment. This is nicely removed by the second set of keyed clamps. The other source is a difference in the dynamic gains of the two channels, and this is corrected by the automatic balancing circuit (Figure 28).

The adjustment procedure for the electronic switch is very simple. With no video input either video output is examined with an oscilloscope at a vertical rate. The d-c balance controls are adjusted so that negligible switching transient is visible during the vertical interval. Disabling the clamp circuits is unnecessary. Next, SW1 is switched to manual balance, and one video signal is connected to either video input. The video inputs are then switched together, and the video input gains are adjusted so that there is no difference in the video output field. The easiest way to make this adjustment is to connect a black and white monitor to the output and adjust the inputs for zero flicker. This is a very easy and positive adjustment. Next, the switch connecting the input video signals together is opened, SW1 is thrown to automatic balance. and appropriate video signals are thereafter put into the two input circuits. No further adjustment is necessary. The automatic balancing circuit requires no adjustment. Usually no further adjustment is needed for several weeks.

The electronic switching system for the film system and the live camera are identical except for one thing. In the video output circuit of the electronic switch for the film system, two additional video amplifiers are inserted. These amplifiers are of a special type which have a phase and amplitude characteristic specially designed for phosphor correction, which must take place after the electronic switching is accomplished.

262 LINE DELAY SYSTEM

One of the problems of this color television system development work was that of delaying a television picture for one full field. Even though the band width required in the storage system is much less than that required for a standard black and white television picture, it is still too wide and the delay is too long to allow the use of conventional electrical lumped constant or distributed parameter delay lines. Several alternative schemes were considered.

The first one was an electrostatic storage and switching system (Figure 29). The input video signal is fed to an electronic switching system which puts alternate fields on two electrostatic storage devices, which could be either a Williams tube, a barrier grid storage tube or any other device operating on similar principles. Both of the devices were given some experimental exploration. When one of the storage tubes is having the signal read in, the other storage tube is having a signal read out. Thus the previous field of chroma information is always available. There must be an electronic read-in switch, an electronic read-out switch and an electronic field switch which performs the same function as before. Experiments were performed with both a Williams tube and a barrier grid storage tube. The output signal of the Williams tube was very low and there were problems of resolution and noise. The output signal of the barrier grid storage tube was adequate, the resolution though not good was sufficient, but it was difficult to avoid residual signal. In other words, the read-out was not completely destructive.[11] Further work was not done with this class of systems simply because a straight delay system proved to be better.

Two possible straight delay systems are attractive. The total delay time of 262 lines in the American standard color television system is 16,651.5 microseconds. A tolerance of plus or minus 0.2 of a microsecond seems reasonable. Very wideband widths (ten megacycles or more) can be delayed acoustically in a fused quartz slab. Delay times can range up to three or four thousand microseconds per slab. The signal is put on a carrier at about 20 megacycles and is sent through the slab through a series of strategically designed reflections at the speed of sound. The possibility of using about five such slabs was actively pursued for several months. Electronic equipment required for the quartz slab delay system using five slabs was designed and built. Unfortunately, on an experimental basis, the quartz slabs required would have cost about $7,000, so alternative schemes were explored. A major difficulty in the quartz slab delay system is that the delay time is fairly sensitive to temperature changes. Specifically, the delay time changes about 70 parts per million per degree centigrade of temperature shift. This means that the entire quartz slab would have to have been held to with plus or minus 0.1 degree centigrade. Temperature controllers to do this have been designed and successfully used. The quartz slabs are a possibility for delaying television pictures in full band width for very long, controlled periods of time. The total quartz slab delay system would take up one full rack, and on an experimental basis would cost about $12,000. Fairly complete economic studies indicated that in production this might have been reduced to $7,000 or $8,000. Further work should be done to explore this method of delaying video information.

Another method of delaying a narrow band television picture proved to be so practical and economical, that it was obviously unwise to pursue further any of the preceding methods as far as this project was concerned.

It is possible to induce in a steel wire a torsional vibration mode which then travels down the wire at a velocity essentially independent of frequency. There are several ways of inducing such a torsional mode. Special magnetostrictive transducers can be built for this purpose. Alternatively, piezoelectric transducers are beginning to be used for this purpose, and these show promise of having better band width characteristics than the magnetostrictive type. Either type transducer converts an electrical signal to a mechanical signal and vice versa, and there is one transducer at each end of the wire.

An experimental magnetostrictive delay line was built for $1,000 by the Ferranti Electric Company. This line had a length of 16,651.5 microseconds and was adjustable plus or minus four microseconds. It had a temperature coefficient of delay of two parts per million per degree centigrade, and thus no temperature control was necessary. The matnetostrictive transducers are essentially inductive, and at the peak of the pass band, a peak to peak input current amplitude of 30 milliamperes gave an output voltage of 3 millivolts peak to peak amplitude. The signal to noise figure was about 30 db, and the useable bandpass was about 600 kilocycles. Subsequent to obtaining this line, this manufacturer and several others stated that a useable bandpass of 1.2 megacycles and a signal to noise figure of 40 db could now be obtained using piezoelectric transducers. However, the line as supplied was adequate to prove the point. Figure 30 shows a picture of the encased line and Figure 31 shows the line with the cover off. The transducers had to be shielded because of crosstalk problems.

The bandpass of the line as supplied was from 200 to 800 kc at the 3 db points. It was necessary to put the picture information on a carrier and send it single sideband through the line. Two picture coding schemes were built. One was a frequency modulated system following the philosophy of Ginsberg in the Video Tape Recorder. This was not successful because the center carrier frequency was low and difficulty was encountered getting undesired patterns out of the picture. Had it been possible to move the center carrier frequency up to just 1.1 megacycles, this would have been overcome. Since all indications are that subsequent commercial lines will accommodate this problem, in the future the Ginsberg F. M. scheme may prove to be one of the more desirable methods to use.

The final coding scheme used in this experiment was a simple amplitude modulated system with a carrier at around 800 kilocycles (Figure 32). There is a transmitter section and a receiver section. In the transmitter the video is brought in, split in phase and fed to a balanced modulator, along with a phase split 800 kc carrier. The balanced modulator is balanced for video and unbalanced for carrier such that none of the original video is in the output, and a full negatively modulated A. M. signal is fed to the delay line drive tubes (Figure 33). The delay line receiver (Figure 34) consists simply of appropriate amplifiers and a balanced detector. The output video amplifiers are sharply attenuated above one megacycle so that second harmonic products of the balanced detector are not passed.

This system has proved to be simple, stable and reliable, and probably represents the best possible commercial approach.

MOTOR DRIVE AMPLIFIER

In both the live camera system and in the film system the motors had to be driven at a rate controlled by the vertical driving pulse. Since the vertical driving pulse is derived from the synchronizing generator which is controlled by a crystal, this can no longer be done from the power line. The motors used were Bodine type NSY-12R, 1/150 horsepower with appropriate worm gear reducers. The motors are easily driven by a single 6AS7 vacuum tube (one tube per motor) provided they are first started on the power line (Figure 36). One unit drives two motors with independent phase controls. A positive vertical driving pulse comes in to V11. This pulse is amplified and is used to drive two one shot multivibrators, V9 and V10. The trailing edge of the one shot multivibrator outputs are differen-iated and are used to drive two other one shot multivibrators, V5 and V6. The outputs of V5 and V6 are set to be 60 cycle square waves which are then fed to two tuned amplifiers, V3 and V4. V3 and V4 convert the 60 cycle square waves to approximately sine waves which are then fed push-pull to the grids of two 6AS7's. One section of each 6AS7 is put in series with the other section of the same tube. The cathode filament isolation appears to be adequate to allow this. A d-c power supply system provides approxi-mately plus 200 volts and minus 200 volts which powers the 6AS7 amplifiers as well as the rest of the motor drive system. One of the motor terminals is connected to the common junction between the plate and cathode (pins two and six) of a 6AS7, and the other motor terminal is grounded. When the system is properly balanced this provides a fairly good sine wave to drive the motor. The motor drive characteristics are considerably improved if a ten microfarad oil-filled capacitor (not electrolytic) is placed across the motor terminals. The motors are started on the 110 volt a-c line and then switched to the motor drive system. Since the bias voltages on the two sections of the same 6AS7 are different, a separate d-c bias supply and current balancing adjustment is provided for each tube. A metering system is provided to check current balance in all sections of both 6AS7's. This motor drive unit appears to be completely reliable. This circuit would probably be adequate for a commercial unit. However, some of the low frequency power transistors now available would probably make possible a much simpler and more compact unit to serve this function. Such a unit was not developed because the one shown was already built before the solid state devices became economical, and it was doing an adequate job (Figure 37).

COLOR MATRIX SYSTEM

In this experimental work it was desirable to handle color signals in both the encoded and unencoded form. Therefore, a special matrixing system was built to convert the Y-R-B signals to standard red, green and blue signals. In a commercial system this would be unnecessary, but in the experimental system it permitted the observation of the picture both before and after encoding. The output of the matrix system could be fed to the red, green and blue guns of a standard display device or it could be fed to the red, green and blue inputs of a standard encoder. The matrix was really a mixed high matrix (Figure 38). It is simply a three channel video amplifier in which one channel is very wideband and the other two channels may be made either wide or narrow band. Negative red and blue signals are fed into the wide channel to get a proper green signal. Since the wide channel carries all the high frequency information, the high frequencies are filtered off and mixed in all three channels in all three outputs. Thus, all of the high frequencies appear in the output signals and low frequency, red, gree and blue information, appears in the red, green and blue outputs respectively. Provisions are made to insert composite blanking in all channels and to control d-c insertion level in all channels independently. The Y channel video response was made to have a rising frequency characteristic up to about 1½ megacycles to compensate for the narrow banding of the other two channels (Figure 38). Both ½ volt and 1 volt video output signals are provided. The ½ volt signals were used to feed other experimental equipment, since they could be obtained with less strain on the power supplies and smaller output cathode followers. The 1 volt signals are used to feed the standard N.T.S.C. encoder.

VIDICON-IMAGE ORTHICON SWEEP CIRCUITS

In the orthicon-vidicon camera work a method for sweeping a vidicon camera tube from image orthicon sweeps was devised. The orthicon yoke coils were placed in series with the vidicon yoke coils but with rather low impedance shunts across the vidicon coils (Figure 39). Series resistance and inductance in the shunts were chosen so that current wave forms could be about the same in both the orthicon and vidicon yokes, although the amplitudes would be radically different. Adequate registration between the vidicon and orthicon was achieved through this system.

Monitoring Facilities. In all of the color work it was necessary to have both black and white and color monitor devices. The Hazeltine Corporation donated a dichroic display (as well as a rack oscilloscope, N.T.S.C. encoder and other equipment), and this was used for a laboratory standard monitor for several years (Figure 40). In addition, several standard color receivers were obtained and converted for laboratory purposes (Figure 41). One is a 21" shadow mask receiver which can be fed with either a standard N.T.S.C. signal or separate red, green and blue signals. An outboard chassis was built for the red, green and blue signal inputs. The type of input could be changed merely by changing a plug on the back of the receiver. Ultimately, three such monitors were built. One was a conversion of an RCA CT 100 15" color receiver. The other two were 21" receivers using 21AXP22A shadow mask picture tubes.

Most of this work was carried on in two main laboratories (Figures 42, 43), plus a dark room and a special studio for camera work. This work encompassed a period of about six years and a total time of approximately ten man years.

CONCLUSIONS

This work has proved conclusively that the Iowa State System is perfectly feasible technically, and it is also highly feasible economically. If color television is to be widespread, all of the work that needs to be done, including recording and live pickup, must be done in color by all stations both large and small. This method provides a way to make this kind of color operation feasible.

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8. Hughes, W. L. Some Theoretical Aspects of Recording Color Television Images on Black and White Film. S.M.P.T.E. Journal, 1957.

9. Hughes, W. L. The Role of Black and White Film in Color Television. S.M.P.T.E. Journal

10. Hughes, W. L. Possibilities of Major Simplifications in Color Television Live Cameras and Recording Devices Through the Use of Chroma Field Switching and Subsequent Automatic Color Balance. IRE Convention Record, Part VII, 1959.

11. Lindgren, T. D. Feasibility of Television Picture Storage on Electrostatic Storage Tubes Utilizing Transistorized Readout. Unpublished Master's Thesis, Iowa State University Library, Ames, Iowa. 1959.

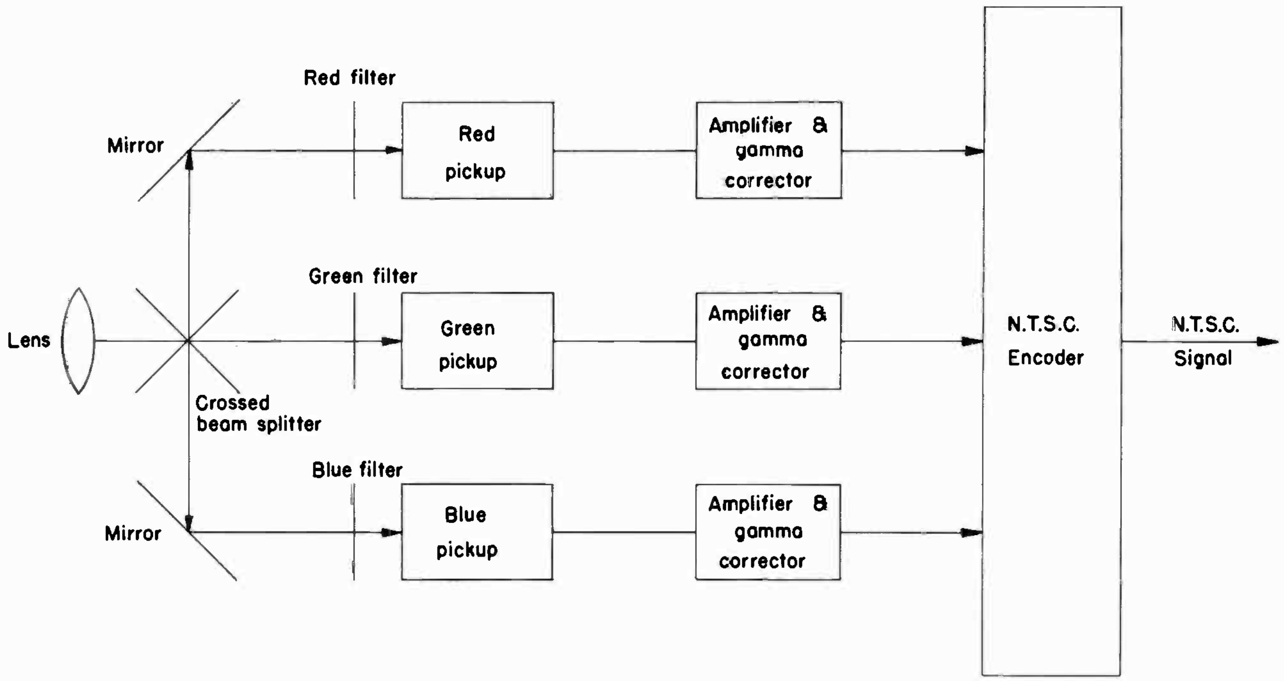


Fig. 1. Conventional approach to color television pickup.

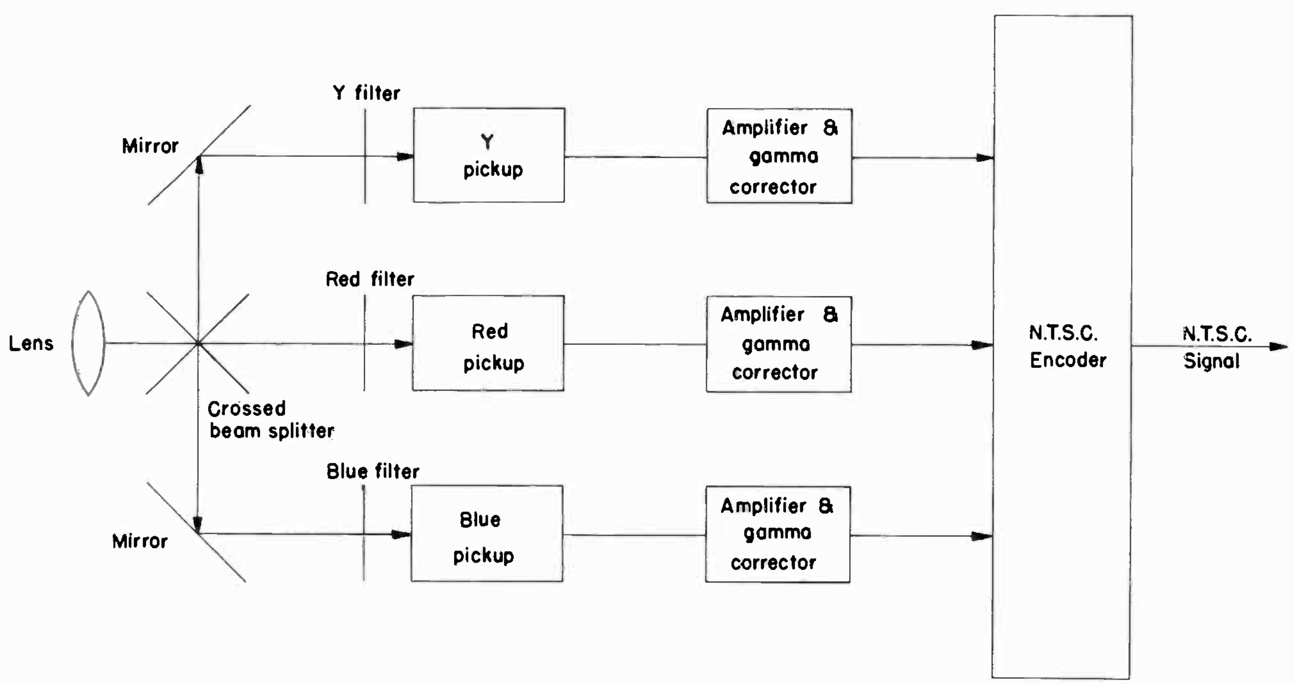


Fig. 2. Modification of conventional approach.

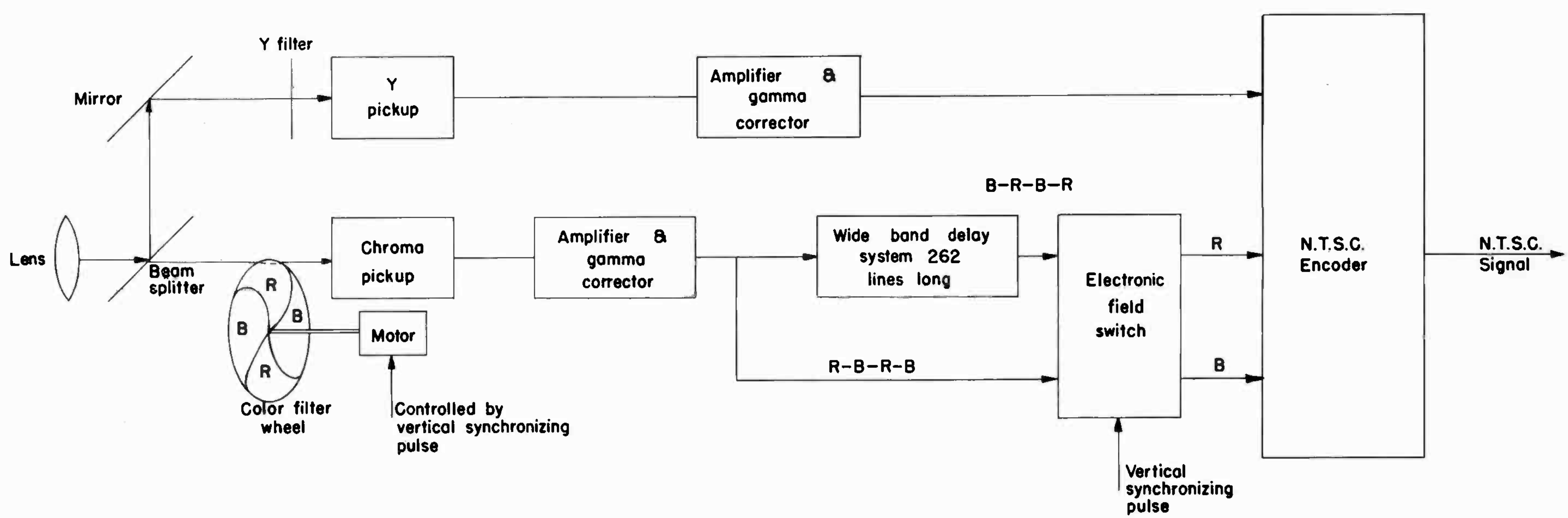


Fig. 3. Basic Iowa State system.

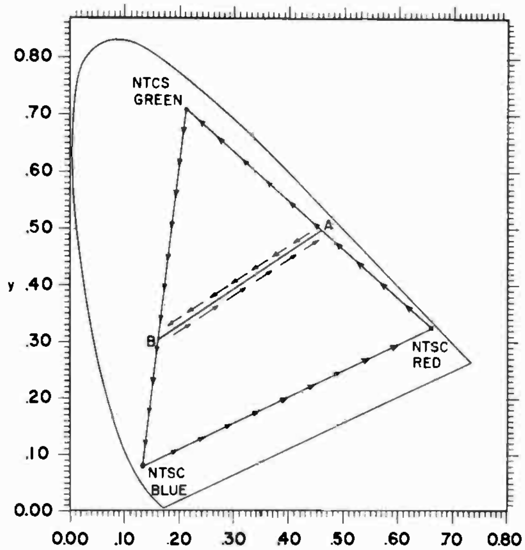


Fig. 4. Color chart.

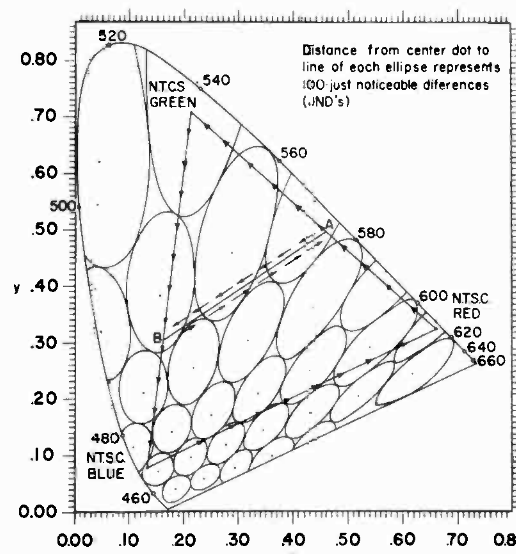


Fig. 5. Ellipses of noticeable difference.

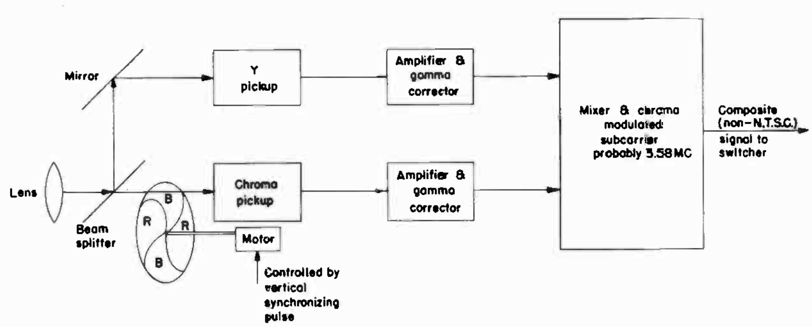


Fig. 6. Simplified camera.

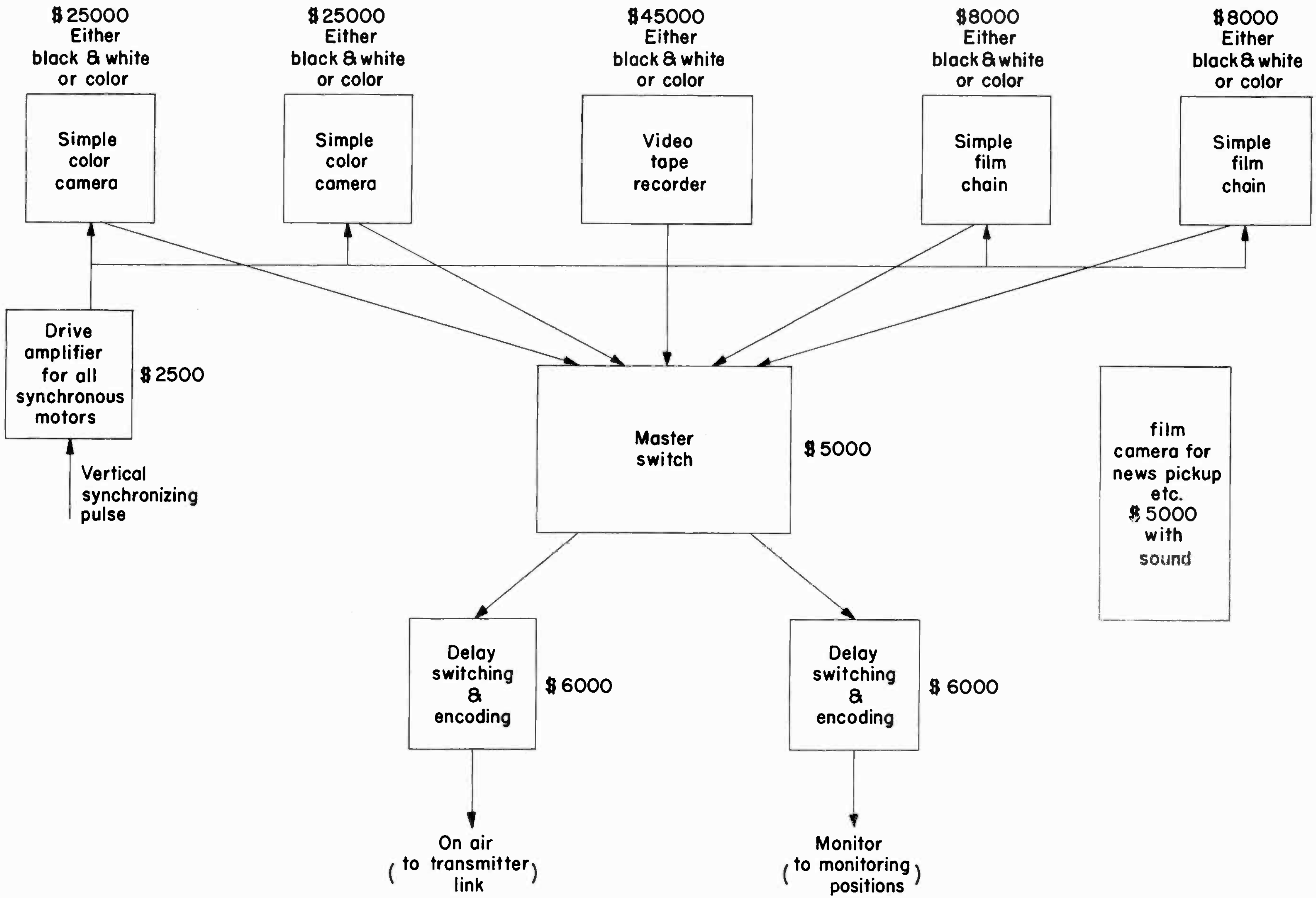


Fig. 7. Complete studio color system.

Continuous film scanner for color television (First type)

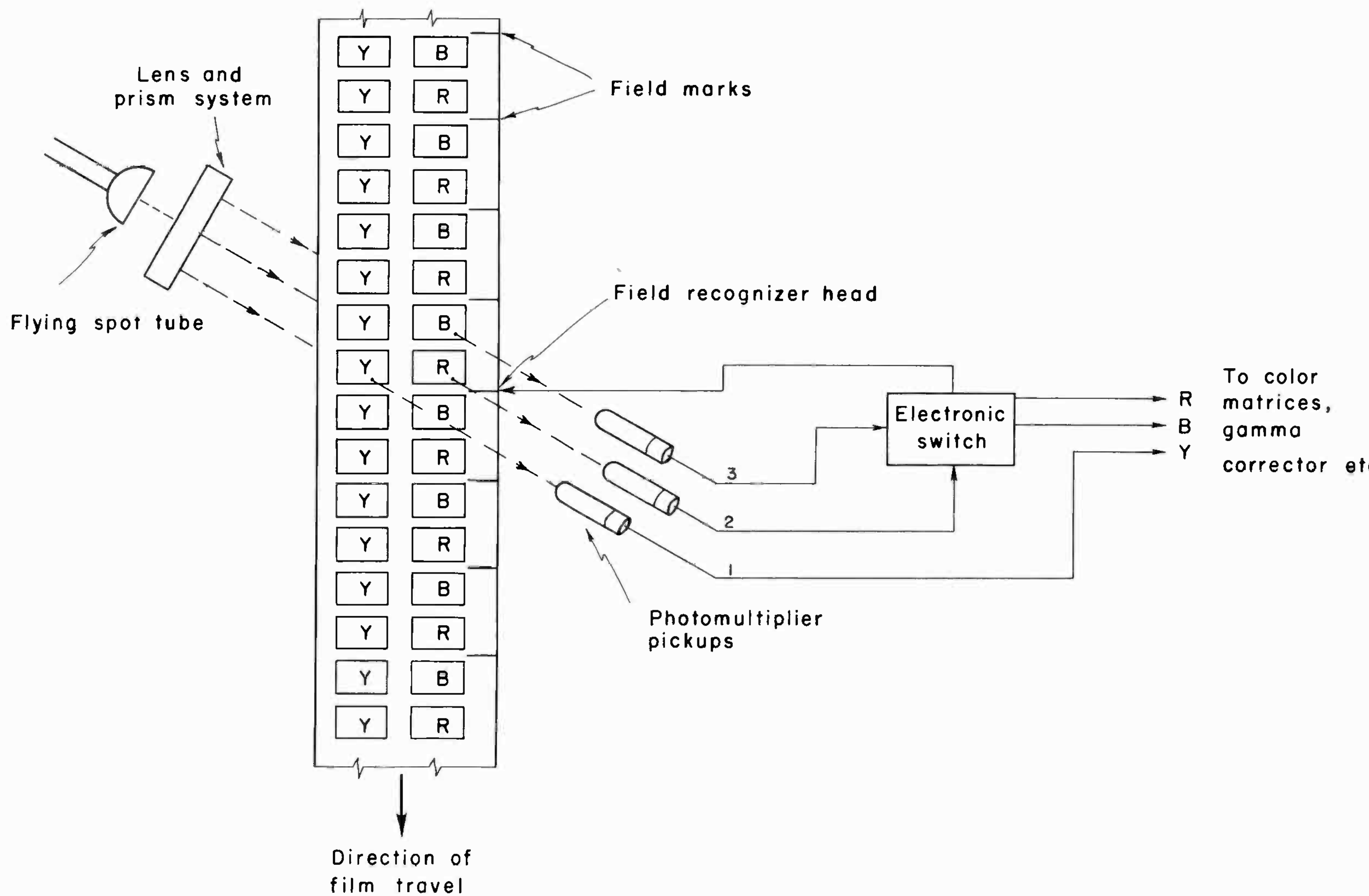


Fig. 8. Film system.

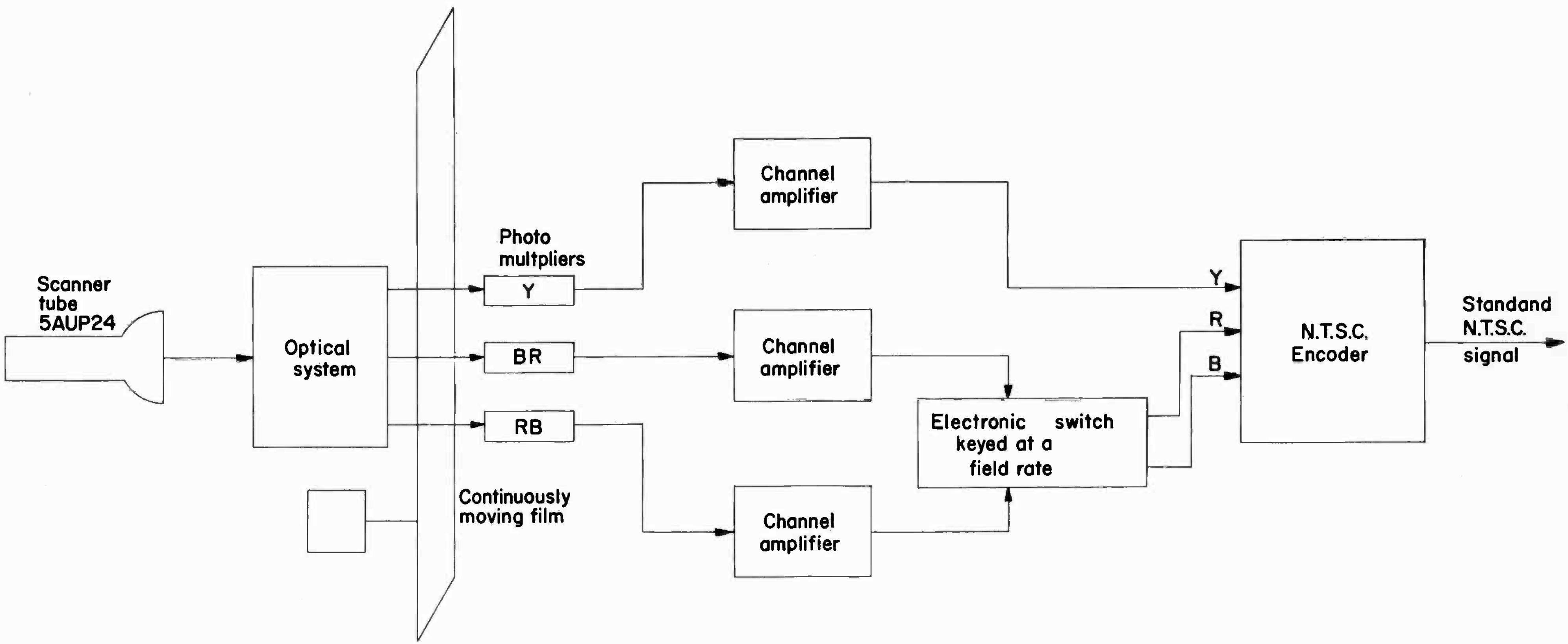
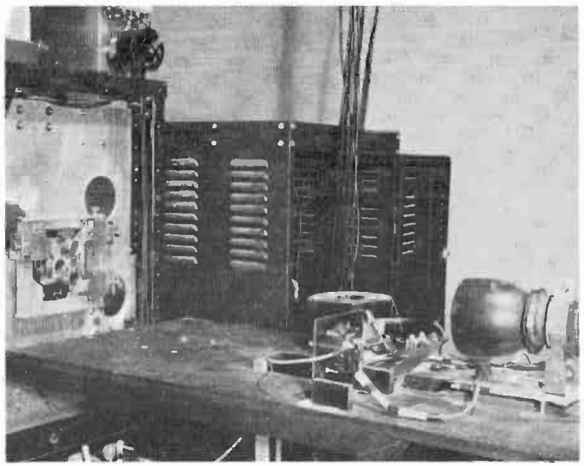
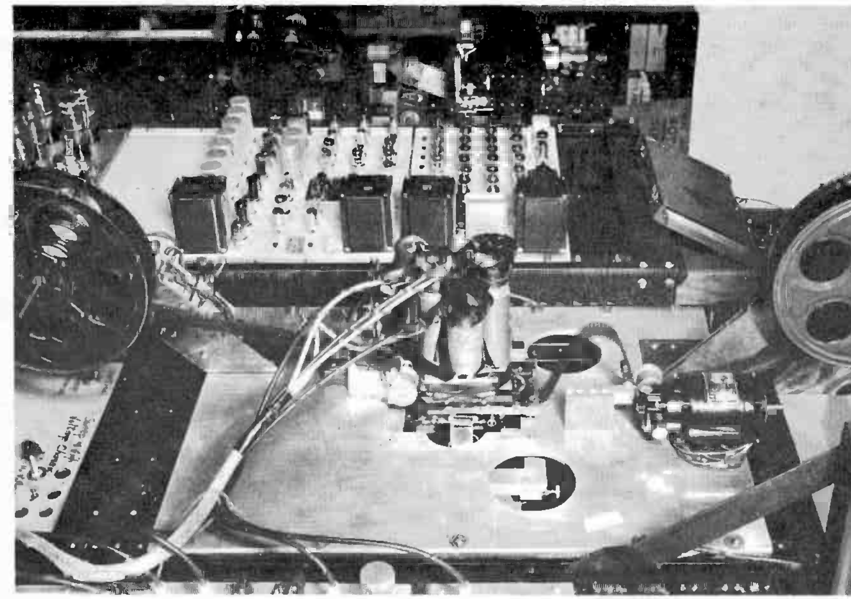


Fig. 9. Block diagram of first film system.





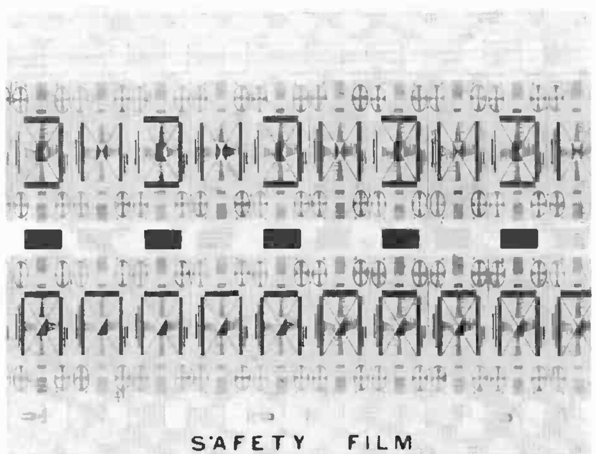


Fig. 10, at left, above. Film transport.
Fig. 11, above. Film transport and photomultiplier pickups.
Fig. 12, at left. Test film.

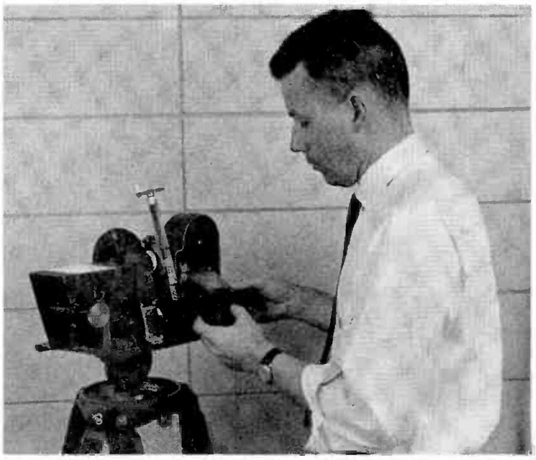
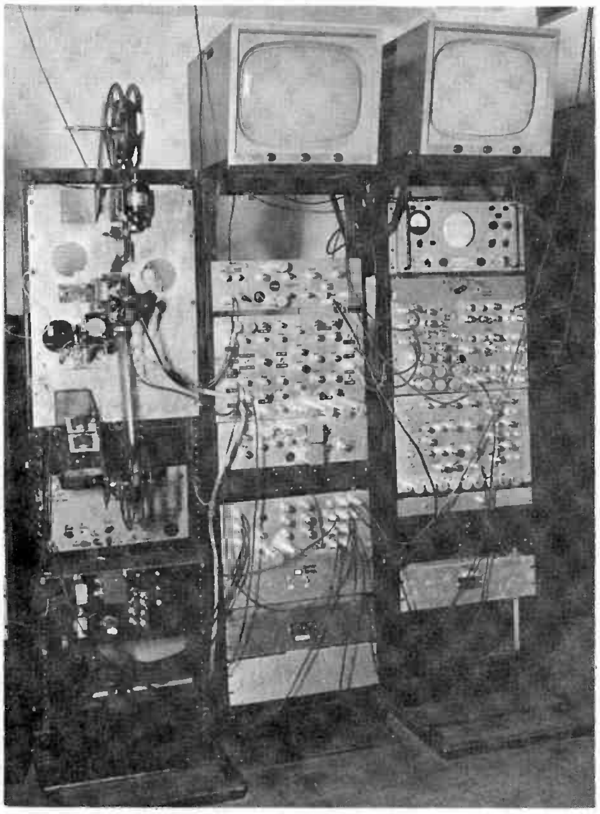


Fig. 13, above. Film taking camera.
Fig. 14, at right. Overall film scanner.



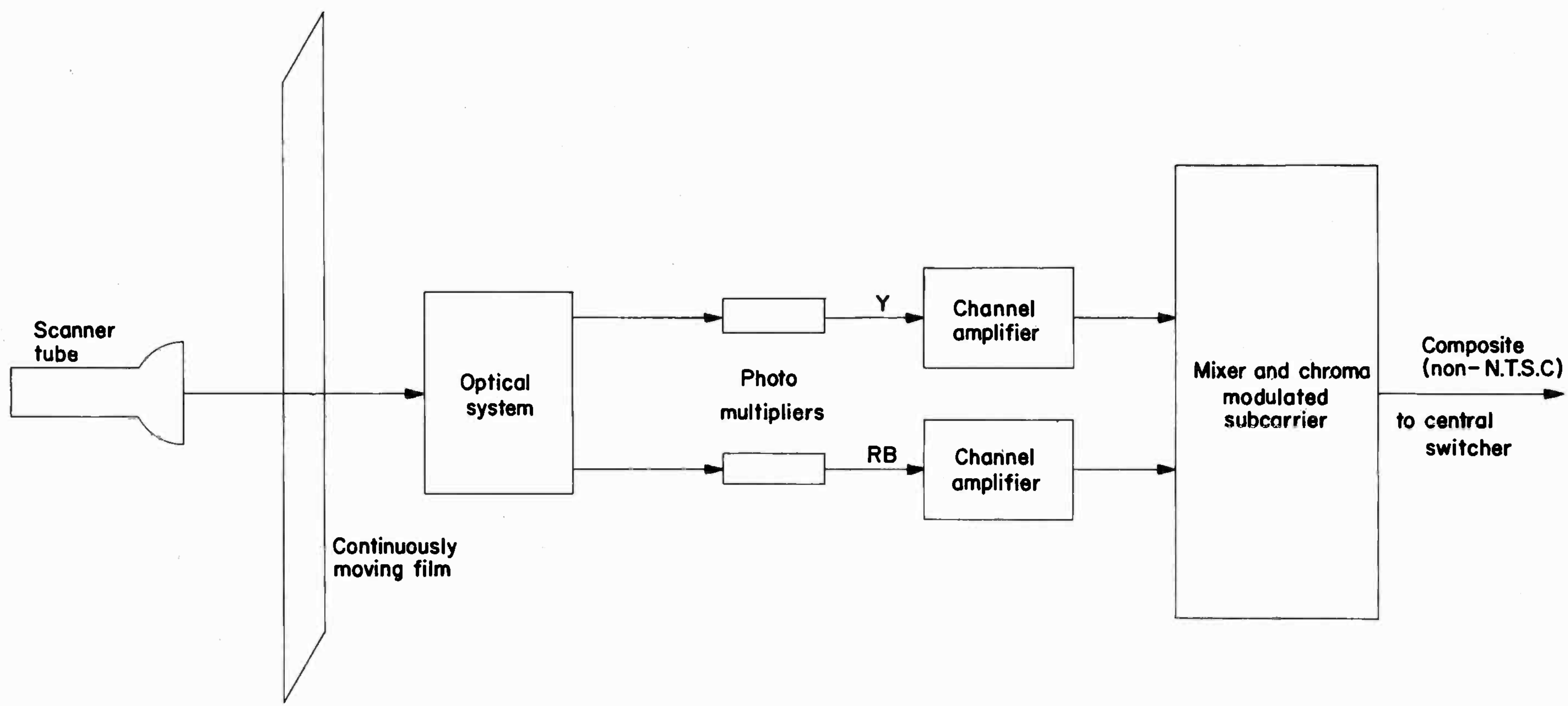


Fig. 15. Probable commercial film system.

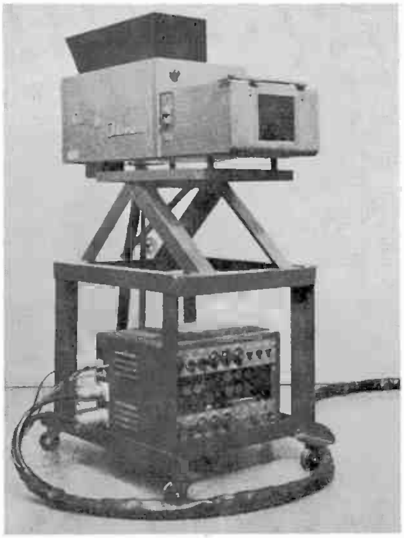


Fig. 16, above. Two image orthicon camera.

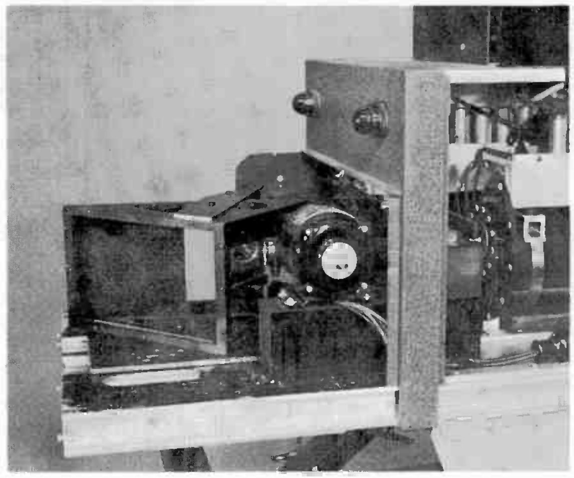


Fig. 17, above. Details of two image orthicon camera.

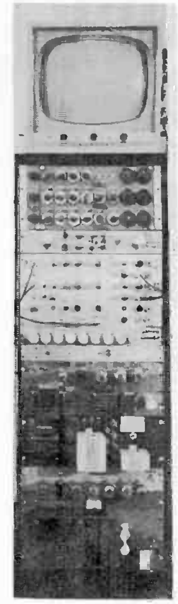


Fig. 18, at right. Control unit and power supplies for two image orthicon camera.

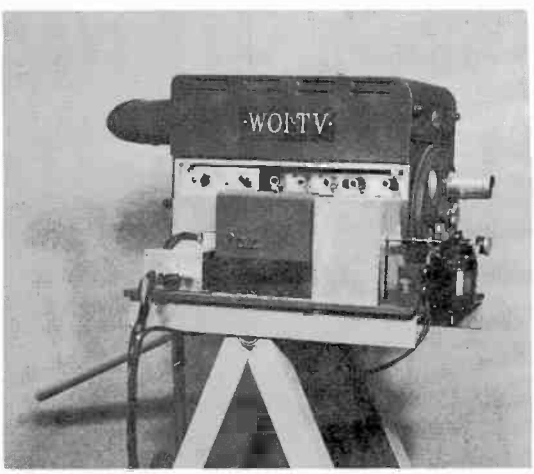


Fig. 19. Image orthicon - vidicon camera.

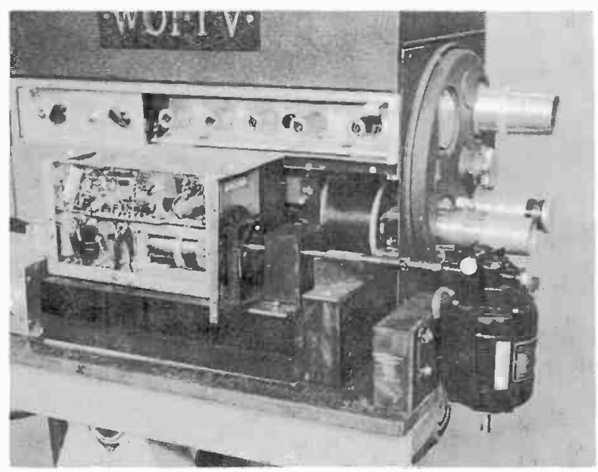


Fig. 20. Details of image orthicon - vidicon camera.

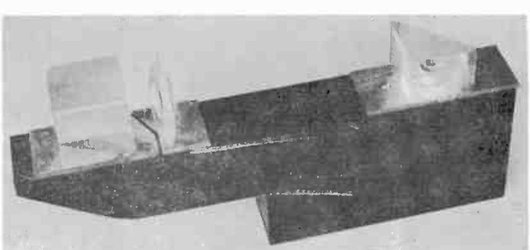


Fig. 21, left. Optical block for image orthicon - vidicon camera.

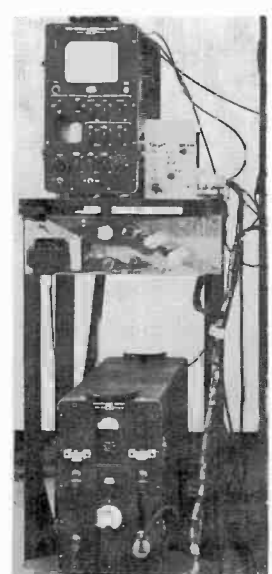


Fig. 22, right. Control unit for image orthicon - vidicon camera.

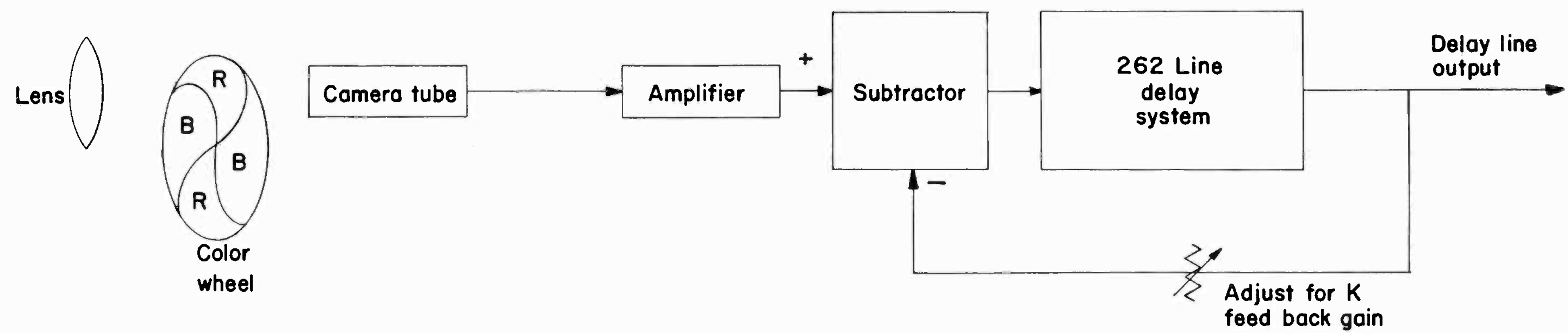


Fig. 23. Sticking correction method #1 (approximate correction).

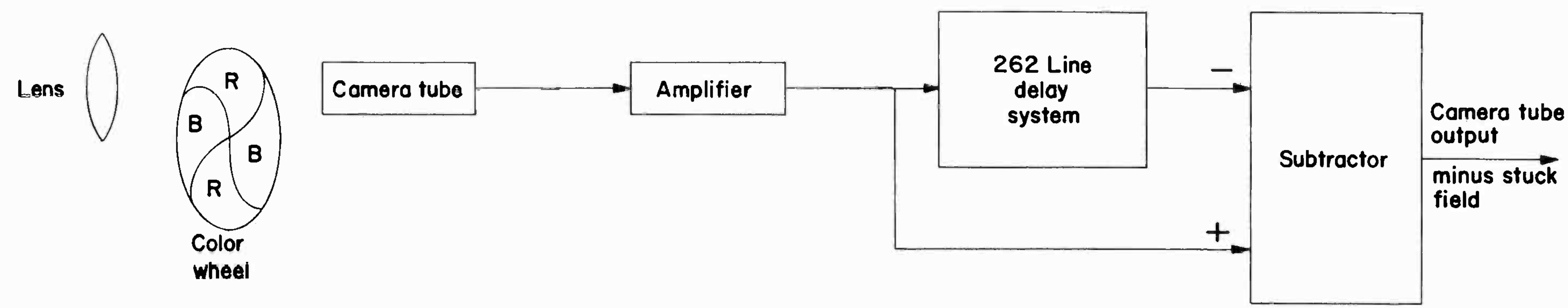


Fig. 24. Sticking correction method #2 (exact correction).

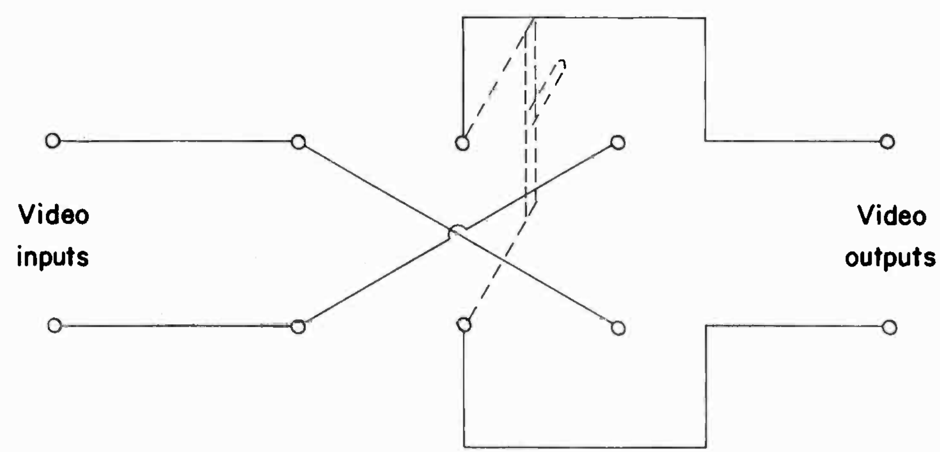


Fig. 25. Functional diagram of electronic switch.

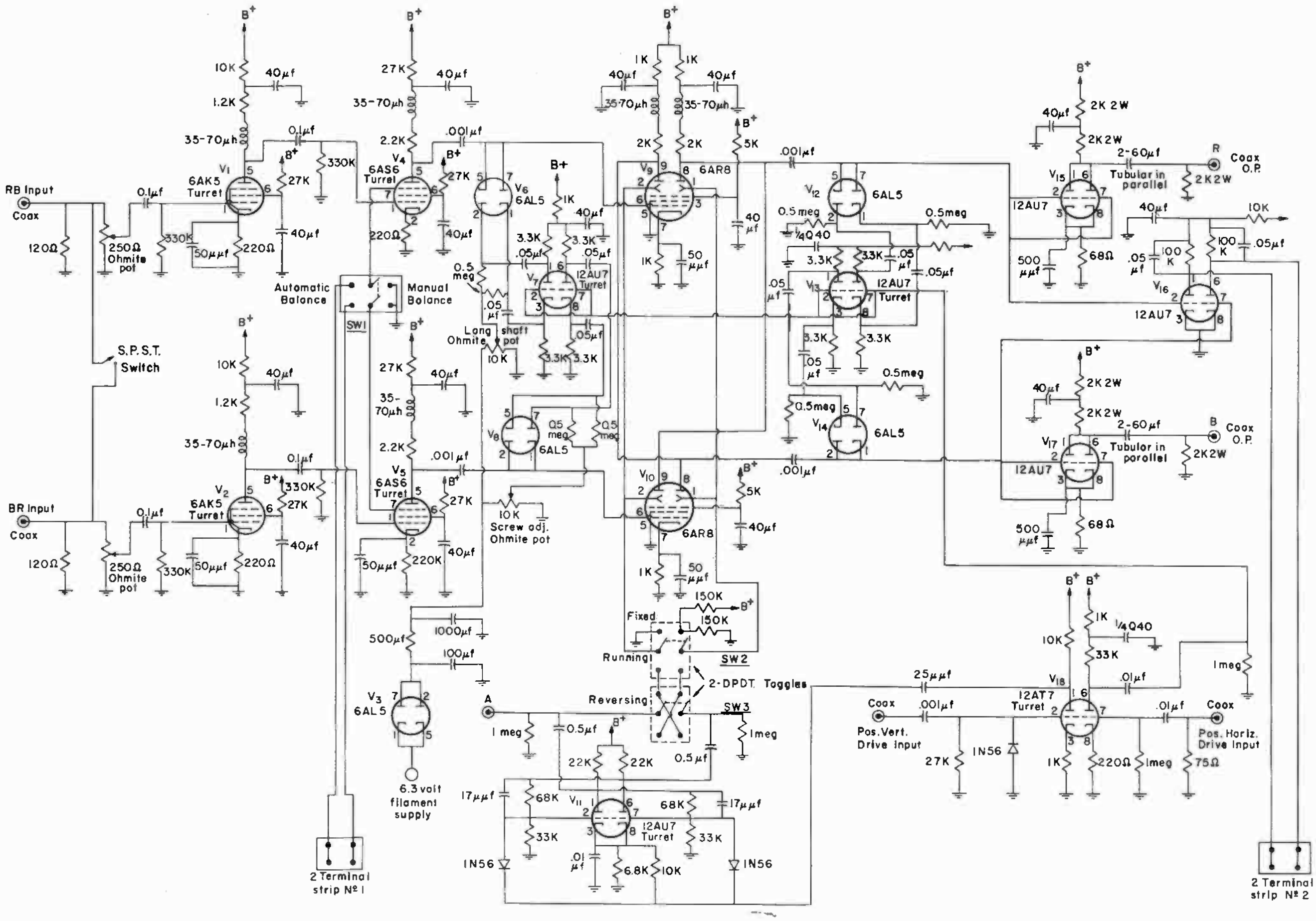


Fig. 26. Electronic switching system.

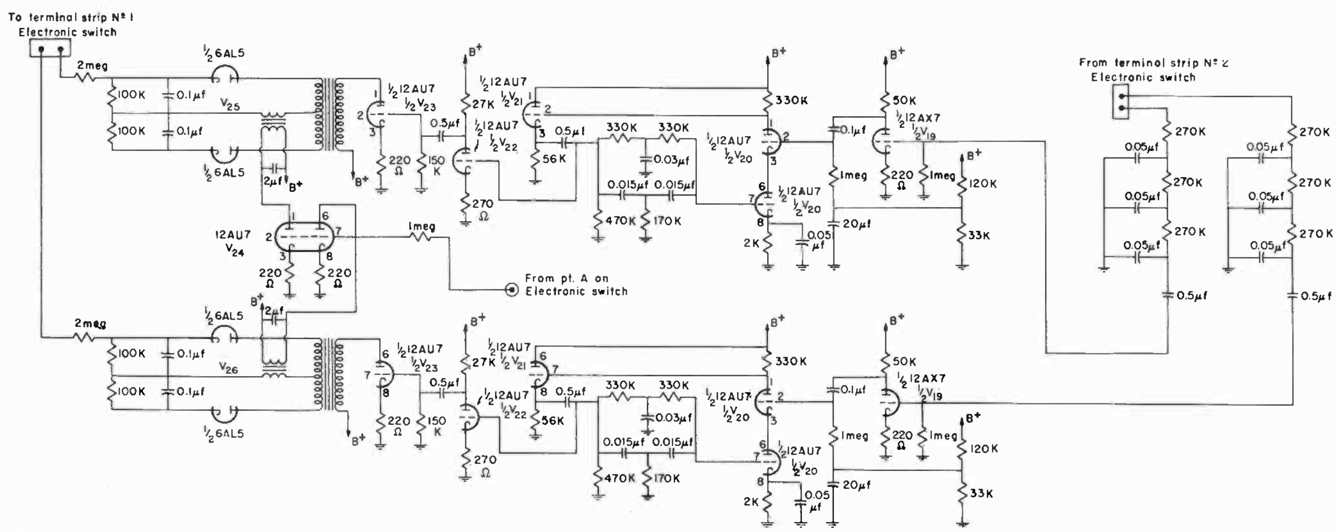


Fig. 27. Automatic balance unit.

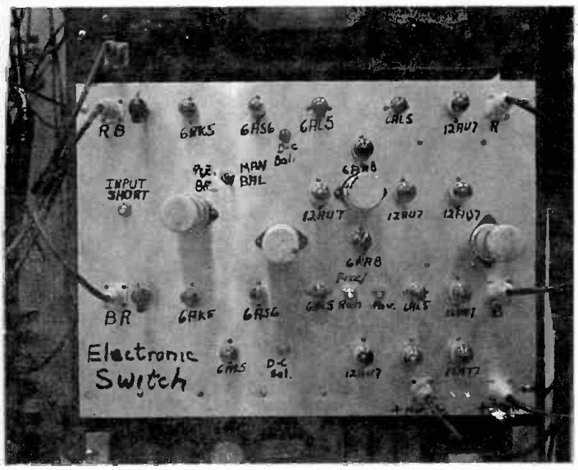
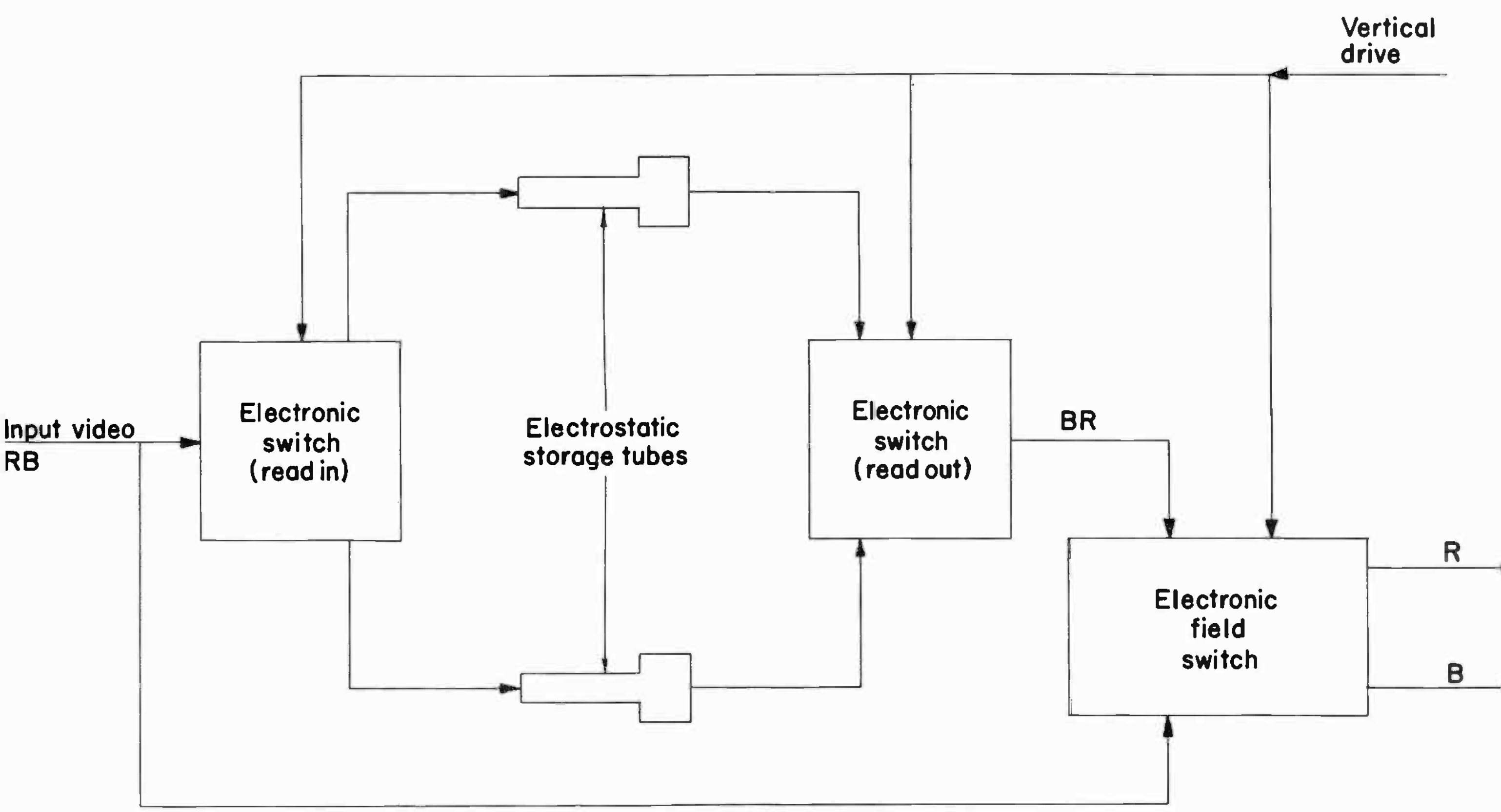
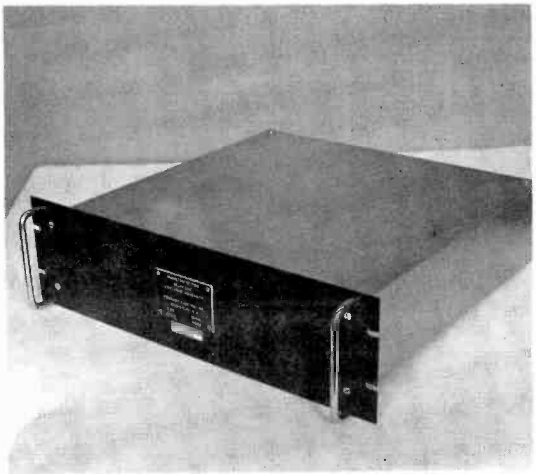


Fig. 28, left. Electronic switch.
Fig. 29, below. Electrostatic storage and switching system.





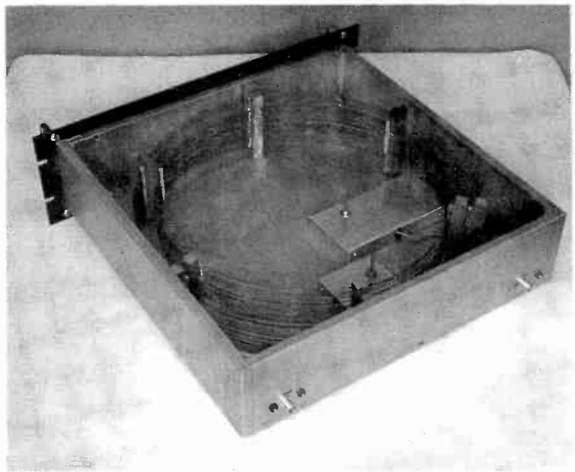
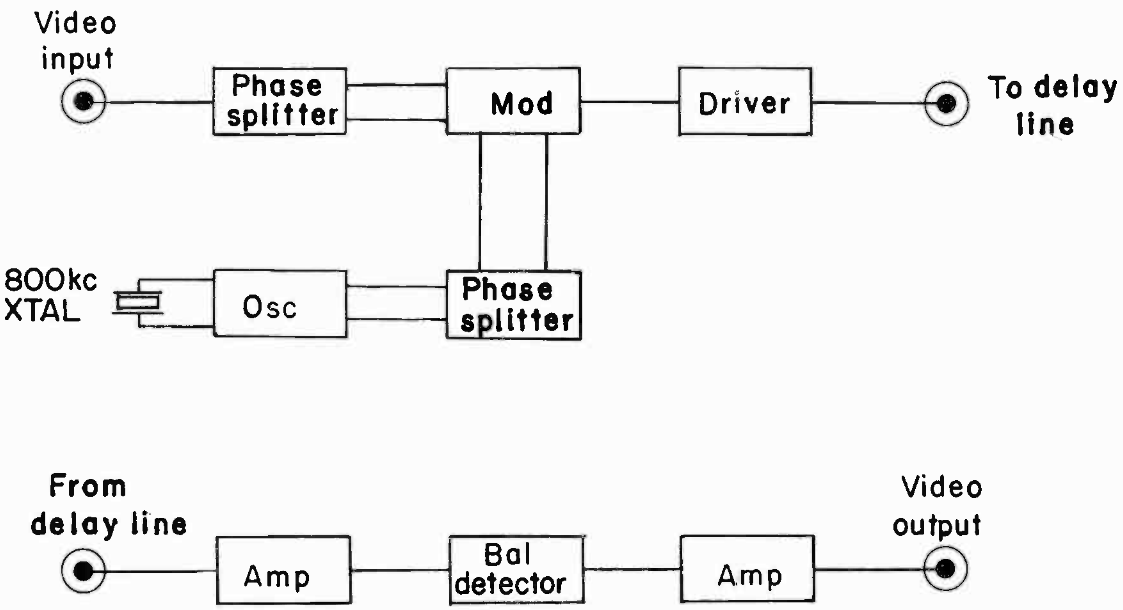


Fig. 30, at left. Encased delay line.
Fig. 31, right. Open delay line.
Fig. 32, below. Block diagram of A.M. delay line electronics.



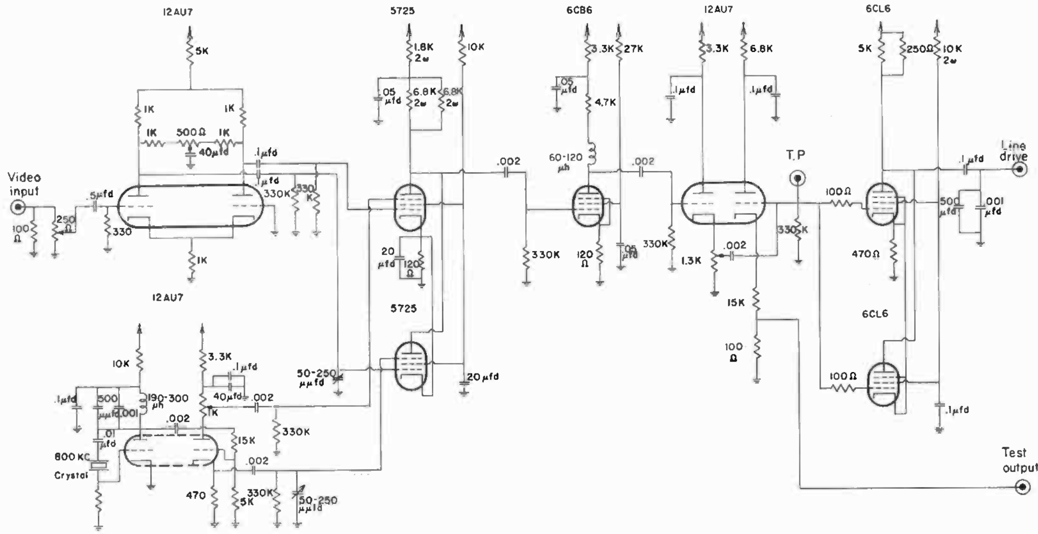


Fig. 33. Delay line transmitter diagram.

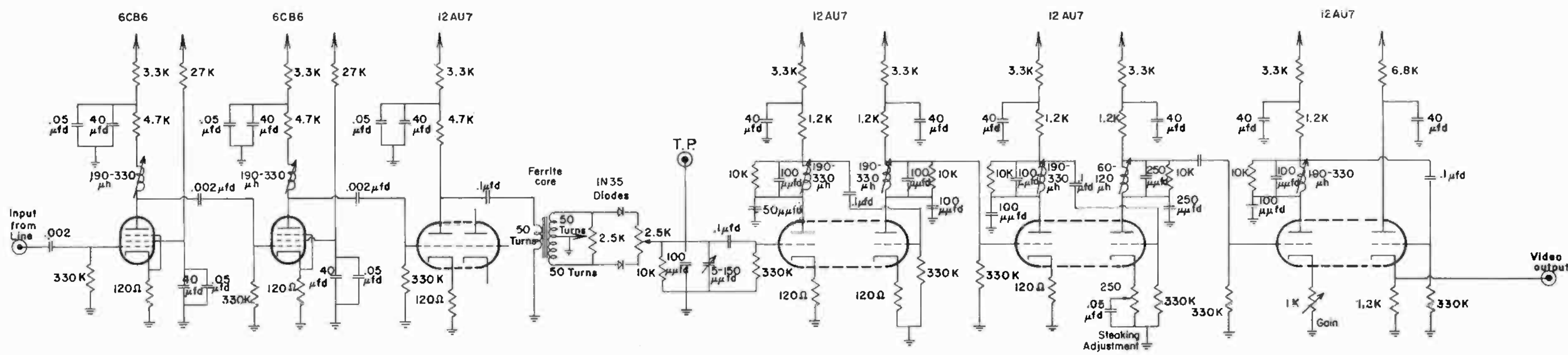


Fig. 34. Delay line receiver.

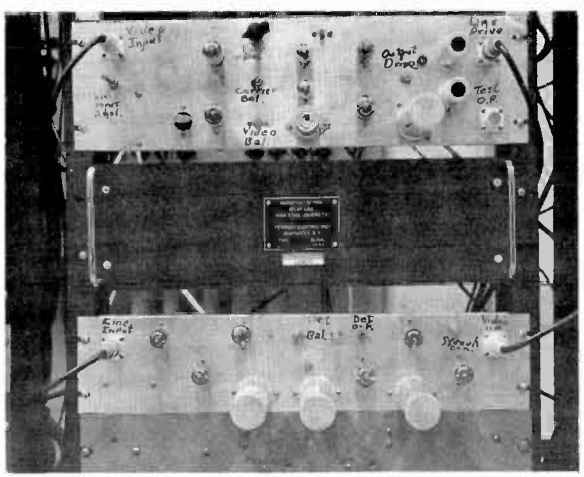


Fig. 35, at left. Complete delay system.

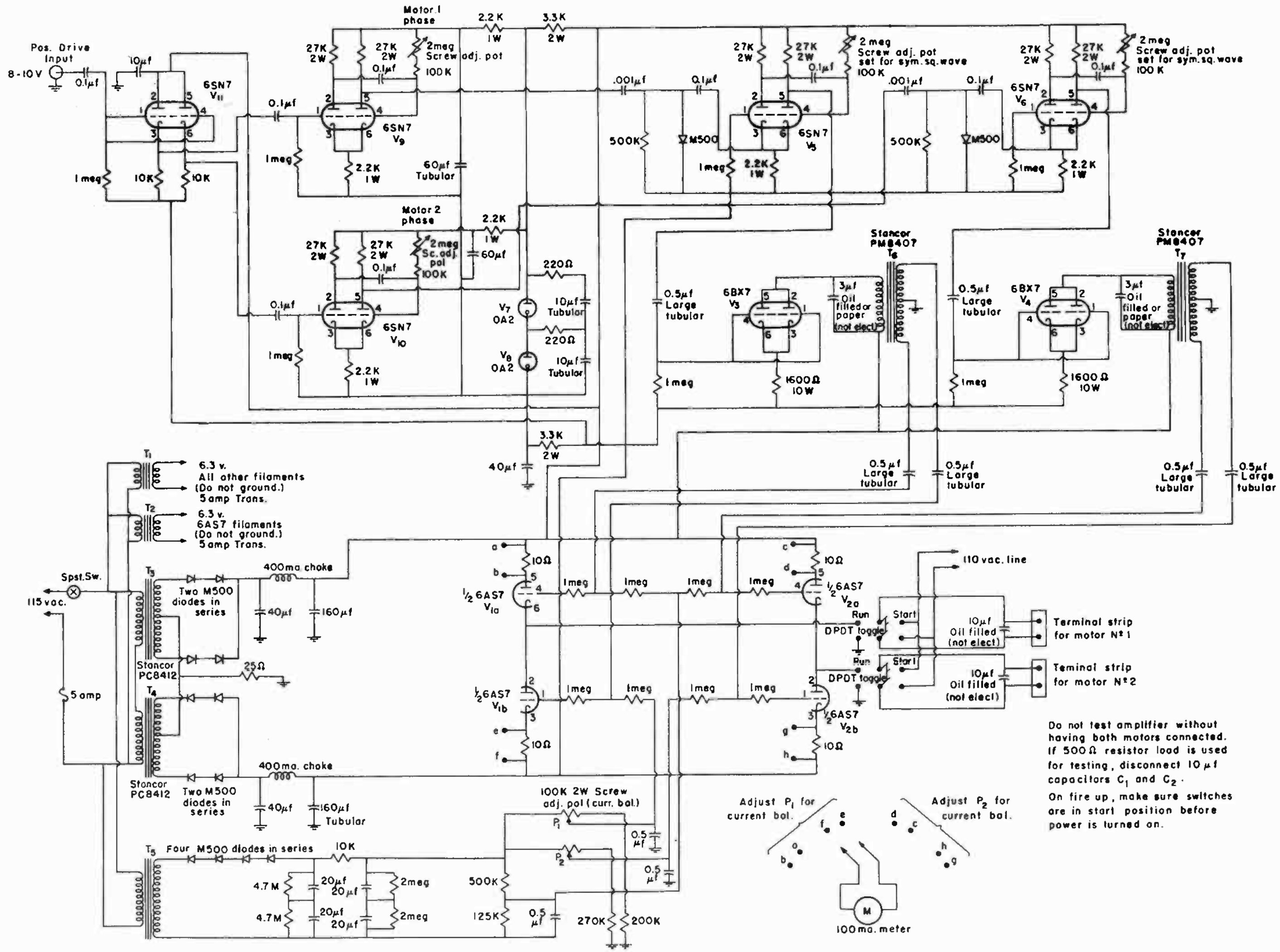


Fig. 36. Motor drive unit circuit.

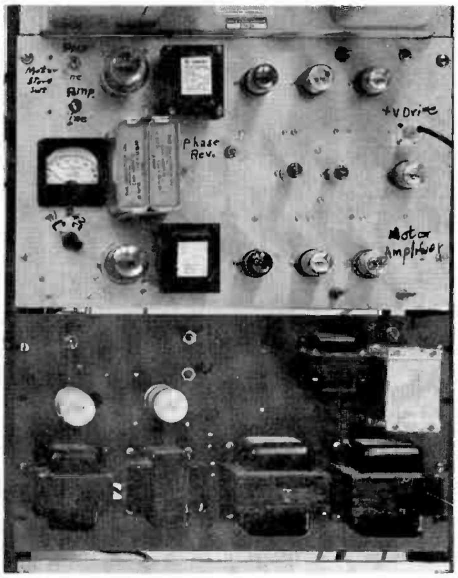
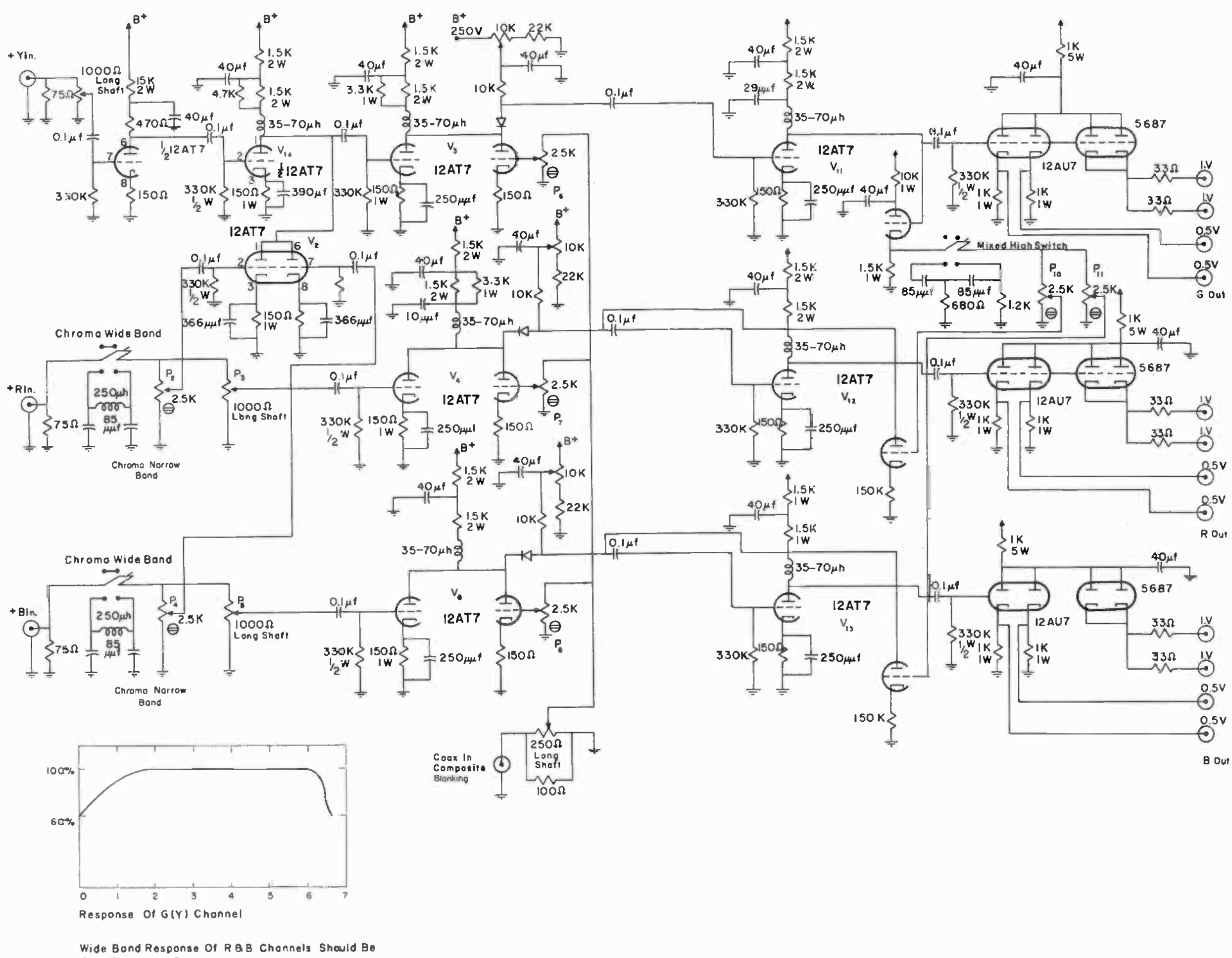


Fig. 37, left. Motor drive unit.
Fig. 38, below. Mixed high matrix.



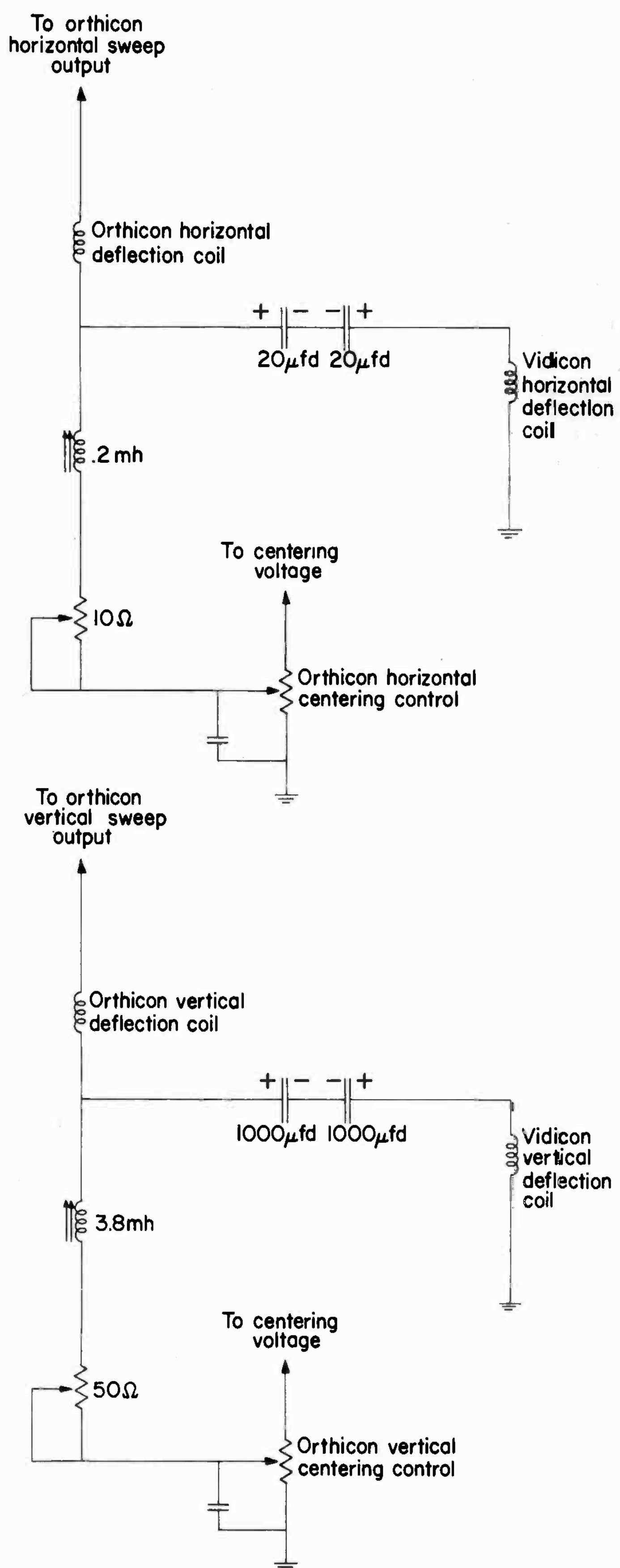


Fig. 39. Circuit for sweeping vidicon from an image orthicon.

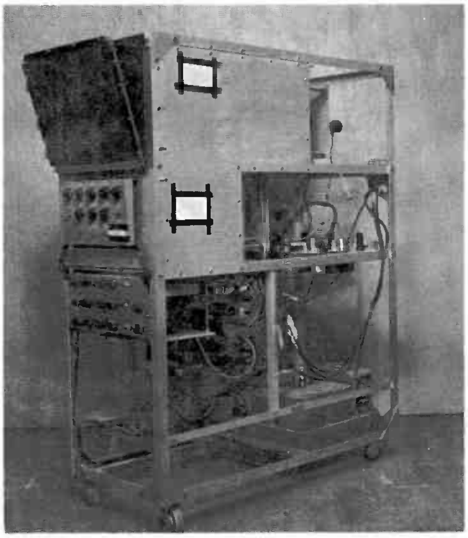


Fig. 40. Dichroic display unit.

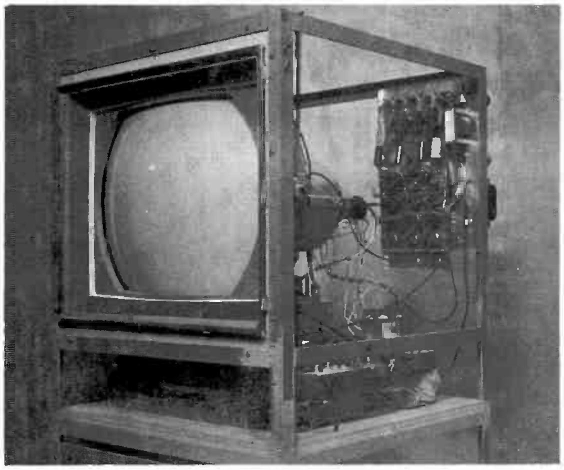


Fig. 41. Converted receiver for laboratory work.

Fig. 42. Film system laboratory.

Fig. 43. Live camera laboratory.

D.C. PULSE GENERATOR

20 MILLIMICROSEC.

Within the past year or so Mr. Donald W. Peterson of the R.C.A Laboratories has outlined a system of pulsing transmission lines which has extraordinary merit. I know that most of you are familiar with his paper. The D.C. pulser that I will describe is a very economical way of making use of one part of the pulsing technique.

About a year ago we completed a 20 millimicrosecond pulser at a cost of $35.00. This pulser can be used with any Tektronix Oscilloscope which has a time base of .1 microsecond to 1 microsecond. Since most of the oscilloscopes used in Television Stations have a time base of .1 microsecond, I feel that this unit can be conveniently used to assist in localising difficulties in coax transmission lines and, as a matter of fact, in video cables using RG8U, RG11U etc. A circuit diagram of this unit is enclosed and I might mention that special care should be exercised in the handling of the mercury wetted contact relay. You should be sure to mount it together with the relay coil in a vertical position only. The relay and the coil are purchased from the C.P. Clare Co., the part numbers are on the print. They are very inexpensive, approximately $7.50 for both.

So that you may have a guide for footage and time, I have included a table based on feet per centimeter for a given time per centimeter.

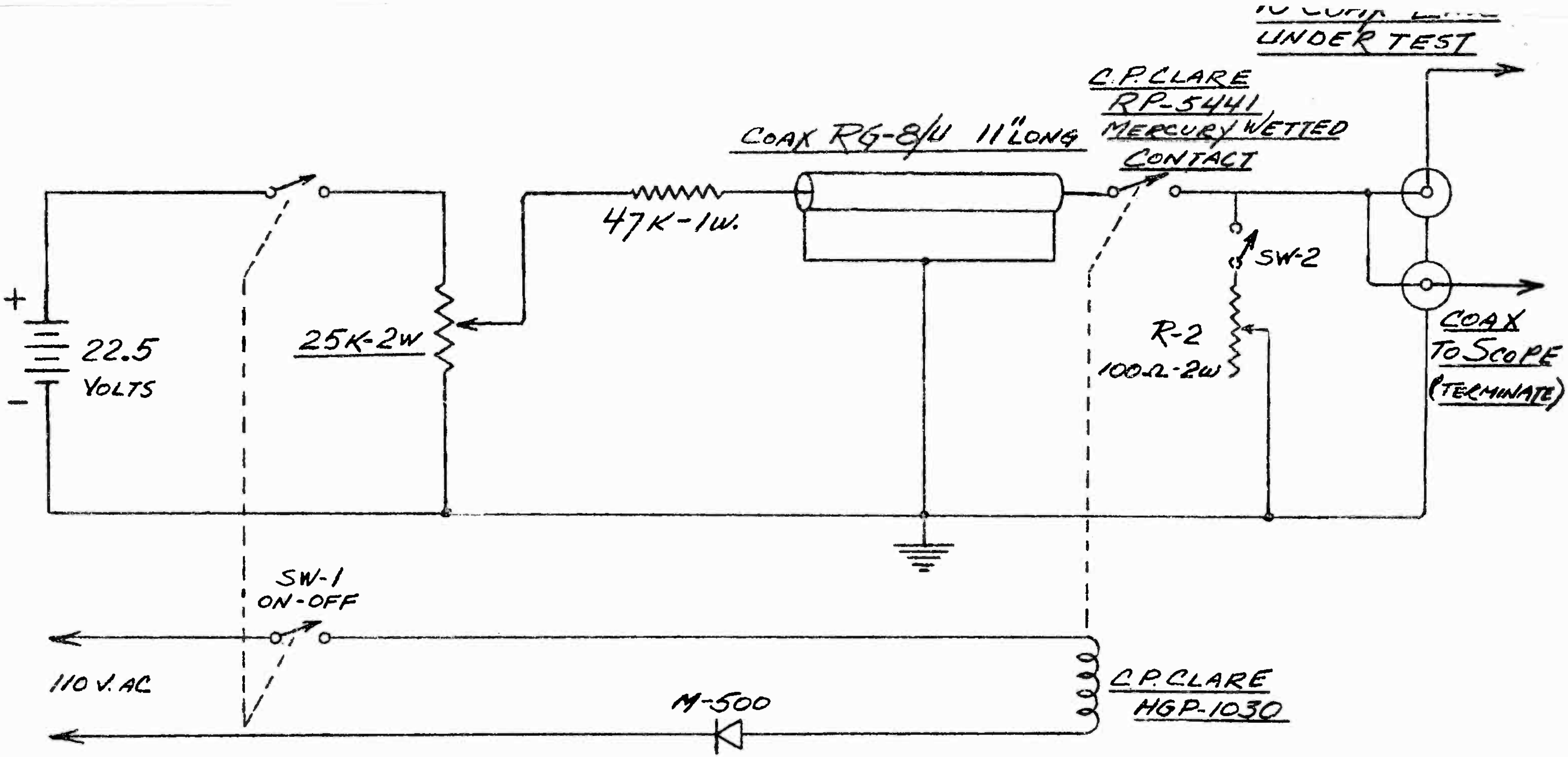
-contd-

Feet Per CM	Base Time/ CM
491.0	1 µ sec.
245.5	0.5 µ sec.
196.4	0.4 µ sec.
98.2	0.2 µ sec.
49.1	0.1 µ sec.
24.55	0.05 µ sec.
19.64	0.04 µ sec.
9.82	0.02 µ sec.
4.92	0.01 µ sec.

Time of above readings include travelling time of pulses both ways in the line. Should you be using this device to check RG11U or RG8U, please remember to multiply the footage per centimeter by the appropriate propagation factor. Of course in measuring 3 1/8" copper line or 6" copper line you may neglect this. Normally, the oscilloscope vertical amplitude is so adjusted that after the main pulse and proper sweep widths have been obtained the vertical amplitude sensitivity is increased by approximately 40 db, so that a continuous inspection of the line is completely discernable. In the event there are discontinuities other than a real short or open, the increased sensitivity will show them as a bump larger in amplitude than normal. A dead short circuit will be indicated by a high amplitude negative pulse. and an open circuit by a high amplitude positive pulse.

The use of this pulser can save hundreds of dollars in "riggers time" during a transmission line emergency.

Ben Wolfe
Chief Engineer
WJZ-TV
Westinghouse Broadcasting Co., Inc.,
Baltimore, Maryland.



WESTINGHOUSE BROADCASTING CO. WJZ-TV

D.C. PULSE GENERATOR

20 Millimicrosecond

B. Wolfe - Jan. 1960

THE TRANSISTORIZED VIDEO DISTRIBUTION AMPLIFIER

BY

BEN WOLFE, CHIEF ENGINEER
WJZ-TV, BALTIMORE, MARYLAND.
WESTINGHOUSE BROADCASTING CO., INC.,

It is recognized that progress in the field of transistorized circuitry has been rapid and extensive and has permeated almost every area previously dominated by vacuum tubes. The television field is currently undergoing intensive development in semi-conductor application and as the new and better transistors appear a corresponding improvement in circuit performance becomes possible. The purpose of this paper is to outline the design considerations entering into the development of a practical transistorized video distribution amplifier. Sufficient design procedure is included to show the basis for the high performance and good stability.

Some of the factors which must be taken into consideration in a transistorized video D.A.

1. Input and output termination.
2. Frequency response.
3. Differential gain and differential phase.
4. Low frequency tilt.
5. Temperature stability.
6. Noise.

Standard engineering practice dictates that input and output impedances should be 75 ohms so as to conform with current bridging and terminating equipment. This automatically makes interchange and comparison with existing vacuum tube distribution equipment possible with a minimum of circuit alteration. Low input capacity is of course desirable when using a number of D.A's in parallel which in practice is generally the rule rather than the exception.

The good performance achieved in the subject design is due to the use of several degenerative feedback circuits combined with the cascoding of the final stage, which results in exceptionally good linearity as well as a high order of stability. While the following analysis deals primarily with only single stages of amplification the design approach is equally applicable to the other stages.

By employing degeneration the input capacity is reduced to low enough values to permit the use of a number of D.A's in parallel. To illustrate, without degeneration, the approximate input capacity of a transistor can be determined by the expression $g_f/2\pi f_a$. Where gf is the transconductance for the given transistor and this is $\cong$ 35 millimhos per milliampere of collector current.* Since the first stage Ic is 3 mils then the input capacity equals $3 \times .035 / 6.28 \times 7 \times 10^7 \cong$ 230 mmfd. However the use of degeneration in this stage reduces the input capacity by (1 - Ke) Cbe. Where Ke = emitter gain and Cbe is base to emitter capacity. $Ke = gf\ Re / \left[1 + (gf\ Re) \right]$ and in the case of Q1 is $\cong .1 \times 380 / \left[1 + (.1 \times 380) \right] = 0.9$. Thus the actual input capacity = (1 - .9) x 230 = 23 mmfd. The frequency bandwidth of the input circuitry with 5 units in parallel and properly terminated equals $1/2\pi\ Ci\ Rt$; $1/6.28 \times 120 \times 10^{-12} \times 75$ Ohm = 17 mcs. The lead line for Q1 may be plotted from the Ic - Ec curve for the 2N 1301 or approximated by RL = E/2 Ic which is 2000 by calculation. Practical measurements indicated that a value of 1500 produced the desired linearity.

The degenerative stage gain of Q1 in terms of forward transconductance (gf) is $K = - gf\ RL / \left[1 + (gi + gf)\ Re \right]$. However the effective input conductance $= gi / \left[1 + (gf\ Re) \right]$ and is small enough to be neglected; thus the actual expression for all practical purposes is therefore $- gf\ RL / \left[1 + (gf\ Re) \right]$. However the actual dynamic load resistance of Q1 must take into consideration the input loading effect of Q2. This turns out to be approximately 580 Ohms. Thus the Dynamic RL equals $1500 \times 580 / \left[1500 + 580 \right] \cong 400$. The stage gain of Q1 then equals $.1 \times 400 / 1 + (.1 \times 380) \cong 1.1$.

Wherever possible it was desired to hold total leakage current effects to a minimum. A good rule of thumb equation for temperature stability is $Re\ (Rb + Rg) / Rb\ Rg = < 0.6$. Thus the Q1 stage is 380 $(68 \times 10^3 + 68 \times 10^2) / 68 \times 10^2 \times 68 \times 10^3 = < 1$. The same temperature stability approach is followed in Q2. Actually fairly good temperature stability can be achieved by making the ratio of the emitter resistance to the parallel combination of Rb and Rg as low as possible. The base current Ib can be determined by dividing the collector current by the ac Beta which $= Ic / ac\beta$.

In attempting to achieve a high order of linearity an additional feedback loop is employed in Q2. The stage gain without this loop is again $\cong$ equal to - gf RL/1 + (gf Re). Since the loading effect of the following cascoded stage is negligible and the $I_c \cong 10$ ma., it follows that K = .35 x 300 / 1 + (.35 x 68) $\cong$ 4 without additional feedback. The voltage of the loop feedback equals:

$$Efb = \frac{Re}{Rfb + Re} = \frac{68}{3750 + 68} = .02$$

and the gain reduction = 1/ [1 + (VG x Efb)].

Numerically then 1/ [1 + (4 x .02)] = 1/1 [1 + .08] = .92 therefore .92 x 4 = 3.7 gain with feedback.

As mentioned previously the last stage transistors Q3 and Q4 are connected cascode. In this stage it is desirable to know the source impedance. If gf is determined, then the source impedance is simply 1/gf and since Ic = 13 ma. then gf $\cong$ 13 x .035 = .455 therefore 1/.455 $\cong$ 2 ohms. A 68 ohm resistor is used to build out for proper line termination match; coax to be terminated in 75 ohms at receiving end thus net terminated dynamic RL = 37.5 ohms. The output voltage gain available from the emitter follower cascode stage = - gf RL/ [1 + (gi + gf) Re] and as before gi is negligible therefore k = - gf RL/ [1 + (gf Re)] and is .455 x 37.5 / [1 + (.455 x 82)] = .45 . The gain figures throughout agree substantially with the measured value.

The maximum collector power dissipation of the 2N 1301 is given by the manufacturer as 150 mw and is of course not exceeded in any of the stages. It would however be prudent to point out that to further minimize temperature changes, the transistors should employ a small fuse clip as a heat sink. Since there are no peaking coils used the only alignment necessary is to vary Q1 emitter by pass capacitor to obtain the flatest high frequency response. The total current drain is approximately 32 milliamperes. The measured noise, using a wide band Ballentine Noise Meter, is 63 db below 1 volt peak-to-peak output.

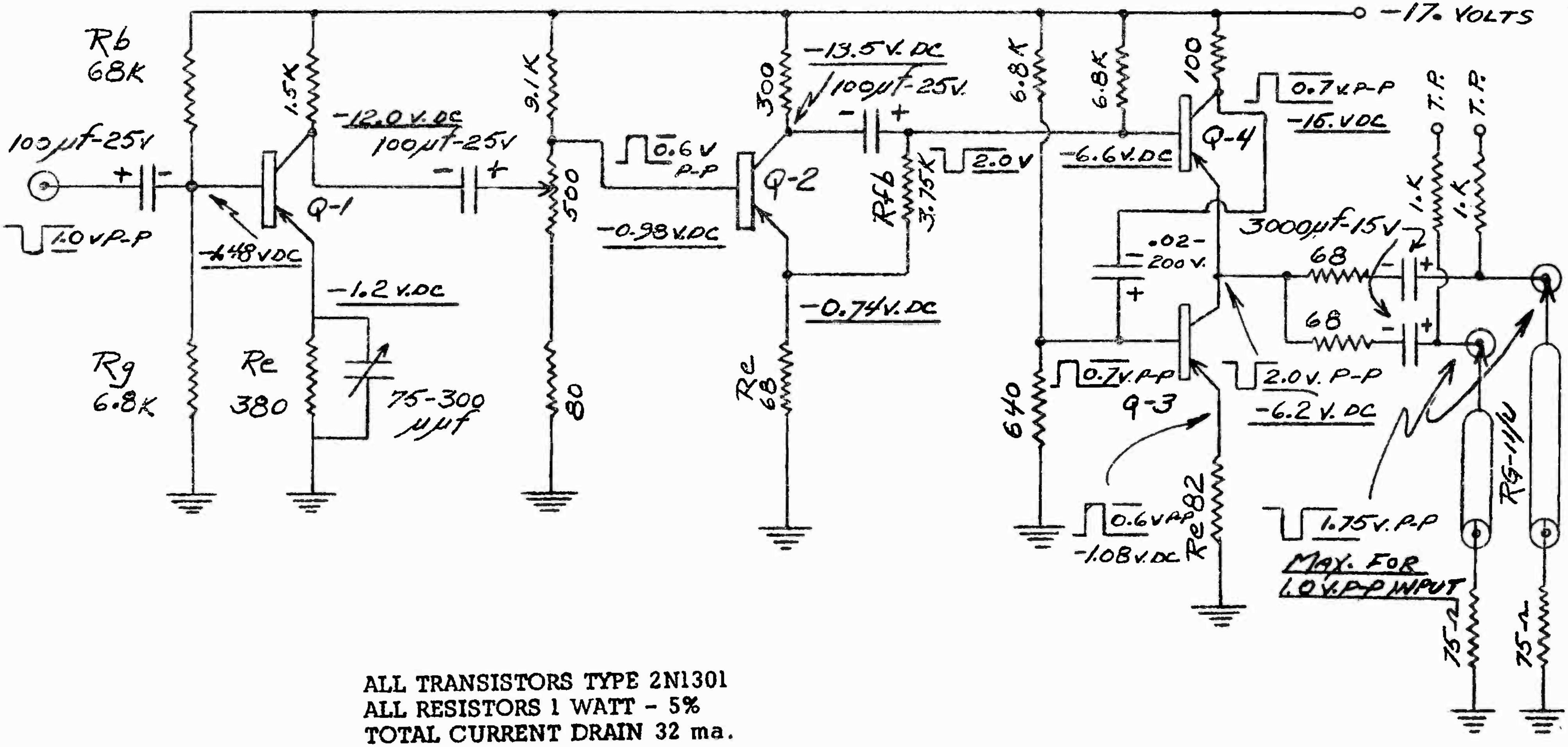
The amplifier will handle peak-to-peak video signals from 0.2 Volts to 2 Volts. A gain control is provided so that an output signal voltage from 0.3 Volts to 2 Volts can be obtained. The frequency response is plus or minus 0.5db from 9 cycles to 9 MC. The low frequency tilt for 60 cycles square-wave is no more than 1% maximum. The differential gain less than the 0.5db and differential phase less than 0.5 degree.

The construction of this DA is very economical; the total cost of the parts is approximately $35.00. While the prototype was built on a regular metal chassis, to conserve space a commercial punched board is preferable. The unit has been on test for the past 3 months and has performed within the specifications set forth in this article.

* Ref: Keats Pullen - Handbook of Transistor Circuit Design (In Press).

LIST OF SYMBOLS

β	-	ac beta
Cbe	-	base to emitter capacity
Ci	-	Actual input capacity
E	-	Supply Voltage
Ec	-	Collector Voltage
Efb	-	Value of feedback Voltage
fα	-	Alpha frequency cut-off
gf	-	forward Transconductance
Ib	-	base current
K	-	Stage gain of degenerative amplifier
Ic	-	Collector current
Ke	-	Emitter gain
Q1	-	Input transistor
Q2	-	2nd stage transistor
Q3 and	-	Last stage transistors
Q4	-	Last stage transistors
Rb	-	Base to Negative Supply Resistor
Re	-	Emitter resistance
Rfb	-	Feedback resistor
Rt	-	Terminating resistance
Rg	-	Base to ground resistor
RL	-	Load resistance
VG	-	Voltage gain



ALL TRANSISTORS TYPE 2N1301
ALL RESISTORS 1 WATT - 5%
TOTAL CURRENT DRAIN 32 ma.

Westinghouse Broadcasting Co., Inc.-WJZ-TV
Circuit Design B.W.
Date: December 15, 1960

DESIGN AND INSTALLATION OF A LARGE STATION AUDIO SYSTEM

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On Wednesday April 5th, 1961, the Dallas Morning News dedicated its new three and a half million dollar WFAA Communications Center. This completely new AM-FM-TV and Recording facility was the culmination of two years of intensive planning and thirty-plus years of experience.

This paper covers only the Audio portion of this new plant. Time and space do not permit more than a review of this complex audio system and the unlimited operational applications which are provided for in this installation.

The following are some of the basic objectives which were to be incorporated in the system design. In the Radio area simplicity of routine operation, combined with maximum flexibility, was the prime design aim. This was necessary because the Radio operation is announcer operated, including operation of the six stereo channel output switching system. Accordingly, a Radio console was developed which is suitable for both monophonic and stereophonic operation.

An important design requirement was that decision making on the part of the operator should be minimized as much as possible. For instance, operator decisions as to which is the right or left channel, and which channel feeds which transmitter were to be eliminated. In a stereo operation, the only decision the operator would be required to make was in regard to number of microphones and whether to use stereo or monaural disc outputs.

It was further decided that normal operation, including a good many standard radio remotes, would require little or no patching. The equipment should enable the announcer to signal and switch to standard remotes without requiring equipment center assistance. Since TV operations require most of the attention of the engineers in the Technical Equipment Center, it was felt that routine Radio operation should be as nearly automatic as possible.

The planning of the TV Audio facilities included, in addition to the studios, a simplified output channel switching system for network feeds, routine building feeds, and a semi-automated transmitter channel, of the preset type, capable of handling up to 25 events.

Careful consideration was given to the TV and recording studio problems. The choice between monophonic and stereophonic systems was a hard one to make. The obvious advances of stereo made at least some stereo mandatory. Since the recording studio required multi-channel stereo, it was thought that building three consoles alike would reduce cost somewhat; therefore, the recording console and the two TV consoles were to be of the same design. After considerable thought on the subject, it was decided that the only way that switching in the equipment center could be handled without error was to also design the output channels for stereo. This results in increased original cost but far less ultimate cost in manpower required to operate the system, and in addition provides increased switching reliability as far as errors are concerned.

With the tremendous amount of equipment involved, the reliability of the components was of prime importance. With hundreds of individual amplifiers in the system. the increased reliability of transistorized amplifiers was deemed advantageous. Therefore, it was decided that the system was to be completely transistorized as possible. To be the first to build a large station with almost all semiconductor equipment was also a challenge. Incidentally, the video and lighting gear is also transistorized wherever possible.

In the selection of facilities, the WFAA goal was to be second to none in any of the three fields of Radio, Television and Recording.

Now that the planning and objectives of this audio system have been outlined briefly, let us consider in detail some of the major components of this installation. A good starting place for a more comprehensive discussion is the facilities installed in the radio studios. This slide shows the floor plan layout of the radio studios and the recording equipment center. There are three radio studios, E, F, and G. It should be noted here, that there are no control rooms associated with these radio studios. The console and auxiliary reproduction mechanisms are mounted in the center of each studio.

Each radio console is a complete single unit assembly. In addition to the usual console controls and switches, all the amplifiers, power supplies, relays, etc. are mounted in the console cabinetry. These consoles are assembled in Textolite covered desk units. The overall dimensions of these consoles are 66 inches long, by 26 inches deep, by $37\frac{1}{2}$ inches high. The center section of the console panels mounts all the usual audio control facilities such as mixers, bus keys, monitor selector and level controls, remote line selector switch, meters and master gain controls. The right hand wing panel is used to mount an assortment of auxiliary controls and switches, while the left hand wing panel mounts all the tally lights, preset selector switches and operating controls for local studio control of the radio master control switching operation. All the preamplifiers, boosters, program amplifiers, monitoring amplifiers and transistorized power supplies are located in the console base.

Let us summarize the programming facilities which have been incorporated into one of these radio consoles.

All functions are outlined in this slide. It should be noted here that all mixer positions and master gain controls are dual channel controls. In addition, all mixers, with the exception of the microphone mixers, are dual cue type attenuators.

Present connections of the microphone facilities permit switching two of four monaural microphones into two stereo preamplifier channels. Wiring and switching circuits are included for future operation of two stereo microphone setups.

Four stereo mixer positions are provided for turntable and tape inputs. Lever keys ahead of the faders permit selection of a tape or turntable source.

The stereo high level mixer positions, each preceded by a ten position interlocked stereo push button switch assembly, permit the mixing of any two of ten possible remote high level stereo signals.

The outputs of the eight stereo mixers may be switched either to the dual program or to dual audition busses. Booster amplifiers are used between the mixer busses and the dual master gain controls. Output from the Master gain controls feeds the program and audition line amplifiers, thence through 6 db pads to the line keys and Master Control.

The monitoring facilities of these consoles comprise a five-position illuminated interlock push button assembly, the outputs of which are connected to bridging coils which feed a stereo monitoring attenuator which in turn feeds dual 10-watt monitoring amplifiers. Inputs to the monitoring selector switch include the stereo outputs from the program channels, the stereo output of the audition channels, plus three external stereo inputs. Additional monitoring facilities include stereo head phone jacks which are interlocked by means of a relay with the console's amplified cue circuit.

All left and right attenuator cue outputs are tied into a common left and right cue buss. This cue buss is wired through a cue selector key which permits the operator to selectively listen to either right or left channel cue or the sum. The output of this cue switch is fed into a cue amplifier which feeds a cue speaker and, by relay, the stereo head phones.

In practice, some of the inputs originally planned as microphone inputs are now being used for other sources. The Studio "F" console is currently being used for most of the "ON-AIR" programming for AM and FM Radio. Inputs to this console at the present time are as follows: Four Turntables, two microphones, two Gates 101 spotters, four Collins cartridge tape machines, one Ampex PR-10-2 and one Ampex 354 plus eight remote lines.

So much for radio, now let us turn our attention to the TV and recording facilities. The TV portion of this new plant includes three TV Studios, A, B and C, handled by Audio Control Centers A and C. In addition, a large recording studio "D" located on the first floor is equipped with similar facilities found in A and C. Figure 6 outlines the location plan of the TV studios and associated Audio Control Centers.

In designing the TV and recording facilities several operational features were given careful consideration. For example:

A primary consideration was that the console handle a complex large studio production, stereo or monophonic, yet be simple to operate for the routine average small production encountered in day to day type operation. All inputs are available for all uses, such as microphones on "hi level" mixers, other studio outputs, announce microphone complete with relay, etc., due to an extensive console jack field. The interlocking circuits for program and communication facilities to the studios must function under all possible conditions of operation. Non-interlock feeds are available to any studio for lip-sync or conditions requiring a hot mike, without a complicated patch cord set-up. An audience reaction mixer for large Studio "A" and an Audience PA system, not fed by the audience reaction mixer, were also required. Echo mixer facilities for 2 EMT 140 Reverberation Generators are available for the three consoles. For WFAA system operation, a design consideration was that the console must supply at least two outputs at all times, either a stereo pair or two, in-phase, matched monophonic signals. In practice, the output may consist of a combination of stereo and mono signals at the same time, or it may be mono inserts in a live stereo pickup. It is a fact that, for TV, most of the uses will be for normal monophonic audio, so it is very important that the controls on the console do not become complicated because of the stereo possibilities. That this has been accomplished is demonstrated by the fact that there are no controls on the console that are not required for monophonic operation, except for a couple of extra monitor input buttons. For stereo, no choice has to be made except at the input. This choice is left channel, right channel, or both (center) channel.

A simplified diagram of a TV Studio Audio Console is shown by this slide.

A total of 66 microphone lines, from Studio A, B, C and D are brought into jacks on the console turret. Patch cords connected to eight preamplifier inputs permit flexible microphone selection. The outputs of the eight preamplifiers, the levels of which are controlled by monaural faders, are combined in a two channel sub-master mixer buss. These busses are then normally connected into stereo input amplifiers which are part of a Master Mixer Group.

The Master Mixer Group is composed of fourteen preamplifiers, connected as seven stereo input amplifier pairs. Each pair of amplifiers is controlled by stereo attenuators. The output of this group is combined into two stereo mixer busses.

Signals fed into this group of inputs include the two sub-master busses, two boom microphone preamplifier outputs, an announce microphone and two stereo turntables.

Ten assorted stereo high level inputs are brought into a group of three interlocked ten position push button switches. The output of each switch group is connected into a pair of preamplifiers.

The outputs of these three high level stereo amplifiers are connected to form two three-position stereo mixer busses.

Eight preamplifiers, used as booster amplifiers, provide amplification between mixer busses and the master gain controls. Eight vertical attenuators are used for master gain use. These units are arranged in pairs so they may be used as individual monaural controls or mechanically locked together as stereo controls.

The output of the master gain attenuators are connected to provide stereo program and stereo audition inputs to the console channel amplifiers.

The stereo program and stereo audition outputs feed thru 6 db pads to Master Control.

Complete monophonic and stereophonic monitoring and metering facilities are incorporated in each console. The monitoring facilities of each console are provided with muting relays which are controlled by transistorized interlocking circuits with the microphone mixer keys and jacks. Special circuiting extends the control to microphones and speakers in other studios when such an arrangement is patched up on the console jack field.

Each console is also equipped with amplified cue and talkback circuits for complete flexibility of operation. In addition, two to four utility amplifiers with mixers and line amplifier for echo purposes are built into each console.

The Studio A Console differs from the Studio C and D consoles in that a four channel audience reaction mixer system and an audience sound reinforcement system are incorporated in the console system. For comparison with an average studio console, the TV Studio A console has a total complement of 58 amplifiers while Studio C and D have a count of 53 amplifiers each. The TV and Recording studio consoles differ from Radio in that two to four racks are utilized with each console in the control rooms.

Having outlined the audio facilities available in a TV studio, let us consider the typical application of this equipment. For a routine operation let us assume the following conditions are set up; on the three high level inputs, Film, Video Tape, and Net are punched up. For this normal operation, only the bottom row of mixers need be used. There might be one boom microphone, an announce microphone (switched by announcer) one or two turntables, and the three high level inputs. No further switching is necessary. Any cueing or previewing needed is provided by the cue pots. This is as simple an operation as you can get (much easier than on small consoles where high level inputs must be switched). Yet with this console, a talented audio operator can easily set up a large multi-microphone show.

A larger monophonic show may include the following: First six microphones on upper mixer level and assigned to submaster 1 on bottom row. Last two mikes on upper level setup for two members of the cast and assigned to submaster 2. A Boom mike setup for a vocalist. The equalizer in this boom may be adjusted for better separation from the band if required. Assume a little liveness is desired on the boom mike pickup. This is obtained by patching the left channel output of the boom mike preamplifier into one of the echo amplifier inputs. The echo return is then brought back through the high level selector and fed into mixer eight.

Any input on the last three pots (hi-level) may be fed to the studio regardless of whether mikes are on or not, by use of the playback facility. This may be done even though the key for this particular channel is not yet operated. This is convenient when it is necessary to rehearse with this facility while the console is already on the air with other material. No microphone voltages ordinarily appear on this portion of the mixer buss so there is no danger of feedback. If it is desired to feedback a turntable input by this means, it can be patched to one of the high level inputs.

The mixer buss is split between the first seven and the last three pots for several reasons. First, this makes it possible to use the studio playback facility with no feedback, and without any special bridge pads or isolation amplifiers. Second, and probably most important, it is possible to fade out a large studio microphone setup for a pre-recorded video tape production number, film commercial, etc., and then fade it back in without a scramble for fader knobs. This makes it possible also to use the board for four full channels by assigning the upper seven pots to the program channel, and the lower three to the audition channel. If this does not give the proper distribution of mike inputs, one of the submaster outputs can be patched to one of the high level inputs, allowing the eight submaster mikes to be assigned to either portion of the mixer buss.

If all the above arrangements do not allow enough input circuits, it is possible to open the large doors between the audio control rooms and operate both TV consoles together, as each console appears as an input on the high level selector switch of the other console. The attenuator on the second console functions as a submaster for the entire first console. There are ample microphone connectors in all three studios for both consoles, and the interlock conditions are still fulfilled.

For stereo operation, pairs of microphones may be patched into the left or right sides of the ten lower row attenuators. As arranged without patching, the announcer and the boom microphones will appear on both left and right channels, and travel through the system as a phantom center channel. The eight submaster microphone channels may be operated as four left and four right microphones by the use of one patch cord. This patch cord should be from the left output of submaster 2 mixer amplifier to the submaster 1 right attenuator input. Microphones assigned to submaster 1 will now appear as left microphones, on submaster 1. Microphones assigned to submaster 2 will now appear as right microphones still on submaster 1. This, in effect, converts the sub 1-sub 2 keys over these eight pots into left-right assignment keys.

One interesting possibility is useful, especially for the recording console operation, if the above mentioned patching is carried one step further. If the right output of submaster 1 mixer amplifier is now patched to the submaster 2 left attenuator input, the same left-right setup on the upper row of mixers appears on both submaster 1 and submaster 2 simultaneously. The following setup is now possible. These eight mikes may be used to pick up a band in stereo. This group is now assigned to submaster 1 and to the program channel. Another input is assigned to a vocalist and to the program channel, while still another is used for an instrumental soloist, still on the program channel. This combination is now mixed on the program channel and recorded on a two track tape. It may be played back and checked if desired. At the same time the above is taking place, the submaster 2 is assigned to the audition channel and recorded on the first two tracks of a separate four track tape. The vocalist and the soloist microphone channels may be bridged by the two remaining channels of the four track tape. As the recording session progresses, we now have a mixed stereo tape for immediate playback and checking. We also have four individual original tracks for later mixing into mono or stereo masters.

Master Control functions for both Radio and TV are provided in the Technical Equipment Center. The Audio portion of the Technical Equipment Center is contained in a group of ten racks. Most of the program amplifying, metering and monitoring facilities are contained in an eight bay portion of the ten racks. This slide shows a front view of the basic Audio Control Center. The three left-hand racks mount the Radio remote and output channel equipment while the three right-hand racks mount the Radio remote and output channel equipment while the three right-hand racks contain the TV audio remote and output channel facilities. The two center racks contain telephone line facilities, common remote and line patching facilities, stereo metering and stereo monitoring facilities. There are three parts to the Equipment Center, the remote section, the switching section and the output section.

The Radio part of the remote section has eight channels. The function of these units is to bring a remote signal up to a standard level (plus 8 dbm) for use in the system and to distribute the signal to the three radio consoles. Four of these units are set up for use as stereo channels and feed the relay switcher as well as the three consoles. With minor modifications, these four units could also operate as separate monophonic remote channels. The other four channels are monophonic, but can be changed to stereo with the addition of amplifiers. In any event, all feeds end up as either a stereo pair, or an in-phase matched monophonic pair.

At WFAA, these remotes are currently set up as follows:

Remote 11 - US Department of Agriculture, for market reports
Remote 12 - Spare
Remote 13 - Dale Milford residence. Milford is our staff meteorologist for both Radio and TV. He has a set of Weather Bureau teletypes in his home as well as here at the station. This line is used to broadcast weather information direct from his home.

Remote 14 - Permanently installed receiving line from Telco. Used as ordered up by WFAA for occasional feeds.
Remote 15 - Fort Worth residence of Ted Gouldy for Livestock Market reports daily.
Remote 16 - Telco permanent receiving loop occasional use.
Remote 17 - NBC Radio Net receiving line for use on 820 KC frequency and FM.
Remote 18 - ABC Radio Net receiving line for use on 570 KC frequency and FM.

These circuits are available at all times on all three radio consoles. The operators also have telephone company facilities on each console for talking to the two radio transmitters as well as to the FM transmitter. The operators can signal or talk to the remote points as needed. Since these circuits are permanent, and the levels set, the announcer-operator can signal and place these remotes on the air independently. The engineers in the Equipment Center have VU meters and monitors for these circuits to check the operation.

The TV remote section is similar to the Radio section except that only three channels are provided. These three channels feed the TV Relay Switcher and the two TV Consoles.

Remote 1 - TV spare channel patchable for remotes.
Remote 2 - Telco permanent receiving loop for occasional use as ordered by WFAA.
Remote 3 - ABC TV Net receiving loop.
The radio and TV remote channels are interchangeable if needed.

There are two units in this section, the Radio relay switcher and the TV relay switcher. The radio switcher is a 10 x 6 stereo unit. There are four control points for this switcher. The Technical Equipment Center has a control panel of the preset and on air type, and a delegate panel. The delegate panel allows the engineer in charge to switch control of any of the six channels to his local panel or to the Radio studios, where it is again delegated to any of the three Radio consoles.

The TV switcher has a total of 21 inputs and 14 outputs. This switcher is used to delegate film and tape outputs to the studio consoles, switch inputs to four video tape machines, as well as switch the five TV output channels. Four of these output channels are controlled by a preset-on-air type control panel as used in radio master control switchers for many years. This panel controls video and audio together with no separation possible. This greatly simplifies switching for routine operation. The fifth TV output channel is controlled by the semi-automated program channel. It will allow simultaneous video and audio switching or separate audio and video switching controlled by direct punch buttons or by information stored in the preselector.

The Radio Output section of TEC has six stereo output channels. These are identical except the first three have AGC tube amplifiers, and the other three have transistorized line amplifiers. The right side of channel 11 feeds the 820 transmitter line. Right side of channel 12 feeds the 570 transmitter line. Channel 13 left side feeds the FM transmitter. This results in an AM or FM transmitter feed which is either an in-phase monophonic signal to each (resulting in sound from the center in stereo broadcasting), or the proper side of a stereo pair, if the channels are switched up to the same console output. The two sides of an output channel can be used to feed the same transmitter for stereo, as in FM and Multiplex stereo, or can be adapted to feed in other manners are required. The remaining three radio channels are used for network feeds, or for feeds within the building as needed.

The TV Output section of TEC has five stereo channels. The first four of these have transistor line amplifiers and are used in a manner similar to the last three radio channels for net feeds, etc. The fifth channel has a pair of AGC tube amplifiers and is used to feed the channel 8 TV transmitter. The left side of this channel feeds the land line. The right side feeds the microwave STL. An interesting by-product of this arrangement is that we now have a 100% spare audio system from the studio microphone all the way to the transmitter input. The transmitter operator can choose at will from either source. The AGC amplifiers are necessary when the system is used with the preset swticher and the signal is not traveling through a studio console.

Monitoring both in the technical areas and in the various offices throughout the building is handled by means of a dial switching unit. Program material is selected by means of a telephone type dial for audio only, or audio and video as the case may be. All of the output channels, as well as many of the remote signals, console outputs, etc., are available on this unit to a total of forty points. Each point may be equipped for video, monophonic audio or stereo audio, as needed.

General Electric's participation in this project required the design of a new high level preamplifier and a transistorized equalized stereo transcription preamplifier.

The new preamplifier, designated as the BA-25-A, is capable of +18 dbm out with half precent or less distortion. Frequency response is ± 1 db from 30 cps to 15 KC, with 46 db of gain. This preamplifier, due to its output rating, is suited for application as a microphone preamplifier, as a booster amplifier or as an isolation amplifier.

The transcription preamplifier is essentially two amplifier channels working from a common supply. Equalization is fixed to provide NAB response when used with the GE VR-225 Stereo cartridge. For monaural reproduction, the two amplifier channels are connected in parallel at the output of the second stage. The resultant signal then feeds equally through the output stages of both channels.

This report has endeavored to outline briefly our objectives in the design and installation of this new plant. It is our belief that the rapid advance of stereo and multi channel audio techniques will justify the magnitude of this installation in the years ahead.

THE APPLICATION OF 8mm MAGNETIC SOUND EQUIPMENT IN TELEVISION

by Kenneth Li Donnici

INTRODUCTION

Those of us engaged in the development of the 8mm magnetic sound camera must make a conscious effort to constrain our enthusiasm when considering any of the numerous applications in entertainment and industry that this new medium can offer. Home sound movies, progress reports, legal evidence, safety campaigns, East Coast pep talks from a West Coast Sales Manager, action interviews of water skiers - all offer possibilities, and, all have been accomplished in the year since its introduction. The intense interest generated by our initial explorations into the use of 8mm sound equipment in television broadcasting, indicated that here was a field that justified additional effort. It is a primary purpose of this report briefly to explain some of the features of three related pieces of equipment:

1. The Fairchild Cinephonic 8mm Sound Camera
2. The Mini-Rapid Film Processor
3. The Cinephonic 8mm Sound Projector

THE CAMERA

The Cinephonic 8mm Sound Camera (Fig. 1) is equipped with a 3-lens turret, with a fixed focus f/1.8 13mm lens furnished as standard equipment. Telephoto and wide angle lenses are available as accessories. It is driven by a 12-volt centrifugally governed motor, powered by a hermetically sealed nickel-cadmium rechargeable battery, which also furnishes power to the fully transistorized amplifier. A separate stage is provided in the ampliflier to permit monitoring sound through a headset. A low-impedance omni-directional dynamic microphone is furnished as standard equipment, as is the monitoring headset. It has a capacity of 50-feet, yielding 100 feet of processed film and runs at 24 pictures-per-second. At this projection rate, uninterrupted screen lengths of 2 minutes and 45 seconds are possible, and after the spool has been reversed in the camera, an additional amount is available yielding 5-1/2 minutes of program material from the 50-foot roll of double-8 film. A 400-foot reel, on projection, offers 22 minutes of running time. The film is fine-grain color, tungsten balanced with an ASA rating of 12. A conversion filter is furnished for daylight use at ASA 10. The film is prestriped with magnetic oxide on the back side along the edge outside the perforations. The magnetic sound head is placed ahead of the picture aperture, and sound is recorded on the film simultaneously with the action.

THE PROCESSOR

The Fairchild Mini-Rapid 16 Processor (Fig. 2) is a relatively small (13"x13"x27" long) and light-weight (65 lbs.) table top unit, capable of handling up to 400 feet of 16mm, or double-eight, film at a single loading. It is a negative processor and requires that, in television, the image be reversed electrically upon projection. When double-eight film is used, it is necessary subsequently to slit it to single 8mm width.

The machine, leaderless and self-threading, passes the film through four processing solutions which are normally:

Developer
Fixer
Water rinse (2)

The stainless-steel solution tanks are heated electrically, and thermostatically controlled to permit processing, at elevated temperatures, films with pre-hardened emulsions. A typical example of processing speed and temperature for Du Pont 931A is 105 degrees F at 6 feet per minute.

The processed film is dried by hot air circulated through the drying chamber unit which contains a 600-watt heater and a 350-cfm blower motor. A thermostat permits regulation of the drying air temperature between 95 degrees F and 165 degrees F.

THE PROJECTOR

The standard Cinephonic 8mm Sound Projector (Fig. 3) accepts 400 feet of film and is housed in an aluminum die-cast housing with the speaker separate to permit its being placed at the screen. It uses a 150-watt Tru-flector type lamp yielding the equivalent in light output of a standard 500-watt machine. Provision is made for playing back films with pre-recorded sound, as well as for adding sound over that already on the film and for complete erasure and recording. The frequency response of the vacuum-tube amplifier is 100 to 6000 cycles, plus or minus 3db and furnishes 4 watts of peak power.

This standard machine has been modified for use in television broadcasting in the following ways (Fig. 4):

a) Its shutter has been redesigned to permit projection into a vidicon chain without causing "shutter bar." More about that later.

b) A synchronous motor is used in place of the standard to insure precisely controlled speed. In this connection, miniature timing belts were substituted for the smooth belt drive to the shutter.

c) Provision is made for picking up directly from the sound head, if desired, or from the last stage of the built-in amplifier.

d) An accessory remote dimmer control and on-off switch is available.

e) Various focal length lenses make it possible to use this equipment under a variety of conditions determined by physical location. It should be noted that the focal length required is just half that used on a 16mm machine located at the same distance from the vidicon face.

GENERAL

The projector shutter has been designed to conform with the requirement of Proposed American Standard PH 22.125, 16mm Television Intermittent Projector for Vidicon Camera Operation, which calls for an illumination period of a minimum of 25 percent of the television field. It is five-bladed, each blade being 50 degrees wide, with resulting 22-degree open spaces. A schematic representation of the operation of the shutter versus the TV fields is shown as Fig. 5. For purposes of simplification, the transition region between shutter open and shutter closed is ignored, as is the blanking period of the TV field.

Time zero in this plot is chosen as the beginning of the odd TV frame, and also the beginning of the first illumination through the shutter opening. The 24-per-second frame rate of the projector, with five illuminations per frame, causes each of the TV fields to be illuminated twice. Examination of the plot will reveal that this design meets the requirement that successive television fields receive substantially the same exposure in both timing and intensity to eliminate flicker disturbances. This situation would obtain for any relative position of the shutter and the TV fields. The film pulldown occurs during one of the dark periods.

The projection lamp is mounted in a base which obviates any requirement for individually focussing the lamps as they are replaced. It can be expected that the normal 15 hour lamp life can be extended greatly by the reduction of voltage effected through the dimmer control. Adequate cooling is achieved by means of a centrifugal blower, and no heat-absorbent filters are used. The dimmer which varies the voltage to the lamp, will affect the color temperature of the projected light. This should not, however, rule out the use of color film, since gross attenuation of the light could be accomplished by the use of neutral density filters, and the dimmer control used for fine adjustment only. Black and white projection is unaffected by variations of lamp voltage.

The projector's ability to erase, re-record and overlay can be expected to add flexibility in the use of 8mm film in television. For example, unwanted audio can be erased, and post-recorded commentary substituted. Or, for effect, commentary can be added over the existing sound track. In this mode, the erase head is de-energized, and the audio merely 'double exposed,' the only attenuation of the original track being caused by the bias current of the recording sound head.

Now, regarding editing of the single-system sound film on which the sound is separated from its corresponding picture by 56 frames (8.4 inches), which in terms of time is equivalent to 2-1/3 seconds, the obvious approach during filming is to allow three seconds at the beginning and end of each scene. This would avoid sound from the preceding scene being reproduced during the first 2-1/3 seconds of the new. But even without such preparation, the relatively short out-of-synch sequence is not necessarily injurious. Remembering that an essential advantage to the use of this equipment is speed, and ease, in presenting timely information, the problems associated with the editing of double system recordings, while possibly allowing more sophistication, do require a corresponding increase in the attention to such details as timing marks, and the like.

Some work has been done on adapting the camera for use in kinescope recording. Here, we should realize that the portability and simplicity of operation that makes the camera so outstanding for in-the-field photographic recording, is not a requirement in a studio where the complexity of the existing electronic equipment dwarfs the requirements of the standard 16mm kinescope camera. It is felt, however, that the use of 8mm kinescopes would find application in areas where it is desired to maintain records where the primary emphasis would be in the area of reference, rather than rebroadcast. In this case, the simplest conversion would consist of the use of a synchronous motor, and a shutter with the characteristics depicted in Fig. 6. This design permits uniform exposure across the entire film frame, irrespective of the relative phasing of camera shutter cycle versus the television field display. Initial experiments prove that the only degredation in picture quality is the typical 16mm-18mm comparison which is already well known.

The presence of the magnetic-oxide sound stripe on the film imposes no restriction on the normal processing method. There is no deleterious effect to either the film or the processing solutions when handled as a negative in the Mini-Rapid Processor, or as a reversal print in any standard processing device.

CASE HISTORY

That the application of this equipment in television broadcasting is already an accomplished fact is best illustrated by the following case history.

In February of 1961, station KPHO-TV, Channel 5, Phoenix, Arizona, a division of the Meredith Broadcasting Company, became the first television station in the country to use Fairchild 8mm sound equipment in a commercial broadcast. At that time, a public display of a full-size Titan missile was the background for an on-the-spot interview of the officer in charge. This interview was conducted and filmed by the station's film director, after nothing more than a brief introduction into the use of this equipment. The point here is that there is no need to restrict the filming of special-event material to highly trained technicians, nor is there any requirement for a lengthy training program. That film, incidentally, was broadcast immediately, while the timing was correct for assuring maximum impact at the local level. It was processed negative in the Mini-Rapid Processor, slit to 8mm width, with a device similar to that shown in Fig. 7, and projected by the Fairchild 8mm TV projector through an existing multiplexing arrangement.

George Mc Clanathan, Director of Engineering for KPHO, is responsible for having worked out the details of this pioneer effort and he is the source of the background material relating to it in this report. The ease of getting into operation with and the utility gained from the use of this equipment has encouraged that station to expand its usage.

CONCLUSION

The prominence that the 8mm magnetic sound medium has achieved in the relatively short time since the introduction of the amateur sound camera is testimony to the correctness of the concept. The increased flexibility it affords, the economies it allows, and indeed the high quality of product that is already being achieved, all militate toward its expanding utilization in television broadcasting. Just as 8mm magnetic cannot be expected to replace existing methods of sound film preproduction, it can neither be considered a passing curiosity. It is seeking its place, and the enlightened approach to the adoption of suitable standards which is being taken, coupled with the expanding usage to which it is already being subjected is certain to assure it a permanent place in the industry.

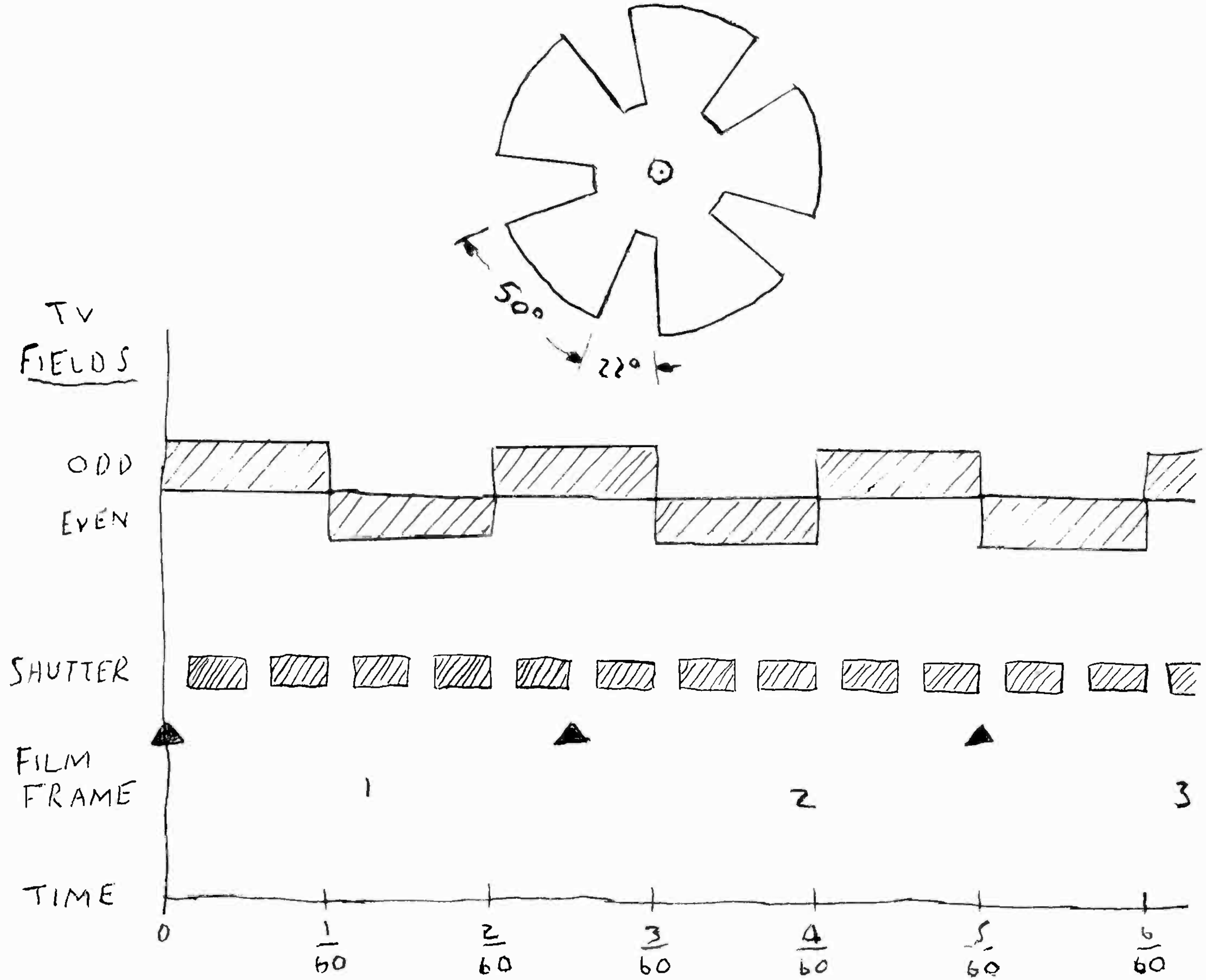
Acknowledgment is gratefully made to Mr. A. Malang, Chief Video Facilities Engineer, of ABC-TV, who furnished much of the technical assistance associated with the early development and testing of the TV projector, to Mr. Richard B. Rawls, Vice President and General Manager of KPHO, and to the library of the Society of Motion Picture and Television Engineers for the comprehensive documentation so readily available for reference.

THE APPLICATION OF 8mm MAGNETIC SOUND EQUIPMENT

IN TELEVISION

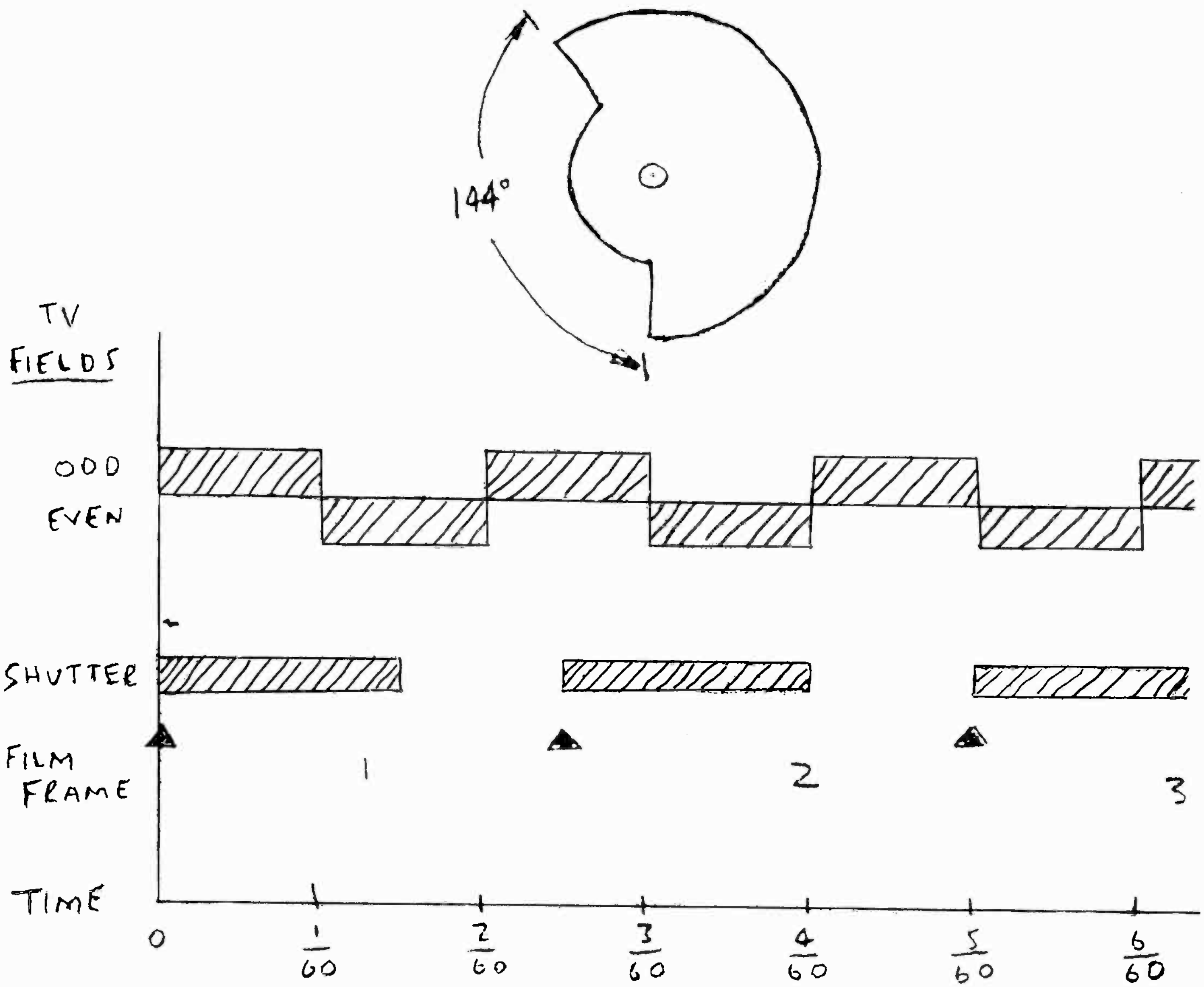
by Kenneth Li Donnici

LIST OF ILLUSTRATIONS:



OPERATING CYCLE, FAIRCHILD KTV TELEVISION PROJECTOR

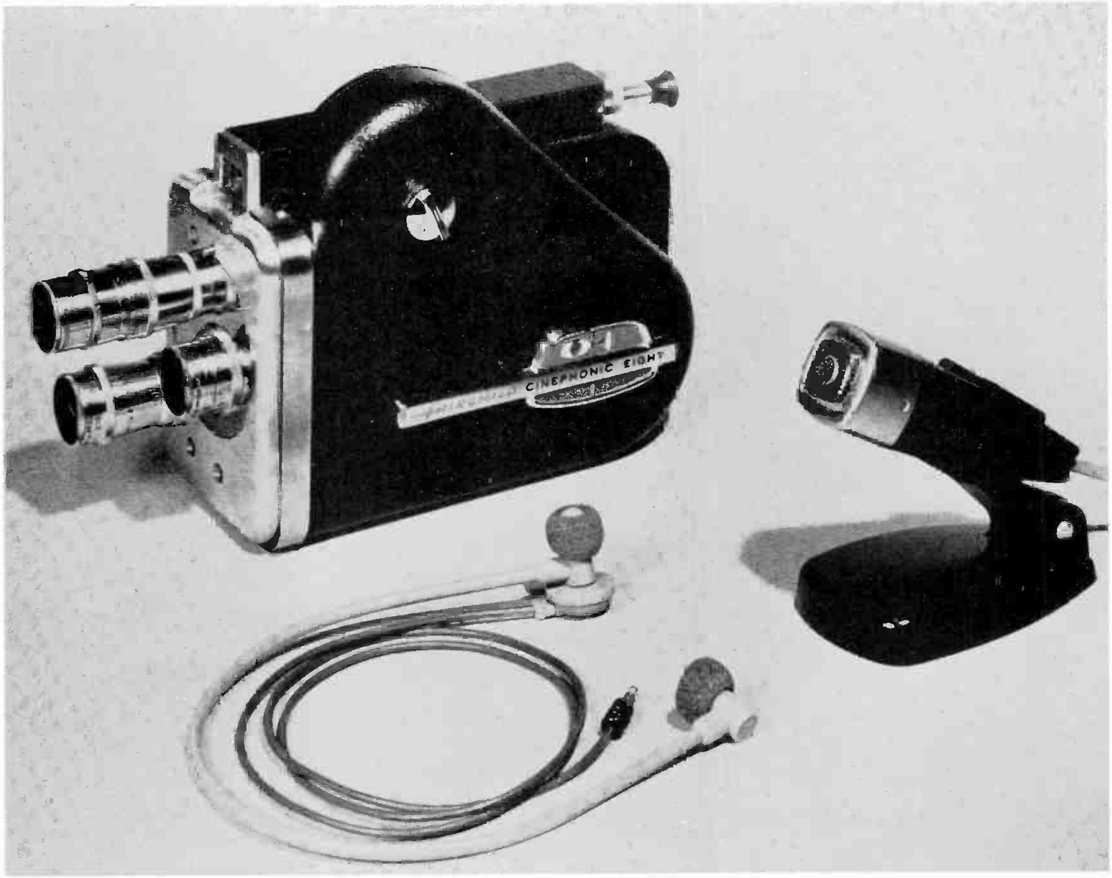
FIG. 5



OPERATING CYCLE, PROPOSED FAIRCHILD 8MM KINESCOPE CAMERA

FIG. 6

Fig. 1



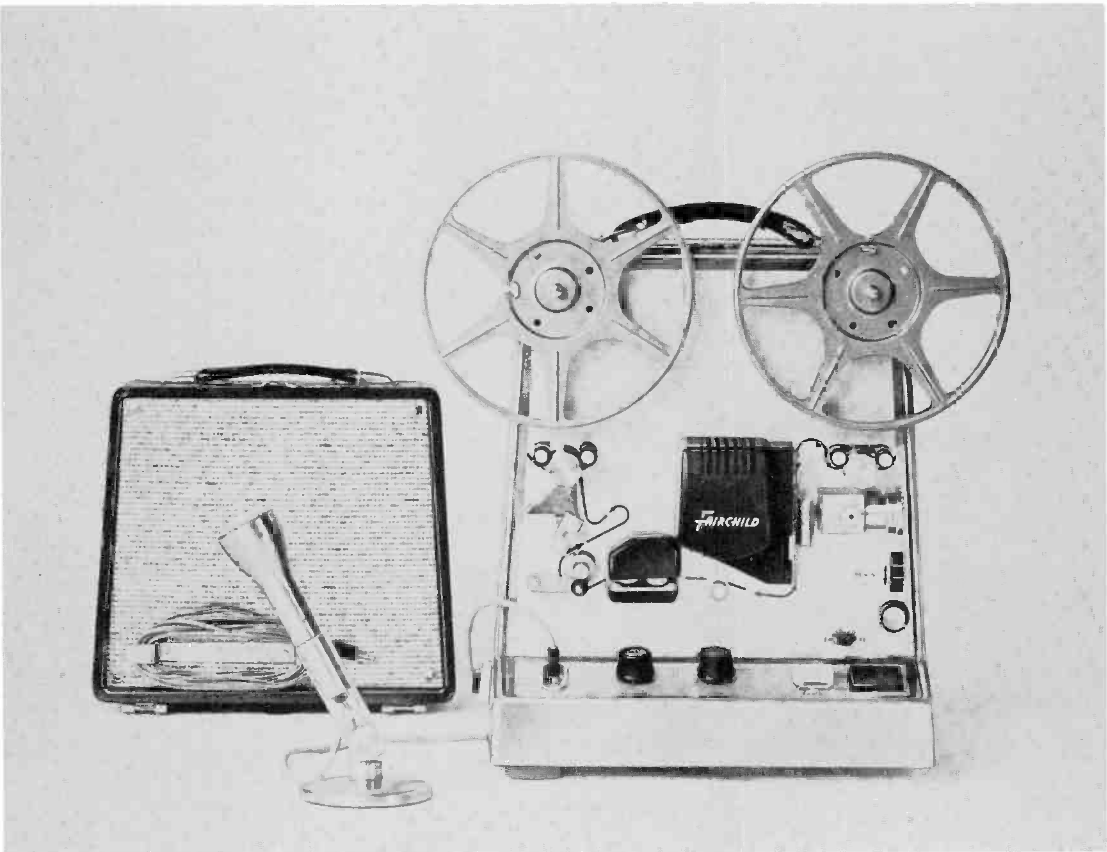


Fig. 3

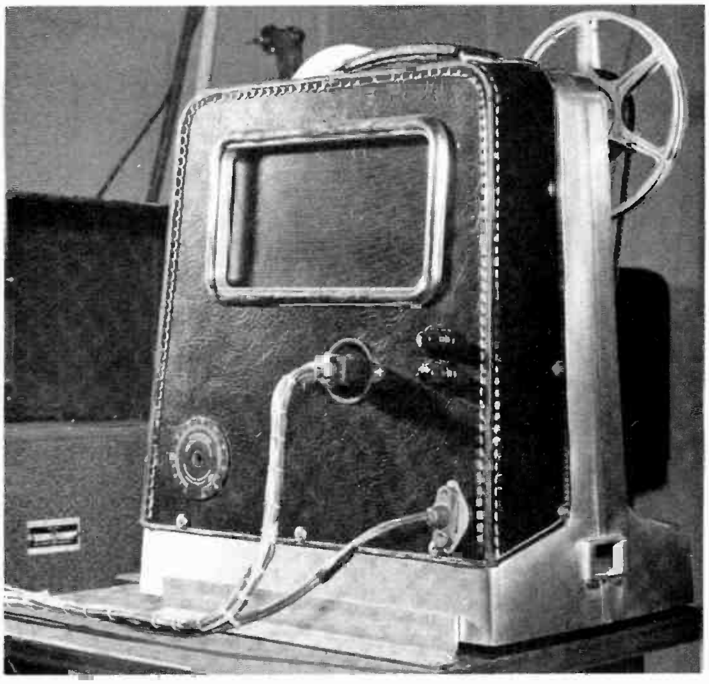


Fig. 4

Fig. 2

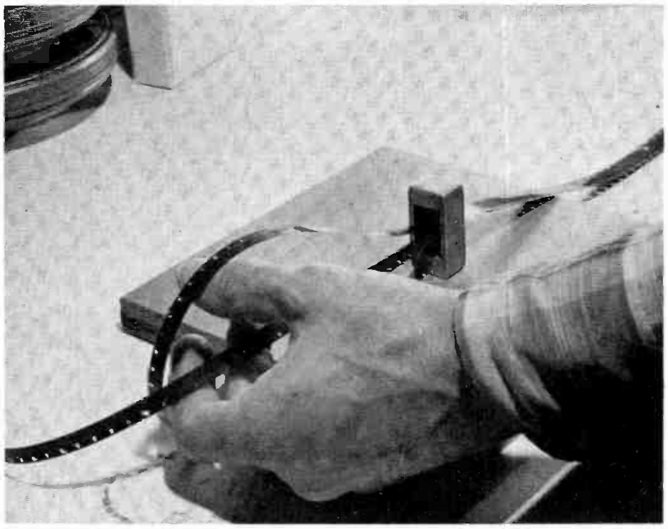


Fig. 7

TIME BASE COMPENSATION IN WIDEBAND MAGNETIC RECORDING

AMPEX

TIME BASE COMPENSATION IN WIDEBAND MAGNETIC RECORDING

Since the inception of the video recorder, designers have had to overcome two cardinal problems. The first and the most obvious problem is that of recording high frequency signals on the tape and retrieving these on playback with some degree of fidelity. The problem was solved by going to a very high writing speed, 1500 ips, and by using a suppressed carrier vestigial sideband FM modulation system. The high writing speeds were obtained by a method, which I am sure you are familiar with and that is, rotating a four headed drum at 14,400 rpm in a transverse scan across the tape as seen in Page 12. Having recorded the high frequency signals and achieved the necessary high writing speeds, the next problem of time base stability on playback becomes evident. It is to this problem of time base stability that I will address myself this morning.

The transverse four headed scan configuration was the obvious choice for achieving a time base stability that would be commensurate with the FCC's specifications for the rate of change of horizontal frequency for a transmitted television signal. With such a scanning assembly we achieve the best possible immunity from tape flutter since the flutter component is a longitudinal one and the head, in effect, is writing perpendicular to the direction of flutter.

I would now like to trace for you the evolution of this art of time base control in the four headed transverse scan wideband recorder. The first bench mark in the growth of the sophistication of time base control occurred in 1956 with the introduction of the first basic video head servo system which permitted the playback of a television signal within the FCC specified rate of change of horizontal frequency of .15 per cent per second per second. The next step came with the ability to tie the playback signal to a station synchronizing generator or another video signal. This was done with a commercial unit which was called Inter-Sync*. Further improvement in time base compensation and elimination of timing error was made through the use of an open loop all electronic variable delay system accurate enough to eliminate all geometric errors in the television signal. Finally we come to the ultimate in time base compensation with an additional open loop electronic delay system which we call Colortec*, which permits us to playback color from a video tape without the use of such debilitating methods as heterodyning. From Page 13 we see we have a time base stability which starts off in the basic servo with a long term accuracy of about 10 microseconds, progresses to the Inter-Sync servo stability where we have time base errors less than .15 of a microsecond line to line, to the voltage variable delay line time base corrector called Amtec* which as a time base correction to ± 30 millimicroseconds line to line, and finally to the Colortec, or a direct color system, in which we achieve a time base stability of ± 4.0 millimicroseconds either line to line or over a long term period. Now these efforts in time base stability correction have two general classes--closed loop electro-mechanical and open loop all electronic. In the coarser efforts, the electro-mechanical system is operated via servos with varying degrees of complexity to achieve up to .15 of a microsecond in time base stability between lines. Extensive analytical work led our Engineering staff to the conclusion that the Inter-Sync with this degree of control was as far as one could practically go in the design and manufacture of an electro-mechanical closed loop system. Thus, the next step was obviously one in which we have an open loop system, in which we control the time base stability via all electronic means, which implies a voltage

* Trademark, Ampex Corporation

variable delay line whose signals to control it are derived from an average of the interval between the leading edges of successive playback horizontal sync pulses.

I would like to turn your attention first to the electro-mechanical closed loop systems.

A quick look at the geometry of the video tape recorder top plate would indicate the necessity for two types of time base control. Admittedly these are both coarse, but obviously both are necessary. One would be the capstan servo control to govern the longitudinal position of the tape, and the other to control the rotational position of the video heads. Both must be inter-related and identical in playback as they were in record mode. Further, if we are to achieve interchangeability of tapes, these two parameters must be the same on all machines at all times. The tape positioning control, or the capstan servo system, does its work by locking the rotation of the capstan motor to that of the head drum motor during the recording process. The 240 cycle output of the photoelectric cell on the head drum is divided down to 60 cycles and serves as the sourve to drive the capstan synchronous motor. This same signal is also recorded longitudinally on the bottom of the tape and serves, in effect, as magnetic sprocket holes. During the reproduce mode, the capstan servo system compares the signal from the reproduced control track with the signal from the photoelectric cell which is an instantaneous tachometer. The capstan motor speed is then governed by a servo which makes this comparison in order to maintain the exact relationship between the angular head position and the longitudinal tape position that existed during the record mode. Now, the head drum motor which is rotating at 14,400 rps is controlled through a two servo loop system. One is a fast servo which provides the proper frequency to the head drum synchronous motor. This serves both servo systems and insures that the vertical sync is recorded at the same position on the tape at all times. The fast servo loop stabilizes the drum motor and suppresses hunting and corrects for the physical and mechanical variations that might tend to affect the rotational speed. In the servo loop, the phase position of the drum motor is determined by 240 cycle output of the photoelectric cell. The fast servo loop in this system uses the photoelectric cell output to control the phase of the voltage that is fed to the head drum motor. Now a combination of these two servo systems in the drum servo control unit result in a timing error of about 1 microsecond short term and 10 microseconds on long term, and rate of change less the .15 per cent per second per second over 2.5 to 6.5 milliseconds. In practical terms this accuracy was sufficient to meet FCC requirements, but would not permit the inter-synchronization that the many broadcast operations require.

Let us now look at the next step in sophistication of servo control which achieved inter-synchronization. Now since the drum is rotating at 240 revolutions per second we know that it will rotate .0864 degrees in one microsecond and further if we are to achieve an accuracy of control to .10 of a microsecond it becomes obvious that the drum rotation must be held to within .00864 degrees of error. This is cumulative in both record and playback. A number of years ago it was felt that to achieve this degree of stability in a tape machine would be quite impractical. In an attempt to verify the feasibility of this type of electro-mechanical control, the Stanford Research Institute carried on a development program for Ampex to prove or disprove such a possibility. Needless to say the results of the experiment indicated that such control was possible. It is interesting to note that these experiments at S.R.I. made use of a microscope, a high sampling rate tachometer disk, and phase detector whose frequency was 126 kilocycles per second or 8 times the horizontal sync pulse repetition rate. In the final practical machine which has now been on the market for over a year, Mr. Harold Clark of the Ampex Corporation devised a method in which the sync pulse information could be used as a measure to accomplish this type of super servo control. The key to the operation involved accomplishing all the high accuracy servo control during the playback mode. Of course, while it is desirable to make as stable a recording as possible since an accurate recording would mean less servo correction on playback, it was found that sufficient control of torque applied to the video head drum in playback could be achieved by controlling the three phase driving signal to the hysteresis synchronous drum motor. The torque developed by a three phase synchronous motor is proportional over a considerable range to the angle between the magnetic pole of the motor and the rotating magnetic field of the stator. Then to control the instantaneous torque developed by the motor, it is only necessary to control the instantaneous phases of the three phase current driving the motor. This block diagram (Page 14) shows the operation of the Inter-Sync. Here we see on the upper left that the vertical sync component of the reference signal, that is, the one to which we are synchronizing the tape playback, is applied to a frequency multiplying circuit. From this circuit we obtain a 240 cycles per second sine-wave voltage locked to the reference sync signal. This is then coupled to a block labelled integrating phase shifter. The output voltage phase of this circuit is shifted with respect to the input phase by an amount proportional to the time interval of the control voltage applied to the circuit. Stated in non-mathematical terms, this indicates that if a small, constant, positive control voltage is applied to the circuit, the output phase will continue to advance from the input phase at a constant rate as long as the control voltage is maintained. When the control voltage is removed the output frequency will revert to the input frequency, but the output phase will remain shifted from the input by the total amount accumulated during the application of the control voltage. The signal is next coupled to the input of a circuit labelled proportional phase shifter. The output 240 cycle voltage from this circuit is shifted in phase with respect to the input by an amount directly proportional to the control voltage. That is, if a small, constant, positive control voltage is applied to the circuit, the output signal voltage will be shifted in phase with respect to the input by a small, constant, positive amount. This phase shift will remain fixed as long as the control voltage is maintained constant. When the control voltage is removed, the output signal will revert to its original phase relation with the input signal. The output 240 cycle voltage is now ready to be amplified by the motor drive amplifiers and applied to the drum motor. So much for the electro-mechanical servo system.

Once the gross errors have been corrected by the Inter-Sync, we can turn out attention to the smaller errors, such as skewing, scalloping, quadrature, geometric distortion of tape, random recorded noise, bearing runout, and tape thickness variations such as due to passage of a splice. The correction of this next class of errors must necessarily be done electrically through variable delay techniques. This is done in Amtec, as may be seen on Page 15, which measures the interval between successive sync pulses in order to measure the extent of these errors. Having thus established the size of the error, the video is passed through an amount of delay sufficient to cancel the error (1 microsecond maximum). The automatic time error correction with Amtec may be used by itself as a picture straightener, or it may be used with Inter-Sync to compensate for the final .1 usec. residual error left by the electro-mechanical servo. This results in a long term stability error of about 30 millimicroseconds. In practical terms, this means that one could superimpose test pattern from tape playback, and station monoscope, and see no differential jitter even at the bottom of the test pattern wedge. Thus it is now possible for VTR's and cameras to be held in dissolves, split screens or inserts, that are absolutely perfect from a timing viewpoint.

Now let us turn to a functional diagram of the Amtec which will a little more fully describe its operation, Page 16.

The error detector is primarily concerned with the timing (or leading) edge of the horizontal sync pulses contained in the incoming composite video signal. For this reason the horizontal sync pulses are clamped to a reference voltage, while en route to the error detector. The gate allows approximately the last 0.75 microsecond of the front porch, and approximately 4.25 microseconds of the sync pulse to pass to the 2 microseconds pulse generator.

As its name implies, this pulse generator produces a rectangular pulse of 2 microseconds duration. It is formed by the leading edge of the sync pulse, and its output is therefore timed by sync. This is the signal that the error detector compares with a stable timing reference, for the derivation of the error (or bias) voltage. The error voltage is developed during the 5 microsecond interval following the leading edge of horizontal sync pulse, and is the bias proportional to the fourth power of the timing error, that is ultimately applied to the voltage controlled delay line. During the interval between sampling pulses, the bias voltage is held constant. In this way the line of picture information following each sync pulse is held at the corrected time until the next sampling pulse occurs. No additional sampling or correction takes place during the visible portion of the picture.

During the "picture straightening mode" the error signal contains only "ac" or high rate-of-change timing error information. The "dc" or low rate-of-change components are not required for the mere correction of picture geometry.

Because the reproduced picture elements must remain stable with respect to the corresponding picture elements of another video signal during the "Inter-Sync" mode, the "dc" and low rate-of-change components of the error signal must be detected and delivered to the delay line. Under this requirement, the reproduced signal is time compared with an external timing reference, instead of an average of the horizontal sync contained in the uncorrected composite video. The external timing reference is the local station sync generator.

In passing it will probably be interesting to note the tracking equalizer in the lower right corner. As you might suspicion, the video band pass characteristics of the voltage controlled delay line vary with changes in delay and, therefore, must be compensated. This is done via a tracking equalizer which has a balanced input and is connected to the push-pull voltage output of the isolation amplifier and as such receives the output of the voltage control delay lines. This tracking equalizer exhibits a variable band pass characteristic that is the conjugate of the band pass characteristic of the delay line. The result then is to maintain the Amtec band pass flat to 4.2 mc throughout its entire range of delay.

The commercial version of the Amtec shown here (Page 17) is fully transistorized with a self contained power supply. It takes 5-1/4" of rack space and, as you will see from the photograph, uses plug-in cards.

We come now to the ultimate in open loop electronic servo systems called Colortec. This is the final step by which we may take a signal that has been corrected by Amtec to an accuracy of ±30 nsecs. through an additional correction stage to bring our time base stability error down to ±4.0 nsecs. In terms of color television, this is equivalent to ±5° of 3.58 subcarrier. In effect, this degree of correction is sufficient to eleminate any perceptible hue changes due to time base instability.

Once having accomplished the geometrical correction with Amtec, the next stage to a direct color playback, through Colortec, is a natural extension of the voltage variable delay line technique. Page 18, shown here is a simplified block diagram of Colortec. As in the case of Amtec, the heart of the system once again is the voltage variable delay line and the error generator. In this instance, instead of comparing the time interval between the leading edges of sync, as in Amtec, we measure the variation in phase of the color burst retrieved from the tape compared to a reference 3.58 signal. You will notice the inputs on the left of this diagram are video, from the playback of the tape, and plant reference 3.58. In the comparator, a DC error signal is generated through the comparison of the reference 3.58 and the burst stripped from playback video. The error signal feeds through a driving amplifier to a control bus of the voltage controlled delay line. You will notice that the video path goes through an auxiliary delay to make the video delay equal to the delay of the error signal. Finally, the corrected video signal from the voltage variable delay line is fed to the processing amplifier.

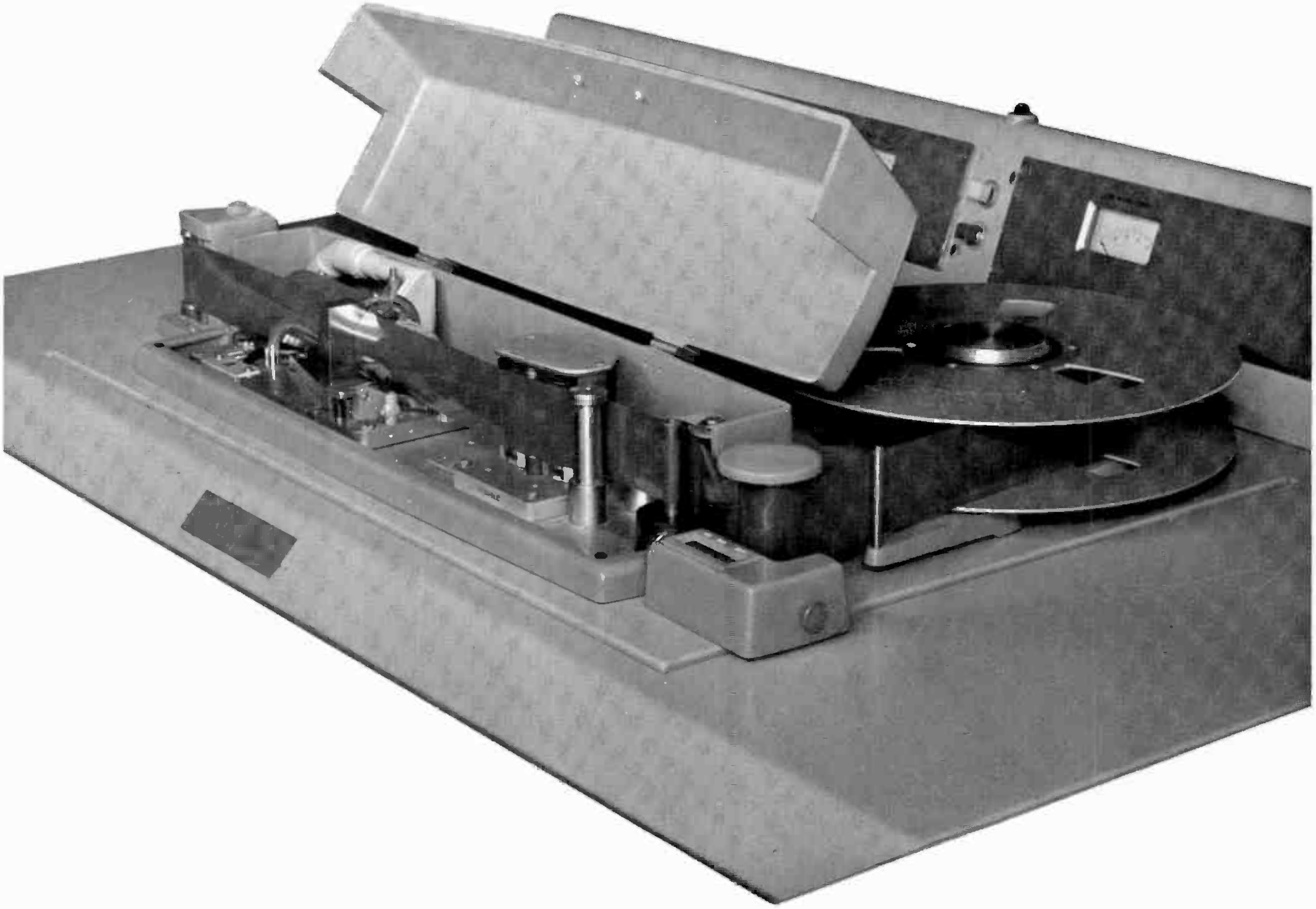
Of necessity, the range in the voltage variable delay line in Colortec is considerably shorter than that in Amtec. However, its resolution is significantly higher, since we are correcting our signal to within ±5° of the 3.58 color subcarrier. It should be pointed out that the Colortec unit must operate in conjunction with the two coarser time-base corrective devices, namely Inter-Sync and Amtec.

The value of this type of direct color playback lies in the rendition of full bandwidth black and white as well as high quality color. In all previous color systems, the integrity of the 3.58 phase was re-established through some sort of heterodyne technique. This could be heterodyning up to the 20 Mc region or down to almost DC. In either case, it was necessary to process the luminance and chrominance through different paths. The technique used to separate the luminance from the chrominance involved a bandpass device which inevitably resulted in very narrow band luminance and chrominance signals, since the luminance and chrominance bandpasses overlapped. With the direct color system, the debilitating effects of heterodyning are eliminated. The viewer sees full bandwidth monochrome reproduction of the color as well as freedom from the "working of the sharp edges" that result in rapid transitions from high to low brightness. Indeed, from the purist's standpoint the playback signal from direct color can be considered the only legal taped color signal on the air, since the older color systems achieve a mere average interlace between horizontal sync and burst frequency, since the Colortec playback provides absolute lock. This absolute lock has a subjective value as well, since the critical observer will no longer see objectionable "dot crawl" in his color tape playbacks from Colortec.

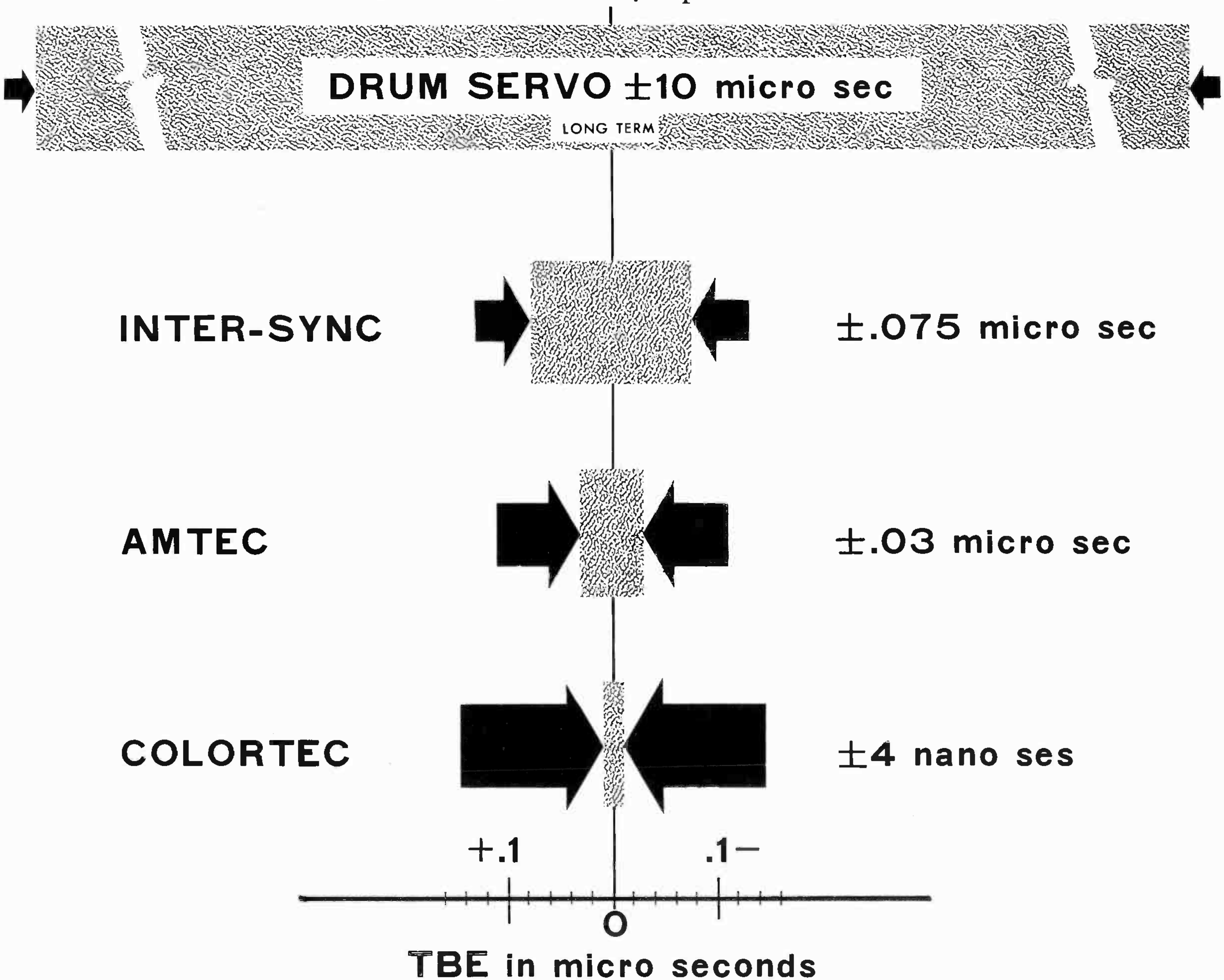
The commercial unit Colortec, like Amtec, will be fully transistorized, contain its own power supply, and take 5-1/2" of rack space. Page 19 is a photograph of one of the first engineering models.

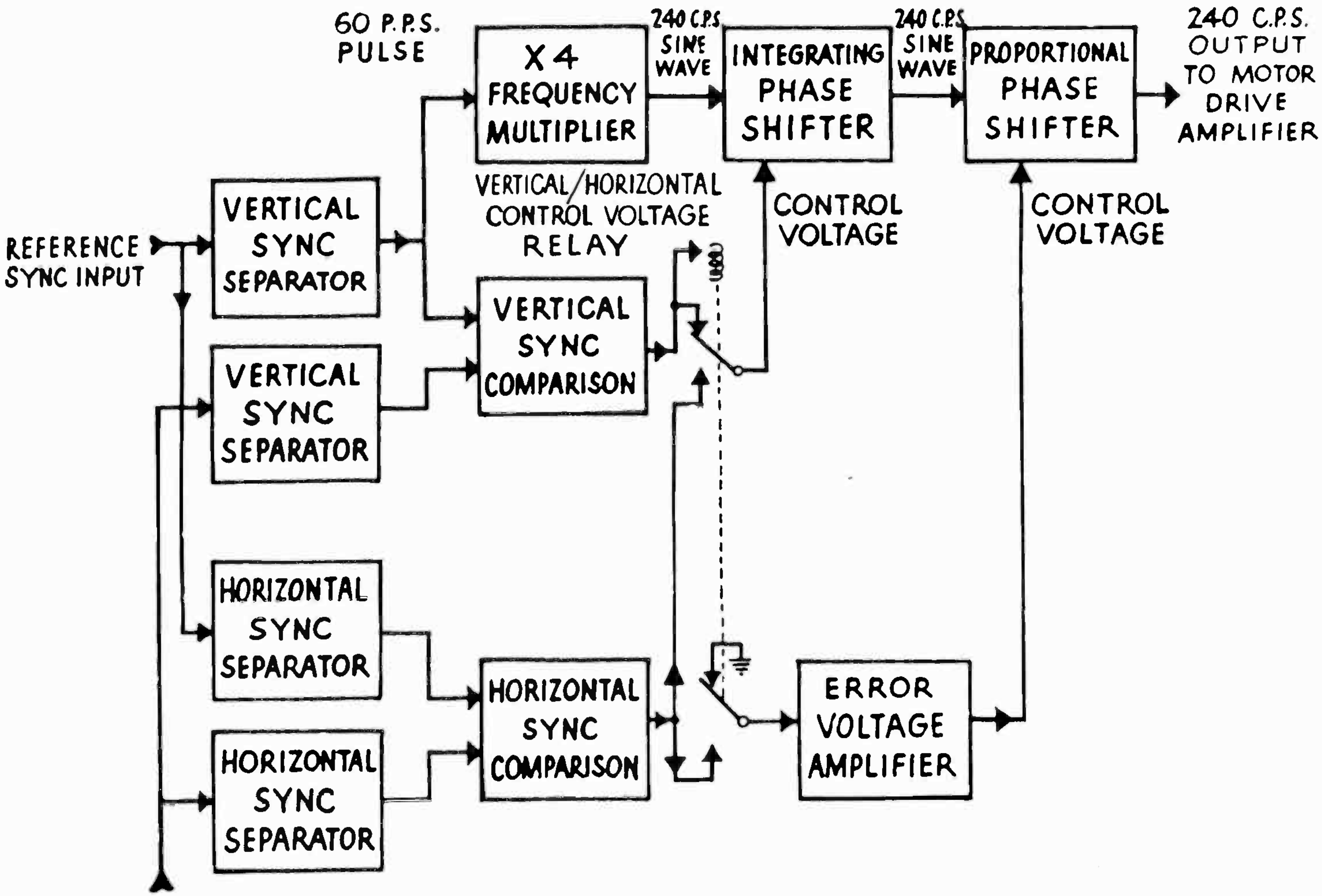
I would like to mention an additional development that has been an outgrowth of these various time base correction techniques in video recording. Using modified broadcast equipment, we now have engineering models of general purpose instrumentation recorders available for scientific applications which are continuous (no transient), wideband, and have time base stabilities of ±30 nsecs. over a long range.

I would like to thank Messrs. Harold Clark, inventor of the Inter-Sync; Charles Coleman, the designer of Amtec; and Peter Jensen, design engineer on Colortec for their assistance in the preparation of this paper.

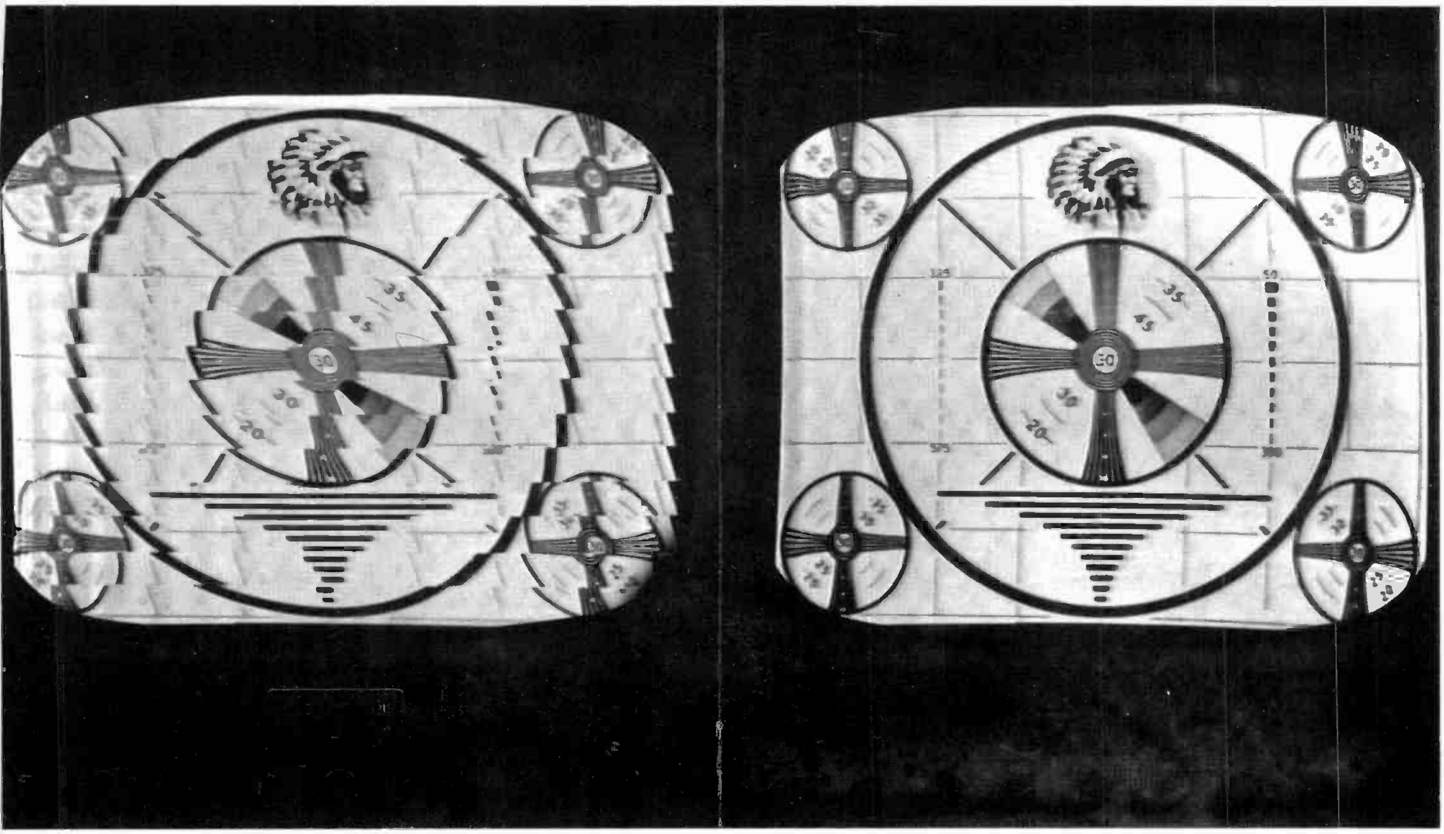


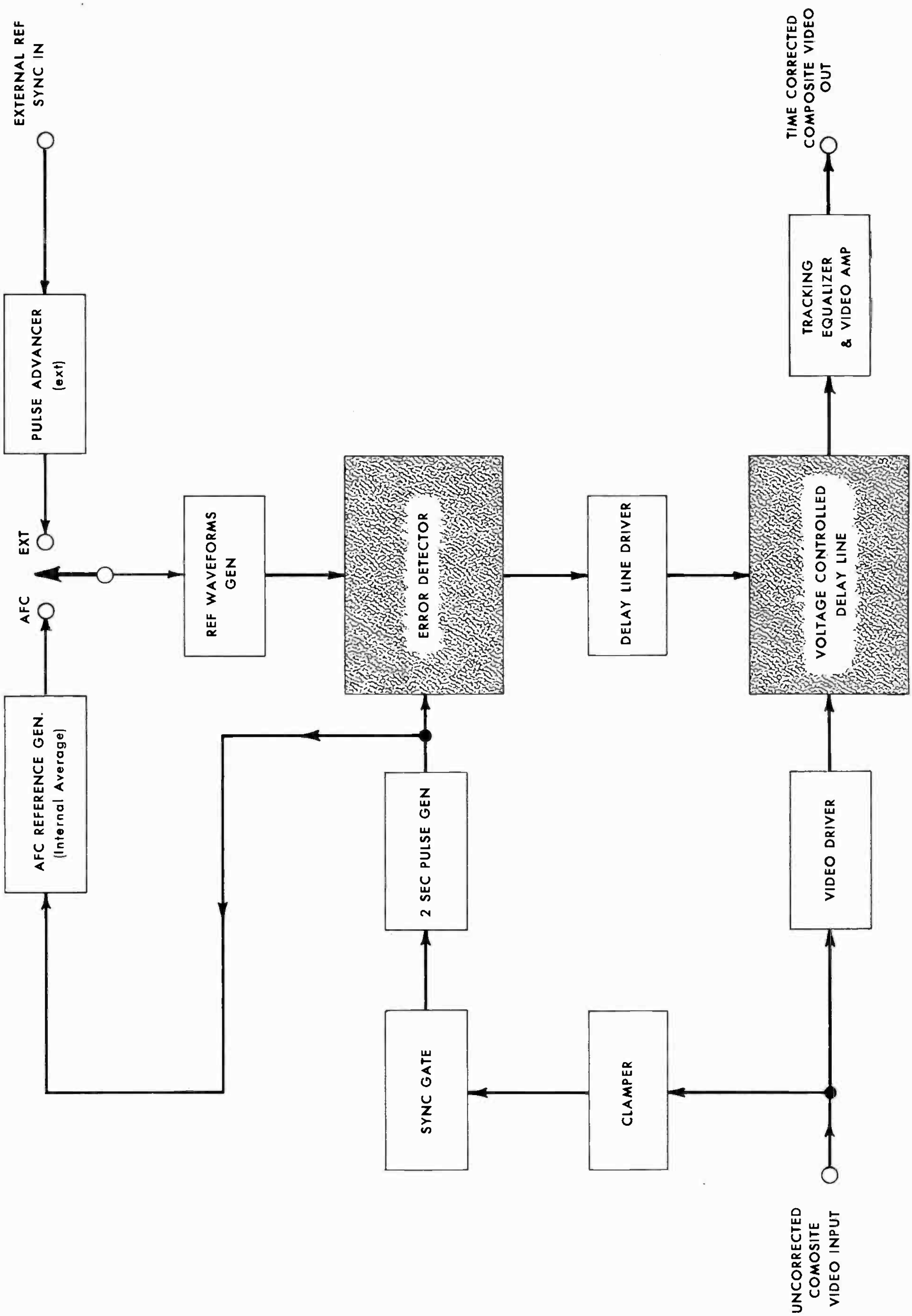
The Time Base Stability Spectrum in VTR



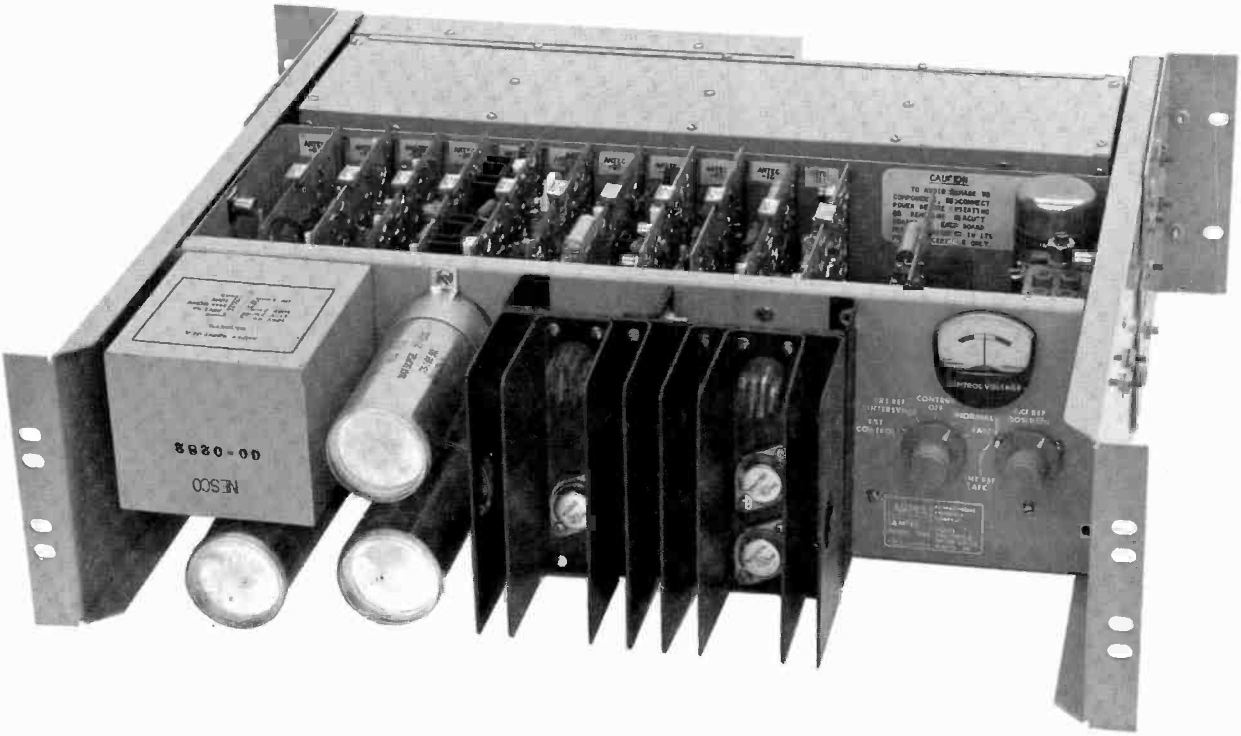


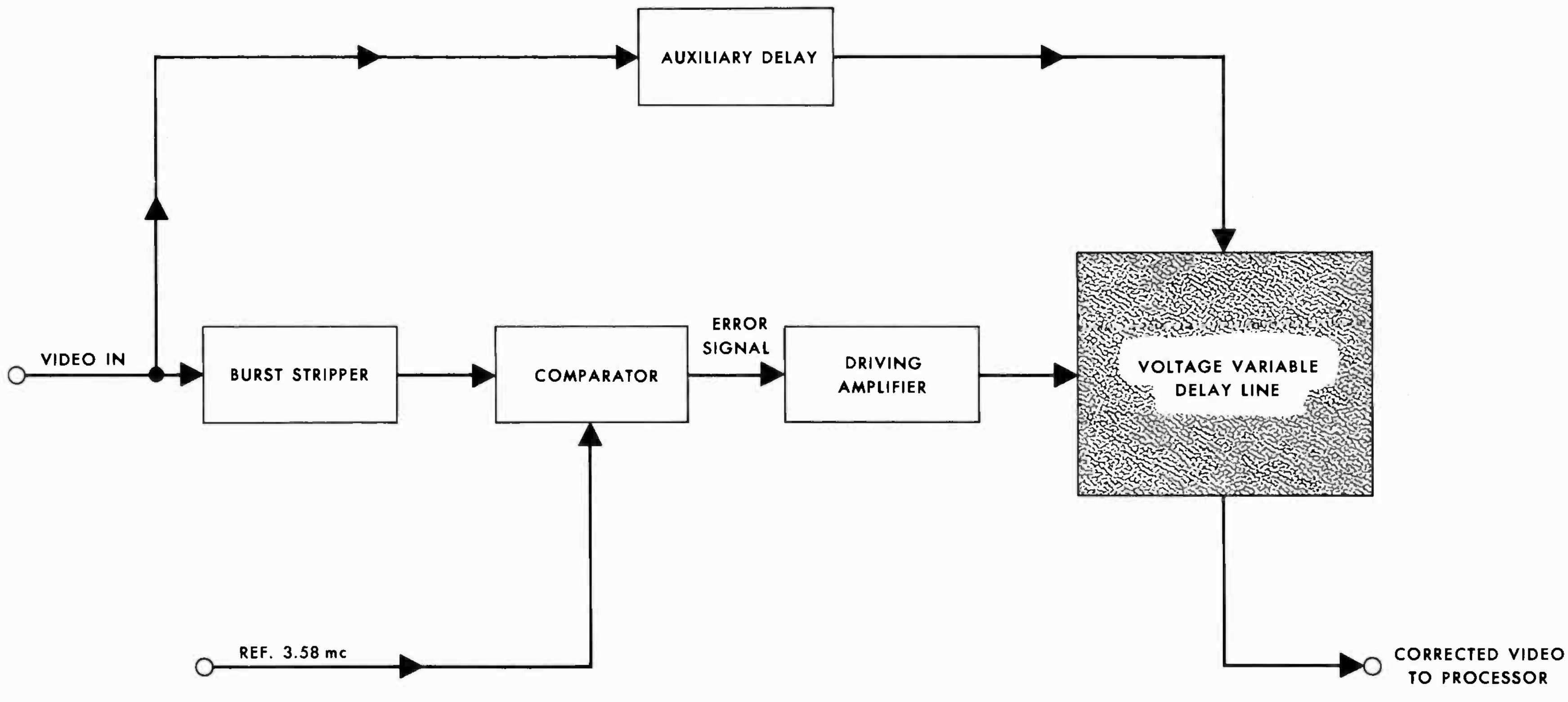
SIMPLIFIED BLOCK DIAGRAM OF INTERSYNC
PLAYBACK CONTROL SYSTEM



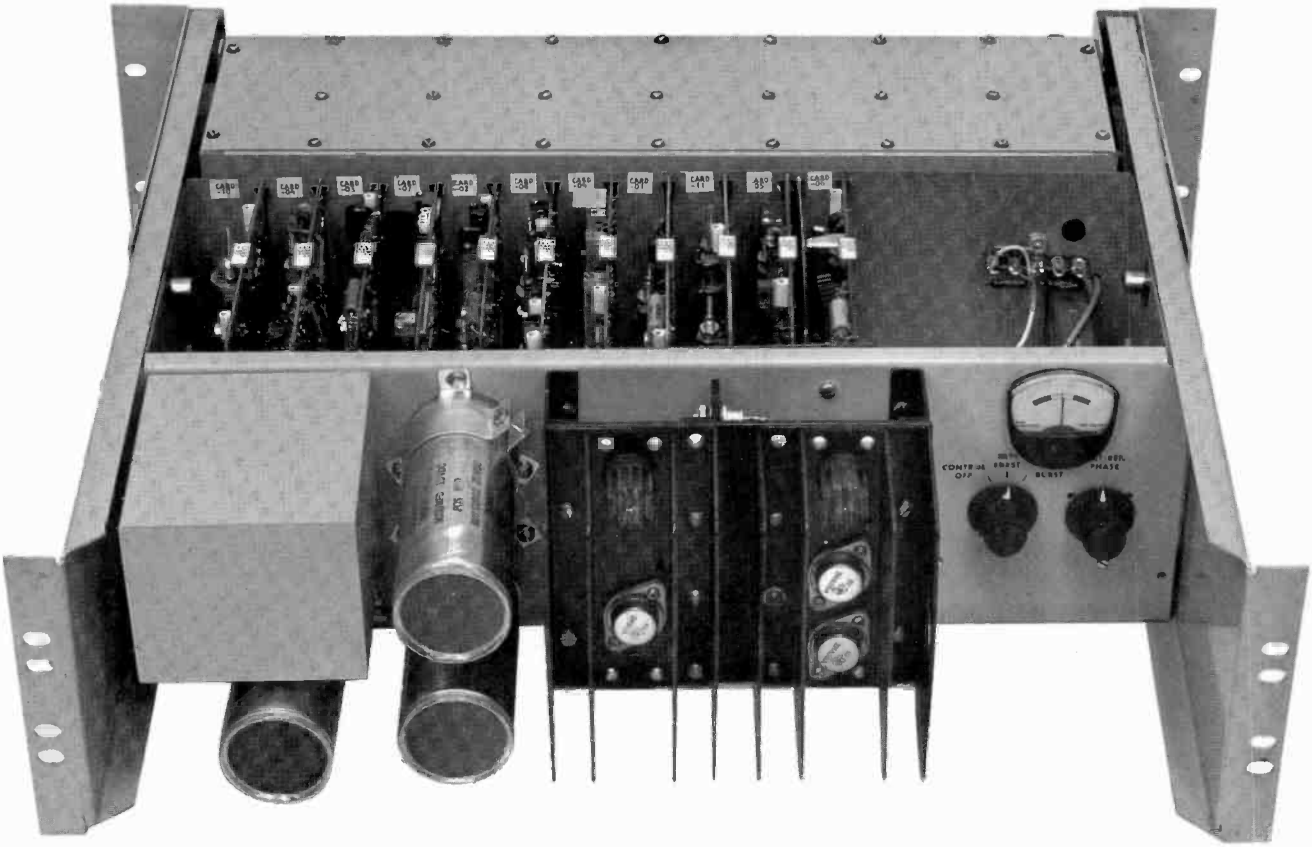


EXTERNAL REF SYNC IN
PULSE ADVANCER (ext)
EXT
AFC
AFC REFERENCE GEN. (Internal Average)
REF WAVEFORMS GEN
ERROR DETECTOR
2 SEC PULSE GEN
SYNC GATE
DELAY LINE DRIVER
CLAMPER
VOLTAGE CONTROLLED DELAY LINE
VIDEO DRIVER
TRACKING EQUALIZER & VIDEO AMP
TIME CORRECTED COMPOSITE VIDEO OUT
UNCORRECTED COMOSITE VIDEO INPUT


CAUTION



AMPEX COLORTEC
SIMPLIFIED DIAGRAM



18

Engineering Department Publications

CBS TELEVISION NETWORK

A Computer Control System for Program Switching

Adrian B. Ettlinger
CBS Television Network

and

Bertram R. Newman
TRW Computers Co.
Div. of Thompson Ramo Wooldridge, Inc.

(Presented at the 1961 NAB Broadcast Engineering Conference)

E2207-D

A COMPUTER CONTROL SYSTEM FOR PROGRAM SWITCHING

On December 31, 1960, CBS-owned television tation KNXT moved into completely new facilities n Sunset Blvd. in Hollywood, adjacent to the long- tanding CBS radio studios. The planning of these ew facilities was carried out with a view to reating the most efficiently integrated operation ossible. Early in the planning stage, it was ecognized that automatic station-break switching ould make a major contribution to such efficiency.

While station-break switching requires a high rder of manual dexterity and sense of timing on the art of the operator, it also has an inherent capa- ility for mechanization, since each operation is ompletely predetermined. The maintenance of icture and sound quality, on the other hand, par- icularly with short sequences of film or video ape, is a difficult problem, only partly alle- iated by some of the recently introduced automatic ontrols. In the design of the KNXT control center, utomatic switching was introduced to permit the perator's attention to be more fully concentrated n supervision of program material transmission uality.

In surveying the various types of automatic witching systems being offered to the broadcasting ndustry, the conclusion was reached that a new pproach would be desirable to avoid certain limi- ations of existing technique.[1] It was desired that he system be capable of storing at least several ours of program continuity data, yet also permit apid changes of stored data from a central control osition. Punched paper tape, the major bulk torage medium then in use, involves an awkward andling problem which is eliminated if a random ccess memory is used. Computer technology was, herefore, explored, and the system which evolved rovided a selection of features and degree of lexibility which would have been prohibitively stly if attempted by more conventional means. The mputer system was supplied by TRW Computers Co., ivision of Thompson Ramo Wooldridge, Inc.

[1] A.B. Ettlinger, "Digital Computers for Tele- sion Automatic Switching Control." I.R.E. trans. Broadcasting, BC-7:29-36, March, 1961; also pub. journal SMPTE, 70:145-149, March, 1961.

THE DESIGN APPROACH

The use of a digital computer for automatic program switching virtually presents the system designer with "an embarrassment of riches". In terms of storage capacity and functional capability, there are very few limitations to what can be accomplished. The major problems lie in the area of optimizing the man-machine relationship, maxi- mizing the efficiency of usage of the available storage, and achieving high inherent reliability.

The introduction of automatic switching into the operation of the new KNXT studio facilities has been planned as a developmental process. In the initial phase, the number of functions to be con- trolled by the automatic system has been limited, and manual initiation of each station break sequence is employed. In the interest of facilitating later expansion into whatever further areas of automatic control prove to be operationally feasible, design flexibility was considered of major importance. Indeed, the computer approach appeared to be the only method of achieving an "open-ended" type of design that would not require extensive reconstruc- tion to accommodate certain types of expansion.

In the design of the display and control panels, the objective was to provide the operator with fully adequate information and control capability, yet in an arrangement as simple, as logical, and as least prone to error, as possible.

The equipment operated by the system consists of the following:

(a) A 21-input video switcher.

(b) Ten (eventually twelve) film projectors (re- quiring 3 second prestarts).

(c) Two (eventually four) video tape recorders (requiring 7 second prestarts).

(d) A special audio switcher, equivalent to four independent, three-input selectors.

(e) Two twelve-input audio preselection switchers.

(f) A 36-position random-access slide projector.

TIME DESIGNATION

The major task of the system is to switch video and audio sources on the air at the proper time. The operator must be provided with a display which keeps him informed of the progress of a sequence. The method of time designation required a choice between two general types of approaches. One method is to designate each event by a clock time, and provide a matching digital clock read-out, so that the event is switched when the two displays match. As an alternate, each event can be designated by its duration, and a "count-down" display can be used to continuously display the time remaining in the event on the air. It is apparent that comparison of two 6-digit displays for similarity, as required if clock time is used, would be more prone to error in an emergency situation than would observation of a direct display of remaining time. Therefore, the count-down method was chosen as the more satisfactory to permit quick recognition of the situation by the operator. Operation by clock time has been allowed for, but in a manner that subordinates the display of clock time information to a lower priority location on the display panel.

DISPLAY PANELS - EVENT FORMAT

The complete computer system is packaged in two broadcast racks. Fig. 1 shows the equipment prior to installation.

On the display panels, the highest priority information, the actual switching event data, is on the right side. A close-up of these panels is shown in Fig. 2. The top panel indicates what is on the air (center), and how much time remains (left) before the next switch. This establishes the format for three similar panels which display similar information in a paralleling manner. The second panel is for the "next event". Here, the parallel display to the dynamic "time remaining" of the on-the-air panel is a static display of the duration of the next event. When "time remaining" counts down to zero, the next event's duration moves up to the time remaining display and immediately starts counting down. The readouts for video and audio in the on-the-air panel are actually connected to station switching equipment and reflect its state, regardless of whether manually or automatically switched. The next event video and audio displays reflect the state of memory relays through which switching power will pass when the next automatic or manual switch is made. The nature of this circuitry is such as to insure virtually foolproof

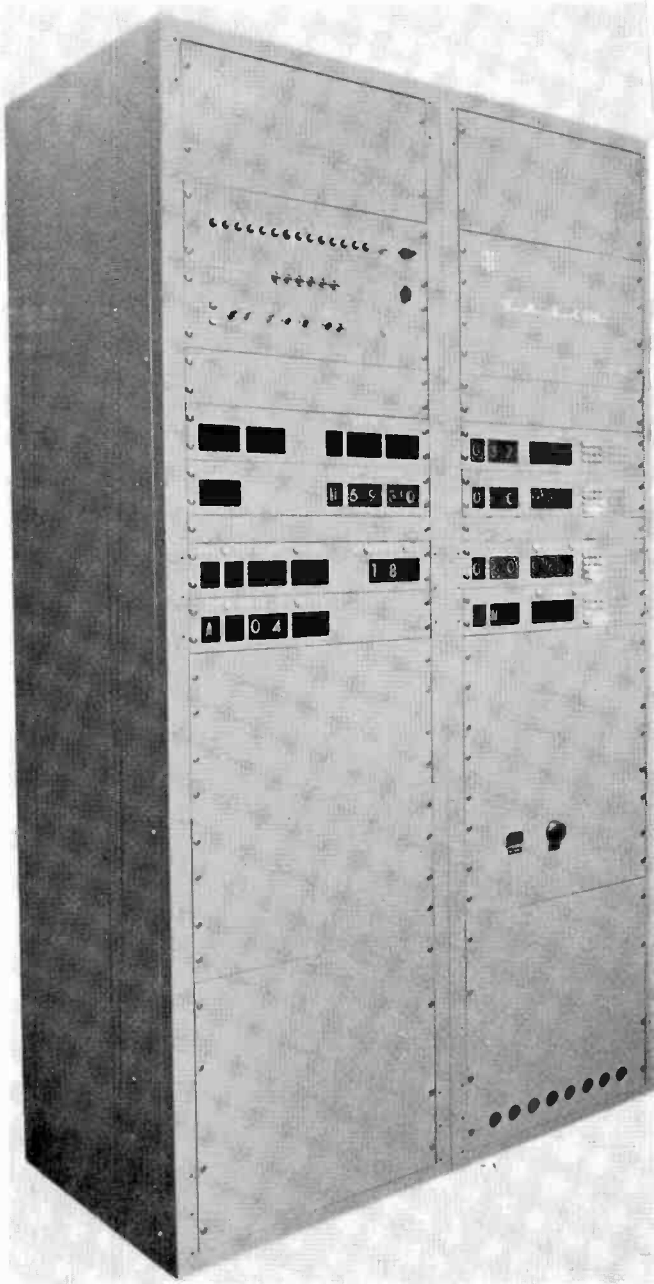


Fig. 1 The computer system is packaged in two broadcast racks, the unit measuring 44" x 24" x 87".

iability between the display and the actual
tching circuit.

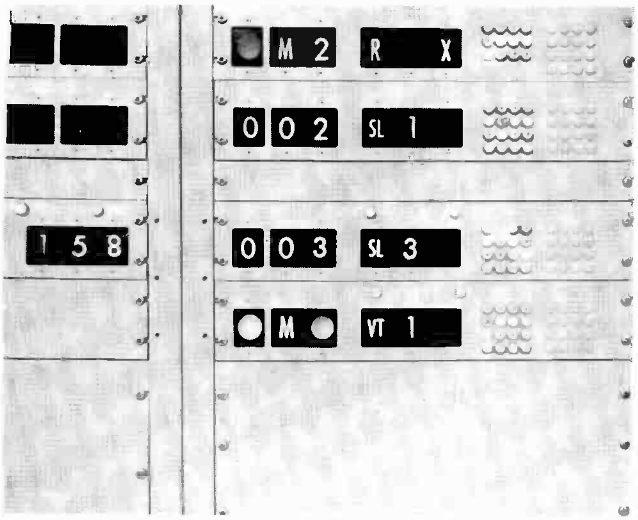


Fig. 2 Event display panel. Program sources are identified by "plain language" designations.

The lower two event displays, being of lower iority in importance, are permitted to serve a al purpose. Their primary function is in search- g out, changing, and entering of switching event ta. As a secondary function, they are used oper- ionally to display the second and third upcoming ents. This function is performed when the system in the "operate" mode. In the "search-entry" de, the upper display shows the content of any sired switching event, while the lower display is ed somewhat as a writing tablet to construct any w switching event to be entered either as a new ent or replacement for an existing event. The ovision of two event displays for search and entry rmits a positive check on a quick comparison sis that an event has been properly entered.

DATA ENTRY

The data entry and control panel is shown in . 3.

The principle of operation of the keyboard can illustrated by a description of the process by ch a switching event is prepared. When the tem is ready to receive event information, the erator uses the data entry keys in a similar ner to the ordinary sequentially-operated ten-key ing machine keyboard. The first key depressed omes the first digit of duration, and is imme- tely displayed as such. Successive key depres- ns are used to spell out the complete event. The numbered keys have alternate meanings for the mne- monic characters used to designate video sources. The characters "A", "BK", "TP", "R", "ST", "VT", "16", "SL" and "35", for example, are used to de- scribe classes of video signals, as the first char- acter of the video source designation, and constitute the alternate meanings of keys "1" through "9", respectively. This system, when combined with the versatility of the projection-type digital display, permits the automatic switching system to use the same "language" to which the operators are accus- tomed in manual operations.

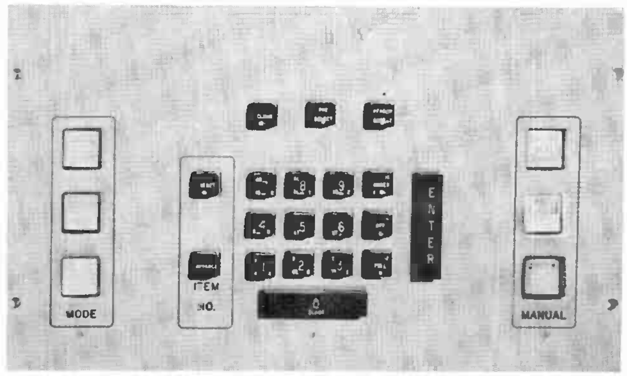


Fig. 3 Data entry and control panel. Mode selectors are on the left, and manual intervention controls on the right. The data entry key group in the center is built up around a ten-key adding machine keyboard.

In the action just described, a pattern of sequential key depressions has caused a corres- ponding pattern of display, combined with an inter- nal storage operation. The effect produced by a given pattern of key depressions is determined completely by the computer program, which consists of magnetic digital information recorded on a memory drum. This program can be changed at will, so it is apparent that a large area of functional modifica- tion and expansion can be carried out on the system without requiring any physical change in the hard- ware.

Switching events are identified by an "item number". The drum storage space allotted for item storage provides a capacity of 220 items. This number was determined arbitrarily on the basis of initial operating needs and a balance in apportion- ment of reserve space between item information and possible future computer program expansion. The item capacity is subject to possible expansion, up to a maximum of 1400 items, should such capacity ever be required.

SWITCHING SEQUENCE CONTROL

A view of the operator's control position, showing the relationship between the displays and the control panel, is shown in Fig. 4.

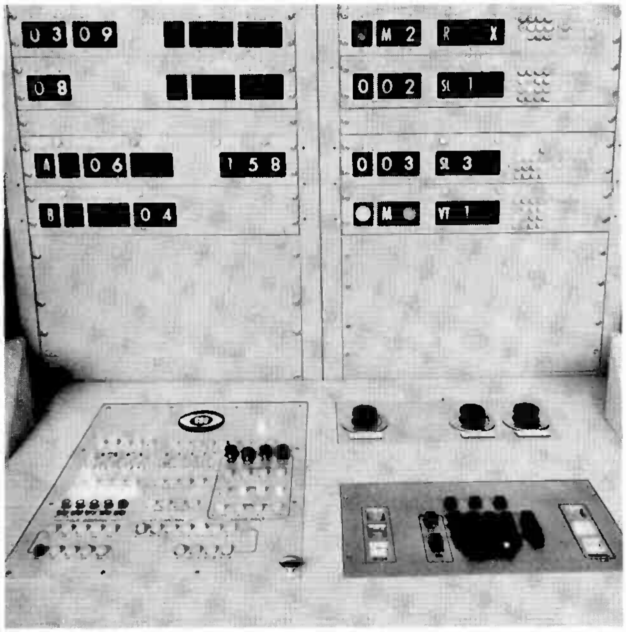


Fig. 4 Over-all view of the operator's position. Complete manual control is provided for all computer-operated station equipment. Display panel features, on the left side, lower priority "preselect" and clock-time information.

To control the operational sequencing of the system, the operator is provided with two primary controls, a "switch" button, and a "hold" button. When a station break sequence is awaiting a manual start, the "time remaining" display shows the letter "M" with two red disks. Any event can have a duration of "manual", which means that, when it goes on the air, the count down will not operate and the event will stay on the air until the "switch" button is operated. The switch button puts the next event on the air, and if it is the first of a series of duration events, as for a station break sequence, the sequence starts counting through. The switch button can also be operated while the count down is running, for the effect of accelerating a sequence by cutting short the present event. The hold button, when actuated during a count down, has the effect of putting "manual" in the time remaining display, to decelerate a sequence by holding the next event off for a manuel switch. A third button is provided to conveniently "discard" the next event, when an event must be bypassed.

Prestarting of film projectors and tape mach during an operating sequence requires no atten from the operator. The computer continually sc advance events and puts out a start impulse th seconds in advance of each film projector event seven seconds ahead of each video tape event. T applies regardless of whether the machine to started is the "next event" or happens to be seve events away because of a series of short even When a video source requiring prestart is coming on a manual start, the operator is notified by last digit of the time remaining display whic instead of showing the usual red disk, shows a di corresponding to the anticipate time. The swit key under these circumstances serves as a start ke and video is not switched until the count-do reaches zero.

While every effort has been made to provide a manual override controls the operator may need, is recognized that, in the last resort, there c be no substitute for taking over manually in emergency. When the film breaks, or the netwo feed fails, human judgment is usually superior to computer's in salvaging the situation. Therefor the operator's position includes a complete set manual controls for operating all equipment co trolled by the computer. The manual control always connected and overrides computer control.

MODES OF OPERATION

The system can be placed in any of three mo by the mode selector buttons (Fig. 3). Sequenc of events, including the operation of the time maining display, and the functions of the man controls, proceeds regardless of the mode. " "operate" mode is the normal state when the da keyboard is not being used, and transfers the lo two events displays to their alternate function showing the second and third upcoming events. "search-entry" mode places the computer in a p gram where key depressions are interpreted in variety of patterns required to prepare and en switching data. The basic event entry process already been described. There are, in additi several convenience keys for such operations clearing erroneous information, repeating inf mation, and similar functions. When the "sear entry" mode is first entered, all associated d plays are cleared. The first three key depressi are then interpreted as an item number which displayed as punched, and when complete, the con is displayed. Two convenience features for item selection are a "reset" button which clears displays for entry of another item number, and vance" button which adds one to the item number play and shows the content of the next higher ber. After display of an item, successive key ressions prepare a new item for entry, as pre- usly described.

SPECIAL ROUTINE MODE

The third mode is known as "special routine". is mode is a major vehicle for implementing the herent flexibility of the computer approach. ere are a number of possible functions of con- derable utility which the computer can perform if structed to do so. Normally, the addition of nctions to any machine requires the addition of ysical controls to actuate the additional func- ons. With a computer, however, having a keyboard ch as this one has, it is only necessary to write e proper program and record it on the drum to have e machine perform any desired internal function en a particular sequence of keys is operated. us, the special routine mode is set up so that try of any of several serial numbers, followed by specific format of data, causes the computer to rform a given operation.

One of the most operationally useful routines to place a given item number in the next event sition of the operating sequence. Ideally, this eration is needed only once each day to start the y's operation, but it also has utility in getting a group of events which may be left in the chine from day to day, such as the sign-on or gn-off procedure. Another useful routine permits ısing any block of items. Test routines are also ›grammed, such as a display-testing routine which luminates any digit called for in all digital splays. Many unassigned serial numbers are re- ved for later addition of whatever routines are wn to be desirable by operating experience.

A particularly interesting special routine is that permits actual computer program modifi- ion by direct use of the data keyboard. The use this special routine permits an operator, merely pushing buttons, to modify functional features of system. As an example, if video tape machines e improved to permit a five-second prestart time, program modification to accommodate this could entered from the keyboard. Likewise, any new cial routines can be so entered. For safety, s feature is inhibited unless a special shorting g is inserted on a rear panel of the equipment.

THE PRESELECT FEATURE

The portion of the system as thus far described does not provide for operation of all the station equipment originally listed. A random-access slide projector and two 12-input audio preselectors are operated, but are not included in the switching event format. An alternative method of handling these functions was developed in order to enchance the efficiency of storage utilization and to provide expansion capability. These functions might have been included within the event format, but it is apparent that doing so would have required expanding the size of each of the four event display panels. In addition, the storage space allocated for each event would have had to be large enough to accommodate the additional information. Such an extension of hardware and storage space would have been inefficient, considering that the supplementary data would be used in conjunction with only a small fraction of events. Furthermore, addition of more similar functions at a later date would be extremely awkward. A method was therefore adopted of an alternative use of an item space to be known as a "preselect". A set of displays for search and entry are provided which are used in a flexible format to designate any of a potentially large number of preselect systems. The first character identifies the station equipment that will be switched, the remaining characters defining the position to which it is switched. Since none of the equipment operated in this manner performs a "hot" switch, precision of timing of preselects is not important, as long as they are actuated in proper sequence with respect to the actual switching events to which they apply. Preselects are thus inserted in sequence as required. and the system outputs the preselect impulses during the one-second interval immediately following the preceding event.

The nature of this system permits its later extension into other areas of station operation at little additional expense. Such tasks as sync-lock control selection, assignment of equipment, and output channel routing could be added without major modification to the computer system. Additional display characters can be used to identify each additional function, so that no displays need be added. The output system is in binary format, using one set of twelve lines for all information and a common line for each function. Several spare common lines are available for expansion.

Another contemplated area of expansion is the tie-in of the computer switching system with any future automatic data processing system which may be adopted for traffic and billing operations. The feasibility of this type of interconnection is much enhanced by the ability of the computer to perform the interpretation and format conversion functions required for such a system.

CLOCK TIME OPERATION

The preselect feature has also provided a neat solution to the problem of economically accommodating clock-time operation. As in the case of preselect switching, clock time might have been included in the event format, but again at the cost of efficiency, since with duration timing it is desired only to predetermine the clock time of the start of each station-break sequence. Clock time is, therefore, inserted as a "preselect" type of item in the data sequence. Whenever a "clock preselect" is output in sequence, a display register is set to retain the time information. An external coincidence circuit takes this register as one input and a continuously-running digital clock as the other input, and supplies an initiating pulse to the computer. The initiating pulse is supplied one minute in advance, and starts a one-minute count down, so that the operator is given an advance warning; and no special action is required for prestarts. The clock-time start is effective only when the "duration" of the on-air event has been established as "clock", identified by two green disks flanking a letter "C". (This is a second alternative to a true duration in a switching event, similar to "manual".) The actual introduction of clock time initiation of station break sequences into KNXT operations has been deferred until a study of network program timing problems can be completed.

The upper panels on the left side contain readouts which display the state of each preselect switcher. Except for "time of next sequence", which reflects a relay register internal to the computer racks, each of these displays are driven from the external station equipment that is operated by the computer.

THE COMPUTER

A block diagram of the system is shown in Fig. 5.

The heart of the system, the computer, is a machine patterned quite closely after the process control computers now in service in the oil refining, chemical, power, and cement industries and is designed specifically for extremely high operating reliability. The machine can be describe a millisecond computer, i.e., one which perf operations at a rate of approximately 1000 second. Usable alternatively as a general pur computer, a fairly complete list of instruct enables the machine to do a variety of computati jobs.

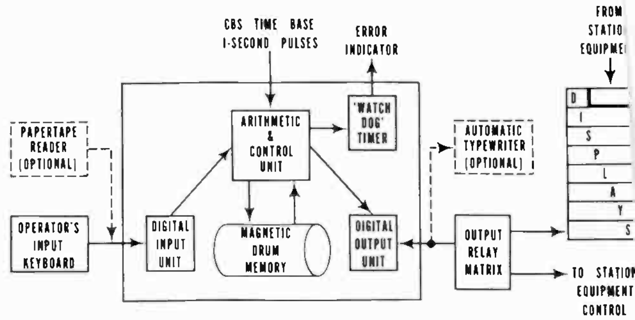


Fig. 5 Block diagram of system. The computer is th central data storage, control and communicatio unit between the operator and station equipment.

As an on-line or real-time switching devi the computer is characterized by features wh enhance its operating reliability and available time to the point where better than 99% availabil is commonplace. Operating expectations are mean time between failures of 1500 hours based similar machines in the field.

The techniques involved in achieving this liability level include the use of precision c ponents rather than the wide tolerance compone usually found in comparable electronic equipme A completely solid-state system, the computer modular in design. Glass epoxy insert boards, w excellent low-warp and corrosion resistance qua ties, are used throughout. Contacts are irrid plated to insure that no corrosion occurs at connectors. Test points are brought out to the f of the insert cards permitting ease of mainten and minimizing the number of withdrawals and in tions required. Among the components utilized precision molded film resistors which exhibit cellent temperature characteristics and low va tion in resistance value with age. Hermetical sealed glass capacitors in the smaller capac ranges and tantalitic hermetically-sealed ones the larger sizes insure accurate and repeat component values here too. A view of one of plug-in module units is shown in Fig. 6.

The computer's magnetic drum memory is fi with a tight dust-cover which prevents the entr all particles. Design of the drum permits the tegration of spindle and synchronous motor and iminates any need for gearing or belt-drive vices. In the memory unit, the use of a single ıcircling shroud from which all read and write ads are suspended has eliminated temperature stress ıd flexure problems. In more than 100,000 operating ours logged in systems employing this design of emory drum, no operating failures have been exerienced.

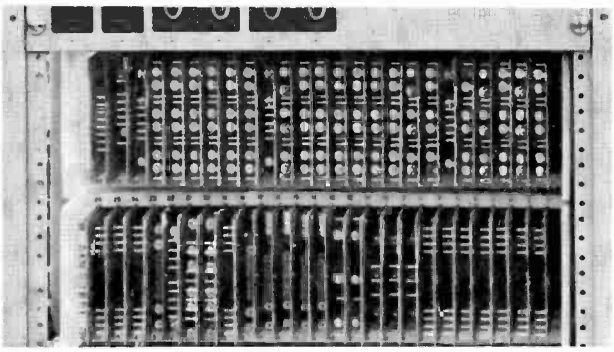


Fig. 6 A plug-in module unit. All computer circuitry is on plug-in printed circuit modules which can be quickly replaced; test points permit in-place maintenance testing.

In the presentation of information to the ıagnetic drum memory, several devices aimed at ncreasing the reliability of the system have been ntroduced. For example, all pieces of information e.g., the data constituting one switching event) re recorded twice on the drum, one in each of two eparate locations. Each time that an instruction r a piece of data is read from the memory, the ord is checked for parity. Should this test be iolated, the system automatically causes control o shift to the data appearing in the other memory ocation set aside for it. This dual recording ethod minimizes the statistical probability for n incorrect piece of information being read or cted upon. The number of parity failures occurring re also tabulated by the computer internally and re indicated to the operator on demand. Thus, hould any component be wavering towards failure, his record-keeping device will warn the operator rior to an actual failure. Maintenance routines, vailable in special routine mode, are used to ocate and repair any imminent or impending malunction.

A device known as the "watch dog timer" is emloyed to insure that major segments of the comuter's operations are checked each second. This evice, essentially a capacitive network, relys on he computer's resetting at the completion of each functional cycle. Should the reset pulse fail to be provided, the time "runs down" and alarms the operator.

Operationally, the computer is a binary machine automatically converting information into the binary system of numbers for internal processing. It has a word-length, or basic information segment, of 24 binary digits and, as mentioned earlier, uses a 4,000 or 8,000 word magnetic drum memory for its bulk storage device. A switching event is stored in two twenty-four bit computer words, in the format shown in Fig. 7. Preselect items are likewise stored in two words, in various formats.

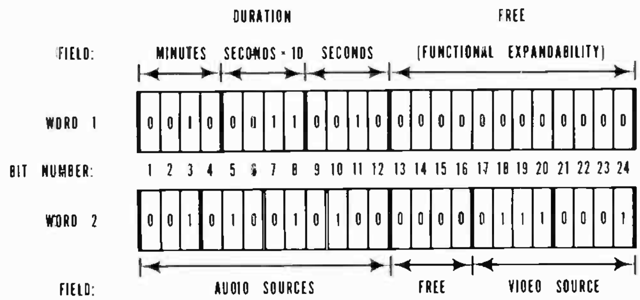


Fig. 7 Two twenty-four bit computer words are used to store each event. Ample reserve space is allowed for more functions to be added.

The system utilizes 115 volt 60 cycle power and consumes less than 1 kilowatt. While no special air conditioning is mandatory, a well ventilated location has been found to be desirable.

OUTPUT RELAY SYSTEM

Approximately 100 relays are used to control station equipment at KNXT and the displays used in the automatic switching system. The output relays are all mercury-wetted contact relays whose operating reliability is guaranteed at over one billion operations. In the duty cycles employed in the typical TV switching operation, this gives an expected life to the relays of over one century!

The relays are set either on or off by means of the digital output commands from the computer. Output information from the main register of the computer is transferred to a buffer output register containing 12 flip-flops. By means of the address portion of the digital output instruction, the particular group of lines to be actuated is determined.

Mercury-wetted latching relays consume about five to six milliseconds in switching. This is the limiting factor to the speed of output commands and is a theoretical limitation to primary switching frequency used throughout.

There is a further relay system external to the computer system which performs a number of auxiliary functions, largely involved in the control of film projectors. This external system provides a change impulse to slide projectors at the end of each slide event. An option is available to stop projectors and video tape machines at the end of the corresponding event. A preview impulse is supplied to each film projector to show it on a still-frame basis when it becomes the next event. Circuit provisions have been made for possible addition of a future preview video switcher to display on a monitor the video signal from the next event source.

PROGRAMMING THE TV SWITCHING CONTROL SYSTEM

While to the broadcasting industry, the term "programming" has a very definite meaning, the computer industry interprets the term rather differently. To a computer user, programming implies the introduction of instructions to the memory of the computer which, in effect, set down the sequence of operations the machine will employ in solving the problems outlined for it. The TV automatic switching controller has been "programmed" in just this way.

The major function, of course, is the correct time execution of the switching functions arrayed in memory. In the aggregate, these functions constitute all the events to be switched during the course of a typical broadcast day.

The computer program must then control the proper execution of these switching functions. The major program subdivision is entitled "the one second count down operation" and, in effect, is a set of instructions which enables the computer to look ahead for the functions which must be performed in the next ensuing second. It is activated by receipt of an input pulse from the KNXT station clock system. This interrupt pulse causes the computer to drop whatever it was doing beforehand and perform the outputting of the pre-arranged information which will constitute the next on-air event. In addition to closing the contacts which take the selected equipment, the computer system will also cause any device which requires a prestart time to be actuated should its on-air time be 3, or 7 seconds away. This requires that each second the system must look at least 7 seconds ahead and interpret the requirements in the future for setting up specific relays.

Another function of the one-second program as its name implies, the job of decrementing t time remaining portion of the on-air display.

OPERATING EXPERIENCE

The computer control system was ready f operation when the new KNXT facilities were inaug rated on Dec. 31, 1960. The initial period operation was attended by the normal amount difficulties encountered in shaking down any ne complex electronic installation. The presence such a radically new and different piece of equip ment in a broadcasting plant gave rise to a somewha new and different pattern of problems. Despite th favorable reception on the part of most operatin personnel, automatic switching poses a very real an unaccustomed burden upon the operator. A singl failure during an automatic sequence, whether th result of control system failure, improper dat entry, or controlled equipment failure, creates sudden shock of emergency from which the operato may be very hard put to recover smoothly. In manua operation a failure can often be recovered mor quickly because the operator has the content of th sequence firmly in mind. In the early period, th scattered failures which occurred were often com pounded by the operator's efforts to recover; th operators, however, quickly developed the appropri ate reflexes to cover emergency situations. Occa sionally, failures would be blamed upon the com puter when it was not even in operation; this i perhaps the inevitable lot of any automation device While some further debugging was necessary on variou aspects of the computer system and its associate equipment, no major shut-downs were required. Th debugging problems were exclusively concerned wit components of the system peripheral to the compute and memory system itself. Some relatively comple relay logic was necessary to permit random-time manual interruption of computer sequencing with fu reliability, and continuous operation revealed a f design loopholes that had been undiscovered in t testing period. General shakedown of controll equipment was a hindering factor, since isolate non-repeatable switching failures were often spec latively attributed to the computer system to t unfair detriment of its reputation. In summary, appears reasonable to state that the shakedo period of this equipment was attended with no great difficulties than usually encountered with any n computer installation, or with any new type equipment in a broadcasting plant. During t month of April, out of all discrepancies of vario kinds logged in the station operation only 7.

urred on computer operation, and the computer used for approximately 70% of all station-break tching. Of the computer-associated discrepan-s, approximately three-quarters were human errors the operation of the system, and one-quarter e presumed or proven to be equipment failures. y one of the equipment failures could be firmly ributed to the control system itself. There is tle doubt that many design features, particularly capability to search out for checking purposes sequence of events, contributed to a minimiza-on of the error rate in the early period. The stem has since about the middle of March, 1961, en used continuously for all functions for which was originally intended.

Inasmuch as so little time has elapsed since e debugging period can be considered finished, it difficult to estimate the ongoing reliability of e system. Any failure of the computer system self will generally be revealed by positive evi-nce that can be recognized before a station-break quence is initiated. The impression established date is that a computer system's reliability is most entirely contingent on its peripheral equip-nt--the power supplies, external relay logic, put-output equipment, etc. The conclusion suggests self that the use of a computer memory and control ement as the core of this system has in no way versely affected the shakedown and reliability oblem as against any other approach that might ve been used, and indeed, may well have eased the oblem because of the convenient operational fea-res it permits.

While a rigorous comparison is difficult, a rvey of the station's discrepancy reports certain-appears to indicate that automatic switching hieves a reduction in the error rate over manual itching. One of the operators volunteered the atement on one occasion that he considers the nputer control system as a tool that makes his easier and permits him to do it more effectively. aim of releasing the operator's attention to important duty of monitoring program quality been achieved.

"FIREPROOF" BUILDINGS DO BURN:
TIPS ON GUARDING AGAINST FIRE LOSSES IN BROADCAST OPERATIONS

By
Gene Ellerman, Vice President and General Manager
WWTV, Fetzer Television, Inc., Cadillac-Traverse City, Michigan
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Good afternoon gentlemen.

I am delighted to have the opportunity of saying a few words on how a manager reacts or should react after operating the hottest television station in the country and getting nationwide notariety for the precedential happening. To my knowledge, we were the first television station that ever went all the way to the cinder pile. I refer, of course, to the fire that totally destroyed the transmitter and studios of WWTV, Cadillac-Traverse City, Michigan.

You could perhaps easily guess that I too was pretty burned up. But after a few months of cool, clear reflection, I am up to the point where I can pull out a few puns and join all the other punsters in discussing our plight on the night of January 23rd. 'On the night of January 23rd' sounds like the title of a good book or a good play. I prefer to think of it as a play because, frankly, it was really a comedy of errors. Thinking back on it, things couldn't have gone more wrong if we had been filming a Mack Sennett three-reeler assisted by the Keystone Cops with Buster Keaton directing; and I certainly don't want this statement to be a reflection on all our fine fire departments or their personnel. The given array of circumstances was just too much for men and machines.

I am going to review the circumstances of our conflagration as Mr. Walker suggested, with the thought in mind that there might be a few ounces of prevention for you in my remarks, and, God forbid, if one of these flame-swallowing acts ever gets out of hand at your shop, please call me because I might be able to offer some real concrete assistance or ideas in your behalf, plus I will be able to practice some of the bedside manners that some of my good broadcaster friends used on me, such as the voice coming over the telephone, "Is this Smokey the Bear," or "I understand your right hand is burned up to the elbow," or "Which is better, oily rags or gasoline?" One frantic woman called and said, "What in the world am I going to do? My baby sitter burned down." But seriously, all the broadcasters were most helpful in their considerate remarks and moral support as well as their real favoritism to us.

Here's what really happened on that unusual night of January 23rd, really the morning of the 24th. The chief engineer's wife called me at approximately 3:30 in the morning. Now this act in itself was quite a shock to me because it is a little unusual for the chief engineer's wife to call me at any hour, since I'm an old bachelor, much less 3:30 a.m. She told me that she thought perhaps I would like to know that the studio was on fire. I thanked her very much and said yes, I would like to know about it and promptly went right back to bed, thinking it was a joke of some kind. Then I thought, this is a pretty wild joke and I'd better call the police to find out if it is really true. They quickly assured me that there was an alarm and that the fire trucks were at the site. I jumped into heavy clothing, and was lucky I did. A strong wind was blowing, and there was no doubt about it being well below zero. (X)

ke slide #1.
use lights out.

This is a picture of our transmitter building before the fire. This is the southwest corner of the building, and our 1282 foot tower is within 100 feet to the east. (X)

ide #2.

You will notice duct work on top of the roof in this area immediately above our transmitter. The heat from the transmitter was exhausted into this duct work (X)

lide #3.

and forced via fans in this direction for studio heat. This was a fine efficient use of heat but it was the source of our trouble on the night of January 23rd. Evidently a fan froze up in this area and the motor caught fire. Our maintenance engineers on duty that night thought they smelled smoke coming through the duct work. They immediately shut off the transmitter, and when they did this, they could not smell the smoke any longer. So they assumed there was no immediate trouble. But what they had done was to stop the the blowers in the transmitter which were moving the smoke through the ducts. They searched the transmitter for trouble and when nothing was found, the fire department was called. Now when the firemen arrived, they went up into this area. They could not find any trouble although there was a great deal of smoke out in the studios by this time but no flames. They hacked a hole through the duct work intending to use a high-pressure fog nozzle to smother the fire. When a fresh flow of air contacted the smoldering embers, the flash point was reached immediately and flames shot through the ducts. The firemen turned on their fog nozzle and -- no water! The hose had frozen solid!

The flames raced into the studio area catching the drapes, fixtures and props and we had a tremendous bonfire in just a few seconds.

I am going to show you some 16mm films, which some of the boys in our news department took for us. They are very bad films, but it was a very dark night, there were no lights other than what the fire produced for us. We didn't have much time to do any real elaborate production work, but this will give you an idea that fireproof buildings do burn -- they burn just fine when the circumstances are right. (X)

.l house lights,
:e film.

Now, the circumstances that were just right -- a wind of about 25-30 miles per hour from the north, and a temperature of about 12^{o} below zero. You will not see one trickle, maybe one slight trickle of water, during this entire film sequence because the fire engine pumps were frozen solid, and by the time blow torches thawed them out, it was too late. It was just about like reaching into your pocket to get a match only to discover you didn't have your pants on. You perhaps are wondering what happened to the foam. Well, the fire departments in our area do not have foam in their fire fighting facilities. There is no doubt in any of the fire chief's minds that if foam had been available, we could have saved practically all the transmitter and studio equipment, and little damage would have been done to the building.

n film ends,
e S-4.

You will notice several areas of twisted metal roof decking and steel beams. These metal roof sections were in a new addition to the original transmitter building. The steel beams and metal roof were exposed to the room's interior and wilted immediately from the excessive heat. Of course, when we build back there will be no exposed steel roof sections. They will be protected by ceiling materials of class "A", or two-hour burning time ratings. It doesn't take flame to destroy metal. Heat will do it, and when the roof collapses, your building is gone. Now we know that it is imperative to have a roof adhesive between the metal deck and the insulation so if there is a fire, the hot tar will not run down into the interior and feed the flames. (X)

-5

In the area of the original building the roof was made of Sofit blocks. They withstood the fire very well. This type of construction consists of concrete blocks held in place by a layer of concrete over the top of them. The wrecking crews had to use jack hammers to dismantle the Sofit block roof sections.(X)

-6

There was also a Dox Plank roof section in one area. These planks are really concrete slabs reinforced with steel but they were supported at one end by a steel I-beam and of course when it collapsed, the Dox Plank ceiling came tumbling down. The one warning I can give you here is to have a two-hour burning material between any potential excessive heat and steel. This will also bring your insurance rates down immeasurably.

Some of the broadcasters who are not present in this assembly may be awfully angry with me for exclusively extending this opportunity to you and to you alone, but, here's the offer. (X)

7

If you hams are looking for slightly used equipment of almost any size and nature, I will be able to make a very good deal for you.

Just come and sort out what you want and take it away, and get in on the last few days of our smoke sale. Of course, the only thing to do when a tragedy like this hits you is to be like the duck, remain calm on top and paddle like hell underneath. That's exactly what we did. (X)

8 The next morning, every conceivable type of activity, bulldozers, graders, cranes, carpenters, plumbers, including cooks for making coffee and sandwiches were on hand. (X)

9 Because of the tremendous efforts extended by everyone involved in getting us back on the air, and a few hundred thousand dollars later, we were able to start our regularly scheduled broadcasts with everything except live cameras two weeks to the day from the date of the fire. (X)

10 This we think was a modern-day miracle brought about with blood, sweat, and, if I dared to recall, a few tears. Within twenty-four hours after the fire, a van loaded with the full station compliment of equipment was on its way from Camden, New Jersey, and twenty-four hours after that, it was being installed by our engineering department with the help of RCA engineers. (X)

11 One week later, prefabricated studios were completed, and we were in business with 170 kilowatts effective radiated power, approximately one-half our full power. (X)

12 We had some luck going with us in the midst of all our setbacks. The reason we could return to the air so quickly was the protection

the high wind gave a portion of the building which was partially erected for our FM transmitter as we were working toward going on the air with our FM radio station early this summer. (X)

-13

The FM building does not show in this picture although it sets in this location. There were just four walls and a roof, but the high winds (25-30 miles per hour) were from the north, and blew the heat and flames away from this section, enabling the contractors to repair what slight damage was done to the FM building and go ahead and complete it for the housing of our 11 kilowatt television transmitter. (X)

Iouse lights on.

One thing we have been advised to do in our new construction is to use steel doors on all interiors in the transmitter section of our new building. In our old building we utilized wooden doors and their reaction was like toothpicks in the fire. I know you were aware that our 1200 foot tower stands within 100 feet of the transmitter building, but luck was with us in this respect, that the wind was so high and out of the north that the flames were whipped to the south away from the tower.

The only thing I would like to re-emphasize here is that you can't go wrong by seeing that your builder or contractor uses the Underwriters' Laboratory building materials list and their fire protection list. If you take heed of the suggestions in these publications, you may enjoy substantial savings, not only by avoiding a fire like we went through, but by receiving a lower insurance rate.

Now we come with our case for full coverage insurance. The building was no trouble at all because the adjusters were well acquainted with this type of fire loss. All we had to do was to get our contractor to itemize in detail the materials and construction costs involved in replacing the building. A normal depreciation factor was applied and we were paid. But the electronics equipment and the other appurtenances used in a television studio and transmitter were not so simple for the adjusters to think on. They had no precedent. We were establishing that. So the wrestling match started, and is still going on as a matter of fact.

One adjuster made a comment which I enjoyed, "If you could only have had a small fire first and we had adjusted that, then we would have had something to work on in the big one."

We were working with replacement costs. So in the first trial balloon toward adjustment, we attempted to take our 1953 equipment costs and apply an inflation factor for present day cost, then depreciate this figure. The system seemed to be all right until they found one item that had gone down in price from 1953. They immediately threw this approach to the problem out. Then they wanted prices for all our new comparable equipment item by item. We immediately got tangled up in such things as how do you replace a 7.5 kilowatt transmitter since they do not make them anymore. And if anyone knows where we can get a 7.5 Federal transmitter, never mind. But you can see that it is impossible to replace equipment with the exact size and specifications of the old equipment.

Depreciation is a real problem. They wanted to use approximately ten years depreciation for much of the equipment. We maintained that such items as the transmitter were really appreciated during certain years due to modification and upgrading. To this date, we are not in agreement. One danger area which may be avoided by good record keeping on the part of engineering and accounting departments is expensed items. We kept good records at WWTV of our capitalized and expensed properties and still it was difficult for us to show that a considerable number of component parts which were expensed went into the building of large pieces of equipment such as switchers. Over a long period of time, our engineers built a very elaborate and expensive switcher. The determination of what this switcher was worth was a source of considerable disagreement between us and the insurance company, and this was just one of the bones of contention in this area. May I emphasize once more that good record keeping is of paramount importance.

This business of full coverage can easily be a misleading term, especially if there is a co-insurance clause in your policy - and this clause exists if there is a partial loss. If there is a total loss, your company automatically becomes a co-insurer if your insurance is not up to 100% of the true value of your equipment. For instance, it is very easy to insure equipment for say the round figure of $200,000 and then over the course of time, you have made other purchases extending the total value of all of your equipment to $300,000. You have forgotten to change your insurance because this extra $100,000 of equipment was added over a period of years and through many small and varied purchases. If you have a partial loss of $100,000 you will receive only two-thirds of the $100,000 loss or $66,666 recovered because you were only two-thirds insured in the first place. Now if you have a total loss, you automatically become a co-insurer. You lost $300,000 worth of equipment, you were insured for $200,000 and you can't collect more than the face value of your policy. So you have lost $100,000 by virtue of not keeping your insurance up to date. I should like to advise everyone that in order to be on the safe side, it would be well to bring in a certified appraisal company (Lloyd Thomas and Company, or American Appraisal Company are two of the best known), and with their findings a matter of record, the adjusters will not have to enter into a full blown research problem in order to find a basis on which to pay your claim. You must be sure that the actual value of your equipment is reflected in your insurance coverage. Always keep your insurance at 100% of the property's actual value. If you don't, you can be made to become pretty hot under the collar by the adjusters.

WWTV is very proud to be a part of a well known name in our industry. The Fetzer organizations have made many contributions to radio and television. WWTV was the victim of a situation that was a precedent, but for some reason we don't like to refer to this precedent as having been set.... it seems to be a bad choice of words somehow.

Thank you very much.

VHF TRANSLATORS

A New Coverage Tool For TV Broadcasters

By

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It is generally accepted that TV broadcast advertising rates are in direct proportion to a station's receiver coverage. Great effort and expense are involved in expanding this coverage - both by technical and programming means.

The coverage of a television broadcast station is divided into four general zones. The first two - principal city and Grade A zones - are usually characterized by strong signals and, therefore, will not be considered in this paper. The third and fourth zones - Grade B and fringe reception areas - wil be considered in detail.

First, we must examine the factors which affect a television station's range.

VHF TV transmitters range in effective radiated output power from a minimum of 100 watts to a maximum of 316 kilowatts. Antenna heights vary from approximately 100 feet above ground, to tall tower installations such as that at Cape Girardeau, Missouri, which is 2,000 feet above average terrain. In New Mexico several stations with mountain top installations transmit from antennas which are more than 4,000 feet above average terrain.

The transmitted signals are quasi-optical with coverage distances extending only slightly beyond the "line of sight." The formula for path attenuation between two isotropic antennas in free space is:

$$(1) \quad A_p = 37 + 20 \log D + \log F$$

A_p = path attenuation in db

D = distance in miles

F = frequency in Megacycles

Assuming a distance of 1000 miles and using 200 mc as a representative frequency, the path attenuation is 143 decibels.

FURTHER EXAMINATION IS REQUIRED TO DETERMINE WHAT POWER TRANSMISSION IS NECESSARY TO OPERATE THE ORDINARY RECEIVER SATISFACTORILY AT THIS RANGE. THE TRANSMITTER POWER FOR A GIVEN SIGNAL TO NOISE RATIO AT THE OUTPUT OF A RECEIVER IS GIVEN BY THE FOLLOWING FORMULA.

$$(2) \quad 10 \log \frac{P_T}{P_N} = A_P + \frac{S}{N} + N.F. - G_T - G_R - N.I.F.$$

WHERE

$\frac{S}{N}$ = REQUIRED OUTPUT SIGNAL TO NOISE RATIO IN DB

N.F = RECEIVER NOISE FIGURE IN DB

P_N = NOISE POWER INPUT TO THE RECEIVER

P_T = TRANSMITTER TERMINAL POWER

G_T = TRANSMITTER ANTENNA GAIN IN DB

G_R = RECEIVER ANTENNA GAIN IN DB

N.I.F = NOISE IMPROVEMENT FACTOR IN DB

A_P = PATH ATTENUATION IN DB

THE JOHNSON NOISE WHICH EXISTS IN THE 6 MC TELEVISION CHANNEL IS 108 DECIBELS BELOW 1 MILLIWATT. USING A TELEVISION RECEIVER WITH A 5 DECIBEL NOISE FIGURE AND A DIPOLE ANTENNA WITH NO GAIN, A SIGNAL TO NOISE RATIO OF 10 DB WOULD REQUIRE A TRANSMITTED POWER OF ONLY 100 WATTS TO OVERCOME THE PATH LOSS OF 143 DB. A ONE HUNDRED MILE PATH WOULD REQUIRE A POWER OF 10 WATTS. IF ANTENNAS WITH GAIN WHERE USED, A 30 DB SIGNAL TO NOISE RATIO COULD BE ACHIEVED AND A NOISE FREE PICTURE WOULD BE AVAILABLE.

FROM THESE FACTS IT CAN BE DEDUCED THAT TRUE LINE OF SIGHT IS THE ONLY LIMITING PARAMETER, SINCE THE EARTH ABSORBS ENERGY WHICH STRIKES IT, AND SKYWARD DIRECTED ENERGY IS NOT REFRACTED. LINE OF SIGHT CAN BE CALCULATED FROM THE FOLLOWING FORMULA.

$$(3) \quad D^2 = H_T^2 + H_R^2 + 2R(H_T + H_R)$$

WHERE

D = DISTANCE IN MILES

R = RADIUS OF EARTH X 4/3

H_T = TRANSMITTER ANTENNA HEIGHT

H_R = RECEIVER ANTENNA HEIGHT

IT IS APPARENT THAT A STATION'S RANGE CAN BE EXTENDED BY INCREASING ANTENNA HEIGHT. HOWEVER, THIS METHOD HAS MANY LIMITATIONS. SUBSTANTIALLY INCREASED HEIGHT INVOLVES ADDITIONAL TRANSMISSION LINE LOSS AND COSTLY INSTALLATION AND MAINTENANCE WHICH RAPIDLY BECOMES PROHIBITIVE. ALSO, THERE ARE LEGAL HEIGHT LIMITS. IF THE INTERVENING TERRAIN IS MOUNTAINOUS, EVEN THE DISTANCE TO THE HORIZON (LINE OF SIGHT) WILL BE MODIFIED - VALLEYS WILL RECEIVE LITTLE OR NO SIGNAL. THE SAME IS TRUE FOR CITIES WITH LARGE BUILDINGS, BUT THIS IS SOMEWHAT OVERCOME BY HIGH EFFECTIVE RADIATED POWER.

WHILE TRANSMISSIONS EXTEND SOMEWHAT BEYOND LINE OF SIGHT AS EVIDENCED BY THE COVERAGE PATTERNS OF EXISTING STATIONS, THE PRINCIPLE STATED IS ESSENTIALLY TRUE. IN MOST CASES, THE COST OF INCREASING THE HEIGHT OF A TOWER IS NOT JUSTIFIED BY THE ADDITIONAL COVERAGE GAINED.

AN IMPORTANT NEW TOOL WHICH CAN BE USED TO INCREASE TELEVISION COVERAGE IS THE VHF TELEVISION TRANSLATOR. WITH 1 WATT PEAK VISUAL POWER, (AND EFFECTIVE RADIATED POWER IN EXCESS OF 10 WATTS,) AND THE VARIOUS TYPES OF ANTENNAS AVAILABLE, COVERAGES OF FROM 12 MILES AT A 75° BEAM WIDTH, TO LINE OF SIGHT AT NARROWER WIDTHS, CAN BE OBTAINED. THIS EQUIPMENT WILL PROVIDE GOOD TV RECEPTION IN ISOLATED AREAS. THE LOGICAL SUPPLIER OF TRANSLATOR SERVICE IS THE ORIGINATING STATION. IT IS TO THE BROADCASTER'S ADVANTAGE TO EXPAND HIS COVERAGE AND KEEP DIRECT CONTROL OVER RECEPTION QUALITY.

While the exact details vary from location to location, a translator site should have an available signal at least 30 db above the noise level at the input to the translator. With a translator noise figure of 5 db maximum, this sensitivity should be about -68 dbm or 350 microvolts into 75 ohms. Since good single channel antennas are available with 15 db gain, and 200 feet of 7/8" foamflex has only 2 db attenuation, a net signal at the antenna of less than 100 microvolts will produce a noise-free picture. 1000 microvolts will allow a 20 db fade margin and still keep a perfect picture.

Pole-mounted equipment should be avoided whenever possible. This will eliminate the cost of running power to the top of the tower, and avoid pole climbing to replace components which have failed. In almost every case, it is possible to compensate for the resulting one or two db transmission line loss.

Additional considerations for selection of a good Translator Transmitter Site are that it be:

1. Near a road, so that the equipment may be readily serviced.

2. Near AC Power Lines, to avoid the heavy expense of bringing in power over long distances.

3. On a higher elevation than the expected coverage area. This eliminates the necessity of costly high towers while preserving available signal for radiation rather than dissapation in line loss.

4. On the edge of the expected coverage area, since available high gain, inexpensive antennas are highly directional.

5. Where the Prime Station's signal is readily available at a level of at least 350-500 microvolts.

The typical installation will include:

1. A Tower or Pole high enough to clear any surrounding obstructions. This usually is between 60-100 feet.

2. A good grade receiving antenna cut to the channel of the Prime Station. This antenna should be mounted high enough to receive a good clean signal of at least 350-500 microvolts.

3. A shelter or building to shield the translator from the elements, and especially to protect a technician during preventive maintenance. This could be similar to a tool shed or Butler building approximately 8 x 8 feet in floor area.

4. A translator transmitter manufactured to broadcast quality specifications to insure uninterrupted service for the greatest number of hours and the least amount of servicing expense.

5. An antenna array with a pattern that serves the maximum number of receivers in the coverage area.

6. High grade, low loss transmission line to insure that a maximum signal enters the translator, and that a maximum output signal reaches the transmitting antenna.

The actual installation of equipment can be accomplished in a short time. The building and tower should be erected before the translator arrives at the site. AC power with its normal disconnects should be provided inside the building. The translator transmitter, completely tested and aligned to the proper receiving and transmitting frequencies, is then uncrated. The AC Lines are connected to the input plug. The antennas are installed on the tower and transmission line connections carefully made. The translator is then turned on -- and with a minimum amount of adjustment will put a signal into the desired area. The timing device is set for proper keying of the translator's coded call letters. From that time on only routine preventive maintenance calls need be made at the Translator Site by any competent technician. The translator will automatically shut down whenever the Prime Station turns off its signal, and will come on again when the Prime Station's signal is received.

From the discussion of translator applications and installations, it is evident that reliability of operation and ease of maintenance are prime requisites. The Adler VST-1 VHF translator is designed for reliability. Studies show that the mean time to failure of vacuum tubes is the shortest of all the components used in a translator system. In the VST-1, the mean time to failure for the fifteen, 10,000 hour tubes used is more than thirty-five hundred hours. This is essentially the mean time to failure for the equipment, since the components other than tubes have a very much longer time to failure. The criterion, established for reliability, is the use of 10,000 hour tubes with a regulated filament supply and operated at 60% or less of maximum ratings. Heat-reducing tube shields are used to further lengthen tube life.

All resistors are capable of dissapating at least twice the actual power and all capacitors are rated for at least 1.5 times their actual voltage. Similar conditions exist for all the other components. This type of design extends the expected failure rate of the entire equipment to only twice per year based on 20 hours per day of operation.

In addition to its reliability features, the VST-1 is designed for ease of maintenance. Modular construction reduces down-time by facilitating servicing. All tubes are removable without the use of tools, and test points for alignment and measurement are readily available.

The translation circuitry is one of the key aspects of the electrical system. A double conversion technique is employed in the VST-1. Commonly available channel amplifiers could work for some channels. However, many channels would be unusable because low channel harmonics would fall in the high channels. Figure 1 shows the interferences that would occur in a single conversion system.

FIGURE I

INPUT CHANNEL	OUTPUT CHANNEL	INTERFERENCES
3	8	3RD HARMONIC IN CH. 8
3	9	3RD " " " 9
3	10	3RD " " " 10
4	11	3RD " " " 11
4	12	3RD " " " 12
4	13	3RD " " " 13
6	7	3RD " " " 7

COMPARED TO SINGLE CONVERSION, DOUBLE CONVERSION HAS MANY ADVANTAGES AND ONLY ONE APPARENT DISADVANTAGE. THE DISADVANTAGE OF USING TWO OSCILLATORS IS OUTWEIGHED BY THE FACT THAT GAIN IS MORE ECONOMICAL AT LOWER FREQUENCIES AND FEWER STAGES ARE NEEDED.

SOME OF THE ADVANTAGES ARE:

1. WITH PROPER DESIGN AND INSTALLATION, EVEN ADJACENT CHANNELS WILL OPERATE FROM INPUT TO OUTPUT.

2. TWO IDENTICAL LOCAL OSCILLATORS OPERATING IN THE SAME ENVIRONMENT TEND TO CANCEL FREQUENCY DRIFTING.

TO ACHIEVE THESE ADVANTAGES THE FOLLOWING STEPS MUST BE TAKEN: (1) PROPER INTERMEDIATE FREQUENCIES MUST BE SELECTED; (2) OUTPUT CHANNELS SHALL CONTAIN NO HARMONIC LOWER THAN THE FOURTH; (3) MIXING MUST BE LINEAR TO REDUCE EVEN HARMONIC COMPONENTS; AND (4) ONLY HIGH ORDER HARMONICS OF THE OSCILLATOR MAY APPEAR IN THE OUTPUT BANDS, AND THESE MUST BE 60 DB DOWN FROM THE SIGNAL.

After examining all the frequency bands, the 44 mc - 50 mc band appears to be the best choice as the intermediate frequency. Its second and third harmonics are out of the television bands. The fourth harmonic of the picture I.F. falls at the edge of Channel 8 and the fourth harmonic of the sound I.F. falls in Channel 10. Care in balancing and linearizing the transmitter mixer eliminates these problems.

The oscillator frequencies used for conversion to and from the I.F. and harmonics are shown in Figure 2.

Figure 2

Channel	Osc. Mixer Freq.	Osc. Fund. Freq.	2nd Harmonic	3rd Harmonic	4th Harmonic	5th Harmonic
2	9.9	--	19.8	29.7	39.6	49.5
3	15.9	--	31.8	47.7	63.6	79.5
4	21.9	--	43.8	65.7	87.6	109.5
5	31.9	--	63.8	95.7	127.6	159.5
6	37.9	--	75.8	113.7	151.6	189.5
7	129.9	32.475	64.95	97.425	--	162.375
8	135.9	33.975	67.95	101.925	--	169.875
9	141.9	35.475	70.95	105.425	--	177.375
10	147.9	36.975	73.95	109.925	--	184.875
11	153.9	38.475	76.95	114.425	--	192.375
12	159.9	39.975	79.95	118.925	--	199.875
13	165.9	41.475	82.95	123.425	--	207.375

Intermediate Frequency Band 44.1 - 50.1 Mc

It is evident from the chart that Channel 3 oscillators generate a third harmonic which falls in the I.F. passband and a fourth harmonic in Channel 3. Care must be taken to provide extremely low harmonic content in the output of the oscillator to prevent birdies from occurring in the passband. The oscillator which is used to eliminate these problems, and to provide the required frequency stability, is the Butler oscillator.

This oscillator consists of a grounded grid amplifier whose output is coupled to a cathode follower. The feedback path is from the cathode of the follower through the crystal to the input of the grounded grid amplifier. In this particular circuit, the plate of the cathode follower is the screen grid of the 6688 tube. The tube's plate acts as an electron coupled amplifier isolating the oscillator from the load.

A block diagram of the Adler double conversion translator is shown in Figure 3. The signal section is composed of three panels; the receiver or input amplifier, the intermediate amplifier, and the transmitter or output amplifier.

The control, metering and power supply also occupy separate panels. In this way a completely functional unit is available. All that must be done to provide a complete translator is to select the input and output channels. Figure 4 shows a front view of the VST-1.

The input channel section consists of a 6688 tube, triode connected and used in a neutrode circuit. The intermediate stages consist of a 6922 dual triode, with each triode connected as a grounded grid amplifier. The output of this amplifier, which has a gain of 40 db, and a noise figure of 3.5 db on the low channels and 4.5 db on the high channels, is fed to a 6688 mixer. This very high gain tube, being used as a mixer raises the input gain to 50 db. The associated circuitry is designed as a triple tuned band pass to provide excellent spurious and harmonic rejection as well as an extremely flat pass band.

The A.G.C. which is an amplified peak detector type operating from the video signal, is applied only to the second grounded grid amplifier and mixer circuits. This provides the control required by the F.C.C.'s specifications and leaves the first stages at ground to produce low noise

EVEN AT STRONG SIGNALS. ITS INPUT AND OUTPUT IMPEDANCE ARE 75 OHMS, BUT THE INPUT IMPEDANCE CAN BE ADJUSTED TO 50 OHMS WITH A SIMPLE RELOCATION OF THE ANTENNA TAP TO FACILITATE FLEXIBILITY OF INSTALLATION.

THE INTERMEDIATE AMPLIFIER IS A STRAIGHT FORWARD, THREE STAGE DOUBLE STAGGER TUNED DEVICE. SINCE THIS UNIT WILL REMAIN THE SAME FOR ALL INPUT AND OUTPUT CHANNELS, IT WAS FELT THAT A PRINTED CIRCUIT BOARD COULD BE USED TO BEST ADVANTAGE.

IT HAS A 75 OHM INPUT AND OUTPUT IMPEDANCE, A GAIN OF 40 DB, AND AN A.G.C. CONTROL LEVEL OF AT LEAST 20 DB. THIS AMPLIFIER, AS WELL AS THE RECEIVER IS DESIGNED TO BE UN-AFFECTED BY ENVIRONMENTAL CONDITIONS, A.G.C. VARIATION AND TUBE CHANGES. REALIGNMENT IS NOT REQUIRED WHEN A TUBE IS CHANGED. THE A.G.C. DETECTORS AND AMPLIFIERS ARE INCLUDED ON THIS PANEL. THE CIRCUIT CONSISTS OF A VIDEO DETECTOR, TWO VIDEO AMPLIFIERS AND A PEAK DETECTOR. TO REITERATE, THIS CIRCUIT IS CONNECTED TO CONTROL TWO STAGES IN THE RECEIVER SUBASSEMBLY AND TWO STAGES IN THE INTERMEDIATE AMPLIFIER. WITH A SINGLE SETTING, THIS IS CAPABLE OF KEEPING UP TO A 50 DB VARIATION IN INPUT LEVEL TO A 2 DB VARIATION IN OUTPUT LEVEL. THE PURPOSE OF MAINTAINING THIS LARGE CONTROL IS TO INSURE THAT THE MAXIMUM POWER OF ONE WATT WILL NOT BE EXCEEDED. IT ALSO PROVIDES FOR THE CONTROL OF AT LEAST 30 DB AT ALL EXPECTED SETTING OF THE A.G.C. LEVEL CONTROL.

THE TRANSMITTER PANEL CONSISTS OF A SECOND 6688 MIXER, BUTLER OSCILLATOR AND TWO CLASS A LINEAR POWER AMPLIFIERS, CONSISTING OF A 6939 STAGE FOLLOWED BY A 6360 STAGE. THESE UNITS ARE ALSO 75 OHMS INPUT AND OUTPUT, BUT THE OUTPUT IMPEDANCE IS ADJUSTABLE BY MEANS OF A VARIABLE CAPACITOR. A CAPABILITY OF 4 WATTS OF LINEAR OUTPUT POWER IS AVAILABLE TO INSURE EXTREME LINEARITY AND TO PREVENT HIGH LEVEL INTER-MODULATION DISTORTION OF THE SOUND BY THE PICTURE.

IN ADDITION, BOTH OUTPUT AMPLIFIERS ARE PUSH-PULL TO SUPPRESS ALL EVEN HARMONIC OUTPUTS.

THE CONTROL, METERING AND POWER SUPPLY FUNCTIONS FOLLOW STANDARD DESIGN PROCEDURES. THE POWER SUPPLY IS A LINE REGULATED TYPE WITH CIRCUIT BREAKER PROTECTION. THE CONTROL KEYER IS THE TIME TESTED UNIT USED IN THIS MANUFACTURER'S U.H.F. TRANSLATORS. METERING OF POWER OUTPUT AND V.S.W.R. ARE ALSO PROVIDED.

The overall system has a gain of 120 db with a ± 5 db flat bandpass of 6 Mc. The response is at least 60 db down 3 Mc on each side of the band edges. The system exceeds, by far, the specifications required by the F.C.C. for this type of translator service. It allows for component aging, temperature variations and fading.

In conclusion, a VHF translator system for extending the coverage of a TV station should be based on:

1. High quality equipment designed to serve the needs of the professional broadcaster.

2. An advantageous site and proper installation.

3. A reliable equipment supplier with the proven experience in all phases of design, manufacture and installation of translator systems.

All of these points will help insure a happy new TV audience as well as a satisfied TV translator operator.

Figure 3

Block Diagram Of Adler VST-1

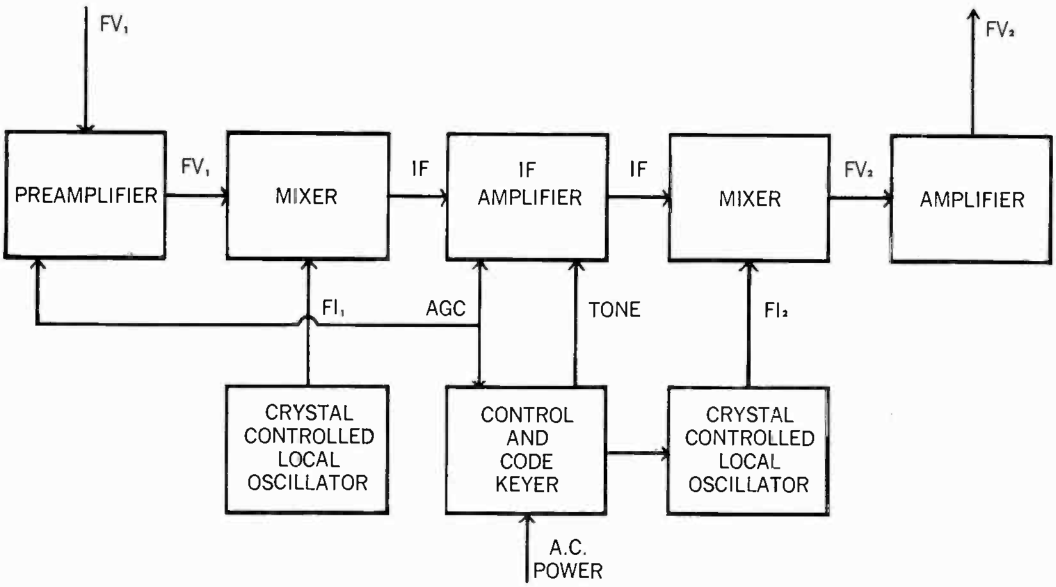
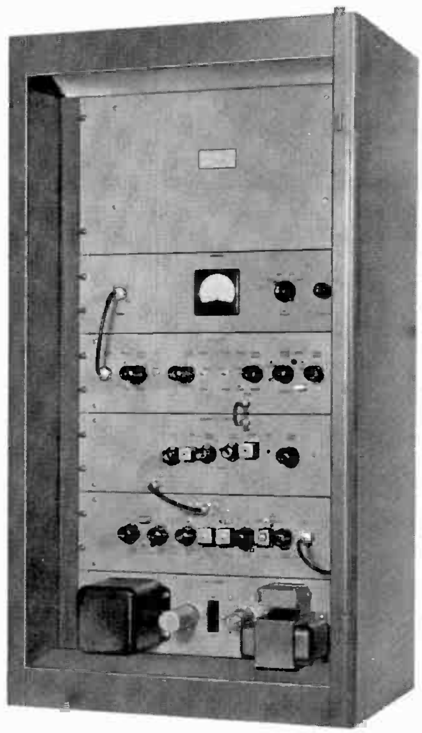


Figure 4

Front View Of Adler VST-1



SATELLITE RELAYS AND BROADCASTING

by

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NATIONAL ASSOCIATION OF BROADCASTERS
Engineering Conference
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SATELLITE RELAYS AND BROADCASTING

J. H. Felker

Science and the telephone business have worked together very closely ever since Alexander Graham Bell's breakthrough in a Boston attic in 1875. The constant search for greater communication capacity led to carrier telephony in the twenties, to coaxial cable systems in the thirties, to microwave in the forties, and long overseas submarine voice cables in the fifties.

The big step in the sixties will, of course, be the use of satellites in microwave communications. Each of these advances has had one thing in common. Each enabled us to get a larger number of circuits over a particular path than we could by previous methods. In carrier telephony, twelve voice circuits on two pairs of wires is common. In a coaxial cable, we get 1,800 voice circuits per pipe, in microwave radio, we get 1,800 circuits per channel and in our first long submarine cables, we got 36 voice circuits.

It may be noted that the submarine cable gives fewer voice circuits than the coaxial cable or microwave radio. Before we deprecate the achievement represented by submarine voice cable, we might remember that it was about 75 years after we had learned how to get a cable under the ocean before we were able to handle even one voice circuit in an underseas cable!

Submarine cables and satellites may seem at the opposite ends of space, yet each require fantastic standards of reliability from electronic parts if they are to be practical. In our cable systems, where the repeaters are almost as inaccessible as they would be in outer space, over 700,000,000 component hours of life have piled up without a single failure. Over 1,500 vacuum tubes have operated 2-6 years without failure.

Figure number one shows our present overseas network. This network began with cables to Cuba in 1921 and transatlantic voice service in 1927. It has now grown until we and our overseas partners have several hundred million dollars invested. You may be interested to know that we have business agreements with 163 overseas telephone agencies and administrations. Many of these are with the iron curtain countries. We have always found the simple yardstick of what makes good communication and business sense adequate to resolve differences of opinion. Our arrangements have worked well. We'd like to continue them.

Despite the great step forward taken with submarine cables, we are still lacking the ability to give the full range of services overseas that we do continentally. Submarine cables do not now, or is it likely that they will in the near future, give us sufficient frequency spectrum to transmit commercial quality video signals whereas microwave radio and coaxial cables do.

Why do we consider it important to have intercontinental television? Basically, we believe it is important because:

1. Common markets are extending everywhere.
2. International news events often transcend national news in importance.
3. Americans, as business men and as citizens on vacation, travel more these days. Seeing the rest of the world at play and at

work is a basic expectation of more and more Americans.

We are so sure of this that the Bell System is willing to take a business risk on it just as it did on TV networking in this country. Some of you may remember that in 1946, in order to stimulate intercity television the Bell System provided facilities to the Broadcasters on an experimental basis before anyone could prove that there was a "need" for a transcontinental video network. This bit of history may seem strange when we realize that there are now 83,000 miles of video facilities which we supply to the broadcasters. Figure two shows our present video network. One might have expected that video tape recording and transportation by high speed jet would make it unnecessary to have overseas TV. The fact that these same tools have not decreased the use of the television network in the United States argue against there being any substitute for overseas networking.

Clearly, if we were able to extend our video network by microwave radio, we could avoid the bandwidth limitation of submarine cable. You may be interested to know that George Gilman in charge of systems engineering at B.T.L. in 1950, directed a study of the economic feasibility of using a string of airplanes carrying microwave repeaters as a means of relaying video across the ocean. Since we did not undertake the venture you may assume correctly that the service did not look economically attractive.

Another way of getting microwave across the ocean would be to build a 475 mile tower out in the middle of the ocean, Figure 3. A repeater on such a tower would provide an optical line of site between New York and Paris. It would permit microwave coverage over even greater distance.

Satellite communication systems are only substitutes for the 475 mile tower in the sky. The rocket is just a cheap way of getting a repeater up there. If you wince when I describe a rocket as cheap, consider the following arithmetic. If a 2 million dollar rocket can replace a 475 mile tower, how much does the rocket cost per foot? The answer is about 80 cents. And anyone in the broadcast business knows that 80 cents a foot for a tall tower is a mighty low price.

It can be argued that it takes many rockets and satellites to have a complete substitute for the tower in the sky. That is true, but the rockets still look cheap in comparison to a tower. As a matter of interest, a rough calculation led to the estimate that a 475 mile tower would have a cost equal to the value of the entire gross national product for 70,000 years.

The Satellite System

Having established satellite systems as merely high tower microwave systems, consider how many repeaters might be required and what kind of orbits should be used to establish world-wide communications.

This gets into the number of channels that each satellite can provide which in turn becomes a problem of the availability of frequency spectrum. This probably does not come as a surprise to broadcasters.

Because of the very difficult transmission path from satellite to the earth, "bird-to-ground," wideband modulation must be used to get a signal that can be gleaned reliably from the noise. We believe that a total frequency band of about 250 megacycles is required for each channel served. A channel is viewed as 600 voice circuits or one video circuit.

Some studies show a demand for twenty such channels. If these were to be provided by one bird, a spectrum of 5,000 megacycles would be required. To put this into perspective, you may recall that the entire TV broadcast band amounts to only 492 megacycles (Channels 2-83).

What this consideration of frequency spectrum means is that to meet the foreseeable needs of the future, many different satellites will be required so that many pairs of ground stations may reuse the same frequencies by pointing their highly directive antennas at different birds. Thus we believe that the ultimate satellite systems will be made up of many birds. This will require that each bird, and the means of launching, will have to be as low cost as possible. Consideration of reliability also leads to the same conclusion. The system must include many birds to avoid excessive dependence on any one.

Choosing the orbit for the satellites is a complex matter. The first proposal which our scientists made was for a system of synchronous satellites, satellites that rotate once in 24 hours. A satellite at about 22,000 miles above the earth has this property. If placed in an equatorial orbit, such a satellite will appear to hover over the same position on the earth's surface. Station keeping facilities, that is a source of motive power, could be used to prevent the satellite from drifting with time or to correct its initial position.

Figure 4 depicts a system of three synchronous satellites in equatorial orbits which would cover 95% of the earth's surface.

As mentioned earlier, although 3 satellites will cover 95% of the earth's surface, frequency considerations will undoubtedly require the use of a greater number of satellites. Reliability considerations also lead in the same direction.

As can be seen from the sketch, the synchronous satellites are a long way from the earth. The transmission path from New York to London is increased from around 4,000 to about 44,000 miles. As will be discussed later, this is not without penalty for two-way to and fro voice communications.

Consider the situation that would prevail if about 50 satellites were put into about 6,000 mile orbits and distributed as a kind of umbrella around the earth. Control over the relative positions of the satellites need not be assumed. Our studies show that in an average 24 hour period, there would be less than one and a half minutes in which there would be fewer than four satellites visible between London and New York. If one of the satellites failed, the time for which less than 4 would be visible increases by only 30 seconds. This means that such a system would be remarkably insensitive to equipment failures. Since it is not necessary to control the orbits of the satellites (they can be allowed to drift), we do not have to depend upon station keeping apparatus.

Such a multi-satellite system is very attractive from the point of view of reliability. It is also attractive because of its efficient use of frequency spectrum because the same frequency band can be reused on each satellite. Furthermore, adding additional satellites, or accepting into the system satellites launched by a foreign partner, is a much simpler matter than it is for any other scheme we know of.

When we face up to the responsibility of using satellites to provide better intercontinental communications than we now have, we discover that the altitude of the satellites is a very important factor. This is because the transmission paths can get so long that the resulting delay interferes with the to-and-fro communication that is the essence of telephone service.

Published statistics show that in telephone conversation, an average burst of talk is about 2 seconds in duration. The other party responds in 0.3 second on the average. A speaker must wait the round trip propagation time of the circuit before he knows whether or not the other party has responded. He expects a delay in response of only 0.3 second and the round trip delay adds to this.

Great doubt exists that synchronous satellites will do for two-way telephony because of an inevitable round-trip delay of about 0.6 second for a single satellite system. This would make the average response time 0.9 second or three times as long. Two satellite systems in tandem (which would occur in some world-wide network connections) would mean a round-trip delay of more than a second to be added to the normal response time. In comparison, there is less than 0.2 second delay for a call from Europe to Hawaii via land lines and submarine cable - the longest cable communication now possible.

One would expect that speakers using circuits in which delay increases each speaker's response time, would take longer to carry out their transactions. On the contrary, we find so far, that the speakers hang up sooner than they do on calls over circuits without delay. This indicates to us that the service has been less satisfactory. The issue is not whether customers will put up with delay in their communications' paths. It is rather, will they find the service so useful that they want to use it freely.

In fact, unless satellites give high quality telephone service the rapid growth of traffic predicted for the future will not occur. We know from previous experience that where service is mediocre, growth is slow or non-existent. Any one in the communications business will confirm the observation that our present level of telephone development in the U.S. is due to the ease and naturalness of the service provided.

There is another aspect to the delay problem that can only be mentioned in passing. All telephone networks create echoes. When delayed, echoes become intolerable. If not suppressed, they can rattle a speaker to such an extent that he can no longer speak. Echo suppressors are, therefore, used on long circuits. Echo suppressors set to work for delays of a few tenths of a second introduce minor degradation. But when set for delays of a half second and longer, the degradation is severe.

The Bell System has long followed the doctrine that new facilities should perform at least as well as the old - preferably better. So, in order to get quality, reliability, and maximum use of the frequency spectrum, our planning has been directed at a system based on many satellites in low-level orbits. A larger number of satellites are required than in a synchronous system, but the satellites are much simpler and frequency spectrum is conserved. Each ground station requires several steerable antennas to change from one satellite to another without interrupting communication. This flexibility insures reliability since it is possible to switch to another satellite when one fails.

Conceivably, suitable propulsion in the satellites could keep them in precise enough orbit for continuous service with fewer satellites. However, planning so far has been mainly for satellites without this station-keeping ability. Our plans may very well change as the art of station-keeping advances and develops the required reliability.

Initially we plan for 30 satellites in about 6,000-mile polar orbits. Even if these orbits are random and uncontrolled, at least one will be visible both in the U.S. and Western Europe except for a period less than two minutes a day. In a different part of the orbit, the 30 satellites also can provide service between the U.S. mainland and Hawaii.

Once the 30-satellite service is established, we could increase international communications with more satellites in the same 6,000-mile orbits so at least two satellites are mutually visible to the two terminals. Add antennas at each ground terminal and you establish two independent communication links via the two satellites between the same terminals. We could repeat this to get three or more satellites mutually visible to increase traffic further. Thus, you can increase traffic without increasing frequency assignments.

Another way to add transmission capacity is to install repeaters for several broadband radio channels in each satellite. This saves in ground installation by using the same antenna for several radio channels. There is an optimum number of channels per satellite to give the cheapest over-all system. It depends on relative costs of satellites (including launching) and costs of antennas. Since we do not know these costs accurately now, we cannot yet definitely determine the optimum.

Our present plans call for satellites with repeaters to handle four broadband two-way radio channels. Each channel could carry 600 telephone signals or one broadcast quality television signal. We estimate that by 1980, we would need 12 broadband two-way channels between the U.S. and Western Europe (including Britain). Thus, in 1980, we will need 50 satellites in orbit to give a high probability that four satellites would be visible to the U.S. and the European countries. This calls for enough frequencies to provide four broadband channels.

This world-wide system is illustrated schematically in Figure 5.

Design of a Satellite Repeater

We have been authorized by the F.C.C. to use frequencies in the 4,000 megacycle and 6,000 megacycle range for an experimental satellite system. We have made considerable progress on the development of such a system. At 4,000 megacycles there is a loss of 185 db between an isotropic antenna on the ground and another one 6,000 miles into space. By building a 60 by 60 foot horn antenna, Figure 6, we can get 57 db of gain. We have work under way on a ground station with such a horn antenna at a site near Rumford, Maine, shielded by a range of hills.

The horn antenna when looking at space, sees only space. That is, the horn antenna does not pick up any radiation from the earth. The horn antenna, when used with a maser receiver enables us to get an effective noise temperature of only 20° Kelvin. This is a really remarkable advancement since the best low noise receiver (low noise traveling wave tube) of a few years ago had a noise temperature of about 700 degrees.

In the ground receiver, we will use a traveling wave maser similar to the one we used in our Holmdel space research station that worked with the Echo balloon. Now the operation of the maser is based on some complex ideas, but it is not so complicated when viewed as hardware.

The maser amplifier is a device developed by the Bell Telephone Laboratories in 1956 which makes it possible to amplify exceedingly weak microwave signals without adding any appreciable amount of noise in the process.

Without going into an explanation of the underlying physics involved, I will attempt to explain briefly what a traveling wave maser is and how it works. Its circuit consists essentially of two microwave transmission lines as shown in Figure 7. These lines operate at different frequencies, occupy the same volume, but are electrically uncoupled. One of them, the rectangular waveguide, carries the pump energy which, together with a strong DC magnetic field, places the active material into a state in which it has energy to release. The pump frequency is several times higher than the frequency of the signal we wish to amplify. Typically, for a 6,000 mc signal, we require a pump frequency of 35,000 mc. The corresponding DC magnetic field is 4,000 gauss. The other transmission line takes the form of a comb. It carries the signal to be amplified and slows it down to approximately 1/100 the velocity of light. This lengthens the duration of the time the signal has to interact with the active material and thereby increases the gain available for a given length of structure by approximately the same factor.

The way to think of the ruby material is as a substance with electrons raised to high energy level from which they are released by the signal. This release creates a strengthened version of the signal.

The active material in the form of the long slab of ruby having a rectangular cross-section is placed on one side of the comb as shown in the figure, in a region where it interacts with the rf magnetic fields both due to the signal and due to the pump.

On the opposite side of the comb we place an iterated ferrite isolator represented by the small black wafers. This isolator is adjusted for ferromagnetic resonance at the signal frequency and, therefore, does not interact with the pump. For a signal launched onto this comb and traveling in the forward direction the senses of polarization of the rf magnetic fields are such that the ruby provides gain while the isolator is essentially non-existent. For a signal traveling in the reverse direction the senses of polarization are reversed. Now the ruby does not, while the isolator does, interact with the signal thereby absorbing it strongly. In practice the reverse loss of this amplifier greatly exceeds its gain thus yielding unconditional stability.

A typical traveling wave maser will provide a gain of 25 db, with an effective instantaneous bandwidth of 25 mc. The effective noise temperature of this amplifier is $10^{o}K$.

As indicated above, the maser itself, is a comparatively simple, compact, and rugged device. However, in order to make ruby amplify it is not sufficient to subject it to a strong DC magnetic field and to microwave pump radiation, but we must also cool it to a very low temperature, namely, that of liquid helium, that is temperatures in the range from 1.5 to 4.2°K. We do this by making use of a closed cycle continuously running helium liquifier.

The success of Project Echo was in no small measure due to the high sensitivity and stable amplification provided by the maser.

To permit launching with contemporary rockets we believe that a satellite should weigh about 100 pounds. The sun's radiation supplies us about 130 watts per square foot of illuminated surface. With solar cells, we can reliably get about 10% of this energy. With a 27-inch satellite, Figure 8, we can get 3,528 solar cells distributed over 55% of the satellite's surface. These will operate a two-watt traveling wave tube and associated circuitry as power amplifiers.

Thus with 2 watts radiated power from the bird, a path loss of 185 db and a transmit plus receive gain of 57 db and a receiver with a noise temperature of 20 degrees K, how can we get a TV signal from the bird to the ground without noticeable picture impairment? We believe we can do it with wideband frequency modulation.

A conventional wideband FM receiver would pick up a great deal of noise and would have little margin against "breaking." By using feedback to cause a narrow-band intermediate frequency amplifier to track the wideband FM signal, the advantages of wideband FM can be achieved with good margin against breaking. FM with feedback is a process invented at Bell Telephone Laboratories a number of years ago (1933) that waited for years for a transmission problem difficult enough to require its use. It was first used during the Holmdel experiment with the Echo balloon.

What I have sketched is merely the skeleton of a truly heroic transmission problem.

The problem of transmitting from the ground to the bird is not so difficult since there is no problem getting adequate power to operate the transmitter on the ground. We plan to use 2 kilowatts and the same wideband transmission. Narrower band transmission could be used but we prefer wideband transmission up because it:

a. Gives such good transmission that you can use up all your margin in the difficult down path.

b. Permits simpler circuitry in the bird because the bird is only a repeater. It does not have to change the modulation technique.

c. Is far less susceptible to interference and so the same frequencies can be reused more freely.

d. The lower power ground station causes less interference to other stations on the same frequency.

I hope that without going into great detail I have given you a picture of the tour-de-force that a satellite repeater represents. I recognize that I have ignored the Van Allen radiation belt problems that lead us to cover our solar cells with sheets of sapphire and the many mechanical and thermodynamic problems that must be solved to create a bird that will operate in the hostile space environment for at least 10 years.

Satellite Broadcasting

This subject is probably of interest to all broadcasters. Here is the way it looks to us.

A satellite broadcasting station should put out a signal that can be received on ordinary home receivers. To avoid requiring home antennas to track a moving satellite, the broadcast station would be operated in a synchronous satellite at 22,000 miles altitude. The transmitting antenna could have no more than 25 db gain if an area the size of the United States were to be covered.

If we assume vestigial sideband transmission in the UHF or VHF band, and a conventional home receiver with a 5 foot dish having 12° beam-width and 22 db gain, a satellite output power of 60,000 watts, Figure 9, is required.

The contrast between 60,000 watts and the two watt output of the bird B.T.L. is designing is tremendous. It represents the difference between having to work with a conventional home receiver and a 60-foot horn antenna with a 20 degree Kelvin maser receiver. This in turn represents the differences between a $150 receiver and a receiver costing approximately 10,000 times as much.

With a parametric amplifier (uncooled) in the home receiver, the satellite output could be reduced to 6 kw. This is still beyond the possibilities of the near future.

I have given the above examples not to prove that there is no future for broadcasting via satellites but merely to show that satellites do not today solve all problems.

They do not today make it possible to get television into areas that are not equipped with a network of broadcast stations. They only permit reception at one point with a costly and elaborate receiver that will be economically justifiable only if there is a network to be fed.

Neither do satellites permit you to bring good telephone service into areas that do not already have a good terrestrial network. But satellites will economically, and on a sound business basis, bring intercontinental TV to those areas that have local broadcast stations and they will bring expanded high quality circuits into areas where there is a ground network to connect to. And that is a very significant package of problem solving.

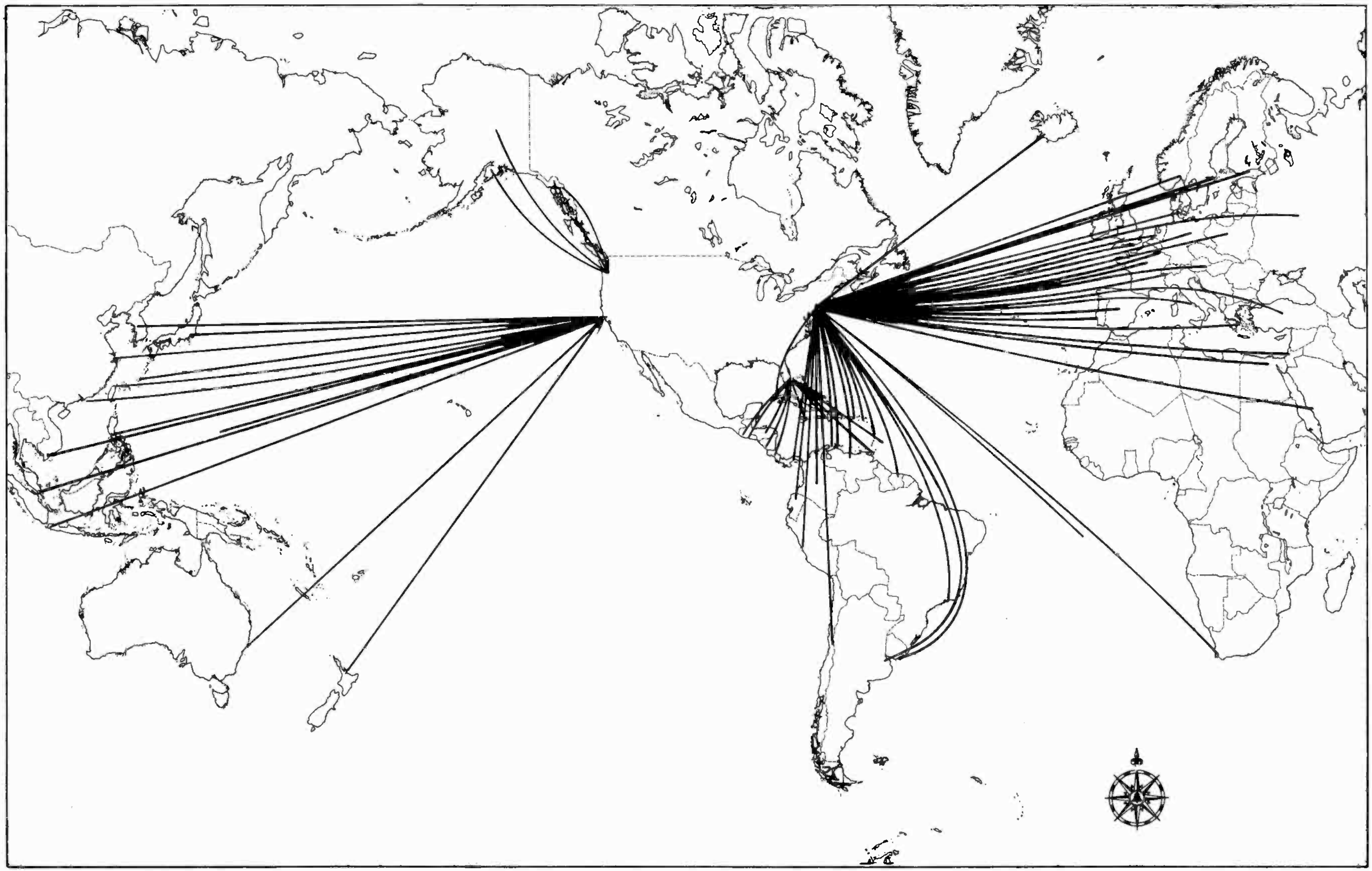

FIGURE 1 COUNTRIES OR AREAS SERVED BY DIRECT CIRCUITS

FIGURE 2 CONTINENTAL VIDEO NETWORK

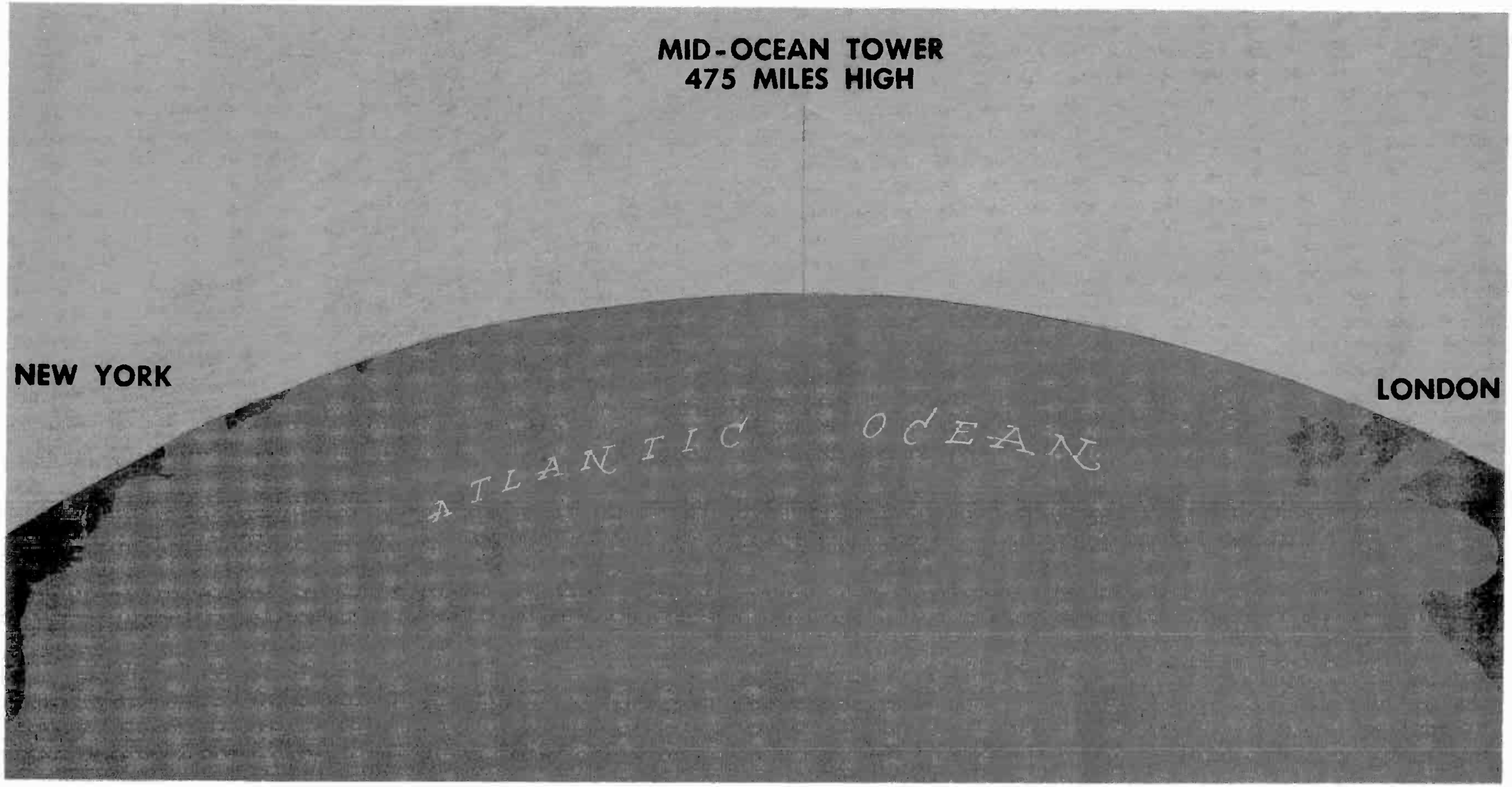

FIGURE 3 MICROWAVE ACROSS THE OCEAN

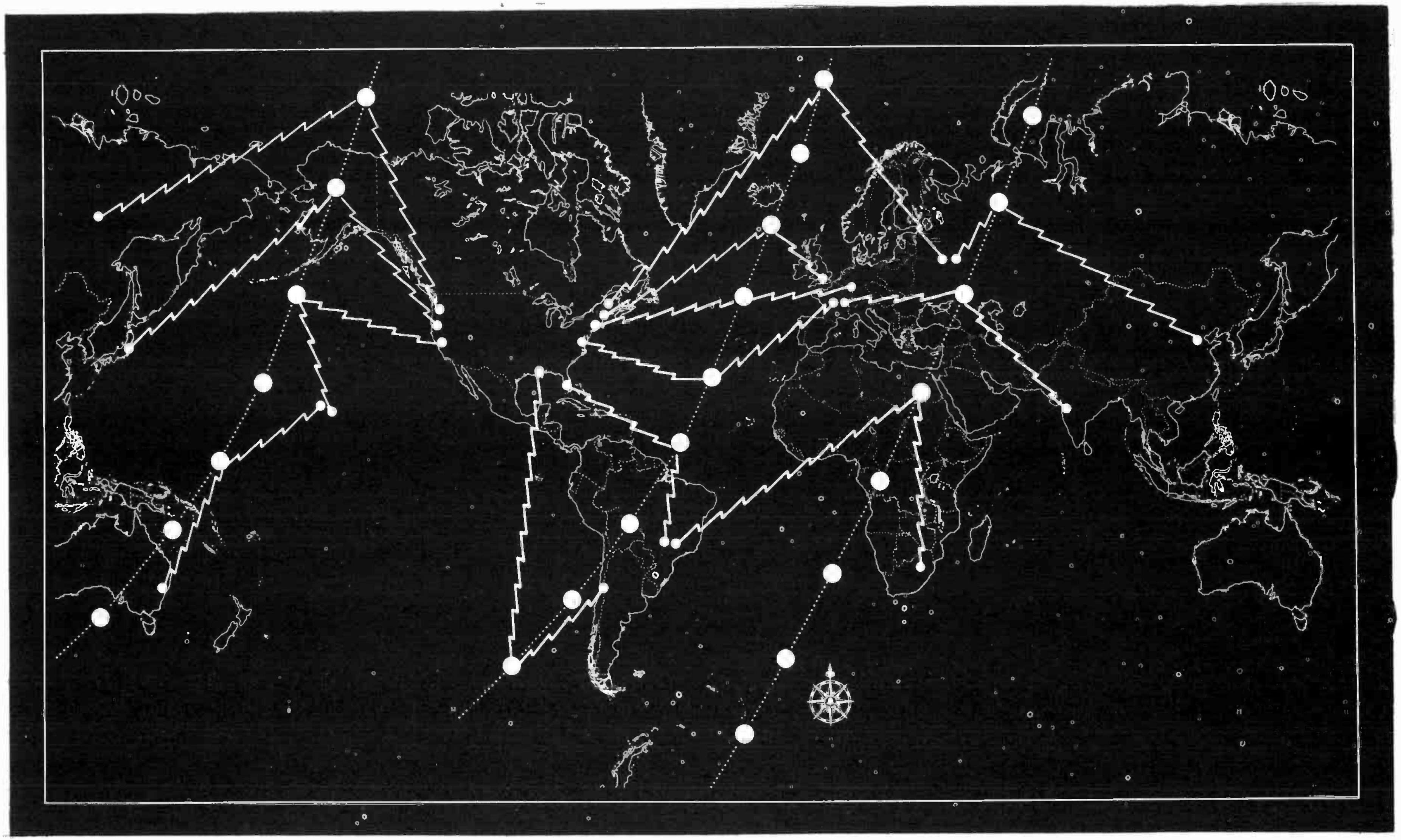

FIGURE 5 GLOBAL COVERAGE PLAN

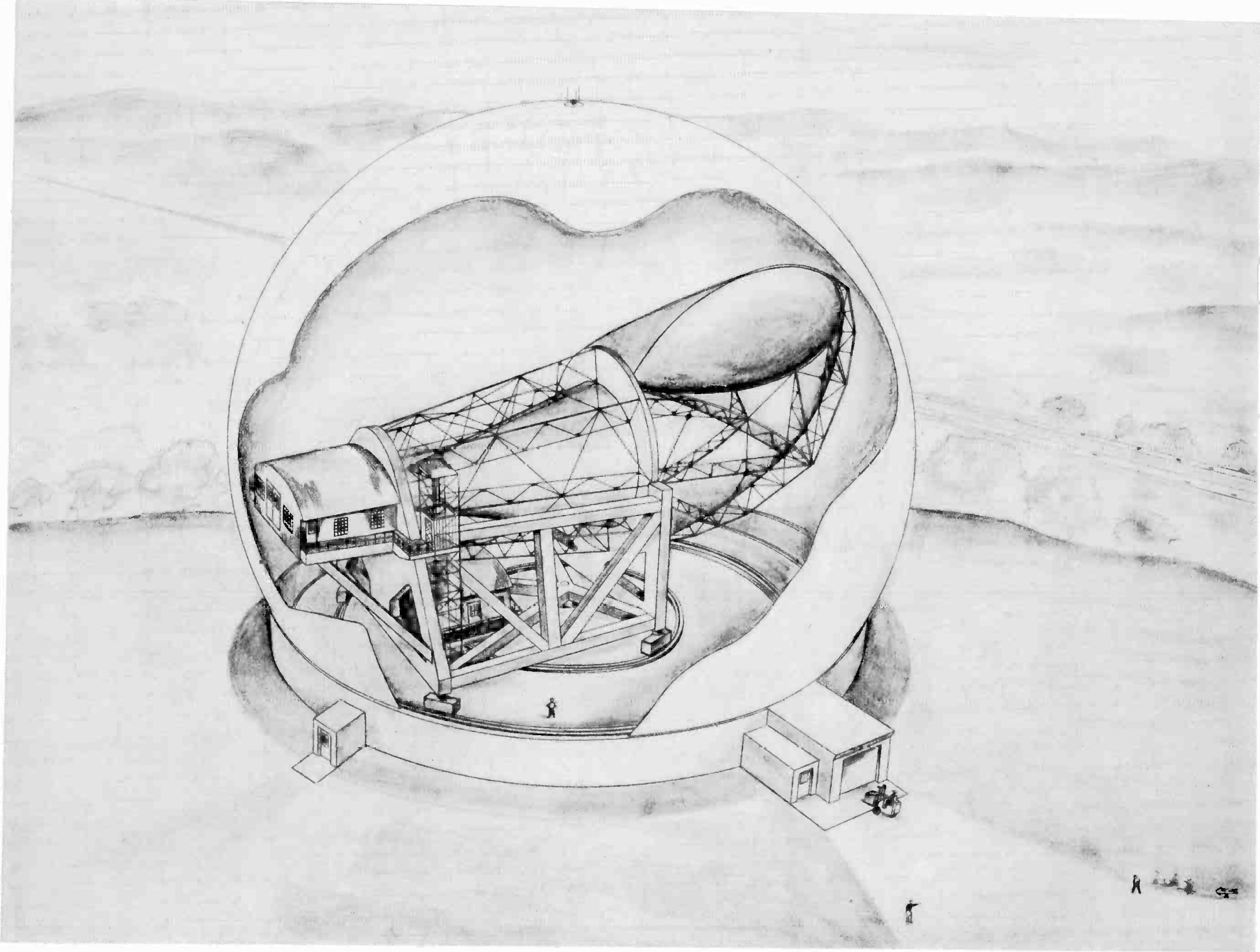

FIGURE 6 HORN REFLECTOR – 60 × 60 FEET

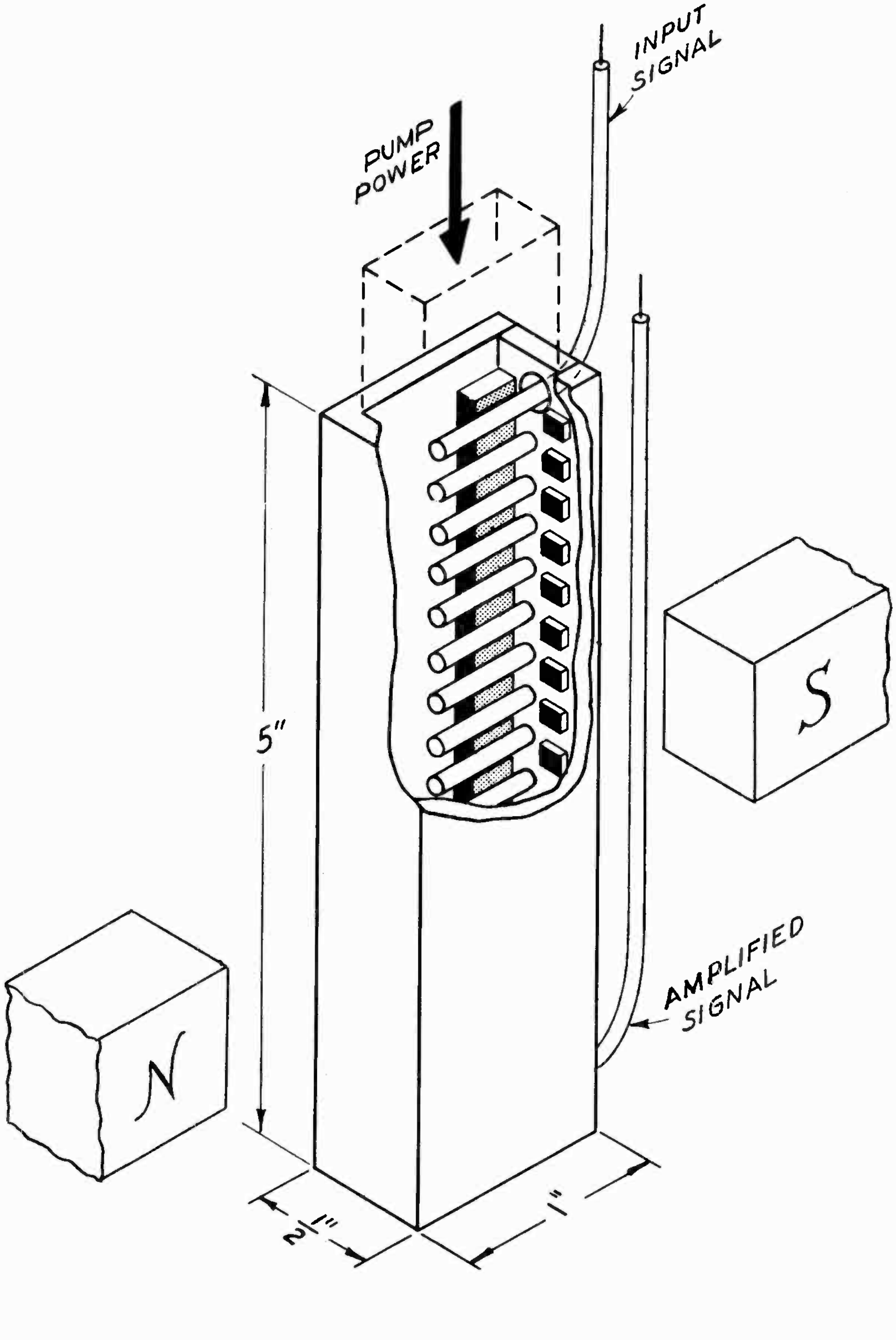

FIGURE 7 MASER

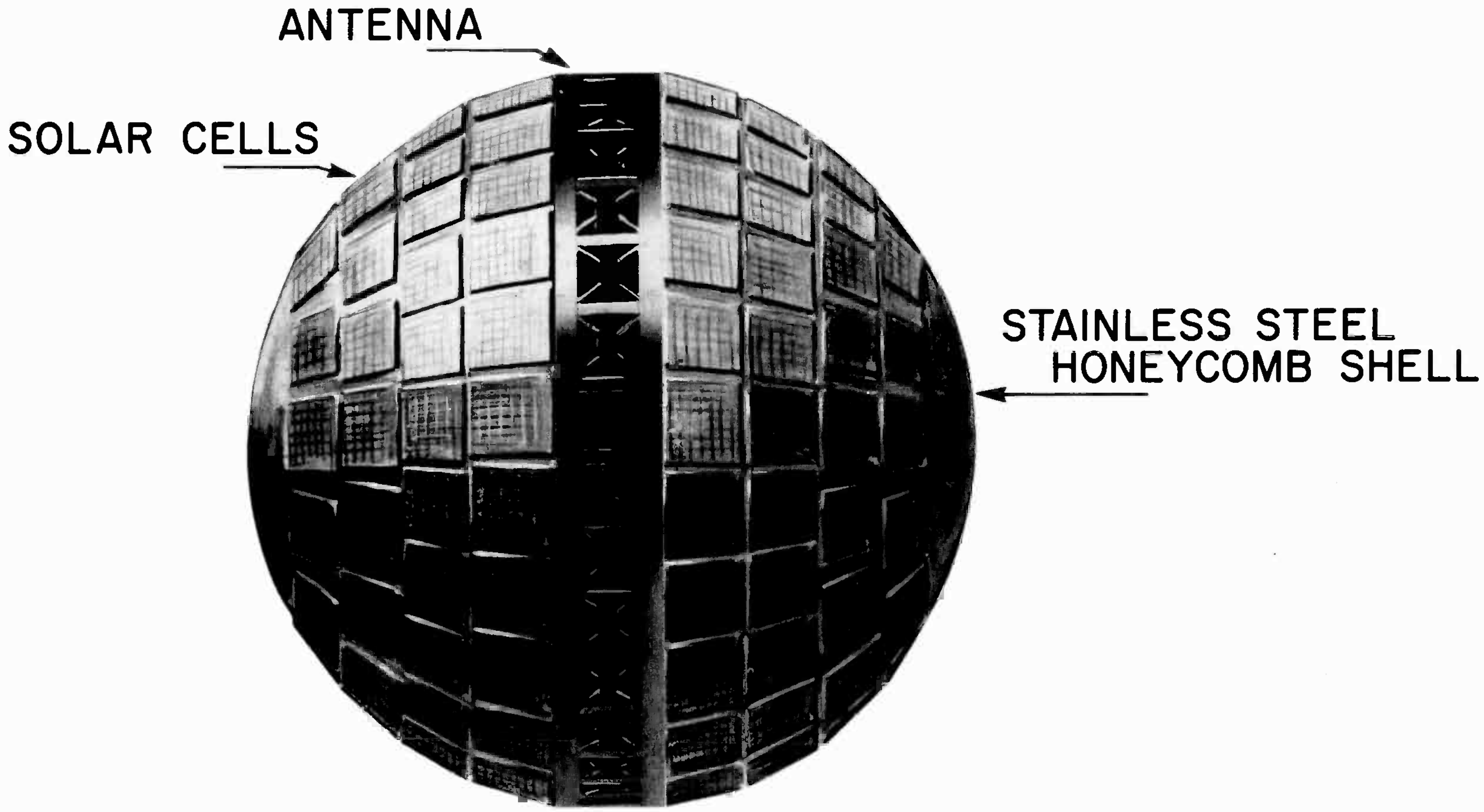

FIGURE 8 SATELLITE

AREA SERVED	USA
FREQUENCY (CHANNEL 52)	700 MC
SATELLITE HEIGHT (SYNCHRONOUS)	22,300 MILES
MODULATION	VESTIGIAL SIDEBAND, AM
SATELLITE ANTENNA (10 FT.) GAIN	25 DB
GROUND RECEIVING ANTENNA (5 FT.) GAIN	18 DB
GROUND RECEIVER NOISE TEMPERATURE	3000° K
GROUND RECEIVER NOISE FIGURE	10.5 DB
PEAK-TO-PEAK SIGNAL TO RMS NOISE AT BASEBAND OUTPUT	37 DB
SATELLITE TRANSMITTER POWER	60 KW

FIGURE 9 SATELLITE BROADCASTING

2

Engineering Department Publications

CBS TELEVISION NETWORK

Experience in Remote Control Operation of AM Plants

Ogden L. Prestholdt

(Presented at the 1961 NAB Broadcast Engineering Conference)

EXPERIENCE IN REMOTE CONTROL OPERATION OF AM PLANTS

INTRODUCTION

The excellent reliability record of high power transmitters over the past decade in combination th decreasing revenue from the operation of radio ations has convinced station management that the onomies to be effected by remote control of radio ansmitters are in order. CBS owns seven radio ations; Table I lists these stations. Six of them erate with a power of 50 Kw; one of these, KCBS, ilizes a directional antenna with different pat- rns day and night; WEEI is a 5 Kw station with a ngle directional pattern day and night. A little er two years ago a project was initiated to remote ntrol these seven transmitting plants. Since the eration of radio and television stations are in parate divisions of the CBS corporate structure, ie remote control points were chosen to be the in studio control area for each radio station. tailed study of the seven plants demonstrated at five of these plants could be quickly adapted r remote control but that major modifications uld be required at the other two plants before itiating remote control. Those five stations iat could be quickly adapted for remote control re so modified and have been remotely controlled r from 5 to 13 months. The major modifications ve been completed at KNX and it has been remotely ntrolled for one month. Construction is in prog- ss at WCBS.

TABLE I

CBS RADIO STATIONS

WBBM	CHICAGO, ILL.	50 KW	780 KC	
WCAU	PHILADELPHIA, PA.	50 KW	1210 KC	
WEEI	BOSTON, MASS.	5 KW	590 KC	DA
KCBS	SAN FRANCISCO, CALIF.	50 KW	740 KC	DA-2
KMOX	ST. LOUIS, MO.	50 KW	1120 KC	
KNX	LOS ANGELES, CALIF.	50 KW	1070 KC	
WCBS	NEW YORK , N.Y.	50 KW	880 KC	

Before delving into the design philosophy nsidered for the modification of these plants, t's take a quick look at that sixth plant - KNX, a plant which was designed from the ground up for remote control. Figure 1 shows that plant as viewed from the south - the main approach. Figure 2 is a peek through the front door - note - no frills. We will return to these and other views of the plant later.

I DESIGN PHILOSOPHY

The seven CBS transmitting plants had been in 24 hour operation for many years and were manned by operators who were very familiar with the plants - many of these operators had seen the current plants go in and had spent many years there. Therefore, these operators knew the equipment intimately and could almost anticipate trouble. Our objective was to approach the past reliability record as closely as possible.

An analysis was made of past performance of these plants; this performance must be transformed into an equivalent performance under remote control. Momentary outages due to overloads, power dips, lightning and similar disturbances, after which operation is restored automatically or by reapplication of plate voltage, are not affected by remote control. Failures requiring some corrective action by the operators at the transmitter plant take on an entirely different aspect under remote control. An outage such as a small tube failure that can be diagnosed and remedial action taken in one to five minutes in a manned plant can become a major failure in a remotely controlled plant. The minimum time to find an available operator and have him travel to the transmitter at most of our stations is about one hour; it is doubtful that many trips will be made in that minimum time.

Table II is a tabulation of the outage record of the first five CBS AM stations to be remotely controlled during the year prior to their conversion to remote control operations. Note that the average number of outages requiring corrective action by an operator at the plant is 5.4 per station per year and that the average outage time per failure was 0.74 hours. Assuming the minimum time of one hour required to get an operator to the plant and that the average time to effect repairs and restore normal operation is 0.74 hours, it is seen that a loss of 9.4 hours per year could be expected. Assuming an operating time of 8500 hours per year, this represents outages of 0.11% of the operating time. This is many times the actual average outage rate of 0.022% for these stations during the last year of manned operation, and would be considered intolerable by our management.

TABLE II

STATION OUTAGE RECORD WITH OPERATORS

	WBBM	WCAU	WEEI	KCBS	KMOX	AVG.
TOTAL OUTAGE						
NUMBER	3	9	11	40	25	17.6
TIME HOURS	0.023	5.015	1.618	0.447	2.065	1.83
PERCENT OF AIR TIME	0.0003	0.059	0.019	0.005	0.024	0.022
OUTAGES REQUIRING REPAIRS						
NUMBER	1	2	11	6	7	5.4
TIME HOURS	0.021	0.181	1.618	0.082	2.002	0.74
PERCENT OF AIR TIME	0.0003	0.002	0.019	0.001	0.024	0.0092

Consider now two transmission systems each with a probable outage of 0.11% of the time and that the causes for such outages are all totally unrelated. Then the probability of failure of both systems at the same time is the product of the probability of failure for each. This factor, 0.00012%, is the probability of failure of these two systems at the same time. This represents a significantly lesser outage time that our past average and is the key to safe design for remote control.

It is impractical to carry the transmission system duplication to the ultimate. However, a practical approach that very materially increases the reliability can be made. Before detailing this system duplication one more factor must be considered. That is, can the second system have some degraded performance such as operation at reduced power. At CBS it was established that some degradation could be accepted in this second transmission system and that it would be acceptable to operate with the second system for substantial segments of time when necessary.

II PLANT CONSTRUCTION

Table III is a listing of the major areas into which the transmission system may be divided for analysis. Six of the CBS stations had no auxiliary antenna system. Therefore, an antenna failur any of these stations would be an extended fail under manned operation; in fact, the outage w most likely be many times the one hour transpor tion delay introduced by remote control. Therefo no justification was found for the duplication CBS antenna systems as a result of remote contr Further support for this decision may be found the fact that CBS has, to my knowledge, had o one tower failure in thirty odd years. Transmiss line and tuning system failures have been rare,l than one per plant per 20 years.

TABLE III

MAJOR SYSTEM DIVISIONS

- ANTENNA SYSTEM
- TRANSMITTER
- AUDIO INPUT FACILITIES
- STUDIO-TRANSMITTER AUDIO CIRCUIT
- PRIMARY POWER
- REMOTE CONTROL SYSTEM
- FIRE PROTECTION
- GENERAL PLANT SECURITY

For the 50Kw plants it was decided that a 10 auxiliary transmitter would maintain adequa emergency service and provide 5 or 10 Kw f Conelrad operation as required. The 5 Kw pla already had an old 5Kw transmitter that was servi as an auxiliary. RF switching was arranged so th the actuation of the remote control plate-on swit for a transmitter, connected that transmitter to properly tuned antenna and then applied the pla voltage. The unused transmitter is always connect to a dummy load but with plate power off. A te switch is provided at the transmitter to bypass th control arrangement so as to permit the testing the unused transmitter into the dummy. This a rangement prevents any confusion in the remo control operator's mind as to which transmitter on the air and which is in the dummy. Although th prevents testing of the auxiliary transmitter remote control, this should not be a hardship. transmitter is tested weekly during the maintena period.

Audio input facilities were revamped so th one channel would feed both transmitters an second identical local channel could be switc into its place if the first one failed. Two stud transmitter audio circuits were maintained, one regular telephone facilities, the second by a d ently routed telephone facility or byutilization the station's FM adjunct when necessary.

Primary power was found tobe the most variable m in the existing systems. The existing equip-t and service ranged froma minimum of one utility vice and an auxiliary generator that was too small carry the new 10 Kw auxiliary transmitter, to a ant with two utility services with automatic itching and with better than average reliability d an auxiliary generator capable of carrying the in transmitter at reduced power. All plants were uipped so that at least two sources of power were ailable: either two separately routed utility rvices with automatic transfer in case of failure the preferred service or, one utility service and local auxiliary generator capable of carrying the Kw transmitter, tower lights, and building serv-es, and arranged to automatically start upon ilure of the utility service for more than 5 conds, and then to take the designated load.

All of the foregoing equipment duplication uld be of no use unless a suitable control system available to control itwith similar reliability. o systems were utilized, one for each transmitter. fferent cable routings were provided by the tele-one companies where possible, so that a cable ilure would not be common to the two systems.

As was noted in Table III, the design of the ant can't stop with the electronic equipment but nsideration must be given to security. The equip-nt was protected against damage from fire by the stallation of automatic CO_2 fire extinguishing stems. These systems are arranged to shut down e transmitter and blower systems immediately upon ceipt of fire signal, then insert about a 30 second lay to permit blowers to stop, and then to release e CO_2 into the transmitter cubicles. The trans-tter cubicles. The transmitter buildings were dified so that all windows were bricked up or rred, and doors were secured so that the danger unauthorized entrance was minimized. Suitable ncing was added to prevent access to the tower ses, coupling houses, guy anchors, transmission ne, power mat and building.

To aid in reporting such events as the opera-on of the fire protection systems, attempts at un-thorized entry, building under or overtemperature, ter in the basement, and many other functions not sociated with the day to day operation of the ansmitter, an automatic alarm system was developed. is system transmitts a signal advising the opera-r of such an occurrence and utilizes the regular mote control lines for this service. The first ve CBS stations were modified in accordance with these concepts and, as stated before, have been in operation for some time. The sixth plant, KNX, was designed from the ground up in accordance with these principles. In addition to the following brief description of the plant, it may be of interest to mention that this building was constructed around the tower while KNX maintained a 24 hour a day 50 KW operation.

Since this plant was designed for unattended operation, a minimum of the normal creature comforts were included. Space is held to a minimum to dis-courage the storage of unnecessary items; the building location and layout were chosen so as to provide maximum security and minimum cost. Figure 3 is a floor plan of the building; note that a minimum of interior partitions are provided. There are only four rooms; the main transmitter room, the trans-former vault, the auxiliary generator room and the lavatory. An open antenna court is also included. It should be noted there are no windows in the building, one outside door and the outlet for generator cooling air are the only openings in the walls. All intake air is provided through the antenna court, thus, protecting the air supply from tampering; all air exhaust is through the roof and hence equally protected. Figure 4 is a close up from the Northeast showing the building, power company transformer area, and the tower as it is protected by the building.

The next group of slides will permit a quick look at the pertinent parts of the plant. Figure 2 again is the interior as viewed from the front door. Figures 2, 5, 6, 7 and 8 show the pertinent areas within the plant including the main transmitter, dummy antenna, antenna network, auxiliary trans-mitter, transformer vault, primary power distribu-tion, and auxiliary generator. It will be noted that the equipment layout is functional; no effort has been made to dress up the plant or to isolate the control area from the equipment. This plant joined our remote control family on April 12, 1961.

III OPERATING EXPERIENCE

CBS's operational experience to date with these six remotely controlled plants has been rewarding. At present the maintenance and inspection schedules have been reduced to about the minimum at most of these plants. Table IV lists this present schedule. Note that KCBS has two inspections daily. This is not required from an equipment operation standpoint but is required by the FCC for surveillance of the antenna system. The same is true for the daily inspection at WEEI. The daily inspection at KNX reflects the newness of their remote control operation. This accumulation of over three years of experience has developed an operating record that is consistent with the expectations and design criteria. Table V is a brief summary of outages under remote control. It should be noted that there is more uniformity in station reliability than existed before remote control and that the average outage time is down.

TABLE IV

PRESENT MAINTENANCE SCHEDULE

	WBBM	WCAU	WEEI	KCBS	KMOX	KNX
MAINTENANCE						
TWO MAN MAINTENANCE 8 HRS. MONDAY MORNING	X	X	X	X	X	X
SUPPLEMENTARY INSPECTIONS						
TWO INSPECTIONS DAILY				X		
ONE INSPECTION DAILY			X			X
ONE INSPECTION PER WEEK	X	X			X	

TABLE V

STATION OUTAGE RECORD WITH REMOTE CONTROL

	WBBM	WCAU	WEEI	KCBS	KMOX	AVERAGE PER STA. PER YEAR
OPERATING TIME HOURS	7800	7600	6900	5800	1400	8500
NUMBER OF OUTAGES	47	55	18	36	4	46
TIME LOST HOURS	0.231	0.655	1.179	2.470	0.083	1.33
PERCENT OF AIR TIME	0.003	0.008	0.017	0.042	0.059	0.0156

Two major problems have been uncovered as a result of this remote control operation. These are, personnel training and reliability of control lines. The personnel training required is in the operation of the transmitter by remote control. Detailed operation procedures must be set up in terms of actions to be taken when various failures occur, as well as thorough training in the proper use of the remote control equipment. This training must also include instructions in keeping the necessary logs.

The main operational complaint was the reliability of the telephone lines used for remote control. The grade of circuit that we are using, and I believe that most other stations are using the same type, is a signal grade circuit, probably the cheapest class of circuit available. Apparently, t reliability of these circuits is given minim consideration by the phone companies. It seems us that an industry wide review of this probl would be in order. The solution might provi another grade of circuit for this function and ha reliability, or at least freedom from telepho company tampering, its main feature.

One other comment that may be in order, th operator who is now in control of an AM transmitte has other duties which occupy his mind a larg portion of the time. As a result of this pre occupation, the operator is not interested in fol lowing any complicated procedure in controlling th transmitter. He is deserving of a system designe for ease operation, not one designed for simplicit of manufacture - in short a system with some huma engineering in it.

In closing I would like to give credits to som of the CBS personnel who have helped to make thi entire project possible. Without the conscientiou cooperation of such men as Bill Fligel, WBBM; Jac Leitch, WCAU; Warren Stevens, WEEI; Alan Cormack KCBS; Larry Burrows, KMOX; and last but not leas Harold Peery and Ted Denton, KNX, this project coul not have been completed.

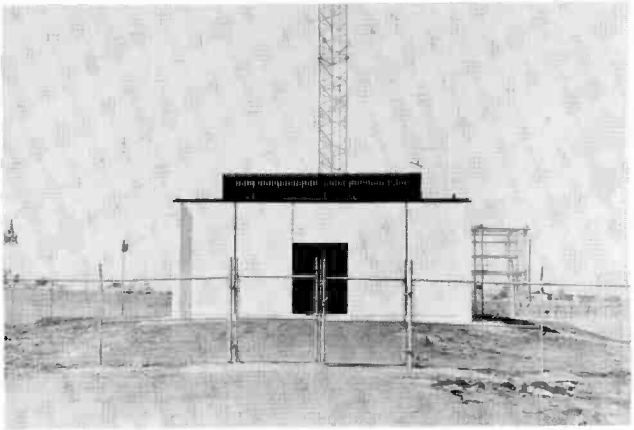

FIG. 1

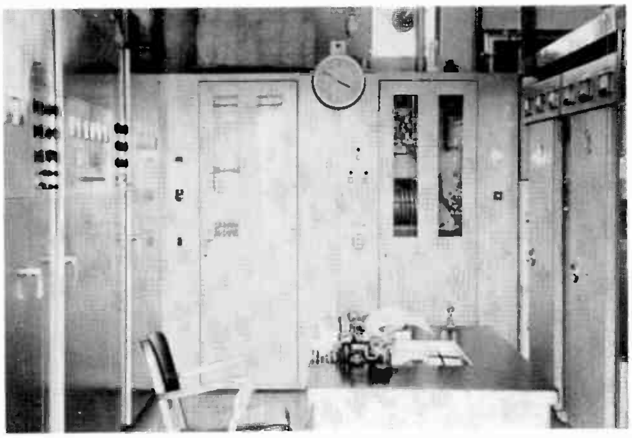

FIG. 2

KNX TRANSMITTER BLDG. FLOOR PLAN

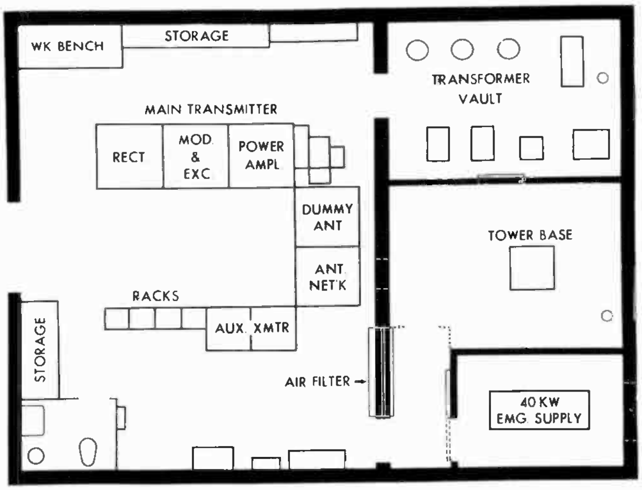

FIG. 3

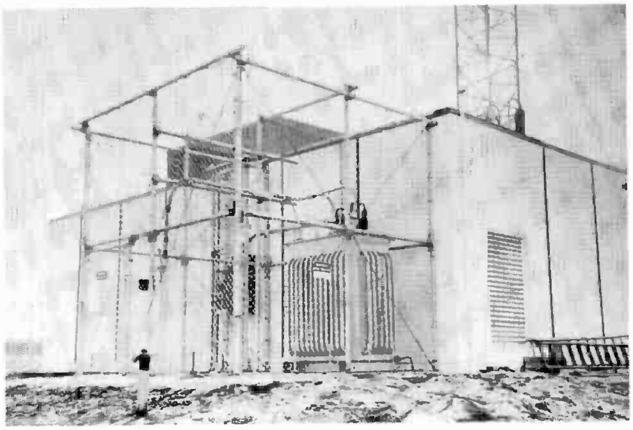

FIG. 4

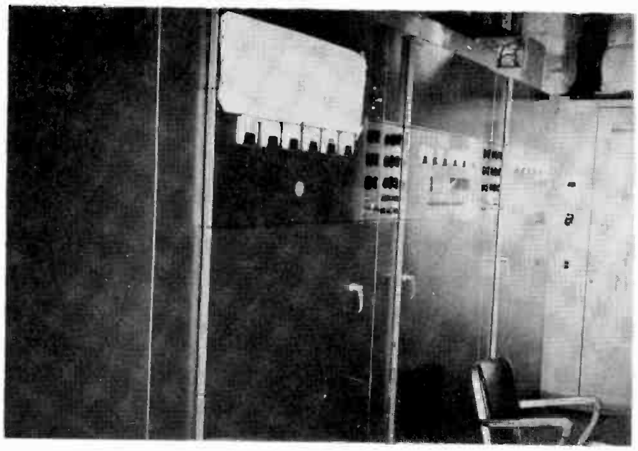

FIG. 5

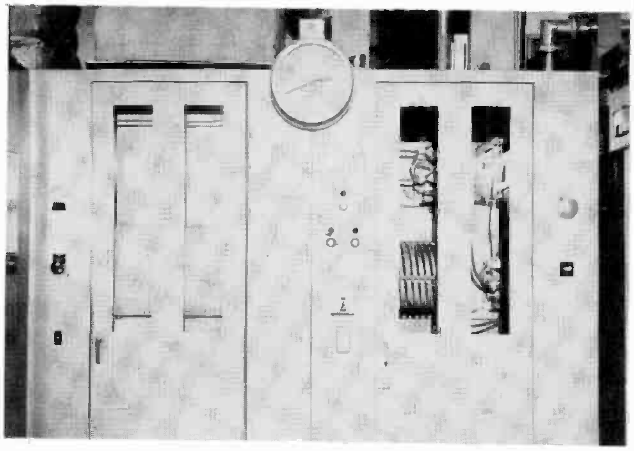

FIG. 6

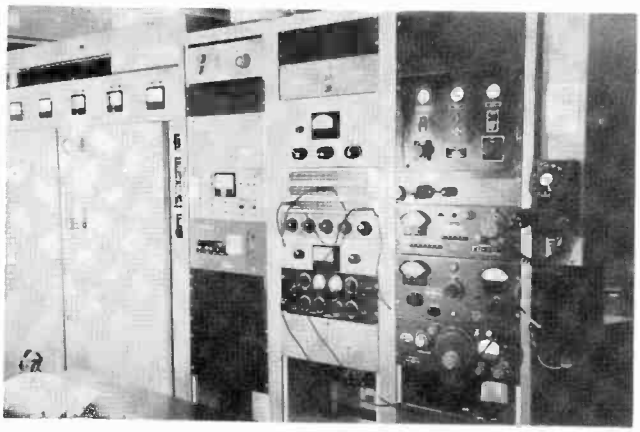

FIG. 7

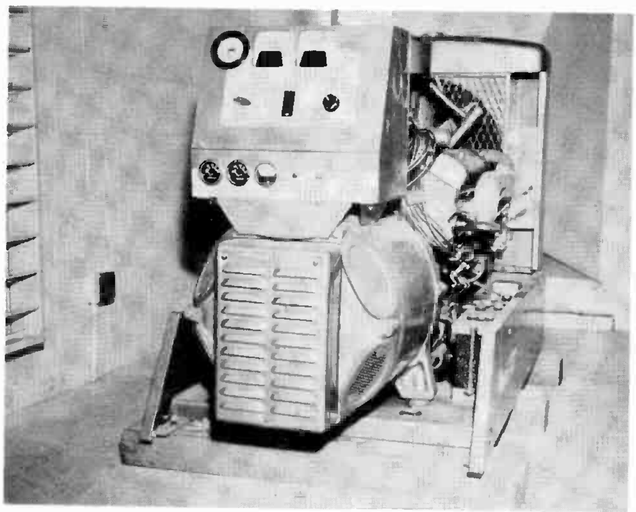

FIG. 8