# SECTION 4: PROGRAM TRANSMISSION FACILITIES

# 4.1

# Television Signal Transmission Standards

## INTRODUCTION

This chapter is intended to assist the broadcast engineer in evaluating the quality of television program transmissions. It consists primarily of the text of NTC Report No. 7, with additional material on audio signal measurements from EIA RS-250-B.

NTC Report No. 7 (1976) was prepared by the Network Transmission Committee of the Video Transmission Engineering Advisory Committee, a joint committee of television network broadcasters and the Bell System. It defines transmission parameters, test signals, measuring methods, and performance objectives. The performance objectives are applicable to an overall transmission system, including both local and inter-city relay facilities.

Since NTC-7 does not include audio channel standards, the audio section of the Electronic Industries Association Standards RS-250-B (1976) has been included.

EIA RS-250-B differs from NTC-7 primarily in that it includes performance objectives agreed upon by the television networks and AT&T for guaranteed performance for the coast to coast video networks. Since measuring methods and test signals are otherwise the same for the two standards, the performance objectives may be compared, as on the following chart. In general, RS-250-B is considered a more rigorous standard, reflecting industry-wide measures of performance, which may be used, for example, to test short, medium, satellite and long haul systems. NTC-7 is usually considered a standard for checking day-to-day operation of a network television interconnection system.

A third standard, said to be compatible with those EIA and NTC, is the AT&T Communications "Commercial Television Transmission Specification" (1984). As with RS-250-B, performance objectives are specified for short haul, medium haul, satellite, long haul, and end-to-end. AT&T also publishes similar standards for non-commercial television, premium grade audio and standard grade audio transmission.

A revised and updated version of EIA RS-250 has been in preparation and should be available some time in 1985.

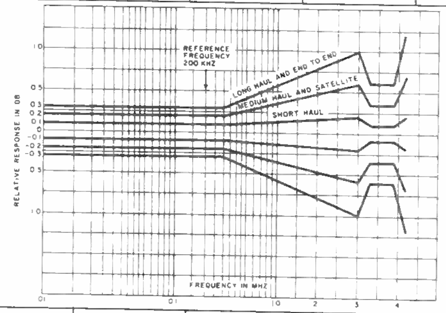
Further information on acquiring complete copies of all three standards follows at the end of this chapter.

### Using This Chapter

The three-page chart presents a summary of the tests and performance objectives of RS-250-B and NTC-7. They are listed in the order consistent with RS-250-B, but there are references to the NTC-7 sections which follow. By referring to the chart and the complete test procedure, the reader may select the tests and performance objectives for a particular application.

For those familiar with NTC-7, the original order and numbering have been preserved.

To supplement NTC-7, the audio section of RS-250-B has been included. These tests, Section 6, appear between NTC-7 Section 5 and the two Appendices.

| TEST NUMBER | VIDEO PERFORMANCE TEST | TELEVISION PERFORMANCE STANDARDS FOR RELAY FACILITIES | | | | | | DISPLAYED VISUAL EFFECT |
|---|---|---|---|---|---|---|---|---|
| | | NTC-7 | EIA RS-250-B | | | | | |
| | | | SHORT HAUL | MEDIUM HAUL | SATELLITE | LONG HAUL | END-TO-END | |
| 1<br>NTC 3.8 | AMPLITUDE VS. FREQUENCY CHARACTERISTIC | WHITE FLAG AMPLITUDE ADJUSTED TO 100 IRE UNITS<br>a) ALL FREQUENCY BURSTS AMPLITUDES SHALL BE:<br>$50^{+3}_{-5}$ IRE UNITS<br>b) COLOR BURST AMPLITUDE SHALL BE:<br>40 ±4 IRE UNITS |  | | | | | THE MOST COMMON AND MOST OBVIOUS LUMINANCE EFFECT RELATED TO LOW HIGH FREQUENCY RESPONSE IN THE VIDEO PASSBAND, IS POOR RESOLUTION OR SOFTNESS OBSERVED IN THE DISPLAYED PICTURE. IT SHOULD ALSO BE NOTED THAT NONLINEAR PHASE CHARACTERISTICS CAN APPEAR AS A CONSEQUENCE OF THE FREQUENCY ROLL RESPONSE OF THE VIDEO PASSBAND.<br>IN THE EVENT THAT THE VIDEO PASSBAND IS PEAKED AT THE UPPER LIMIT, THIS WILL DISPLAY AN UNUSUAL CRISPNESS OR ENHANCEMENT IN THE DISPLAYED PICTURE. THE USE OF HIGH FREQUENCY PEAKING CIRCUITS IN VIDEO EQUIPMENT, AND TRANSMISSION CHANNELS IS REFERRED TO AS "IMAGE ENHANCEMENT." |
| 2<br>NTC 3.6 | CHROMINANCE TO LUMINANCE GAIN INEQUALITY | CHROMINANCE AMPLITUDE REFERENCED TO LINE BAR SHALL BE:<br>100 ±3 IRE UNITS (±6 %) | ±1 IRE UNITS | ±4 IRE UNITS | ±4 IRE UNITS | ±7 IRE UNITS | ±7 IRE UNITS | THIS PROBLEM WILL AFFECT THE SATURATION LEVELS IN RECEIVED PICTURE WHICH WILL APPEAR AS OVER OR UNDER SATURATED COLORS.<br>THIS DISTORTION IS SOMETIME REFERRED TO AS "SATURATION ERRORS." |
| 3<br>NTC 3.7 | CHROMINANCE TO LUMINANCE DELAY INEQUALITY | ±75 nSEC | ±20 nSEC | ±33 nSEC | ±26 nSEC | ±54 nSEC | ±60 nSEC | THIS DISTORTION IS MOST NOTICEABLE WITH RED LETTERING SMEARING INTO A NEUTRAL BACKGROUND. IN MORE SEVERE EXAMPLES OF THIS DISTORTION, THE EFFECT OF COLOR GHOSTING OR MISREGISTRATION IS DISPLAYED ON THE RECEIVED PICTURE. |
| 4<br>NTC 3.3 | FIELD TIME WAVEFORM DISTORTION | <4 IRE UNITS PEAK-TO-PEAK | 3 IRE UNITS PEAK-TO-PEAK | 3 IRE UNITS PEAK-TO-PEAK | 3 IRE UNITS PEAK-TO-PEAK | 3 IRE UNITS PEAK-TO-PEAK | 3 IRE UNITS PEAK-TO-PEAK | OBVIOUS FIELD TIME ERRORS DISPLAY OBJECTIONAL VERTICAL SHADING FROM TOP TO BOTTOM IN THE RECEIVED PICTURE. |
| 5<br>NTC 3.4 | LINE TIME WAVEFORM DISTORTION | <4 IRE UNITS PEAK-TO-PEAK | 0.5 IRE UNIT PEAK-TO-PEAK | 1 IRE UNIT PEAK-TO-PEAK | 1 IRE UNIT PEAK-TO-PEAK | 1.5 IRE UNITS PEAK-TO-PEAK | 2 IRE UNITS PEAK-TO-PEAK | APPEARS AS SMEARING OR STREAKING FROM LEFT TO RIGHT IN RECEIVED PICTURE.<br>ALSO, UNEVEN SHADING MAY BE NOTICED FROM LEFT TO RIGHT. POOR CONTRAST NOTED. |
| 6<br>NTC 3.5 | SHORT TIME WAVEFORM DISTORTION | 2T PULSE AMPLITUDE SHALL BE:<br>100 ±6 IRE UNITS<br>LINE BAR EDGE OVERSHOOT SHALL NOT EXCEED 10 IRE UNITS (PEAK-TO-PEAK) | 4 IRE UNITS PEAK-TO-PEAK | 4 IRE UNITS PEAK-TO-PEAK | 4 IRE UNITS PEAK-TO-PEAK | 6.5 IRE UNITS PEAK-TO-PEAK | 7 IRE UNITS PEAK-TO-PEAK | THIS TYPE OF DISTORTION AFFECTS HORIZONTAL RESOLUTION, SOMETIMES REFERRED TO AS DEFINITION.<br>ALSO, CONTOURING OR RINGING CAN BE OBSERVED WHEN EXCESSIVE HIGH FREQUENCY RESPONSE OF THE VIDEO PASSBAND IS PRESENT. |
| 7<br>NTC 3.12 | LONG TIME WAVEFORM DISTORTION (BOUNCE) | PEAK OVERSHOOT AT BLANKING SHALL NOT EXCEED 5 IRE UNITS. SETTLING TIME: LESS THAN 1 SEC | 8 IRE UNITS PEAK<br>3 SEC SETTLING TIME | 8 IRE UNITS PEAK<br>3 SEC SETTLING TIME | 8 IRE UNITS PEAK<br>3 SEC SETTLING TIME | 8 IRE UNITS PEAK<br>3 SEC SETTLING TIME | 8 IRE UNITS PEAK<br>3 SEC SETTLING TIME | INTERMITTENT AND SLOW VARIATION IN PICTURE BRIGHTNESS.<br>THESE DISTORTIONS ARE USUALLY VIEWED OVER LONG PERIODS OF TIME. FLICKER IS AN EXAMPLE OF A LONG TIME DISTORTION. |
| 8<br>NTC 3.2 | INSERTION GAIN VARIATION | SHALL NOT EXCEED ZERO ±3 IRE UNITS<br>SHORT PERIOD (e.g. 5 SEC.) ±1 IRE UNIT<br>MEDIUM PERIOD (e.g. 1 HR.) ±2 IRE UNITS | ±0.15 DB HOURLY<br>±0.1 DB OVER ONE SEC | ±0.3 DB HOURLY<br>±0.15 DB OVER ONE SEC | ±0.2 DB HOURLY<br>±0.15 DB OVER ONE SEC | ±0.45 DB HOURLY<br>±0.25 DB OVER ONE SEC | ±0.5 DB HOURLY<br>±0.3 DB OVER ONE SEC | MAY BE NOTED BY OVER OR UNDER CONTRASTED PICTURES IN MONOCHROME TRANSMISSIONS. ALSO, OVER OR UNDER CONTRASTED AND SATURATED PICTURES IN COLOR TRANSMISSIONS. |
| 9<br>NTC 3.9 | LUMINANCE NON-LINEARITY | LARGEST DIFFERENTIATED PULSE REF AT 100 IRE.<br>SMALLEST PULSE NO LESS THAN 90 IRE UNITS<br>10%, 50% OR 90% APL. | 2% | 4% | 6% | 8% | 10% | NON-LINEAR TRANSFER CHARACTERISTICS IN A VIDEO CHANNEL WILL RESULT IN CONTRAST ERRORS RELATIVE TO THE TRANSMITTED PICTURE IN MONOCHROME SYSTEMS. MORE SERIOUS PROBLEMS OCCUR IN COLOR SYSTEMS, SUCH AS HUE AND SATURATION ERRORS RESULTING FROM NON-UNIFORMITIES IN THE LUMINANCE COMPONENT RELATIVE TO THE CHROMINANCE INFORMATION. |

NTSC-M color television performance measurements for communication systems. (Page 1 of 3.)

| TEST NUMBER | VIDEO PERFORMANCE TEST | TELEVISION PERFORMANCE STANDARDS FOR RELAY FACILITIES | | | | | | DISPLAYED VISUAL EFFECT |
|---|---|---|---|---|---|---|---|---|
| | | NTC-7 | EIA RS-250-B | | | | | |
| | | | SHORT HAUL | MEDIUM HAUL | SATELLITE | LONG HAUL | END-TO-END | |
| 10<br>NTC 3.13 | DIFFERENTIAL GAIN | ± 15%<br>(± 15 IRE UNITS) | 2% | 5% | 4% | 8% | 10% | THE VISUAL OBSERVATIONS NOTED AS A RESULT OF THIS DEGRADATION, ARE SATURATION ERRORS IN THE RECEIVED PICTURE INFORMATION. |
| 11<br>NTC 3.14 | DIFFERENTIAL PHASE | <5° | .5° | 1.3° | 1.5° | 2.5° | 3.0° | THE VISUAL OBSERVATIONS DISPLAYED ON THE RECEIVED PICTURE ARE CHANGES OR ERRORS IN HUE AS A FUNCTION OF LUMINANCE AMPLITUDE VARIATIONS |
| 12<br>NTC 3.15 | CHROMINANCE TO LUMINANCE INTERMODULATION | <3 IRE UNITS | 1.0% | 2.0% | 2.0% | 4.0% | 4.0% | INCORRECT REPRODUCTION OF THE INCREASED SATURATED COLORED AREAS OF THE RECEIVED PICTURE. |
| 13<br>NTC 3.10 | CHROMINANCE NON-LINEAR GAIN | SMALLEST SUB-CARRIER AMPLITUDE 20 ±2 IRE UNITS<br>LARGEST SUB CARRIER AMPLITUDE 80 ±8 IRE UNITS | 1.0% | 2.0% | 2.0% | 4.0% | 5.0% | THE VISUAL EFFECT FOR THIS VIDEO IMPAIRMENT COULD ALSO BE THE INCORRECT REPRODUCTION OF INCREASED SATURATED AREAS. HOWEVER, THIS MAY NOT BE APPARENT BY JUST OBSERVING THE RECEIVED PICTURE WITHOUT COMPARING IT TO THE TRANSMITTED INFORMATION. |
| 14<br>NTC 3.11 | CHROMINANCE NON-LINEAR PHASE | <5° | 1° | 2° | 2° | 4° | 5° | THE VISUAL OBSERVATION NOTED AT THE RECEIVER WOULD BE HUE SHIFTING IN HIGHLY SATURATED AREAS. |
| 15<br>NTC 3.12 | DYNAMIC GAIN OF THE PICTURE SIGNAL | DYNAMIC GAIN AT 10% OR 90% APL. REF 50% APL.<br>±3 IRE UNITS | 2% | 3% | 4% | 5% | 6% | IF THE SYSTEM GAIN IS REDUCED AS A FUNCTION OF APL, THE DYNAMIC RANGE OF THE VIDEO SIGNAL WILL TYPICALLY BE COMPRESSED. THIS WILL CONTRIBUTE TO ALL NON-LINEAR DISTORTIONS WITH REDUCED CONTRAST RATIOS DISPLAYED ON THE RECEIVER PICTURE. |
| 16<br>NTC 3.12 | DYNAMIC GAIN OF THE SYNCHRONIZING SIGNAL | DYNAMIC GAIN AT 10% OR 90% APL. REF 50% APL.<br>±2 IRE UNITS | 3% | 4% | 5% | 6% | 7% | NON-LINEAR TRANSFER CHARACTERISTIC OF THE VIDEO CHANNEL. THIS PROBLEM CONTRIBUTES TO ALL NON-LINEAR DISTORTIONS AS A FUNCTION OF APL.<br>SEE ABOVE DISCUSSION.<br>TYPICALLY A REDUCTION IN SYNCHRONIZING PULSE AMPLITUDE BELOW A DEFINED THRESHOLD WILL RESULT IN LOSS OF PICTURE LOCK-HORIZONTAL, VERTICAL, OR BOTH. |
| 17 | TRANSIENT SYNCHRONIZING SIGNAL NON-LINEARITY | — | 1% | 2% | 3% | 4% | 5% | — |
| 18<br>NTC 3.16 | SIGNAL-TO-NOISE RATIO (10 KHZ – 5.0 MHZ) | ≥53 DB<br>(10 KHZ – 4.2 MHZ) | 67 DB | 60 DB | 56 DB | 54 DB | 54 DB | SNOWEY PICTURE DISPLAYED ON MONOCHROME MONITORS.<br>ON COLOR MONITORS THE EFFECT NOTED IS COLORED SNOW, ALSO REFERRED TO AS "CONFETTI". |
| 19 | SIGNAL-TO-LOW FREQUENCY NOISE RATIO (0 – 10 KHZ) | — | 53 DB | 48 DB | 50 DB | 44 DB | 43 DB | TYPICAL SOURCES OF LOW FREQUENCY NOISE ARE POWER LINE OR POWER SUPPLY RELATED.<br>OBSERVED VISUAL EFFECT FOR POWER LINE OR 60HZ PROBLEMS WOULD APPEAR AS ONE WIDE HORIZONTAL BAR ACROSS THE SCREEN.<br>THE APPEARANCE OF TWO NARROWER BARS INDICATES 120HZ RIPPLE LEAKING IN FROM POWER SUPPLIES. |

NTSC-M color television performance measurements for communication systems. (Page 2 of 3.)

| TEST NUMBER | VIDEO PERFORMANCE TEST | TELEVISION PERFORMANCE STANDARDS FOR RELAY FACILITIES | | | | | | DISPLAYED VISUAL EFFECT |
|---|---|---|---|---|---|---|---|---|
| | | NTC-7 | EIA RS-250B | | | | | |
| | | | SHORT HAUL | MEDIUM HAUL | SATELLITE | LONG HAUL | END-TO-END | |
| 20<br>NTC 3.18 | SIGNAL-TO-PERIODIC NOISE RATIO (300 HZ – 4.2 MHZ) | ≥50 DB<br>( < 1 KHZ)<br>≥50 DB<br>(1 KHZ – 4.2 MHZ) | 67 DB | 62 DB | 64 DB | 58 DB | 57 DB | OBSERVED VISUAL EFFECT OF EXTRANEOUS TONE IN THE DESIGNATED PASSBAND (300HZ-4.2 MHZ), DISPLAYED WITH THE RECEIVED PICTURE COULD BE FIVE OR MORE HORIZONTAL LINES NOTED ACROSS THE SCREEN OF VARYING INTENSITY. THIS WOULD TYPICALLY OCCUR BELOW LINE FREQUENCY 15734.264HZ AT OR MULTIPLES OF LINE FREQUENCY. THE DISPLAYED VIDEO COULD INCLUDE FROM ONE WIDE VERTICAL COLUMN TO SEVERAL LINES NOTED ACROSS THE RECEIVED PICTURE. HOWEVER, EXTRANEOUS SIGNALS ARE SELDOM AT LINE FREQUENCY. THEREFORE, DIAGONAL LINES RACING WOULD BE VIEWED. |
| 21<br>NTC 3.17 | SIGNAL-TO-IMPULSE NOISE RATIO | ≥ 23 DB (e.g. IMPULSE NOISE <7 IRE PEAK-TO-PEAK, FREQUENCY OF OCCURENCE ≤ 1 PER MINUTE). | NOT SET | NOT SET | NOT SET | NOT SET | NOT SET | THE VISUAL EFFECT NOTED FOR IMPULSE NOISE DISPLAYED ON A MONOCHROME SYSTEM WOULD BE BLACK AND WHITE DOTS RACING ACROSS THE SCREEN IN A HAPHAZARD ARRANGEMENT. IN COLOR SYSTEMS: BLACK AND WHITE, AND COLOR SPECKLES WOULD BE VIEWED. |
| 22<br>NTC 3.19 | SIGNAL-TO CROSSTALK NOISE RATIO | ≥ 60 DB | — | — | — | — | — | THIS DISTORTION COULD TYPICALLY PRODUCE MANY DIFFERENT TYPES OF ERRATIC PATTERNS DISPLAYED ON THE RECEIVED PICTURE. THE OBSERVATIONS NOTED WOULD BE INDICATIVE OF OTHER VIDEO SOURCES OR EXTRANEOUS TONES IN DISPLAYED PICTURE. |
| 23 | CONTINUITY OF VIDEO SERVICE | | 99.99% OBJECTIVE | 99.99% OBJECTIVE | 99.99% OBJECTIVE | 99.99% OBJECTIVE | 99.99% OBJECTIVE | — |
| 24 | K-FACTOR | — | — | — | — | — | — | K-FACTORS SPECIFICALLY RELATE TO THE MONOCHROME OR LUMINANCE COMPONENT IN VIDEO SYSTEMS. THE PARTICULAR DISPLAYED VISUAL EFFECT WOULD BE OBTAINED UNDER TEST NUMBER 5, (LINE TIME DISTORTION) AND TEST NUMBER 6, (SHORT TIME DISTORTION). ASYMMETRY IN THE 2T SINE SQUARE PULSE DENOTE GROUP ENVELOPE DELAY IN THE 1-3 MHZ REGION. |
| 25 | COLOR BURST AMPLITUDE | 40 IRE UNITS ±4 IRE UNITS | 40 IRE UNITS ±0.5 IRE BASED ON GAIN/ FREQUENCY SPECIFICATION | 40 IRE UNITS ±2.0 IRE BASED ON GAIN/ FREQUENCY SPECIFICATION | 40 IRE UNITS ±2.0 IRE BASED ON GAIN/ FREQUENCY SPECIFICATION | 40 IRE UNITS ±3.0 IRE BASED ON GAIN/ FREQUENCY SPECIFICATION | 40 IRE UNITS ±3.0 IRE BASED ON GAIN/ FREQUENCY SPECIFICATION | LOW AMPLITUDE OF THE COLOR BURST WILL RESULT IN LOSS OF COLOR SNYCHRONIZATION. LOSS OF COLOR SYNCHRONIZATION WILL FIRST BE NOTICED WITH A RED, BLUE, AND GREEN "RAINBOW" EFFECT ACROSS THE ENTIRE VIDEO DISPLAY. THIS IS SOMETIMES REFERRED TO AS THE (BARBER POLE EFFECT). FURTHER REDUCTION OF THE REFERENCE BURST WILL TURN A COLOR TRANSMISSION INTO A MONOCHROME DISPLAY. |
| 26<br>NTC 5.1 | RELATIVE BURST GAIN ERROR | 40 IRE UNITS ±1 IRE UNIT | — | — | — | — | — | HIGH OR LOW COLOR SATURATION OBSERVED IN THE RECEIVED PICTURE AS A CONSEQUENCE OF A MISADJUSTED PROCESSING AMPLIFIER INSERTED IN THE SIGNAL CHANNEL.<br>NOTE, THE EXISTENCE OR NON-EXISTENCE OF A PROCESSING AMPLIFIER IN THE SIGNAL CHANNEL, MAY NOT BE APPARENT BY VISUAL OBSERVATION ALONE. |
| 27<br>NTC 5.2 | RELATIVE BURST PHASE ERROR | ZERO ±1° | — | — | — | — | — | A CHANGE OR VARIATION IN HUE OBSERVED IN THE RECEIVED PICTURE, AS A CONSEQUENCE OF A MISADJUSTED VIDEO PROCESSING AMPLIFIER, INSERTED IN THE SIGNAL CHANNEL.<br>NOTE, THE EXISTENCE OR NON-EXISTENCE OF A PROCESSING AMPLIFIER IN THE SIGNAL CHANNEL, MAY NOT BE APPARENT BY VISUAL OBSERVATION ALONE. |

**Credit:** Michael J. Shumila
Member, Technical Staff
RCA Laboratories
David Sarnoff Research Center
Princeton, NJ

NTSC-M color television performance measurements for communication systems. (Page 3 of 3.)

# Section 3*: Parameters, Measuring Techniques and Performance Objectives

## GENERAL AND WAVEFORM TECHNOLOGY

This section describes the transmission parameters, measuring techniques and performance objectives that are applicable to all video transmission facilities leased from the Bell System.

It should be noted that except where full-field test signals are essential to the measurement of a particular transmission parameter, e.g., field-time waveform distortion, the measuring technique and its associated performance objective specified for each transmission parameter apply equally to both vertical interval test signals (VITS) and full-field test signals. Furthermore the performance objectives apply irrespective of the average picture level (APL) within the APL range 10% to 90%. This is an important point to remember when making VITS measurements, particularly during program transmission periods where control cannot be exercised over the APL value of picture signal. Many of the transmission parameters can be markedly affected by APL variations. Acordingly, the operator should allow sufficient time when making VITS measurements to ensure a good portion of the APL range is explored by the picture signal before recording the test signal measurement. In every case the highest distortion measurement observed during this period should be recorded and then compared with the performance objective to determine whether or not the facility is within the stated objective.

Waveform measurement techniques described in this report are based on the IRE scale units of measurement (see Fig. 1) except where specifically noted otherwise. The waveform technology used throughout the report is in accordance with the definitions shown in Fig. 2 wherein the standard composite color video signal is defined.

The two principal test signals that are required to conduct the various measurements described in this report are:

A. The composite test signal shown in Fig. 3, which consists of a line bar, a 2T pulse, a chrominance pulse, and a 5-riser staircase signal.

B. The combination test signal shown in Fig. 4, which consists of a white flag, a multiburst and a 3-level chrominance signal.

When conducting in-service VITS measurements the composite test signal shall be inserted on line 17, field 1, and the combination test signal shall be inserted on line 17, field 2.

*NOTE:* The performance objectives specified in this report pertaining to television transmission facilities, apply only when the recommended test signals are originated directly at the designated broadcaster/TELCO interface. No broadcaster maintained and operated equipment shall be used between the test signal generator output and the interface point.

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*Section and test numbers are original NTC-7 numbers.

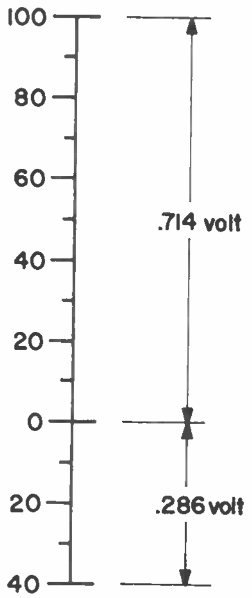
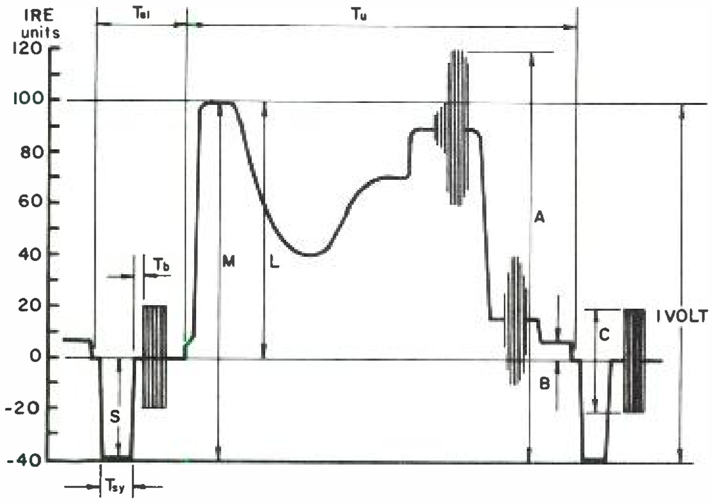


Fig. 1. The IRE scale units.
(For a 1V P-P composite signal)



**WAVEFORM TERMINOLOGY**

A: The peak-to-peak amplitude of the composite color video signal
B: The difference between black level and blanking level (set-up)
C: The peak-to-peak amplitude of the color burst
L: Luminance signal—nominal value
M: Monochrome video signal peak-to-peak amplitude ($M = L + S$)
S: Synchronizing signal—amplitude
$T_b$: Duration of breezeway
$T_{sl}$: Duration of line blanking period
$T_{sy}$: Duration of line synchronizing pulse
$T_u$: Duration of active line period

Fig. 2. The standard composite color video signal.

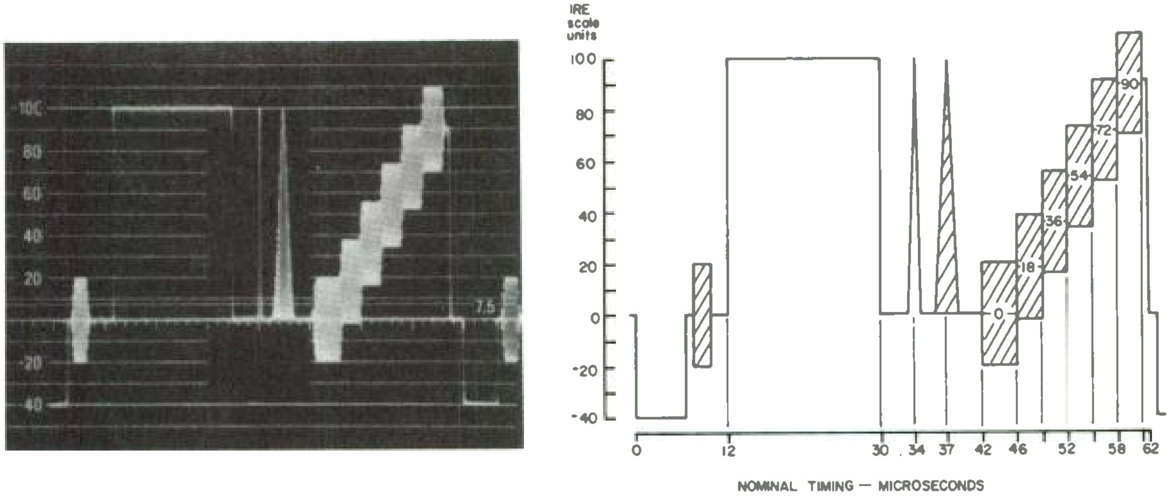


Fig. 3. The composite test signal.

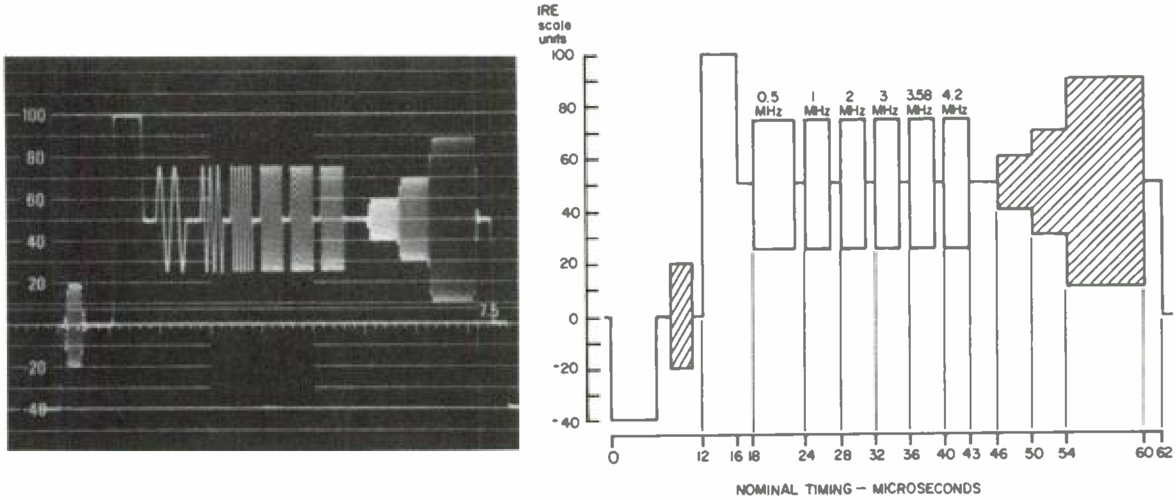


Fig. 4. The combination test signal.

## 3.2 INSERTION GAIN

### Definition:

Insertion gain is defined as the difference, in IRE units, between the peak-to-peak amplitude of a specified test signal at the receiving end of a television facility and the nominal amplitude of the test signal at the sending end.

### Measurement:

The line bar portion of the composite test signal shown in Fig. 5 is used when measuring insertion gain. The test signal's amplitude must be accurately adjusted at the sending end prior to the commencement of the test. Similarly, the waveform monitor at the receiving end should be properly calibrated.

Following the above, the peak-to-peak amplitude of the test signal should be measured, in IRE units, at the receiving end using the points approximating to $b_1$ and $b_2$ as shown in Fig. 5. The difference between the measured amplitude of the test signal and its nominal amplitude of 100 IRE units is the insertion gain of the television facility. If the measured amplitude is less than 100 IRE units then the insertion gain should be recorded with a negative sign. Such an example is shown in Fig. 6.

### Performance Objectives:

a. The insertion gain shall not exceed zero ± 3 IRE units.

b. Variations in insertion gain shall not exceed

   i. Short period (e.g., 5 seconds): ± 1 IRE unit.

   ii. Medium period (e.g., 1 hour): ± 2 IRE units.

These variations in gain are permissible only within the range specified in objective a.

*NOTE 1:* The performance objectives shown above apply equally to full-field and in-service VITS measurements.

*NOTE 2:* Insertion gain may also vary as a function of APL. This is termed dynamic gain, and is covered in section 3.12.

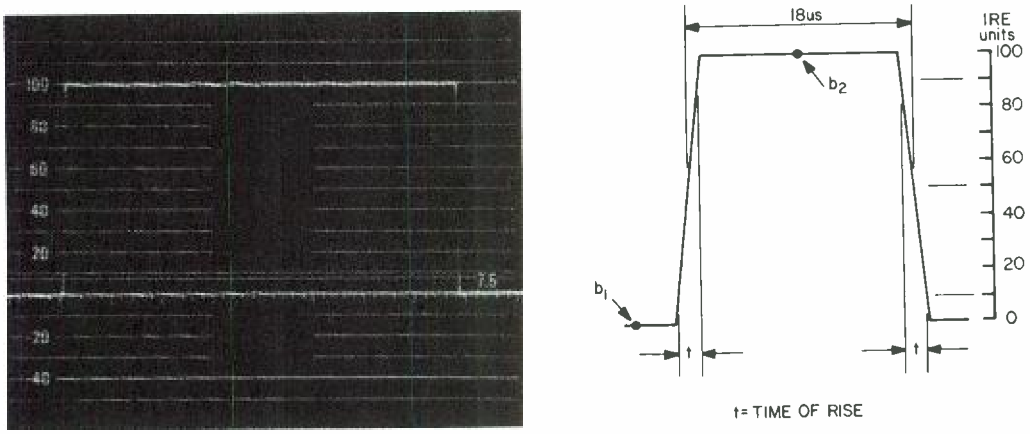


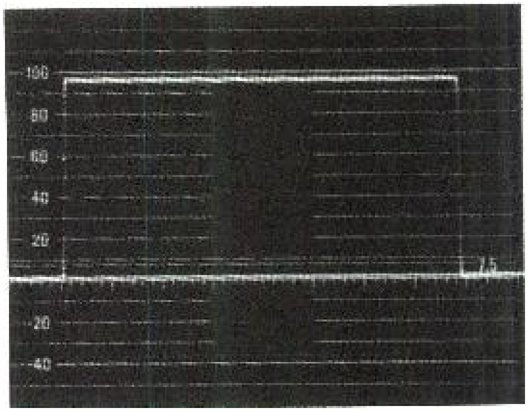
Fig. 5. The line bar test signal.

## Generator Output Specifications

Peak amplitude : 100 ± 0.5 IRE units *(reference white amplitude)*

Line-time waveform distortion : less than 0.3 IRE units

Time of rise and time of fall of bar edges (10%-90%) : t = 125 ± 5 nanoseconds with integrated sine-squared shape



Insertion gain is -3 IRE units.

Fig. 6. An example of negative insertion gain.

## 3.3 FIELD-TIME WAVEFORM DISTORTION

**Definition:**

When a television test signal having a period of one television field, and of reference white amplitude is applied to the sending end of a television facility, the field-time waveform distortion is defined as the change in shape of the top of the test signal at the receiving end. The beginning and end of the test signal, equivalent to a few scanning lines, are excluded from the measurement.

**Measurement:**

The field bar test signal shown in Fig. 7 is used when measuring field-time waveform distortion. The test signal's amplitude must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the magnitude of the distortion is obtained by measuring, in IRE units, the peak-to-peak change in amplitude of the bar top with the amplitude of the bar center adjusted to 100 IRE units. In order to avoid leading and trailing overshoots, the first and last 250 microseconds (approximately four television lines) are ignored in this measurement. An example of field-time waveform distortion is shown in Fig. 8.

**Performance Objective:**

The peak-to-peak excursions of the bar top shall not exceed 4 IRE units.

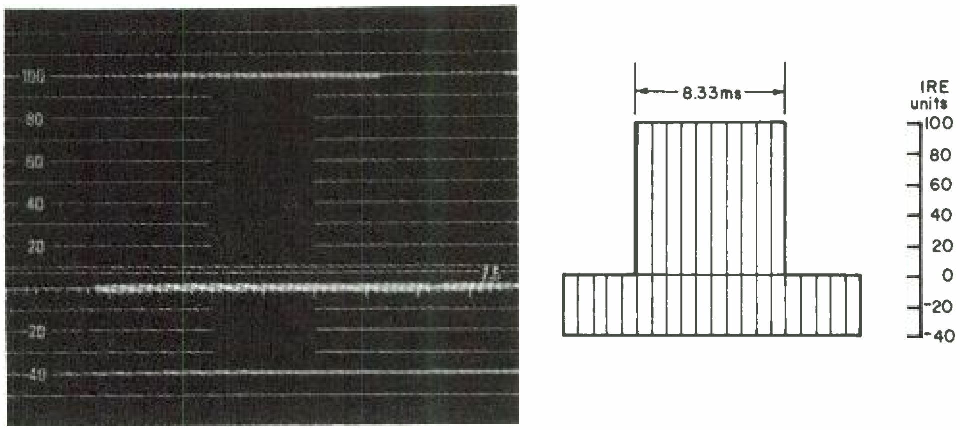


Fig. 7. The field bar test signal.

## Generator Output Specifications

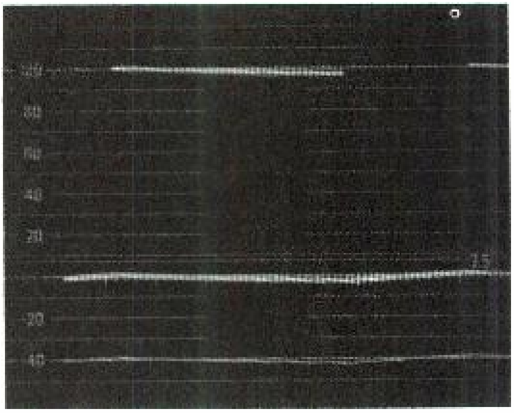
Peak amplitude of luminance signal : 100 ± 0.5 IRE units

Peak amplitude of synchronizing signal : 40 ± 0.5 IRE units

Field-time waveform distortion : less than 0.3 IRE units

Horizontal component : 100 IRE unit flat field of 52.45 microsecond nominal duration

**NOTE:** This signal should be generated with field and line synchronizing pulses.



Field-Time Distortion is 3 IRE units. (+1, −2)

Fig. 8. An example of field-time distortion.

## 3.4 LINE-TIME WAVEFORM DISTORTION

### Definition:

When a television test signal having a period of one television line and of reference white amplitude is applied to the sending end of a television facility, the line-time waveform distortion is defined as the change in shape of the top of the test signal at the receiving end. The beginning and end of the test signal, equivalent to a few picture elements, are excluded from the measurement.

### Measurement:

The line bar test portion of the composite test signal shown in Fig. 9 is used when measuring line-time waveform distortion. The test signal's amplitude must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the magnitude of the distortion is obtained by measuring, in IRE units, the peak-to-peak change in amplitude of the bar top with the amplitude of the bar center adjusted to 100 IRE units. The first and last one microsecond are ignored in this measurement. An example of line-time waveform distortion is shown in Fig. 10.

### Performance Objective:

The peak-to-peak excursions of the bar top shall not exceed 4 IRE units.

*NOTE:* The performance objective shown above applies equally to both full-field and in-service VITS measurements.

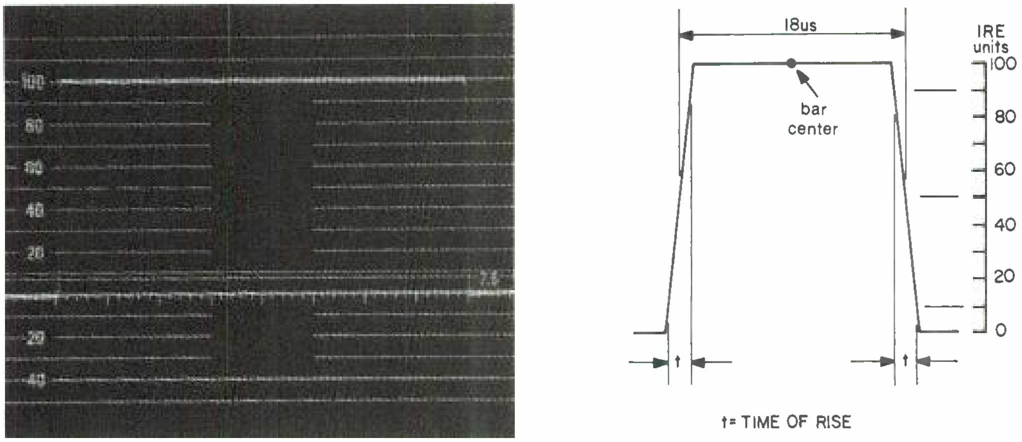
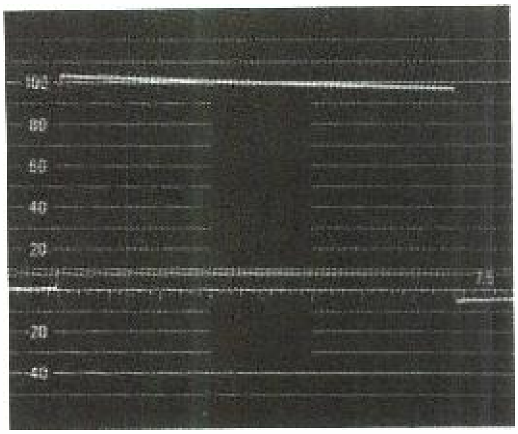


Fig. 9. Line bar test signal.

## Generator Output Specifications

| | | |
|---|---|---|
| Peak amplitude | : | 100 ± 0.5 IRE units |
| Line-time waveform distortion | : | less than 0.3 IRE units |
| Time of rise and time of fall of bar edges (10%-90%) | : | t = 125 ± 5 nanoseconds with integrated sine-squared shape |



Line-Time Distortion is 4 IRE units. (+2, −2)

Fig. 10. An example of line-time distortion.

## 3.5 SHORT-TIME WAVEFORM DISTORTION

### Definition:

If a short pulse or rapid step function of reference white amplitude and defined shape is applied to the sending end of a television facility, the short-time waveform distortion is defined as the departure of the output pulse or step from its original shape. The choice of the half amplitude duration of the pulse or the rise-time of the step is determined by the nominal cutoff frequency of the television facility.

### Measurement:

The line bar portion of the composite test signal shown in Fig. 9 and the 2T pulse test signal shown in Fig. 11 are used when measuring short-time waveform distortion. The test signal's amplitude must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the amplitude of the 2T pulse test signal is measured, in IRE units, having previously adjusted the amplitude of the line bar test signal to exactly 100 IRE units.

The peak-to-peak variations within the 1 microsecond intervals on either side (preceding and following) the T-step transitions (rise and fall) are then measured with the amplitude of the line bar test signal adjusted to 100 IRE units as measured between blanking and a point approximately 2 microseconds from the bar edge. (A graticule method of measuring short-time waveform distortion is currently under study by IEEE.) Examples of short-time waveform distortion are shown in Figs. 12 and 13.

### Performance Objective:

a. The 2T pulse amplitude shall be 100 ± 6 IRE units.
b. The peak-to-peak amplitude variations preceding or following the T-step transitions to the line bar test signal shall not exceed 10 IRE units.

*NOTE:* The performance objectives shown above apply equally to both full-field and in-service VITS measurements.

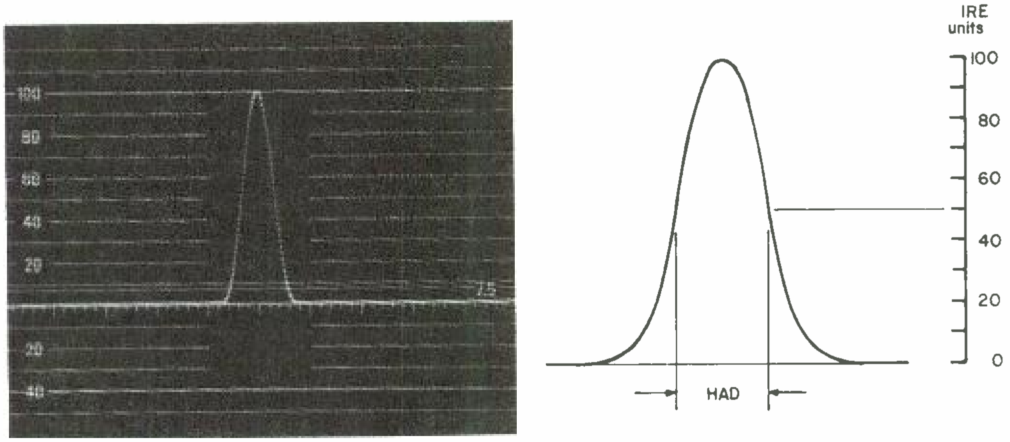


Fig. 11. The 2T pulse test signal.

## Generator Output Specifications

Peak amplitude : 100 ± 0.5 IRE units

Half amplitude duration (HAD) : 250 ± 10 nanoseconds

2T Amplitude
is 92 IRE units.

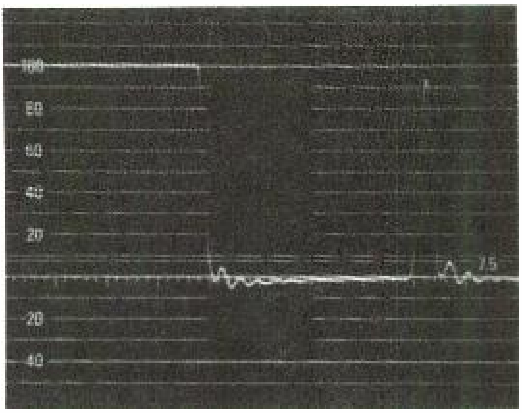


Fig. 12. An example of short-time distortion as it affects the 2T pulse amplitude.

Amplitude variations following the T-step
transition are 10 IRE units peak-to-peak.

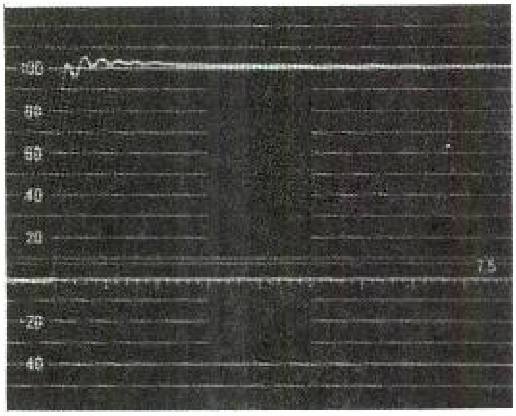


Fig. 13. An example of short-time distortion as it affects the edge response of the line bar.

## 3.6 CHROMINANCE-LUMINANCE GAIN INEQUALITY

### Definition:

When a test signal having defined luminance and chrominance components is applied to the sending end of a television facility, the chrominance-luminance gain inequality is defined as the change in amplitude at the receiving end of the color component of the test signal relative to the luminance component.

### Measurement:

The chrominance pulse portion of the composite test signal shown in Fig. 14 is used when measuring chrominance-luminance gain inequality.* The test signal's amplitude must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the amplitude of the Chrominance Pulse Test Signal is measured in IRE units, having previously adjusted the amplitude of the line bar test signal to exactly 100 IRE units. This method is accurate to within 2% with up to 300 nanoseconds of chrominance-to-luminance delay present. The convention of Fig. 17B shows how the chrominance pulse will look with different types of gain and delay distortion. If harmonic distortion is present on the chroma pulse, as evidenced by multiple irregularities of the baseline, this method is invalid and an accurate measurement cannot be made. Methods to make measurements in the presence of harmonic distortion are presently under study.

An example of low chrominance amplitude is shown in Fig. 15.

### Performance Objective:

The amplitude of the chrominance pulse shall be 100 ± 3 IRE units.

*NOTE:* The performance objective shown above applies equally to both full-field and in-service VITS measurements.

---

*This parameter is also called Realtive Chroma Level (RCL), and is expressed as a percentage of P-P chrominance referenced to the line bar amplitude, as shown in Fig. 15. Hence, the performance objective expressed as RCL would be ± 6%.

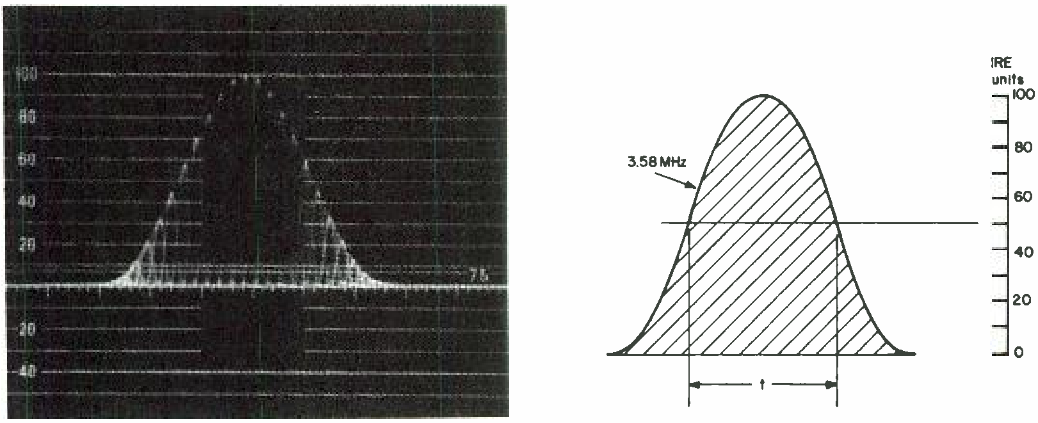


Fig. 14. The chrominance pulse test signal.

## Generator Output Specifications

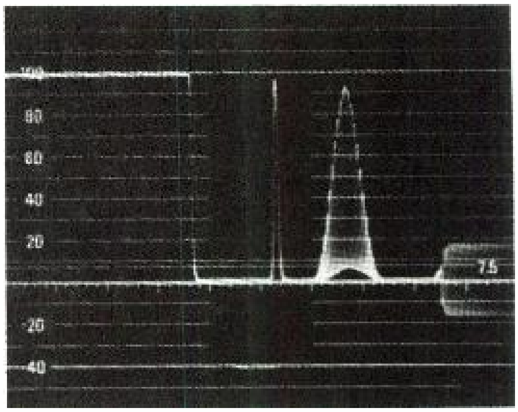
Peak amplitude : 100 ± 0.5 IRE units

Half amplitude duration : t = 1562.5 ± 50 nanoseconds

Inherent chrominance luminance
a) gain inequality (RCL) : less than ± 0.5 IRE (± 1%)
b) delay inequality (RCT) : less than 5 nanoseconds, delayed or advanced

Subcarrier harmonic distortion : less than 1%

Irregularities in the pulse base line : less than ± 0.5 IRE units



Chrominance Pulse Amplitude is 94 IRE units (RCL = −12%) no delay inequality is present.

Fig. 15. An example of chrominance-luminance gain inequality.

## 3.7 CHROMINANCE-LUMINANCE DELAY INEQUALITY

### Definition:

When a test signal having defined luminance and chrominance components is applied to the sending end of a television facility, the chrominance-luminance delay inequality is defined as the change in relative timing, at the receiving end, of the chrominance component of the test signal relative to the luminance component.

### Measurement:

The chrominance pulse portion of the composite test signal shown in Fig. 14 is used when measuring chrominance-luminance delay inequality.* The test signal's amplitude must be acurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the amplitude of the chrominance pulse test signal should be adjusted to exactly 100 IRE units. The nomogram shown in Fig. 17A should be used to compute the magnitude of the chrominance-luminance delay inequality. If the chrominance component of the test signal starts with a positive going lobe then the chrominance-luminance delay inequality should be recorded as delayed chroma. The delay inequality can also be computed by the formula: CLDI (RCT) in ns = $20 \sqrt{Y_1 \cdot Y_2}$. If harmonic distortion is present, as evidenced by multiple irregularities of the baseline, this method is invalid and an accurate measurement cannot be made. Methods to determine chrominance-luminance delay inequality in the presence of harmonic distortion are currently under study.

An example of chrominance-luminance delay inequality is shown in Fig. 16 below.

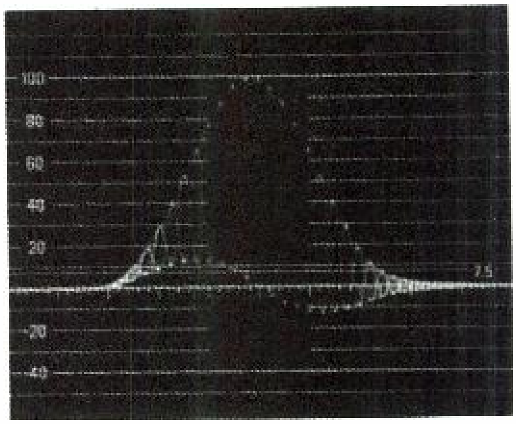
### Performance Objective:

The chrominance-luminance delay inequality shall be no greater than 75 nanoseconds, advanced or delayed chroma.

*NOTE:* The performance objective shown above applies equally to both full-field and in-service VITS measurements.

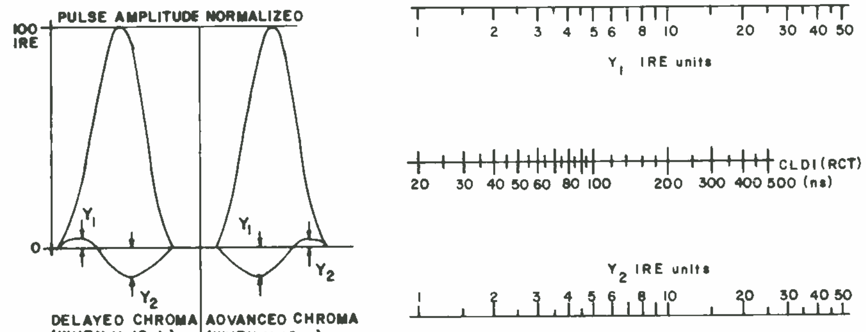
---

*This parameter is also called **Relative Chroma Time**.



CLDI(RCT) is 240 Nanoseconds Delayed Chroma with no gain inequality present.

Fig. 16. An example of chrominance-luminance delay inequality.



NOMOGRAM COURTESY IEEE

Fig. 17A. Chrominance-luminance delay nomogram with measurement convention.

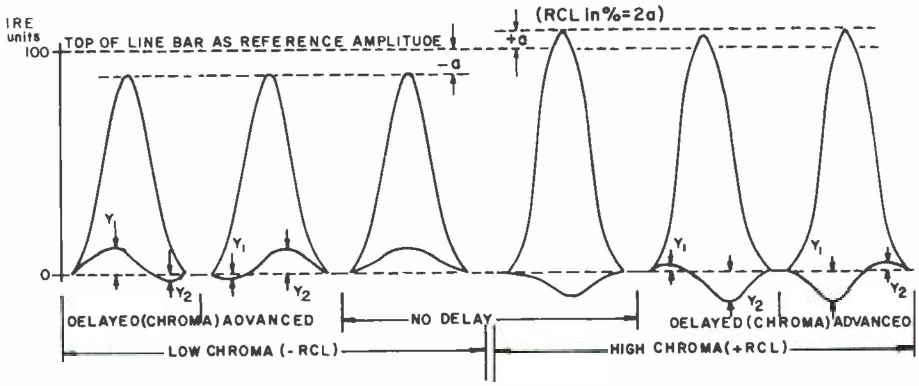


Fig. 17B. Chrominance-luminance gain measurement convention.

## 3.8 GAIN/FREQUENCY DISTORTION

### Definition:

The gain/frequency distortion of a television facility is defined as the variation in gain over the frequency band extending from the television field repetition frequency to the nominal cutoff frequency of the facility, relative to the gain at a suitable reference frequency.

### Measurement:

The multiburst portion of the combination test signal shown in Fig. 18 is used when measuring gain/frequency distortion in the range from 500 kHz to 4.2 MHz. The test signal's amplitude must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the amplitude of the white flag should be adjusted to exactly 100 IRE units and then the peak-to-peak amplitude of each burst frequency should be measured and recorded. An example of gain/frequency distortion is shown in Fig. 19.

### Performance Objective:

With the white flag amplitude adjusted to 100 IRE units:

a. All frequency burst amplitudes shall be 50 +3, −5 IRE units.
b. Color burst amplitude shall be 40 ± 4 IRE units.

*NOTE:* The performance objective shown above applies equally to both full-field and in-service VITS measurements.

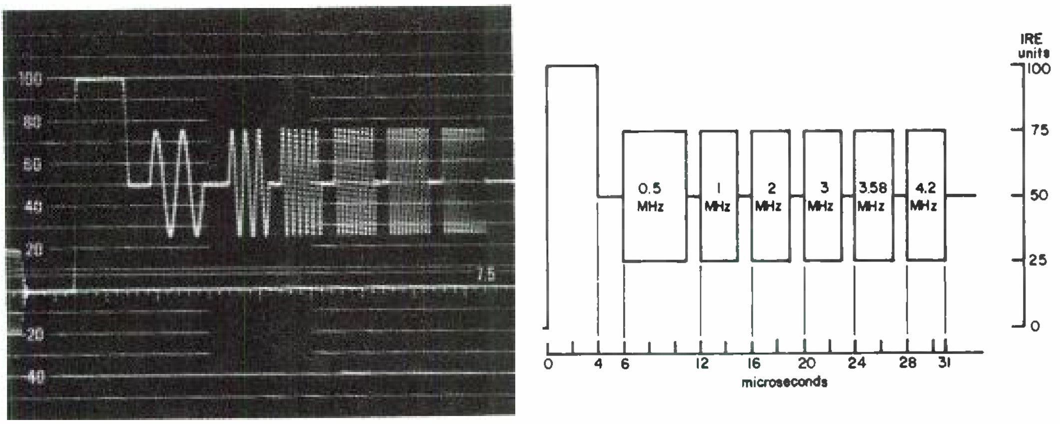


**Fig. 18. The multiburst test signal.**

## Generator Output Specifications

A) **White Flag**

Peak amplitude : 100 ± 1 IRE unit.

Time of rise and time of fall of flag edges : derived from the shaping network of the 2T sine-squared pulse.

Overshoot : less than ± 1 IRE unit.

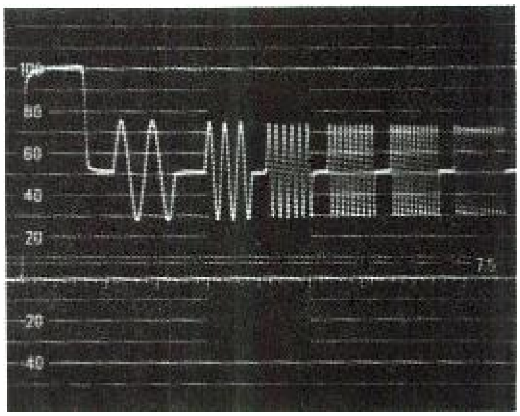
Tilt : less than ± 1 IRE unit.

B) **Multiburst Frequencies**

All half-amplitude points of all burst frequencies : 50 ± 1 IRE unit.

(The starting point of each burst frequency shall be at zero phase of each sinewave.)

Peak-to-peak amplitude of all bursts 50 ± 0.5 IRE units.



In this example, high frequency roll-off is shown. The burst amplitudes vary from 50 IRE units in the 500 kHz burst to 42 IRE units in the 4.2 MHz burst.

**Fig. 19. An example of gain/frequency distortion.**

## 3.9 LUMINANCE NON-LINEAR DISTORTION

### Definition:

For a particular value of average picture level (APL), the non-linear distortion of the luminance signal is defined as the departure from proportionality between the amplitude of a small unit step function at the sending end of a television facility and the corresponding amplitude at the receiving end, as the level of the step is shifted from blanking level to white level.

### Measurement:

The modulated 5-riser staircase portion of the composite test signal shown in Fig. 20 is used when measuring luminance non-linear distortion. The test signals amplitude at each step level must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the test signal is passed through a differentiating and shaping network of the type shown in Fig. 21 with the output of the network connected to the waveform monitor being used for the measurement. The function of the network is that of transforming the test signal into a train of 5 pulses of equal amplitude under zero distortion conditions. The gain of the waveform monitor should be increased to the point where the largest pulse amplitude is 100 IRE units and then the amplitude of the smallest pulse can be measured and recorded. This is the Luminance non-Linear Distortion at 50% APL. The above measurement procedure should be repeated using the same test signal transmitted on every fifth television line with intermediate lines set at blanking level for a 10% APL value and then at peak white for a 90% APL value.*

An example of Luminance non-Linear Distortion is shown in Fig. 22.

### Performance Objective:

With the largest pulse amplitude adjusted to 100 IRE units, the difference between it and the smallest pulse amplitude shall not be greater than 10 IRE units at 10%, 50%, or 90% APL.

*NOTE:* The performance objectives above also apply to in-service VITS measurements.

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*For in-service VITS measurements the procedures outlined in Section 3 introduction should be followed.

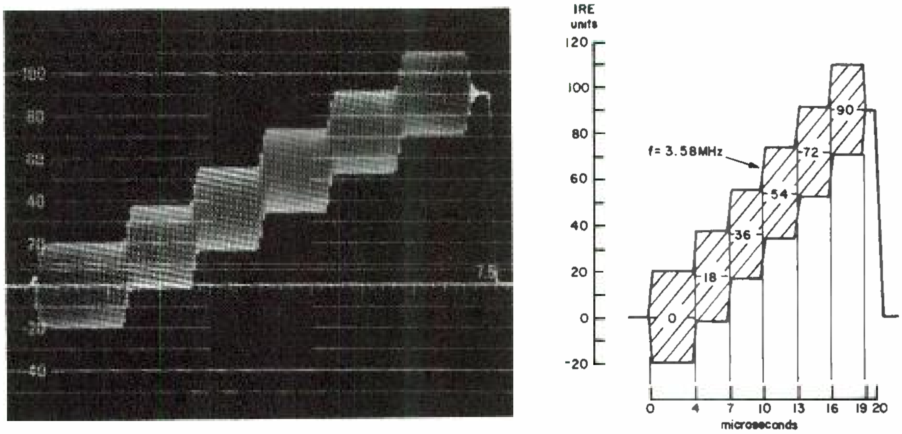
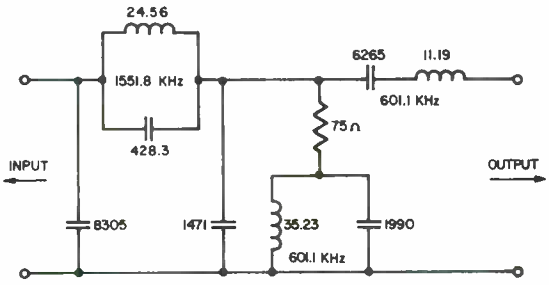


**Fig. 20. The modulated 5-riser staircase test signal (see section 3.13 for chrominance specifications).**

## Generator Output Specifications

| | | |
|---|---|---|
| Peak amplitude of each riser | : | shall be such that the luminance non-linear distortion shall be greater than 99.5 IRE units. |
| Rise time of each riser | : | 250 ± 10 nanoseconds |
| Step duration | : | 3.0 ± 0.1 usecs;<br>final step 4.0 ± 0.1 microseconds (4.0 ± 0.1 microseconds at blanking level). |
| Tilt on any step | : | less than 0.3 IRE units |
| Overshoot on any step | : | less than 0.3 IRE units |



Inductances are given in uH, capacitances in pF.

**Fig. 21. Differentiating and shaping network for luminance non-linearity measurement.**

Luminance Non-Linear Distortion is 4 IRE units.

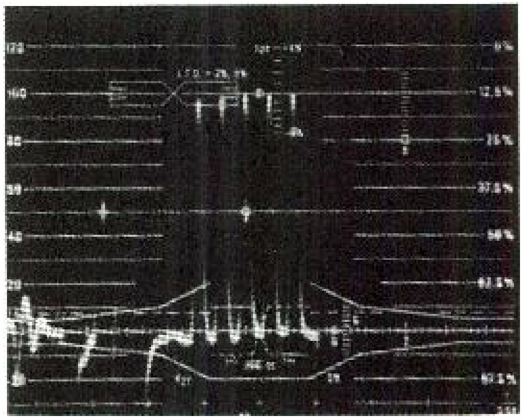


**Fig. 22. An example of luminance non-linear distortion.**

## 3.10 CHROMINANCE NON-LINEAR GAIN DISTORTION

### Definition:

For fixed values of luminance level and average picture level, the non-linear gain distortion of the chrominance signal is defined as the departure from proportionality between the amplitude of the chrominance subcarrier at the sending end of a television facility and the corresponding amplitude at the receiving end as the amplitude of the subcarrier is varied from a specified minimum value to a specified maximum value.

### Measurement:

The 3-level chrominance portion of the combination test signal shown in Fig. 23 is used when measuring chrominance non-linear gain distortion. The test signal's amplitude at each chrominance level must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the test signal is passed through a high-pass filter network* and the output of the network is connected to the waveform monitor being used for the measurement. The gain of the waveform monitor is adjusted to the point where the *middle* subcarrier amplitude is exactly 40 IRE units and then the amplitude of the largest and smallest subcarrier levels are measured and recorded. An example of chrominance non-linear gain distortion is shown in Fig. 24.

### Performance Objective:

With the middle subcarrier amplitude adjusted to 40 IRE units the amplitude of the other two subcarrier levels shall be:

a. The smallest subcarrier amplitude shall be 20 ± 2 IRE units.
b. The largest subcarrier amplitude shall be 80 ± 8 IRE units.

*NOTE:* The performance objective shown above applies equally to both full-field and in-service VITS measurements.

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*The chroma filter network incorporated into most television waveform monitors is suitable for this test.

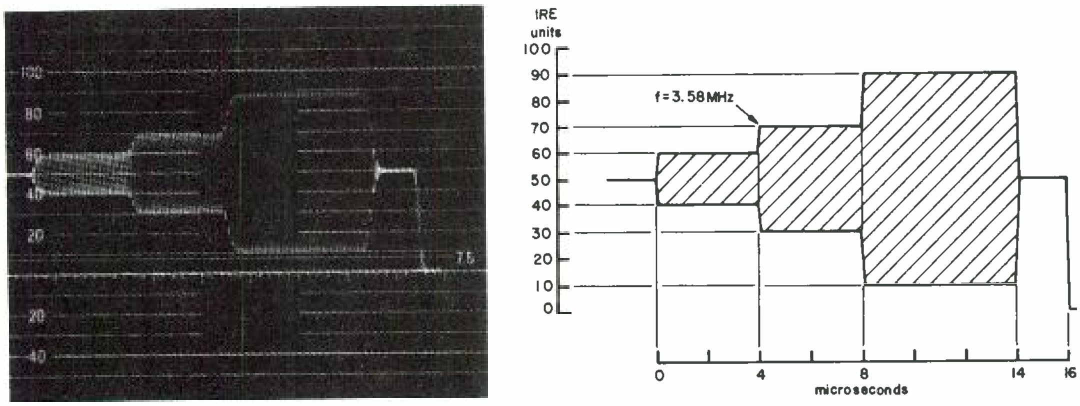
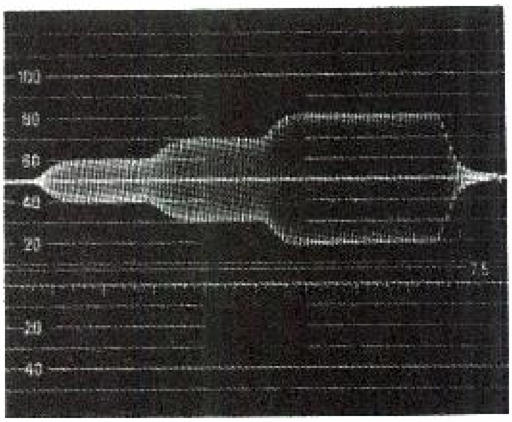


Fig. 23. The 3-level chrominance test signal.

## Generator Output Specifications

| | | |
|---|---|---|
| Peak-to-peak amplitudes of the 3-levels | : | 20,40 and 80 IRE units<br>± 0.5 IRE units |
| Sub-carrier frequency phase | : | 90° ± 1° relative to reference burst; 0° ± 0.2° any one relative to the other two. |
| Rise and fall of chrominance envelopes | : | 400 ± 25 nanoseconds |
| Duration of entire signal | : | 14 ± 0.5 microseconds |



The chrominance non-linear gain distortion is evidenced by the largest burst being equal to 64 IRE units.

Fig. 24. An example of chrominance non-linear gain distortion.

## 3.11 CHROMINANCE NON-LINEAR PHASE DISTORTION

### Definition:

For fixed values of luminance signal level and average picture level, the non-linear phase distortion of the chrominance signal is defined as the variation in phase of the chrominance subcarrier at the receiving end of a television facility as the amplitude of the subcarrier is varied from a specified minimum value to a specified maximum value.

### Measurement:

The 3-level chrominance portion of the combination test signal shown in Fig. 23 is used when measuring chrominance non-linear phase distortion. The test signal's amplitude and *phase* at each chrominance level must be accurately adusted at the sending end prior to the commencement of the test. Similarly the waveform monitor and phase comparator (e.g., vectorscope) at the receiving end should be properly calibrated.

Following the above, the test signal should be fed through a high pass filter network to the phase comparator (or directly to the vectorscope). Under zero distortion conditions the phase at each level of the 3-level chrominance test signal should be −90° relative to the phase of the color burst (see Fig. 25).

The phase of the three levels of the test signal should be measured relative to the phase of the color burst and recorded.

The peak-to-peak variation of the phase of the 3-level chrominance test signal is the difference between the largest and smallest readings obtained.

It should be noted that processing amplifiers can change the phase of the test signal chrominance information relative to the phase of the color burst. Care should be taken to ensure a processing amplifier is not in the circuit during tests of this kind on television facilities.

An example of chrominance non-linear phase distortion is shown in Fig. 26.

### Performance Objective:

The peak-to-peak phase variation of the 3-level chrominance test signal shall not exceed 5°.

*NOTE:* The performance objective shown above applies equally to both full-field and in-service VITS measurements.

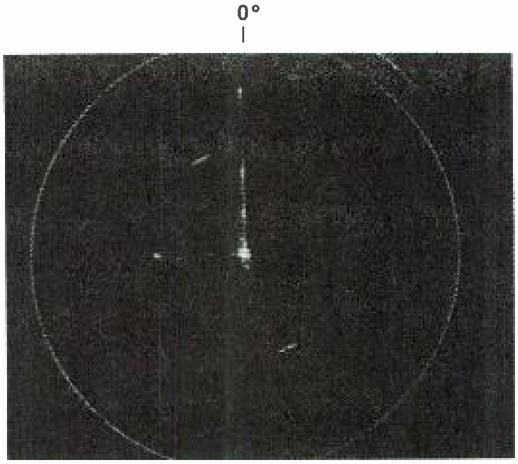
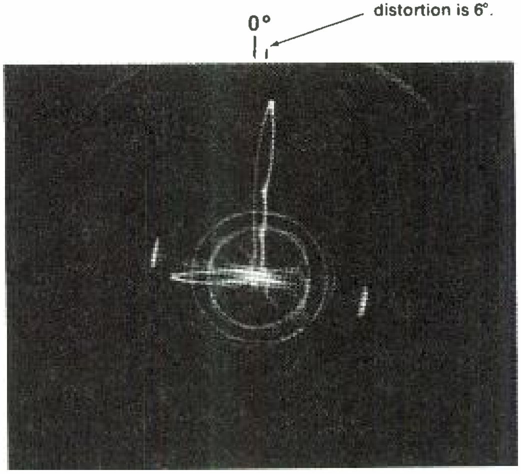


Fig. 25. Chrominance non-linear phase distortion display showing zero distortion.



The chrominance non-linear phase distortion is 6°.

Fig. 26. An example of chrominance non-linear phase distortion.

## 3.12 DYNAMIC GAIN DISTORTIONS

### Definitions:

If, at the sending end of a television facility, the average picture level (APL) of a video signal is stepped from a low value to a high value, or vice versa, the operating point within the transfer characteristic of the system may be affected and introduce various distortions on the receiving end. This section covers two such distortions known, respectively, as long-time waveform distortion and dynamic gain.

## Long-Time Waveform Distortion (Bounce)*

### Measurement:

The flat-field 'bounce' test signal, as shown in Fig. 27, is used when measuring long-time waveform distortion. The test signal is switched between 10 and 90 IRE units, at an appropriate rate, while the following measurements are made on a properly calibrated dc-coupled oscilloscope or waveform monitor, with any internal clamp in the instrument disabled.

With the waveform monitor on the field rate, observe any instantaneous peak excursion of the blanking level when the switch from 10 to 90 IRE, or vice versa, is made and record in IRE units. Also, observe the time necessary for blanking to settle to within 1 IRE unit of its final position. This may be as long as several seconds and the blanking level may undergo several peak-to-peak changes before stabilizing.

If an oscilloscope is used, a sweep time of 1 sec./cm will generally enable the entire transient to be observed. The Tektronix 1480 MOD. 6 or 7 is presently the only waveform monitor with a slow sweep feature.

A photograph of this slow sweep is the best method of observing these distortions.

An example of long-time waveform distortion is shown in Fig. 28.

### Performance Objectives:

Peak overshoot at blanking shall be no greater than 5 IRE units and the time for blanking to settle to within 1 IRE unit of its final level shall be less than 1 sec.

*NOTE:* This distortion only occurs when the APL change is accompanied by a change in dc component.

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*For in-service measurement of long-time waveform distortion the procedure outlined in Section 3 introduction should be followed.

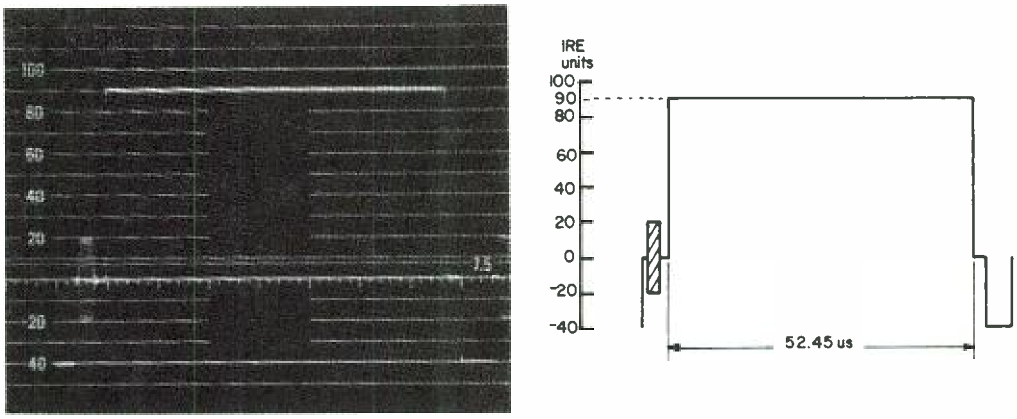

Fig. 27. The flat-field bounce test signal (90% APL value shown).

## Generator Output Specifications

| | | |
|---|---|---|
| Time of rise and fall of bar edge | : | derived from the shaping network of the sine-squared pulse. |
| Bar Duration | : | nominally 52.45 microseconds |
| Bar Amplitude | : | (High) 90 ± 1 IRE unit<br>(Low) 10 ± .5 IRE units |
| Tilt | : | Less than 1 IRE unit (10-90 IRE units) |
| Time of Transition (10-90 or 90-10) | : | Less than 10 microseconds |
| Rate of Transition | : | ≃ 5 sec. |

Peak overshoot is 50mV (7 IRE), settling time .75 sec.
sweep = 1 sec./CM gain = .2V/CM (DC—Coupled)

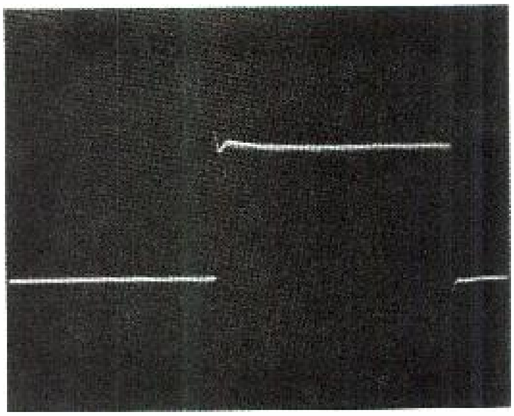

Fig. 28. An example of long-time waveform distortion.

## Dynamic Gain*

### Measurement:

Switch the flat-field test signal out of the 'bounce' mode and select 50% APL (Fig. 29A). Next, switch the waveform monitor to display the composite test signal on line 17, field one (Fig. 3). If necessary, normalize the gain of the waveform monitor for 100 IRE units at bar center. This is the reference amplitude for the following measurements.

Next, switch the test signal to 10% APL and observe and record, in IRE units, any change in amplitude of the line bar and/or synchronizing pulses. Finally, select 90% APL and record again any change in amplitude of the line bar and/or synchronizing pulses from the reference amplitude at 50% APL.

Examples of dynamic gain distortion are shown in Fig. 29B and C.

### Performance Objectives:

At 10% or 90% APL, dynamic gain-picture shall not exceed ± 3 IRE units and dynamic gain-sync shall not exceed ± 2 IRE units referenced to the amplitude at 50% APL.

*NOTE:* This distortion may occur with or without a change in dc component accompanying the APL change.

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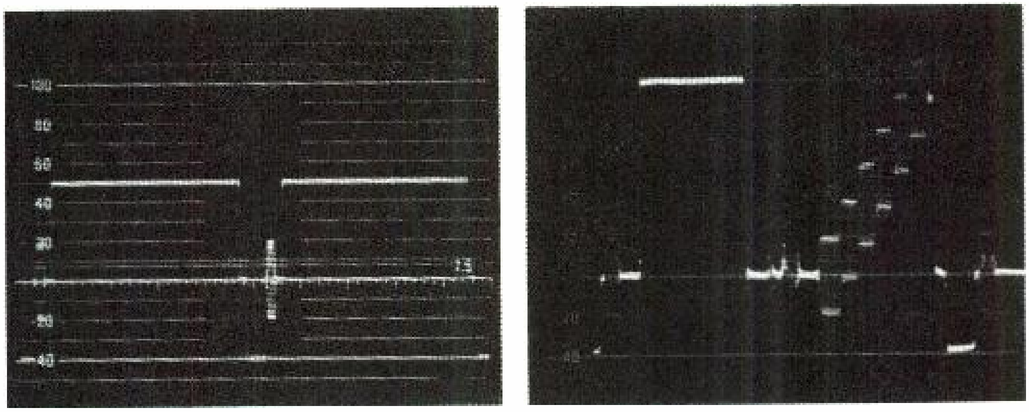
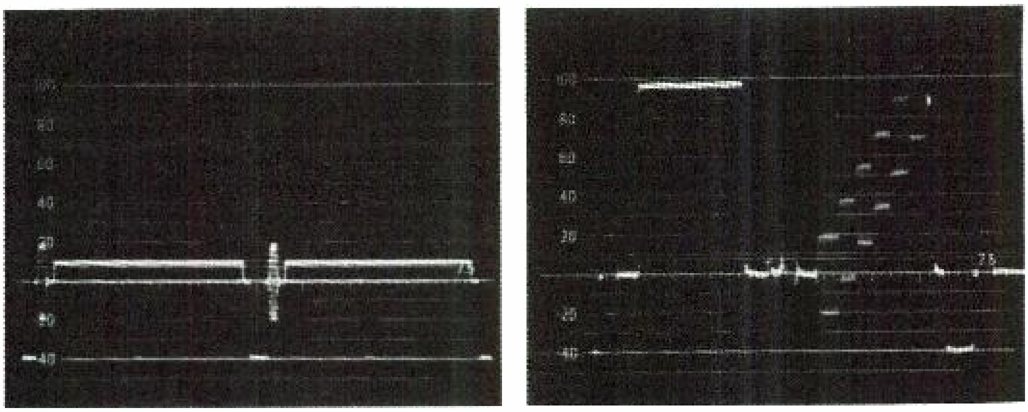
*For in-service measurements of dynamic gain the procedure outlined in Section 3 introduction should be followed.



Full field test signal at 50% APL

Fig. 29A.

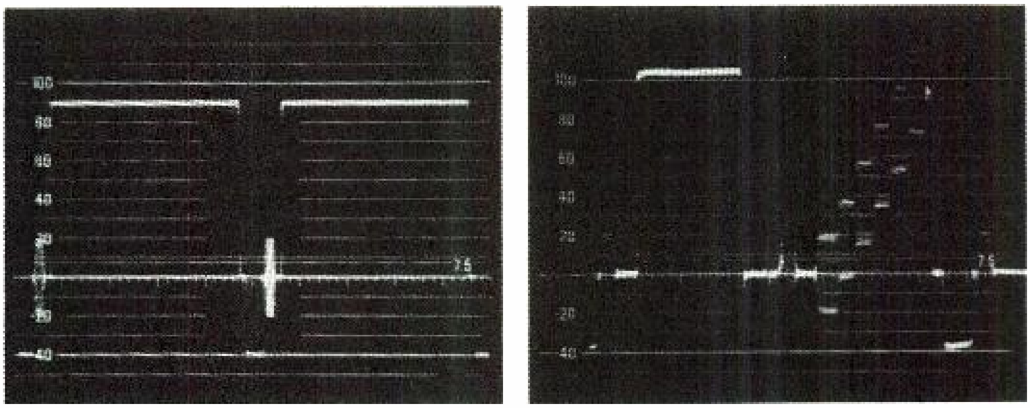
Line 17 field one, reference amplitude
Picture 100 IRE units
Sync 38 IRE units



Full field test signal at 10% APL

Fig. 29B.

Dynamic gain distortion at 10% APL is
Picture: −3 IRE units
Sync: +2 IRE units



Full field test signal at 90% APL

Fig. 29C.

Dynamic gain distortion at 90% APL is
Picture: +3 IRE units
Sync: 0 IRE units

## 3.13 DIFFERENTIAL GAIN

### Definition:

If a small constant amplitude of chrominance subcarrier, superimposed on a luminance signal, is applied to the sending end of a television facility, the differential gain is defined as the change in amplitude of the subcarier at the receiving end as the luminance varies from blanking level to white level, the average picture level being maintained at a particular value.

### Measurement:

The modulated 5-riser staircase portion of the composite test signal shown in Fig. 30 is used when measuring differential gain. The test signal's amplitude at each step level must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the test signal should be fed through a high-pass filter network* and the output of the network connected to the waveform monitor being used for the measurement. The gain of the waveform monitor is then adjusted until the highest subcarrier peak-to-peak amplitude is exactly 100 IRE units. The peak-to-peak amplitude of the lowest subcarrier is then measured. The difference between the highest subcarrier amplitude and the lowest subcarrier amplitude is the differential gain distortion at 50% APL. The above measurement procedure should be repeated using the same test signal transmitted on every fifth television line with intermedite lines set at blanking level for a 10% APL value and then at peak white level for a 90% APL value. The maximum differential gain distortion measured should be recorded.**

An example of differential gain distortion is shown in Fig. 31.

### Performance Objective:

At 10%, 50%, and 90% APL, the differential gain shall not exceed 15 percent (15 IRE units).

*NOTE:* The performance objective shown above also applies to the in-service VITS measurement.

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*The chroma filter network incorporated into most television waveform monitors is suitable for this test.

**For in-service VITS measurement of differential gain the procedure outlined in Section 3 introduction should be followed.

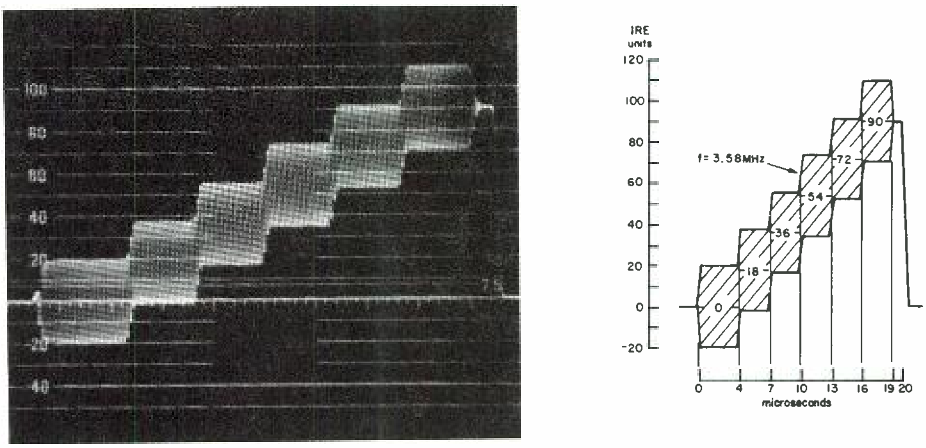
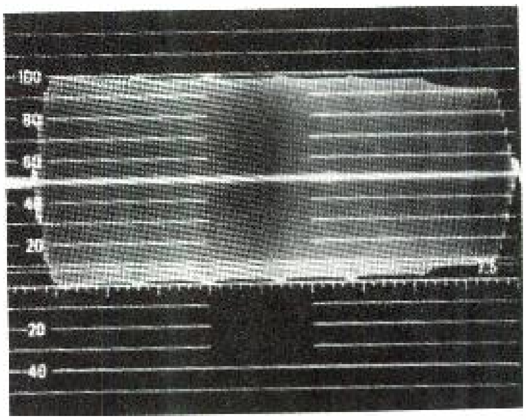


Fig. 30. The modulated 5-riser staircase test signal.

### Generator Output Specifications

(In addition to the luminance specifications shown with Figure 20 in Section 3.9)

| | | |
|---|---|---|
| Chrominance amplitude | : | 40 ± 0.5 IRE units |
| Inherent differential gain | : | less than 0.5 percent |
| and differential phase | : | less than 0.2° |
| Rise and fall times of the modulation envelope | : | 400 ± 25 nanoseconds |
| Phase of chrominance signal relative to reference burst phase | : | 0° ± 1.0° over the range 10% to 90% APL |



Differential gain is 16 percent.

Fig. 31. An example of differential gain distortion.

## 3.14 DIFFERENTIAL PHASE

### Definition:

If a constant amplitude of chrominance subcarrier without phase modulation, superimposed on a luminance signal, is applied to the sending end of a television facility, the differential phase is defined as the change in the phase of the subcarrier at the receiving end as the luminance varies from blanking level to white level, the average picture level being maintained at a particular value.

### Measurement:

The modulated 5-riser staircase portion of the composite test signal shown in Fig. 30 is used when measuring differential phase. The test signal's amplitude and its subcarrier phase at each step level must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor and phase comparator (e.g., vectorscope) at the receiving end should be properly calibrated. A vectorscope display of differential phase with zero distortion is shown in Fig. 32.

Following the above, the test signal should be fed through a high-pass filter network to the phase comparator (or directly to the vectorscope). The differential phase distortion is the measured peak-to-peak change in subcarrier phase at 50% APL. The above measurement procedure should be repeated using the same test signal transmitted on every fifth television line with intermediate lines set at blanking level for a 10% APL value and then at peak white level for a 90% APL value. The maximum differential phase distortion should be recorded.*

An example of differential phase distortion is shown in Fig. 33.

### Performance Objective:

At 10%, 50% and 90% APL the differential phase shall not exceed 5 degrees.

*NOTE:* The performance objective shown above also applies to the in-service VITS measurement.

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*For in-service VITS measurement of differential phase the procedure outlined in Section 3 introduction should be followed.

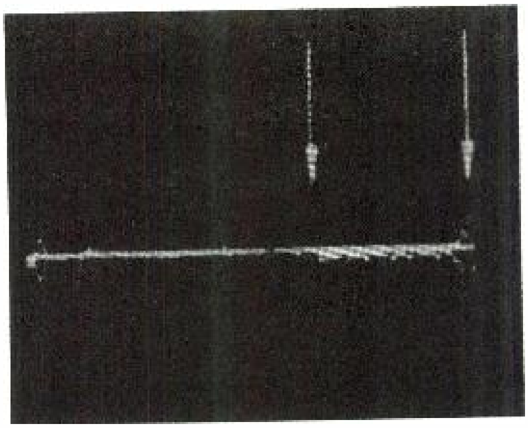

Fig. 32. Vectorscope display of differential phase showing zero distortion (between arrows).

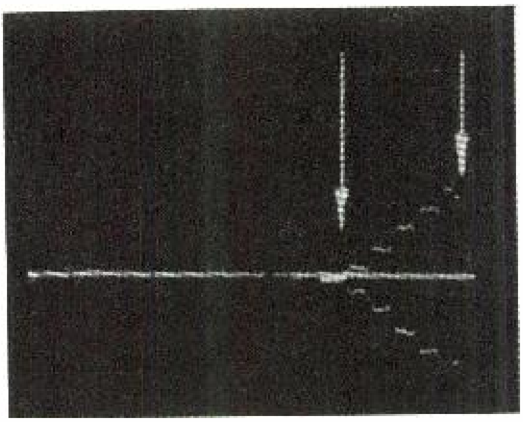

Fig. 33. Vectorscope display showing differential phase distortion (between arrows).

## 3.15 CHROMINANCE-TO-LUMINANCE INTERMODULATION

### Definition:

If a luminance signal of constant amplitude is applied to the sending end of a television facility, the intermodulation is defined as the variation of the amplitude of the luminance signal at the receiving end resulting from the superimposition on the luminance signal of a chrominance signal of specified amplitude.

### Measurement:

The 3-level chrominance portion of the combination test signal shown in Fig. 34 is used when measuring chrominance-to-luminance distortion. The test signal's amplitude at each chrominance level must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated. A waveform monitor display of chrominance-to-luminance intermodulation with zero distortion is shown in Fig. 35.

Following the above, the test signal is passed through a low-pass filter network* the output of which is connected to the waveform monitor being used for the measurement. The chrominance-to-luminance intermodulation is the maximum amplitude departure in IRE units of the filtered luminance pedestal from the amplitude of that portion of the luminance pedestal which did not contain the superimposed subcarrier, with the pedestal adjusted to exactly 50 IRE units.

An example of chrominance-to-luminance intermodulation is shown in Fig. 36.

### Performance Objective:

Chrominance-to-luminance intermodulation shall displace the luminance component no more than 3 IRE units from the 50 IRE unit reference level.

*NOTE:* The performance objective shown above applies equally to both full-field and in-service VITS measurements.

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*The low-pass filter network incorporated into most television waveform monitors is suitable for this test.

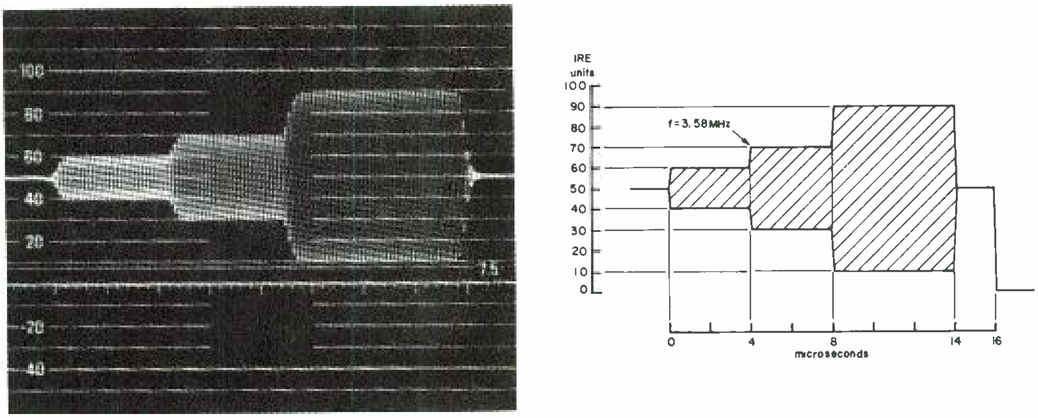


Fig. 34. The 3-level chrominance signal.

## Generator Output Specifications

| | | |
|---|---|---|
| Peak-to-peak amplitudes of the 3-levels | : | 20,40 and 80 IRE units ± 0.5 IRE units |
| Sub-carrier frequency phase | : | 90° ± 1° relative to reference burst; 0° ± 0.2° any one relative to the other two. |
| Rise and fall of chrominance envelopes | : | 400 ± 25 nanoseconds |
| Duration of entire signal | : | 14 ± 0.5 microseconds |

The chrominance-to-luminance intermodulation is + 3 IRE units.

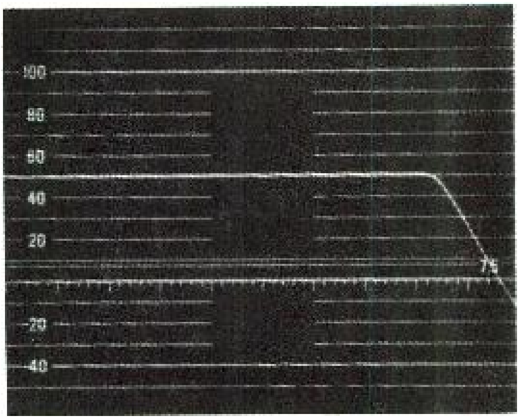


Fig. 35. Waveform monitor display showing zero chrominance-luminance intermodulation.

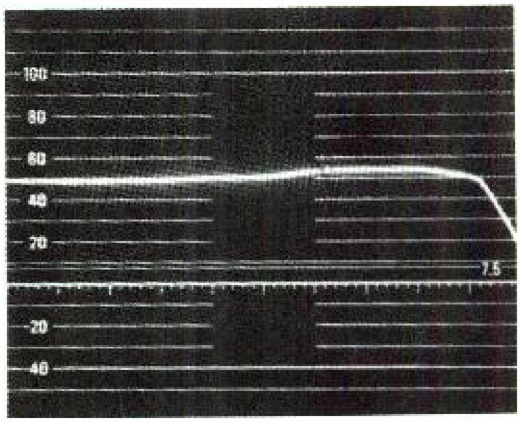


Fig. 36. Waveform monitor display showing chrominance-luminance intermodulation distortion.

## 3.16 RANDOM NOISE—WEIGHTED

### Definition:

The signal-to-weighted noise ratio of a television facility is defined as the ratio, expressed in decibels, of the nominal amplitude of the *luminance* signal (100 IRE units) to the RMS amplitude of the noise measured at the receiving end after band-limiting and weighting with a specified network. The measurement should be made with an instrument having, in terms of power, a time constant or integrating time of 0.4 seconds.

### Measurements:

In general, the random noise-weighted measurement should be made with an RMS reading instrument with the video signal removed from the television facility and the input to the facility terminated in its characteristic impedance. However, the measurement can also be made either with a flat-field test signal as shown in Fig. 37 or using a specified line in the vertical blanking interval which is kept free of picture information, provided the measuring instrument accurately integrates the measured noise over the full-field period. In all of the above measurements the band-limiting and weighting networks shown in Fig. 38 shall be inserted at the receiving end of the television facility prior to the noise measuring instrument.

The signal-to-weighted noise ratio in decibles can be computed using the following formula:

$$\text{Signal-to-weighted noise (dB)} = 20 \log_{10} \frac{\text{P-P signal amplitude}}{\text{RMS weighted noise}}$$

An example of random noise is shown in Fig. 39.

### Performance Objective:

The signal-to-random noise ratio shall be greater than or equal to 53 dB.

*NOTE:* Appendix II describes a technique for approximating weighted video random noie.

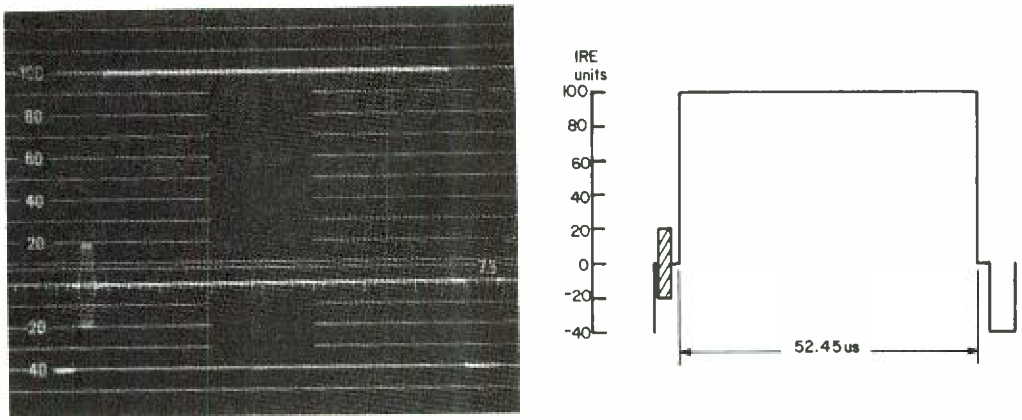


Fig. 37. The 100% flat-field test signal.

## Generator Output Specifications

| | | |
|---|---|---|
| Time of rise and fall | : | derived from the shaping network of the sine-squared pulse. |
| Amplitude | : | 100 ± 1 IRE unit. |
| Tilt | : | less than 1 IRE unit. |
| Time of bar duration | : | nominally 52.45 microseconds. |

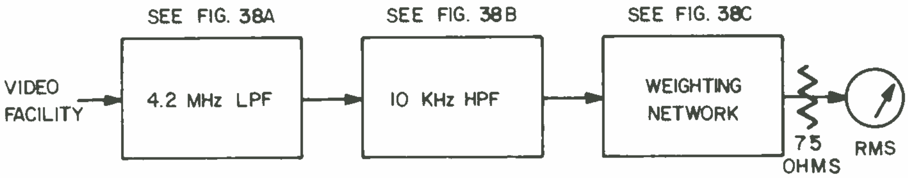


Fig. 38 Band limiting and weighting network for measurement of random noise—weighted.

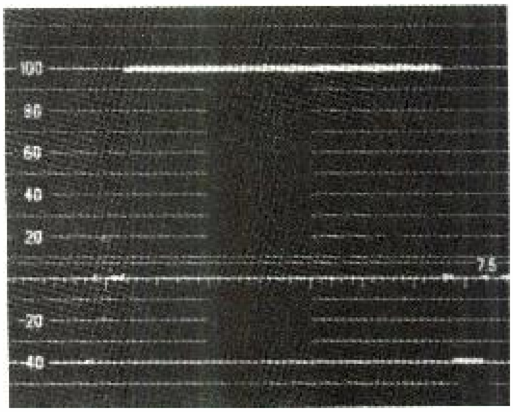
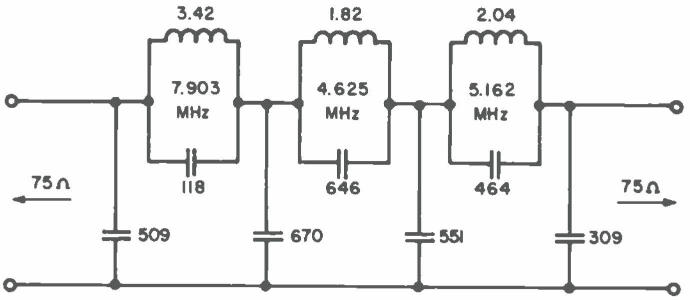
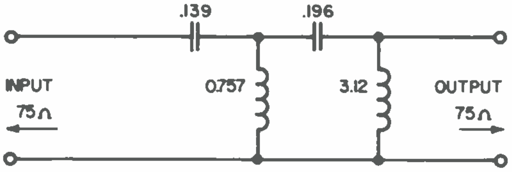


Fig. 39. An example of random noise.



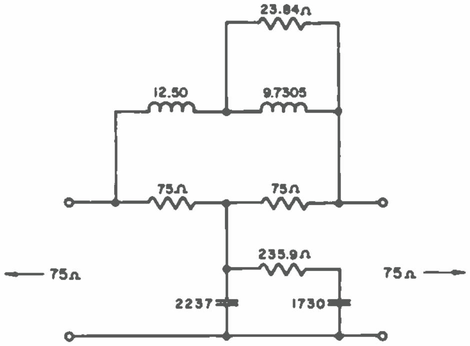
Inductances are given in uH, and capacitances in pF. Q measured at 5 MHz is between 80 and 125 for all inductors.

Fig. 38A. Low-pass filter for use in noise measurements ($f_c$ = 4.2 MHz).



Inductances are given in MH, capacitances in pF. Q measured at 10 kHz should be 100 or more.

Fig. 38B. High-pass Filter ($f_c$ = 10 kHz).



Capacitances are given in pF, inductances in uH.
Capacitor and resistor tolerance ± 1%.

$$\text{Insertion loss (dB)} = 10 \log_{10} \frac{[1+(f/f_1)^2][1+(f/f_2)^2]}{[1+(f/f_3)^2]},$$

where $f_1$ = 0.270 MHz, $f_2$ = 1.37 MHz, and $f_3$ = 0.390 MHz.

Fig. 38C. Random noise weighting network.

## 3.17 IMPULSIVE NOISE

### Definition:

The signal-to-impulsive noise ratio of a television facility is defined as the ratio, expressed in decibels, of the nominal amplitude of the *luminance* signal (100 IRE units) to the peak-to-peak amplitude of the noise.

### Measurement:

The flat-field test signal shown in Fig. 37 is used when measuring impulsive noise. The test signal's amplitude must be accurately adjusted to 100 IRE units at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the test signal's amplitude should be adjusted to be exactly 100 IRE units at the receiving end and the waveform display then examined closely to determine if impulsive noise interference (occasional random spikes or transients) is present. The peak-to-peak amplitude of the interference is then measured, in IRE units, and recorded. To compute the signal-to-impulsive noise ratio in decibels, the following formula can be used:

Signal-to-impulsive noise (dB) =

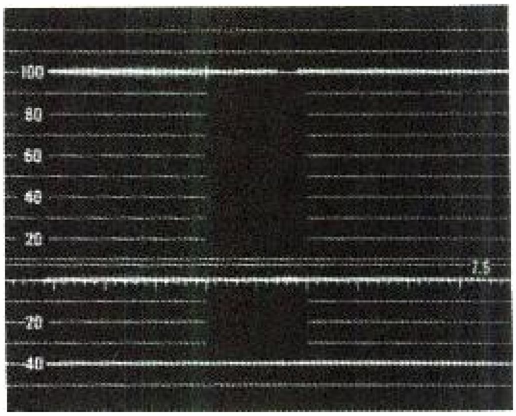
$$20 \log_{10} \frac{\text{100 IRE units}}{\text{peak-to-peak amplitude of impulsive noise}}$$

Alternatively, the actual peak-to-peak amplitude of the impulsive noise, in IRE units, can be used directly to determine if the television facility meets the performance objective stated below.

An example of impulsive noise interference is shown in Fig. 40.

### Performance Objective:

The impulsive noise shall be no greater than 7 IRE units peak-to-peak which equals a signal-to-impulsive noise ratio of no greater than 23 dB. The frequency of occurrence of noise impulses shall not exceed one per minute.



Impulsive noise is 12 IRE units peak-to-peak.

Fig. 40. An example of impulsive noise interference.

## 3.18 PERIODIC NOISE

**Definition:**

The signal-to-periodic noise ratio is defined as the ratio in decibels of the nominal amplitude of the *luminance* signal (100 IRE units) to the peak-to-peak amplitude of the noise. Different performance objectives are sometimes specified for periodic noise (single frequency) between 1 kHz and the upper limit of the video frequency band and for power supply hum, including low-order harmonics.

**Measurement:**

The flat-field test signal shown in Fig. 37 is used when measuring periodic noise. The test signal's amplitude must be accurately adjusted to 100 IRE units at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the test signal's amplitude should be adjusted to be exactly 100 IRE units at the receiving end and the waveform display then examined to determine if periodic noise interference is present. The peak-to-peak amplitude, in IRE units, of periodic noise which is low-frequency in nature (power-supply hum, etc.) should be measured and recorded separately from the periodic noise in the nominal frequency range 1 kHz to 4.2. MHz.* Examples of periodic noise interference are shown in Figs. 41 and 42. To compute the signal-to-periodic noise ratio in decibels the following formula can be used:

Signal-to-periodic noise (dB) =

$$20 \log_{10} \frac{\text{100 IRE units}}{\text{peak-to-peak amplitude of periodic noise}}$$

**Performance Objective:**

The signal-to-periodic noise ratio,

a. below 1 kHz (including power-supply hum and lower order harmonics) shall be greater than or equal to 50 dB.

b. between 1 kHz and 4.2 MHz** shall be greater than or equal to 50 dB.

*NOTE:* In specific instances where an exact measurement must be made, a spectrum analyzer or a frequency-selective voltmeter should be used. As these devices are normally RMS reading instruments, 9 dB should be substracted from the performance objective (to convert from peak-to-peak noise to RMS noise).

---

*It may be necessary to use the high-gain setting on the waveform monitor when making this measurement. If so, care should be taken to ensure that it is properly calibrated.

**The low-pass filter network shown in Figure 38A should be used when measuring periodic noise interference in the range 1 kHz to 4.2 MHz.

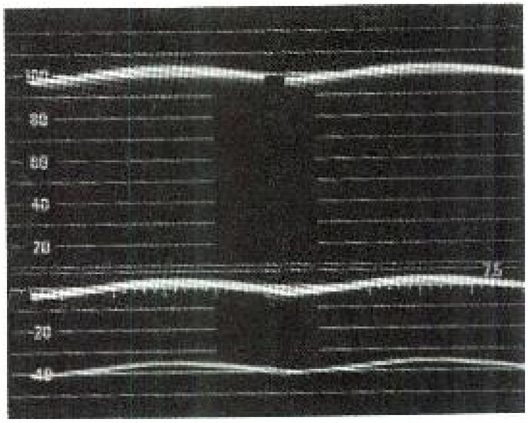


Fig. 41. Example of below 1 kHz (i.e., 60 Hz.) periodic noise—field rate display.

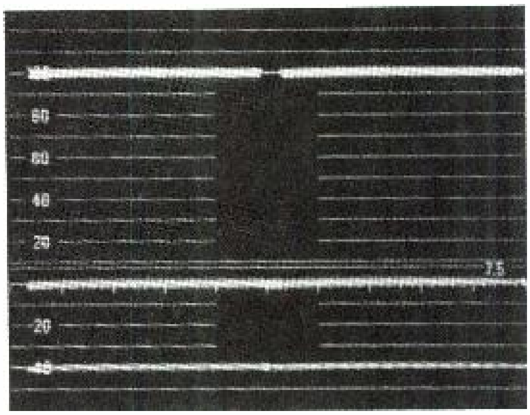


Fig. 42. An example of above 1 kHz (i.e., 5 kHz) periodic noise—field rate display.

## 3.19 CROSSTALK NOISE

### Definition:

The signal-to-crosstalk ratio is defined as the ratio, in decibels, of the nominal amplitude of the *luminance* signal (100 IRE units) to the peak-to-peak amplitude of the interfering waveform.

### Measurement:

The flat-field test signal shown in Fig. 37 is used when measuring crosstalk. The test signal's amplitude must be accurately adjusted to 100 IRE units at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

Following the above, the test signal's amplitude should be adjusted to be exactly 100 IRE units at the receiving end. The waveform display and a suitable broadcast-quality picture monitor can then be examined to determine if crosstalk interference is present. The peak-to-peak amplitude of the interfering waveform is then measured, in IRE units, and recorded.*

To compute the signal-to-crosstalk ratio in decibles the following formula can be used:

Signal-to-crosstalk (dB) =

$$20 \log_{10} \frac{\text{100 IRE units}}{\text{peak-to-peak amplitude of crosstalk}}$$

### Performance Objective:

The signal-to-crosstalk ratio shall be greater than or equal to 60 dB.**

---

*It may be necessary to use the high gain setting on the waveform monitor when making this measurement. If so, care should be taken to ensure that it is properly calibrated.

**The low-pass filter network shown in Figure 38A should be used when measuring crosstalk noise interference.

# Section 4: Interconnection Requirements

## INTRODUCTION

This section defines the accepted standard interconnection requirements that both the Bell System and the major television networks must comply with at their common interface points. Deviations from these requirements are permitted only if mutually agreed upon prior to the provision and acceptance of the service.

## IMPEDANCE

At the points of interconnection between the customer and the telephone company, the input and output impedance ($Z_0$), of each link shall be specified as unbalanced to ground.

### Performance Objective:

Nominally 75 ohms resistive, unbalanced to ground.

## SIGNAL AMPLITUDE

The nominal video signal amplitude shall be 1.0 volt peak-to-peak (140 IRE units).

## SIGNAL POLARITY

The polarity of the signal shall be "positive," i.e., such that black-to-white transitions are positive going.

## NON-USEFUL DC COMPONENT

The non-useful dc component present across the interface point with or without the load impedance connected shall be zero ±50mv. (Non-useful dc component is that which is produced by the transmission equipment and is not related to picture content.)

## RETURN LOSS

### Definition:

The return loss , relative to $Z_o$, of an impedance Z, in the frequency domain is

$$20 \log_{10} \left| \frac{Z_o + Z(f)}{Z_o - Z(f)} \right| \text{dB}$$

and in the time domain

$$20 \log_{10} \left| \frac{A_1}{A_2} \right| \text{dB}$$

Where $A_1$ is the peak-to-peak amplitude of the incident signal and $A_2$ is the peak-to-peak amplitude of the reflected picture signal. Numerically, the result is the same as that obtained by the frequency domain method if the return loss is independent of frequency.

### Performance Objective:

Greater than 30 dB from 0 to 4.2 MHz at the point of interconnection.

# Section 5: Processing Errors

## INTRODUCTION

This section describes two types of signal processing errors that can arise when a video signal is fed through a processing amplifier that has been incorrectly adjusted. It should be noted that while it is not the practice of the Bell System to use processing amplifiers in the provision of television facilities and therefore processing errors will not arise on these facilities, these errors can and do significantly affect the technical quality of color television transmission. Accordingly, it was felt that the two most commonly encountered processing errors should be included in this document.

## 5.1 RELATIVE BURST GAIN ERROR

### Definition:

Relative burst gain error is defined as the change in gain (amplitude) of the color burst signal relative to the gain (amplitude) of the chrominance subcarrier, in the active line time, caused by processing the video signal.

### Measurement:

The 5-riser modulated staircase signal shown in Fig. 30 is used when measuring relative burst gain error. The test signal's amplitude must be accurately adjusted prior to the commencement of the test. Similarly, the waveform monitor to be used for the measurement should be properly calibrated.

Following the above, the test signal is fed to the processing amplifier input and the output of the processing amplifier is fed to the waveform monitor via a high-pass filter network.* The gain of the waveform monitor is then adjusted until the blanking level burst of the 5-riser staircase signal is exactly 40 IRE units. The amplitude of color burst is then measured and recorded.

### Performance Objective:

The amplitude of the color burst shall be 40 ± 1 IRE units with respect to the amplitude of the blanking level burst of the 5-riser modulated staircase.

## 5.2 RELATIVE BURST PHASE ERROR

### Definition:

Relative burst phase error is defined as the change in phase of the color burst signal relative to the phase of the chrominance subcarrier, in the active line time, caused by processing the video signal.

### Measurement:

The 5-riser modulated staircase signal shown in Fig. 30 is used when measuring relative burst phase error. The test signal's amplitude and phase must be accurately adjusted prior to the commencement of the test. Similarly, the phase comparator (e.g., vectorscope) to be used for the measurement should be properly calibrated.

Following the above, the test signal is fed to the processing amplifier input and the output of the processing amplifier is fed to the phase comparator. The phase of the color burst signal is then measured relative to the phase of the blanking level chrominance burst of the 5-riser staircase signal and recorded.

### Peformance Objective:

The relative phase of the color burst signal shall be zero ± 1° with respect to the phase of the blanking level burst of the 5-riser modulated staircase.

---

*The high pass filter network incorporated into most television waveform monitors is sufficient for this purpose.

# Section 6: Performance Characteristics of the Audio Signal Channel

The following is from EIA RS-250-B*, for single channel audio. NTC-7 does not cover audio transmission.

## 6.1 AMPLITUDE VS. FREQUENCY RESPONSE

### Definition:

The audio amplitude versus frequency characteristic of a television relay system is an expression of amplitude variation as a function of audio frequency of a sine-wave voltage when applied to the system audio input and measured at the system audio output. The amplitude variation is expressed in decibels.

### Standard:

The audio amplitude versus frequency characteristic shall be within the applicable limits specified in Figure 43. This standard applies equally to short haul, medium haul, satellite, long haul, and end-to-end performance on the assumption that audio will be demodulated from its subcarrier only once in any system or interconnection.

### Method of Measurement:

The measuring equipment shall terminate the output of the audio channel under test in a standard load impedance. The grounded or balanced-to-ground connection normally used shall be maintained. Standard test tone of 1000 Hz shall be applied to the input of the system and rated modulation shall be established. The output level control shall be set to deliver standard output. If no preemphasis and no deemphasis are used, the response shall be measured under the above conditions while maintaining constant input to the system and measuring output variations. If preemphasis and deemphasis are used, after adjusting the circuit as described above, the input to the system shall be decreased approximately 20 dB, and maintained at this level during the complete frequency response measurement. The output level control shall not be reset. This requirement is necessary to prevent overload of the audio system at the higher audio frequencies due to the "boost" provided by the preemphasis network.

## 6.2 HARMONIC DISTORTION

### Definition:

Audio frequency harmonic distortion is the production of harmonic frequencies at the output of the system caused by nonlinearities, when a non-distorted sinusoidal voltage is applied to the input of the system.

### Standard:

The harmonic distortion of the audio frequency signal, including all harmonics up to 30 kHz, shall not exceed the values given in the following table.

| Frequency Range | Limit Distortion in % |
|---|---|
| 50-15,000 Hz | 1.0 |

This standard applies equally to short haul, medium haul, satellite, long haul and end-to-end performance on the assumption that audio will be demodulated from its subcarrier only once in any system or interconnection.

### Method of Measurement:

The audio channel shall be operated at standard input and output test tone level and the measuring equipment shall terminate the circuit in a standard load impedance. A test tone of 1000 Hz, having less than 0.1% RMS harmonic distortion, shall be applied to the audio input of the system and rated maximum modulation established. If no preemphasis and no deemphasis are employed, distortion shall be measured at this level, with readings taken on as many frequencies as necessary to ensure compliance. If preemphasis and deemphasis are employed, the input level to the system shall be adjusted at each measurement to operate the system at rated maximum modulation. This will require dropping the input voltage level with increasing frequency as many dB as the preemphasis curve rises. The input and output level controls shall not be readjusted during this procedure.

## 6.3 SIGNAL-TO-NOISE RATIO

### Definiton:

The audio signal-to-noise ratio of the system is the ratio of RMS standard test tone voltage

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to the RMS noise voltage at the system output terminals. Noise is any extraneous output voltage in the frequency band from 50 Hz to 15 kHz.

### Standard:

The signal-to-noise ratio for the systems listed shall be at least:

| | |
|---|---|
| Short Haul | 66 dB |
| Medium Haul | 65 dB |
| Satellite | 58 dB |
| Long Haul | 57 dB |
| End-to-End | 56 dB |

### Method of Measurement:

The system shall be operated at standard input and output test tone levels, and the measuring equipment shall terminate the system in a standard load impedance. A test tone of 1000 Hz shall be applied to the audio input of the system and rated maximum modulation established. The system output shall be measured with an RMS indicator. The test tone shall then be removed, the system input terminated with a standard impedance, and the noise output of the system measured with the RMS indicator.

NOTE

Should the system utilize circuits that are common to the audio and video signals, the audio signal-to-noise measurements shall be made in the presence of a standard composite picture under standard input and output conditions. The staircase signal of Figure 9, shall be used for this purpose at 50% APL.

## 6.4 INSERTION GAIN

### Definition:

The audio signal insertion gain of a relay system is the ratio in dB of the output signal level with respect to the input signal level.

### Standard:

The preferred standard of insertion gain is 0 dB ±0.5 dB. In order to accommodate the input level and output level*, equipment may have input and output level adjustment capability to allow insertion gains of up to ±18 dB.

### Method of Measurement:

The audio signal input and output levels shall be measured as described below* and the difference expressed in dB. Generally accepted audio measuring equipment, shall be used.

## 6.5 CONTINUITY OF AUDIO SERVICE

### Definition:

The performance tolerances designed into a television relay system as detailed in this standard are not only system objectives describing the initial performance of such a system but also describe the performance of that system with time to the extent indicated in the standards that follow.

### Standards:

a) The objective for continuity of audio service is 99.99% of the annual operating time.

b) The continuity of audio service will be deemed as interrupted if one or more of the following conditions exist:

  (1) There is a total loss of the desired audio signal.

---

### *INPUT SIGNAL LEVEL

**Definition:** The audio signal level is the test tone level which produces rated maximum modulation of the audio signal channel at test tone frequency. It is expressed in dBm.

NOTE

Nominal program transmission level should be at least 10 dB and preferably as much as 18 dB below test tone level.

**Standard:** The audio test tone input level for rated maximum modulation shall be in the range from 0 dB to + 18 dBm. The frequency of the test tone signal shall be 1000 Hz.

**Method of Measurement:** The audio input level shall be measured directly across the audio input terminals of the relay system. Generally accepted audio measuring equipment shall be used.

### OUTPUT SIGNAL LEVEL

**Definition:** The audio output signal level is the test tone level which results from rated maximum modulation of the audio signal channel at the test tone frequency. It is expressed in dBm.

NOTE

Nominal program transmission level should be at least 10 dB and preferably as much as 18 dB below test tone level.

**Standard:** The audio test tone output level for rated maximum modulation shall be in the range from 0 dBm to + 18 dBm. The frequency of the test tone shall be 1000 Hz.

**Method of Measurement:** The audio output level shall be measured directly across the audio output terminals of the relay system. Generally accepted audio measuring equipment shall be used.

(2) The signal-to-noise ratio is less than 25 dB.

(3) The performance standards are exceeded to the extent that the audio signal is not usable.

## Method of Measurement:

Parameters of paragraph b. provide guidelines for the calculation of system statistical performance. Methods of measurement for real systems cannot be readily established at this time.

## 6.6 AUDIO-VIDEO TIME DIFFERENTIAL

### Definition:

Audio-video time differential is the departure from equality in the transmission time of associated audio and video signals. It is usually exhibited as a delay of the audio signal with respect to the video signal.

### Standard:

The time differential between the audio signal with respect to its associated video signal shall not exceed 25 ms lead or 40 ms lag for all systems.

REF: CMTT Report 412-1 (Geneva 1974)

### Method of Measurement:

The system shall be operated at standard input and output levels of both audio and video signals and terminated in standard load impedances. The measurement shall be made with a storage oscilloscope with a dual trace amplifier. Provisions shall be made at the system input to simultaneously initiate or interrupt the audio and video signals. The time differential is read on the oscilloscope display at the system output.

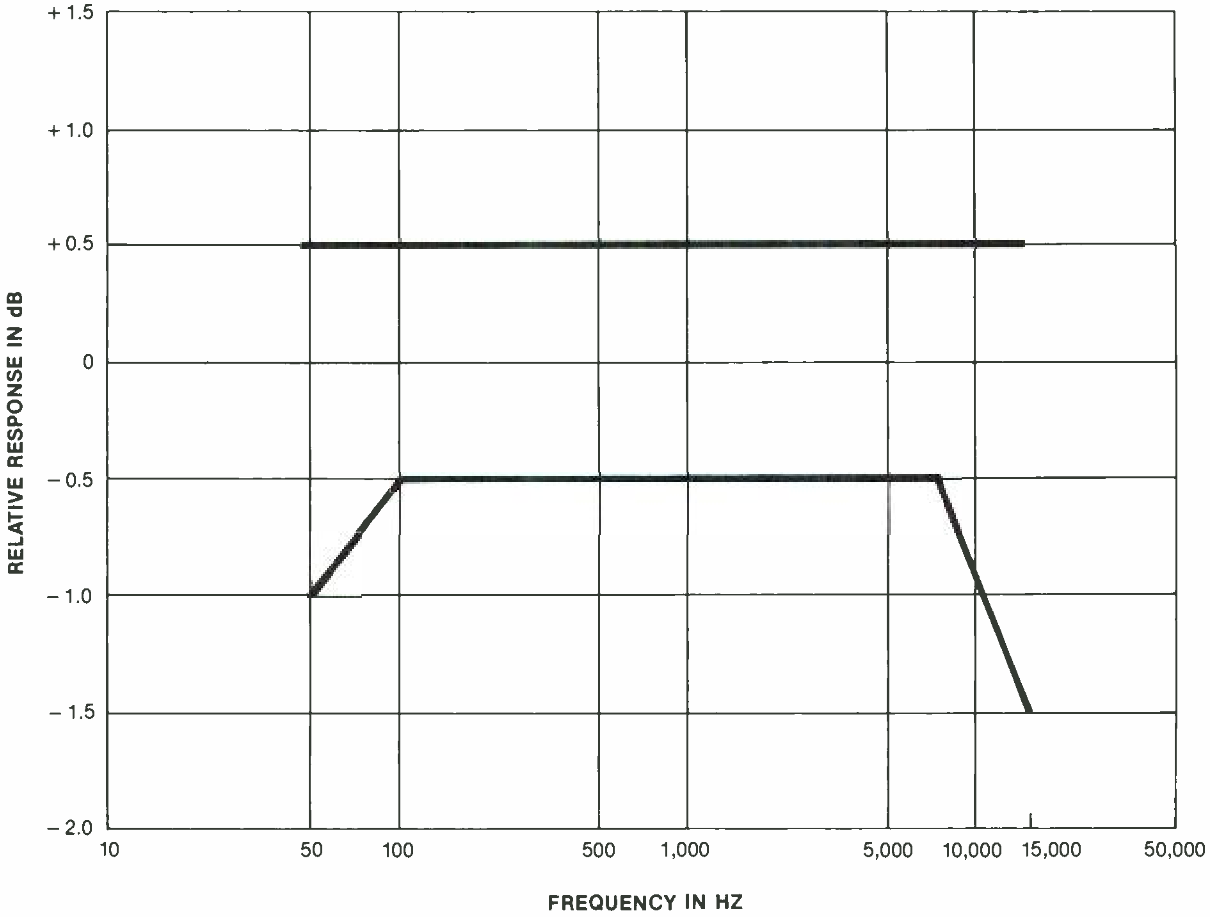


Fig. 43. Audio amplitude vs. frequency response.

# Appendix I. Example of a Weekly VITS Log

## WEEKLY VITS LOG

WEEK BEGINNING SUNDAY ________

STATION ________________ LOCATION ________________

| PARAMETER | SIGNAL | LIMIT | SUN | MON | TUES | WED | THUR | FRI | SAT |
|---|---|---|---|---|---|---|---|---|---|
| INSERTION GAIN (See Sec. 3.2) | BAR | ±3 IRE | | | | | | | |
| LINE TIME DISTORTION (See Sec. 3.4) | BAR | 4 IRE PK-PK | | | | | | | |
| SHORT TIME DISTORTION (See Sec. 3.5) | 2T | ±6 IRE P/B | | | | | | | |
| | BAR EDGE | 10 IRE PK-PK | | | | | | | |
| CHROMA-LUMINANCE GAIN INEQUALITY (See Sec. 3.6) | CHROMA PULSE | 100 ±3 IRE | | | | | | | |
| CHROMA-LUMINANCE DELAY INEQUALITY (See Sec. 3.7) | CHROMA PULSE | (CHROMA) 75nSec ADV or DLY | | | | | | | |
| GAIN-FREQUENCY (See Sec. 3.8) | MULTI-BURST | 45-53 IRE<br>0.5 | | | | | | | |
| | | 1.0 | | | | | | | |
| | | 2.0 | | | | | | | |
| | | 3.0 | | | | | | | |
| | | 3.58 | | | | | | | |
| | | 4.2 | | | | | | | |
| DIFFERENTIAL GAIN (See Sec. 3.13) | STAIR-CASE | 15 % | | | | | | | |
| DIFFERENTIAL PHASE (See Sec. 3.14) | STAIR-CASE | 5° | | | | | | | |
| CHROMA NON-LINEAR GAIN DISTORTION (See Sec. 3.10) | 3 LEVEL CHROMA | 40 REF:<br>20±2 IRE<br>80±8 IRE | | | | | | | |
| CHROMA NON-LINEAR PHASE DISTORTION (See Sec. 3.11) | 3 LEVEL CHROMA | 5° | | | | | | | |
| CHROMA-LUMINANCE INTERMODULATION (See Sec. 3.15) | 3 LEVEL CHROMA | 3 IRE | | | | | | | |
| RANDOM NOISE (See Appendix II) | "GRASS" ESTI-MATE | 53dB | | | | | | | |

NOTES: OBSERVATIONS TO BE MADE AHEAD OF ANY STATION EQUIPMENT.

THESE NETWORK TRANSMISSION OBSERVATIONS SHOULD BE SUPPLEMENTED, AS APPROPRIATE, BY OBSERVATIONS OR MEASUREMENTS OF THE OTHER PARAMETERS COVERED IN NTC REPORT NO. 7.

SECTION NO. UNDER PARAMETER REFERS TO APPROPRIATE SECTION OF NTC REPORT NO. 7.

# Appendix II.

## TECHNIQUE FOR APPROXIMATING WEIGHTED VIDEO RANDOM NOISE

When an RMS reading noise meter is not available, an alternate method of determining video S/N should be used. The one suggested here is accurate to within 2 dB if care is taken in setting scope brightness and operator estimation of the peak-to-peak noise is done in a consistent manner.

This procedure uses the low-pass filter and video weighting networks shown in Fig. 38A and 38C, respectively, of Sect. 3.16. Place these two networks in tandem between the video facility and the waveform monitor. After noting the amplitude of the line bar (for VITS) or the 100% flat field (for a full-field test) place the waveform monitor vertical gain to the 0.2 volt range* and estimate the quasi peak-to-peak** amplitude of the grass at blanking level. Transfer this reading to the S/N nomograph and determine the weighted video S/N ratio.

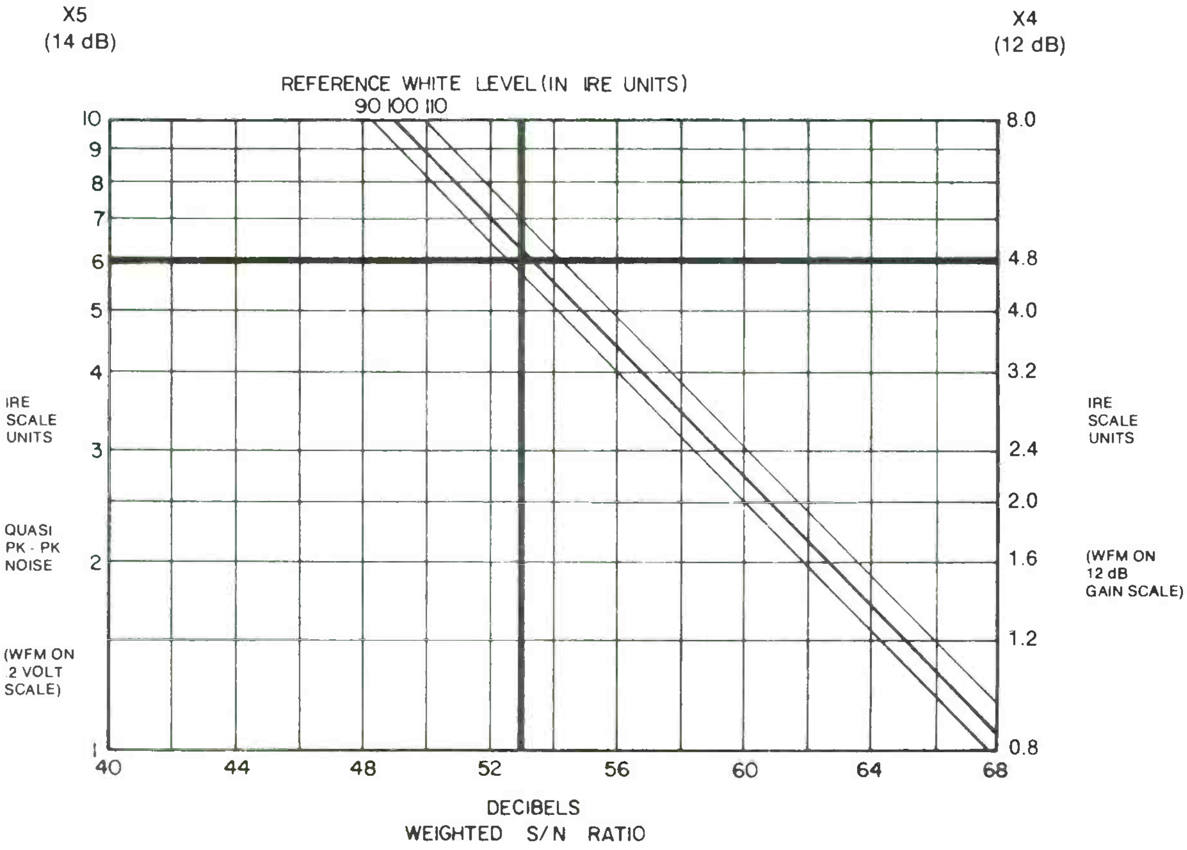
The objective is 53 dB or greater as shown by the heavy line.

---

*14 dB gain.

**Quasi peak-to-peak is the average level ignoring large occasional spikes of noise.

*NOTE:* The network of Fig. 38B, 10 kHz high-pass filter, is not needed as the line selector acts as a digital filter and cuts off frequencies below 15 kHz.



# STANDARDS AND SOURCES

ANSI/EIA Standard RS-250-B "Electrical Performance Standards for Television Relay Facilities" September 1976.

**For further information, contact:**

Electronic Industries Association
Engineering Department
2001 Eye Street, NW
Washington, DC 20006

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NTC Report No. 7 "Video Facility Testing Technical Performance Objectives"

**For further information, contact:**

Public Broadcasting Service
Engineering Services
475 L'Enfant Plaza, SW
Washington, DC 20024

The following four Technical References are from AT&T Communications.

"Commercial Television Transmission Specification" January 1984, 326-031, PUB 62600.

"Noncommercial Television Transmission Specification" January 1984, 326-032, PUB 62601.

"Premium-grade Program Audio Transmission Specification" January 1984, 326-033, PUB 62602.

"Standard-grade Program Audio Transmission Specification" January 1984, 326-034, PUB 62603.

**For further information, contact:**

Engineering Director
Network Capabilities Planning
AT&T Communications
295 North Maple Avenue
Basking Ridge, NJ 07920

# 4.2

# Microwave Engineering for the Broadcaster

J. C. Carroll
E. M. Hickin
D. J. McCarthy
*M/A-COM MAC, Inc.*
*Burlington, Massachusetts*

## INTRODUCTION

Microwave transmission has become increasingly important in the broadcast engineer's operation. The Studio-to-Transmitter Link (STL) has been the backbone of the industry for decades. Equipment design today allows for essentially transparent, full color video transmission, as well as subcarriers capable of full FM audio bandwidth and multiple voice and remote control functions.

The more recent development of Electronic News and Field Production— as well as Satellite Earth Stations (TVRO's) which require local back-haul, Satellite Studios and Regional News Networks—has demanded a continuous awareness on the part of the broadcast engineer.

In most cases, microwave equipment suppliers are prepared to support broadcast engineers in their design needs. Path profiling, surveying and predicting path performance, are services available from consultants and suppliers.

The following discussions are presented to aid broadcast engineers in their own understanding of this techonology.

## PATH PERFORMANCE

### Free Space Path Loss

Free space path loss for any electromagnetic wave arises from the spreading of the wavefront radiating from the source, like ripples on a pond after a stone has been thrown in. The loss increases by 6 dB (4:1 in power) every time the range doubles once outside the near field of the antenna. Since a 2:1 increase in range gives

$$4{:}1(2^2{:}1) \qquad [1]$$

reduction in power, this relationship is sometimes referred to as the inverse square law.

Free-space loss (i.e. the loss which is independent of ground or atmospheric effects) is given by:

$$L_{fs}(dB) = 36.6 + 20 \log F\ (MHz) + 20 \log D \text{ (miles)}$$
$$\text{or } 96.6 + 20 \log F\ (GHz) + 20 \log D \text{ (miles)}$$

This loss is expressed between isotropic antennas (a theoretical antenna which radiates equally in all directions). The gain ($G$) of a microwave antenna is then expressed in dBi (gain relative to isotropic). Below about 1000 MHz it is usual to express gain as dBd (gain relative to a dipole): OdBd = 2.2 dBi. Strictly the "gain" is the amount by which the directional properties of the

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*The authors gratefully acknowledge the assistance of Mrs. Rosemary MacKay in the preparation of this section.

antenna reduce the coupling loss (20 log $F$ in the above formula). Thus the ratio of received power to transmitted power between two antennas of gain $G$, $D$ miles apart will be:

$$+G_1 \ -36.6 \ -20 \log F \ - \ 20 \log D + G_2 = L_p$$

This number will be negative; the numerical value is referred to as "path loss".

If the antennas are 6-foot diameter parabolic type and $D$ is 30 miles then:

At 2 *GHz* + 28.6 − 132.2 + 28.6 = −75.0 *dB* path loss
7 *GHz* + 39.8 − 143.0 + 39.8 = −63.4 *dB* path loss
13 *GHz* + 45.1 − 148.4 + 45.1 = −58.2 dB path loss

If the antennas are 4-foot diameter parabolic type and $D$ is 10 miles then:

At 13 *GHz* + 41.7 − 138.9 + 41.7 = −55.5 *dB* path loss
18 *Ghz* + 44.4 − 141.7 + 44.4 = −52.9 *dB* path loss
23 *GHz* + 46.5 − 143.8 + 46.5 = −50.8 *dB* path loss

Fig. 1 shows path loss for free space and between pairs of antennas of various sizes for 2, 6.8, 13, and 23 GHz.

## Other Sources of Path Loss

As shown in Fig. 1 below, the free space loss is easily calculated, and antenna manufacturers issue slide rules from which the loss and antenna gains can be read.

However, atmospheric and other changes will cause the loss to vary from time to time and the effects must be considered when planning a system.

*Multipath* (i.e. signals arriving at the receiving antenna by reflections from water, hills, buildings or atmospheric discontinuities as well as by the direct path) can add to or cancel the signal causing an increase up to 6 dB or a decrease of more than 50 dB.

*Atmospheric bending* of the wavefront due to abnormal changes of temperature and/or humidity with height can cause loss of signal due to diversion from the desired direction. This effect is discussed below under "K factor".

*Rainfall*, and to a lesser extent snowfall, can attenuate the signal, an effect which increases markedly with increasing frequency.

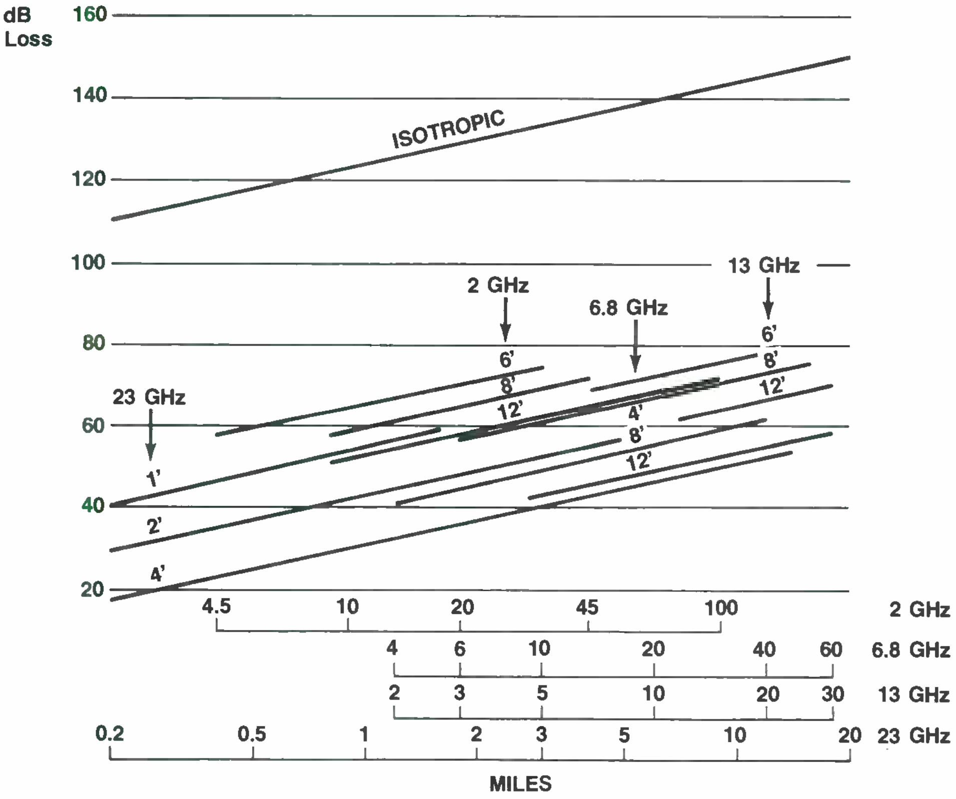


Fig. 1. Path loss versus distance between antennas of various sizes at 2, 6.8, 13 and 23 GHz.

To offset these effects a system is designed to have a more than adequate signal level at the receiver under free space loss conditions (which is the norm for at least 90% of the time). The excess of signal over the minimum required is called the fade margin. Typical fade margins are in the range 26 to 46 dB and ideally will be larger for higher frequencies, longer paths and over-water or similar difficult paths.

The choice of fade margins may involve compromises for example when existing towers of masts limit the size of the antenna. It should also be influenced by the environment, more being desirable in humid, flat country and less in dry mountainous areas.

## Outages

Outage time (time out of service due to propagation), or availability, equals 100x (1-outage) when the latter is expressed as a fraction of time, can be calculated from an accepted formula. This assumes the path has adequate clearance for the area, and is based on frequency, path length and two factors related to terrain roughness (the rougher the better as this breaks up the atmosphere) and humidity (the lower the better as moisture can cause discontinuities).

The formula, derived by Barnett and Vigants from the average of many Bell paths, is

$$a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \times 10^{-0.1F} \qquad [2]$$

$a$ = 4: for very smooth terrain, including over water
1: for average terrain with some roughness
0.25: for mountainous, very rough or very dry areas
$b$ = 0.5: Gulf Coast or similar low, humid areas
0.25: normal, interior, temperate or northern
0.125: mountainous or very dry
$f$ = frequency in *GHz*
$D$ = path length in miles
$F$ = fade margin to minimum acceptable point in *dB*

However, rainfall is not covered by this formula and can be more or less important depending on the area.

Figs. 2 and 3 show outage time in hours per year for 30 mile paths at 2 GHz and 20 mile paths at 13 GHz, in both Wyoming and Alabama (extremes of rainfall).

The vertical scale is fade margin, i.e. the amount by which the "free-space" receiver input signal exceeds the threshold or minimum acceptable input level.

A third figure (Fig. 4) shows (for the Wyoming case) how the performance varies with path length for various fade margins.

## K Factor

The pressure and hence the density of the atmosphere surrounding the earth varies with height, getting less as the height increases and the weight of air above decreases.

As a result, the dielectric constant also decreases with height and thus has a prismatic effect causing microwaves (and light waves) to bend towards the earth. Under normal conditions the bending is less than the curvature of the earth, but nonetheless the microwaves will go further than simple geometry would suggest. A convenient radius way in which to allow for this is to increase the effective radius of the earth until the microwaves appear to be travelling in straight lines.

The ratio of the effective to the true earth radius is called K and is approximately 4/3 or 1.33 for over 90% of the time in most parts of the world. However, there are times when K can be anything from infinity to as low as 0.45. K = infinity (flat earth) is a condition where mirages will be seen and radar echoes received from hundreds of miles away. It is an embarrassment as interference between systems is increased; fortunately, it is relatively rare.

K values between 1 and 0.5 can occur for a few percent of a year and it is necessary to design a link to take this into account if a reliable system is to be achieved. Within the USA a map showing contours of minimum K factor is available (Fig. 5) and should be consulted before settling on the necessary antenna heights.

## Clearance Requirements

Fig. 6 shows the way in which the microwave signal is attenuated when the path is close to an obstruction. Clearance is stated as a ratio of the first Fresnel zone, a function of frequency.

First Fresnel zone (feet) is given by:

$$FZC = 2280\sqrt{\frac{d.(D-d.)}{FD}} \qquad [3]$$

Where:
$F$ = frequency (MHz)
$D$ = path length (miles)
$d.$ = distance of obstruction from either end of path (miles)

From Fig. 6 it will be seen that the attenuation with a clearance 0.6 FZC is equal to the free space attenuation. However, as noted in the figure above, K factor variation will mean that more clearance must be built in to allow for values less than 4/3, and a typical design parameter is to plan for 0.3 FZC for the lowest K value expected on the path (taken from Fig. 5). While such a

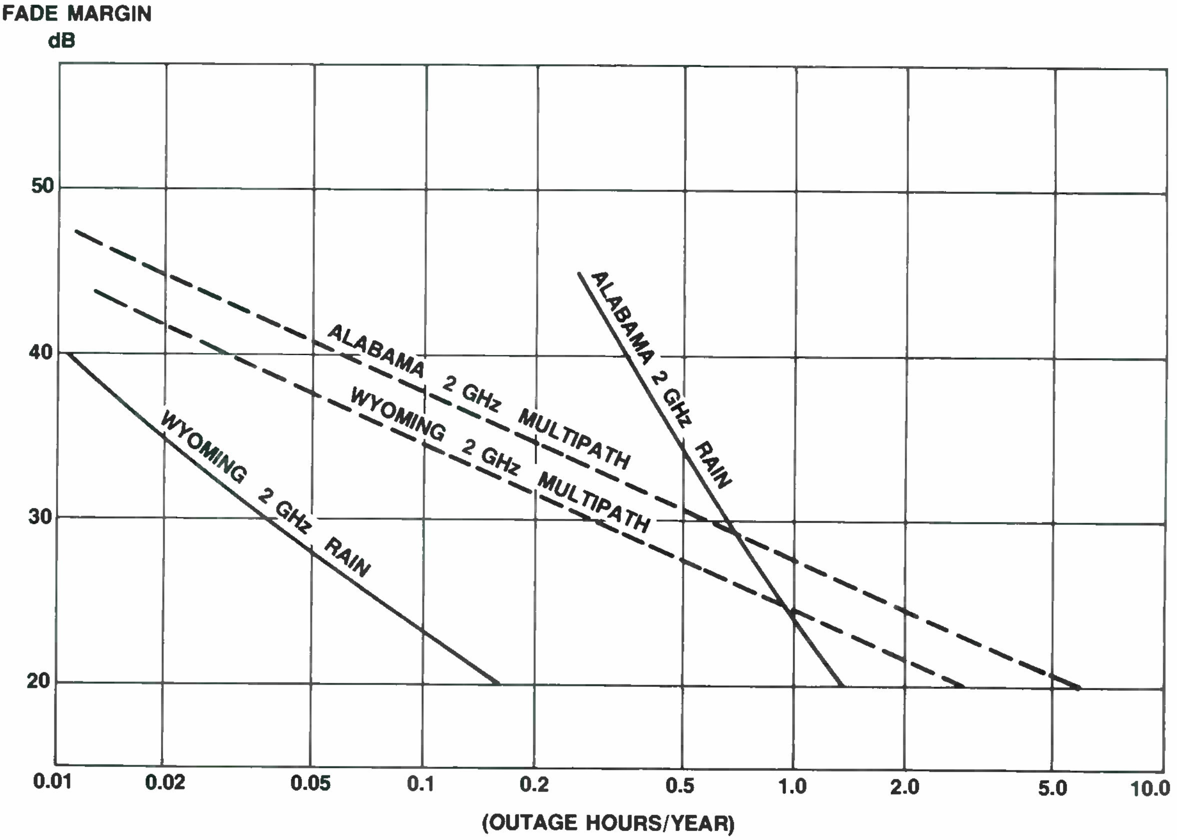


Fig. 2. Outage time in hours for differing fade margins on 2GHz, 30 mile path in Wyoming and Alabama.

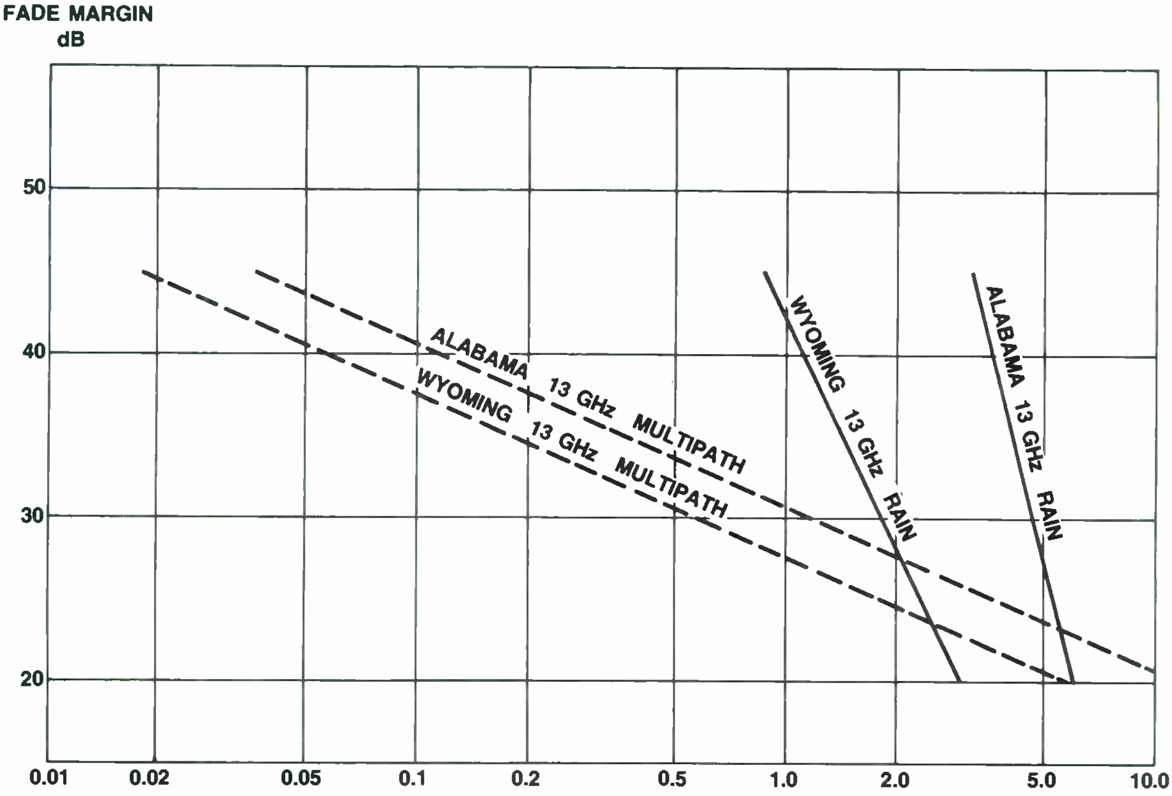


Fig. 3. Outage time in hours for differing fade margins on 13GHz, 20 mile path in Wyoming and Alabama.

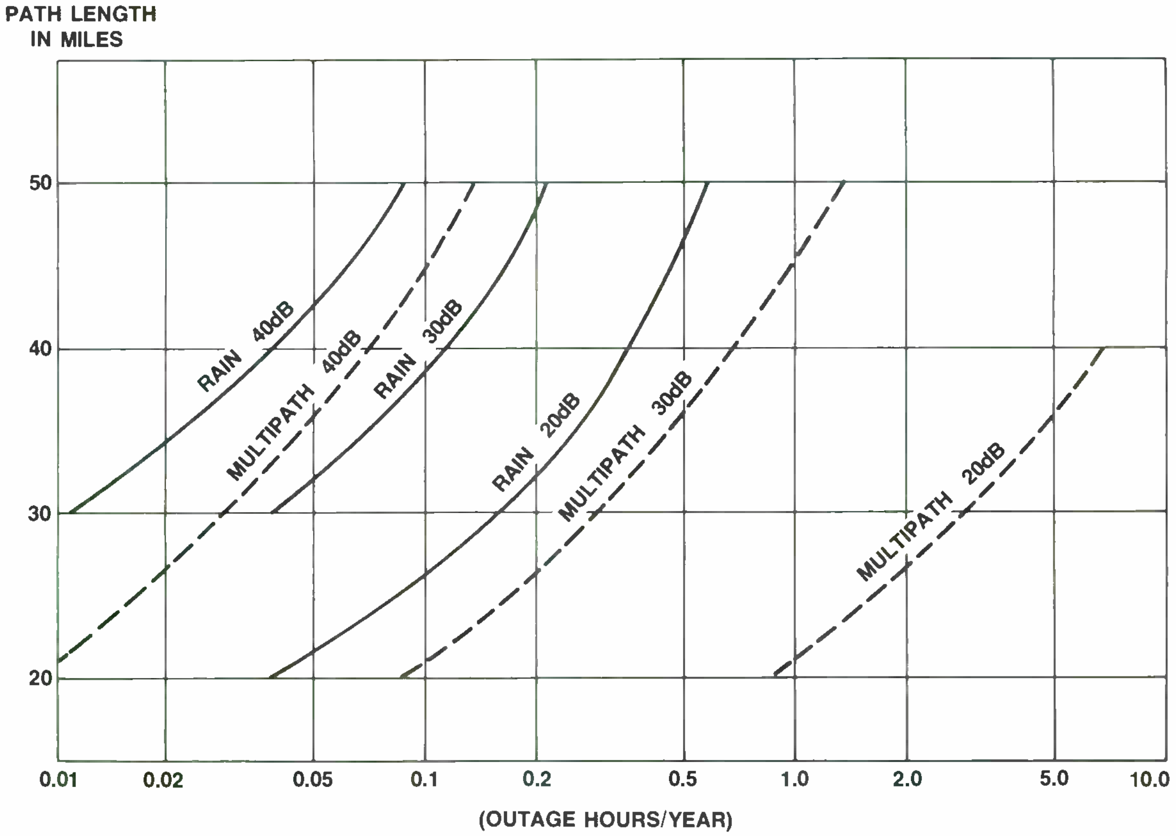


Fig. 4. Outage time in hours as a function of path length and fade margin for 2 GHz path in Wyoming.

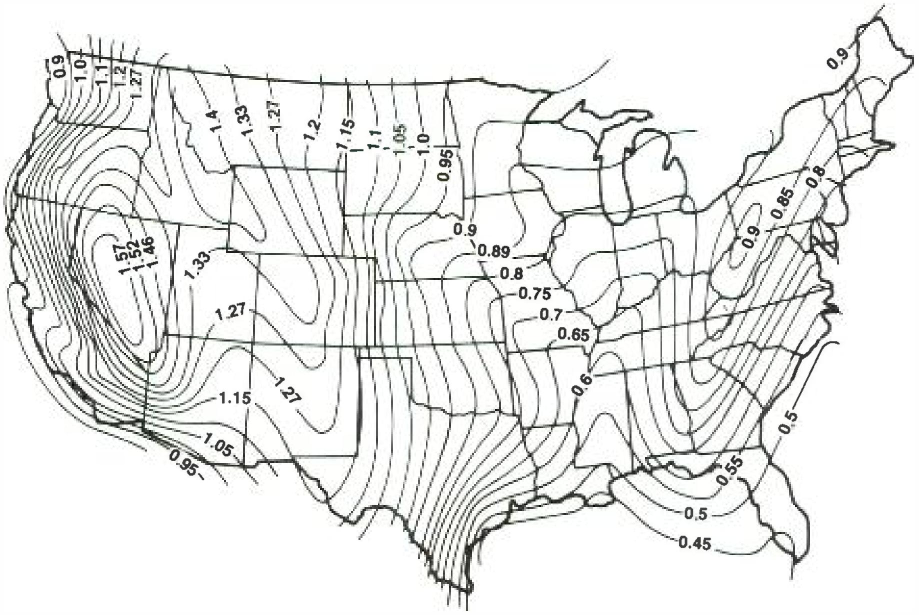


Fig. 5. Estimated minimum K-factor for the Continental United States.

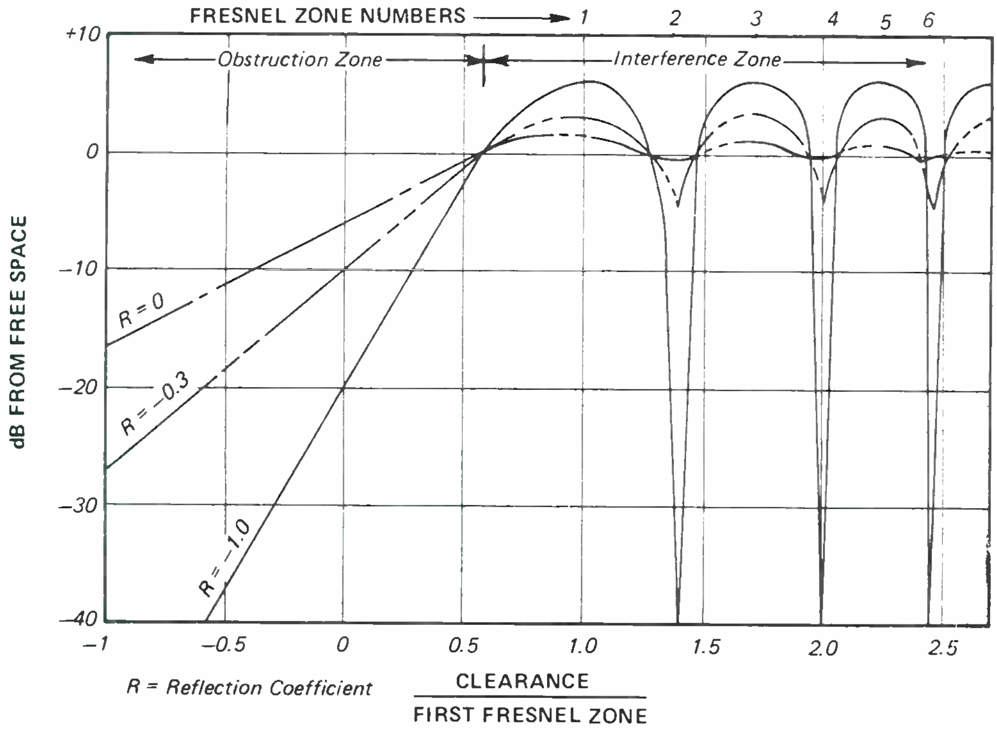


**Fig. 6. Behavior of attenuation vs. path clearance for various types of obstruction.**

clearance will introduce 2 to 8 dB of loss, this is well within the fade margin of a well-designed link.

### Path Profiles

Sites for microwave link terminals are likely to be studios, earth stations or TV transmitters, all of which are pre-determined. Choice of sites for repeaters, if they are necessary, may be constrained by availability and access.

To see if any combination of sites is viable, and to determine the antenna heights at each end of the chosen path, will require the plotting of a profile.

The profile, a plot of ground height against distance, can be drawn on simple squared or special K factor paper (usually K = 4/3). Squared paper has the advantage that any convenient scales can be used for $x$ and $y$ axes; 4/3 paper has the advantage that potential obstructions are more obvious and the effect of path length on necessary clearance stands out. Whichever paper is used, the next step after plotting the profile is to add an allowance to high points for trees on buildings. Then the effect of low values of K must be added to any potential obstruction point, using the following formulae:

a) If using squared paper:

To each obstruction point add

1) $0.6\ FZC + d(D - d.)/2 + T$
2) $0.3\ FZC + d(D - d.)3K/2 + T$

*Where:*

$T$ is height of trees or buildings in feet.

or

b) if using 4/3 paper:

1) $0.6\ FZC + T$
2) $0.3\ FZC + d(D - d)\,3K/4 + T$

Then a straight line clearing the upper values at each point will pass through the terminals at the minimum antenna height for adequate clearance. If most obstructions are near one end of the path, it may be more economic to raise the antenna at that end and save more height at the other end.

Figs. 7 and 8 show an example of the same profile plotted on rectangular and 4/3 paper and the final selection of antenna height; the worst-condition K factor assumed was 2/3 (−2 on each profile at the main obstruction point at 8 miles).

## ANTENNA AND WAVEGUIDE CONSIDERATIONS

### Antenna Systems

Several different types of antenna are used in a TV microwave system. Omnidirectional vertical and directional horizontal stacked arrays are used for portable and vehicular applications. Parabolic

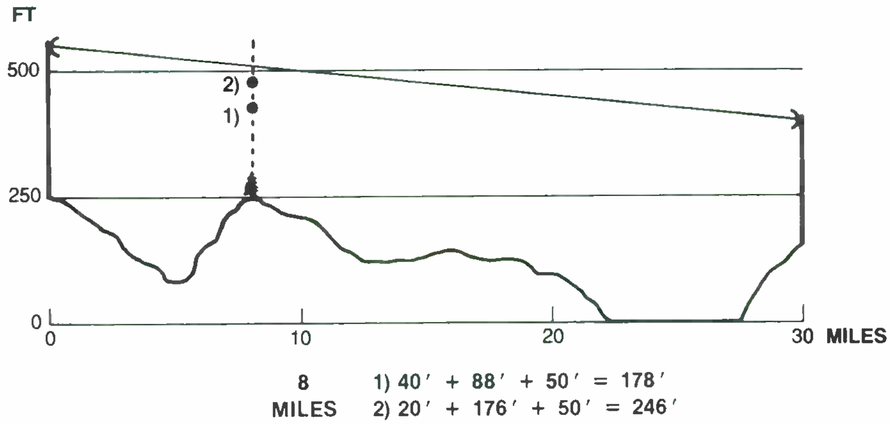


Fig. 7. Example of profile plotted on squared paper, with required clearances for (1) 0.6 × first Fresnel Zone when K = 4/3 and (2) 0.3 × first Fresnel Zone when K = 2/3 (50 foot tree allowance).

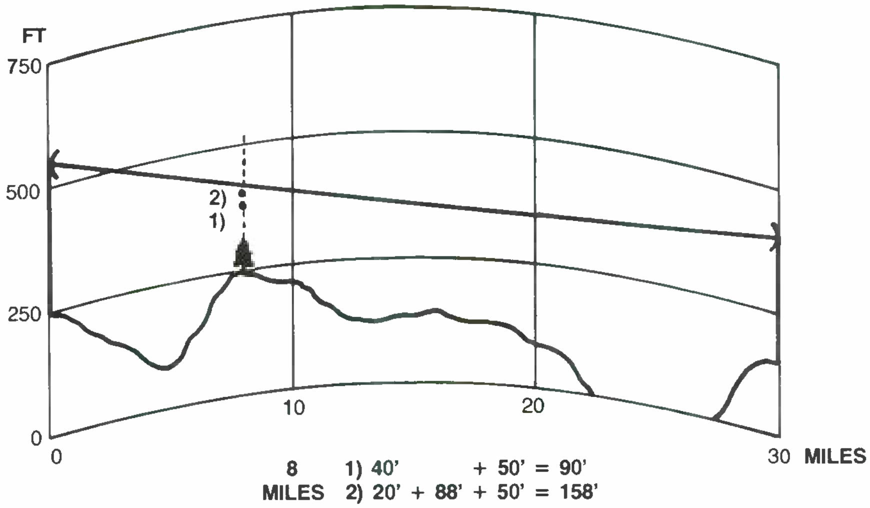


Fig. 8. Example of the profile of Fig. 7. plotted on K = 4/3 paper: (1) and (2) marked as on that figure.

reflector antennas are used for STL, intercity, ETV, and CARS systems. Corner reflectors and modified parabolas are sometimes used for 950 MHz STLs. Horn or shrouded parabolic antennas may be used for high front-to-back isolation ratios. Simple dipoles are often used for back pack and wireless microphone equipment. Selection of the antenna is usually based upon the application and the antennas available. The reader is referred to EIA Standard RS 195A for mechanical and electrical specifications.

### *Isotropic*

As noted above, the isotropic antenna is a hypothetical antenna used as a reference against which the gain of other microwave antennas is measured. The term dBi denotes gain over an isotropic antenna. The isotropic antenna by definition has a radiation pattern which is a perfect sphere. The power density per unit area at a point in space due to the power PT radiated by an isotropic antenna is

$$P = \frac{P_T}{4 \pi d^2} \qquad [4]$$

Where: $d$ = Distance from radiator.
$4 \pi d^2$ = Surface area of a sphere with radius $d$.

By definition, the effective area of an isotropic antenna is $\lambda^2/4\pi$ and the power received $P_i$ is Equation 4 times the isotropic area, or

$$P_i = \frac{P_T \lambda^2}{(4\pi)^2\, d^2} \qquad [5]$$

Where:

$\lambda$ = wavelength

### *Other Antennas*

For other antennas of effective area $A$, the power received $P_R$ is from Equation 4,

$$P_R = \frac{P_T\, A_{ef}}{4\, \pi\, d^2} \qquad [6]$$

The gain of an antenna is defined as the ration of its radiated or received power to that of an isotropic antenna. The ratio of Equation 6 to Equation 5 gives the gain ($G$) as,

$$G = \frac{4\, \pi\, A_{ef}}{\lambda^2} \qquad [7]$$

Where:

$A$ and $\lambda$ are in same units of measurement.

$$G = 12.77\, A_{ef} f^2 \qquad [8]$$

Where:

$G$ = Gain
$A_{ef}$ = Effective area in square feet
$f$ = Frequency in Ghz.

Using Equation 8, the gains of various types of antennas are listed below:

| *Type* | *Gain (dBi)* | |
|---|---|---|
| Parabola | 10 log 5.5 $D_2 f^2$ | [9] |
| Horn (optimum) | 10 log. 10.3 $Af^2$ | [10] |
| Omnidirectional (stacked array) | 10 log 2 $Lf^2$ | [11] |

Where:

$D$ = Diameter of parabola-feet
$A$ = Mouth area of horn-feet$^2$
$L$ = Length in feet
$f$ = Frequency in GHz.

### *Parabolas*

The parabolic antenna is available with several useful refinements. Radomes, heated and unheated, are available to prevent icing which rapidly reduces efficiency, especially at the higher frequencies. Special shrouds are available to improve the radiation pattern and increase front-to-back gain ratios. Dual cross-polarized feeds are available which provide 25 dB or so of isolation between two signals using the same reflector. Antennas at 1 and 2 GHz normally use coaxial dipole feeds while those at 7 and 13 GHz usually use waveguide horn feeds. Standard mounting structures are available for attaching the antenna to a 4.5-inch OD pipe, along with clamps which can be loosened for aiming the antenna after installation on a tower. Special light weight 950 MHz antennas sometimes mount to a 2-inch pipe. Special roof mounts are available for aiming the antenna upward when passive reflectors are used on the tower. Feeders must be airtight so that when pressurized moisture will not enter and reduce feed efficiency. At the lower frequencies, grid and mesh construction is often used to reduce weight and wind loading on the towers. Grid antennas cannot be used with cross-polarized feeds as they will only reflect signals which are polarized in parallel with the grids.

### *Horns*

Several variations of the horn antenna are available for microwave use. They are characterized by better radiation patterns than parabolic reflectors but their weight and windage requires heavy towers and their use is limited to severely congested areas.

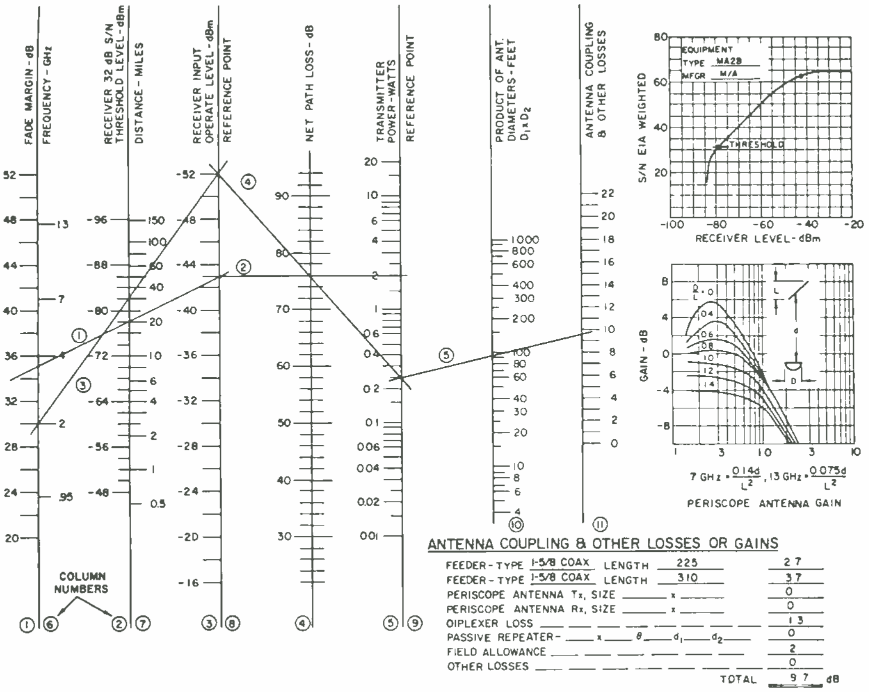
### *Omni*

The omnidirectional antenna is characterized by a radiation pattern resembling a doughnut. Gain is achieved by reducing radiation in the vertical direction. They are often used to eliminate the need for tracking in mobile systems with typical gains of 6 dB on the vehicle or 10 dB at fixed points. The higher gain antenna is not used on helicopters or motor cycles as the signal loss when the vehicle banks during turns would be excessive.

### *Passive Reflectors*

Passive reflectors are often used at 7 and 13 GHz instead of feeder waveguide to effect radiation at the top of the tower. The advantage of passive reflectors is the elimination of waveguide feeder loss and cost; the disadvantage is stray reradiation from the tower structure which limits frequency re-use by degrading the radiation pattern. The installation consists of a parabola near the equipment aimed at a reflector tilted about 45 degrees with the earth which reflects the energy away from the tower in a horizontal line. The efficiency of the reflector depends upon how well it is illuminated by the parabola. Curved reflectors are sometimes used to improve efficiency by 2 dB or so. All installations must meet FCC A standards.

Analysis of the "gain" of a parabola/reflector antenna system is complex, but useful relationships have been determined empirically which are shown on the transmission work sheet in Fig.



ANTENNA COUPLING & OTHER LOSSES OR GAINS

FEEDER - TYPE 1-5/8 COAX LENGTH 225 2.7
FEEDER - TYPE 1-5/8 COAX LENGTH 310 3.7
PERISCOPE ANTENNA Tx, SIZE ____ x ____ 0
PERISCOPE ANTENNA Rx, SIZE ____ x ____ 0
DIPLEXER LOSS ____ 1.3
PASSIVE REPEATER - ____ x ____ θ ____ $d_1$ ____ $d_2$ ____ 0
FIELD ALLOWANCE ____ 2
OTHER LOSSES ____ 0
TOTAL 9.7 dB

Fig. 9. Transmission calculation worksheet.

9. These curves may be used to determine gain of any size combination for use in system calculations. Gain here is defined as the increase in effective radiated power of the antenna/reflector combination over that of the primary antenna alone, had it been mounted at the same point; it can be positive when the reflector has significantly greater surface area than the primary antenna.

Adjustment of reflectors in the field requires skill but is accomplished with the assistance of surveying equipment for initial adjustment and trial and error for best received signal after the equipment is installed. Most popular sizes are 6 x 8, 8 x 10, 8 x 12, and 10 x 15 feet fed by 4, 6, 8, and 10 foot parabolas. The larger the antenna-reflector spacing the larger the antenna needed to concentrate the energy onto the reflector; over or under concentration leads to inefficient illumination of the reflector and loss of performance.

## Antenna Feeders

Microwave equipment is connected to the antenna with either coaxial cable or waveguide. Coax is used for 1 and 2 GHz and may be either foam filled or air dielectric. Waveguide is used for 7 and 13 GHz and may be either rigid rectangular waveguide, elliptical flexible waveguide, or circular waveguide. Short sections of flexible rectangular waveguide are often used to simplify installation. In addition to the lines, various hangers, clamps, bending tools, hoisting grips, and pressuring equipment are required for installation. It is recommended that transmission lines be installed in continuous lengths to avoid potential problems with splices or joints.

The Andrew Corporation, Orland Park, Illinois, provides a wealth of information in its standard catalogue on the characteristics of feeder systems. Typical losses vary from 1.0 to 10.0 dB per hundred feet, depending upon the type of feeder used. Rather than list all characteristics here the reader is referred to vendor catalogues.

Care must be taken during installation to avoid pressure leaks, dents, and discontinuities, all of which will affect the system performance. Professional, experienced riggers are normally used with supervision by the equipment manufacturer. Foam-filled coax is the easiest line to install but has higher loss than air dielectric: it must only be used in conjunction with a foam-filled (non-pressurized) antenna.

When waveguide, or air-filled coaxial cable, is being used it must be maintained at a positive pressure (0.5-5.0 lb/ square inch) above atmospheric with dry air or nitrogen. Compressor/dehydrator units to supply regulated dry air can be fully automatic (the dessicant is dried out periodically by the unit) or semi-automatic (where the dessicant must be replaced or dried out by an operator). To avoid rapid cycling of the compressor the volume of air in the system should not be less than 1.5 cubic feet; this can be achieved in small systems by fitting a regulating tank.

The typical loss per hundred feet of several types of feeder is listed below:

| | Loss per 100 feet |
|---|---|
| **At 950 MHz** | |
| Foam dielectric (aluminum) coax: | |
| 1/2 inch diameter | 3.7 dB |
| 7/8 inch diameter | 2.0 dB |
| Air dielectric coax: | |
| 7/8 inch diameter | 1.6 dB |
| 1-5/8 inch diameter | 0.8 dB |
| **At 2 GHz** | |
| Foam dielectric (copper) coax: | |
| 1/2 inch diameter | 3.5 dB |
| 7/8 inch diameter | 1.9 dB |
| 1-5/8 inch diameter | 1.4 dB |
| Air dielectric coax: | |
| 7/8 inch diameter | 1.9 dB |
| 1-5/8 inch diameter | 1.0 dB |
| **At 7 GHz** | |
| Elliptical waveguide— Andrew type EW-63 | 1.4 dB |
| Rigid rectangular waveguide WR 137 | 1.8 dB |
| **At 13 GHz** | |
| Elliptical waveguide— Andrew type EW 127A | 3.6 dB |
| Rigid rectangular waveguide WR 75 | 4.2 dB |
| **At 18 GHz** | |
| Elliptical waveguide— Andrew type EW 180 | 5.9 dB |
| Rectangular waveguide WR 42 | 14.0 dB |

## Passive Repeaters

On some hops a passive repeater is used to clear an obstacle rather than an active repeater. The passive repeater may be either a billboard type or two parabolas back to back. The flat billboard type has an efficiency near 55 percent.

Because the "gain" of a passive repeater of a given size is proportional to the square of the frequency, their use is mostly limited to frequencies of 6 GHz and above. The gain of a flat billboard is derived from Equation 8 as:

$$G = \left(12.77\ Af^2 \cos \frac{\theta}{2}\right)^2 \qquad [12]$$

Where:

$A$ = Area of reflector in square feet (width x height)
$f$ = Frequency in GHz
$G$ = Gain in dB
$\theta$ = Angle between microwave beams extending to both adjacent stations.

Equation 12 is squared because the passive repeater has equal gain receiving and transmitting. Gain here is defined as the ratio of the power at a given (far-field) point relative to that which would be received at that point if the passive were replaced by a matched isotropic antenna fed with the same RF power. (This is the same definition as is used for a parabolic antenna.)

The performance of the hop may be calculated by considering 2 hops with a passive repeater with gain given in Equation 12.

When $\theta$ is too large to realize practical gain, a double billboard is often used, with one reflector illuminating the other. A loss of 1 to 3 dB is normally used for reflector-reflector coupling loss. The path is analyzed the same way as a single reflector except for the extra loss.

For transmission calculations it is simpler to consider a single hop equal in length to the sum of the two legs extending to the passive repeater. In this case the passive repeater is considered to have a loss given by:

$$\alpha = \frac{2.9 \times 10^7\, d_1^2\, d_2^2}{(d_2 + d_2)^2 f^2 A^2 \left(\cos \frac{\theta}{2}\right)^2} \qquad [13]$$

and in *dB*,

$$\alpha = 74.6 + 20 \log d_1 + 20 \log d_2 - 20 \log (d_1 + d_2) - 20 \log f - 20 \log A - 20 \log \cos \frac{\theta}{2} \qquad [14]$$

A solution to Equation 14 is given in Fig. 10.

When back-to-back antennas are used a coupling loss of 3 dB is included. To increase the gain of the two dishes a low noise amplifier is sometimes used between the antennas. Performance calculations are best left to the manufacturer because of possible overloading of the LNA. The path is analyzed in the same manner using Fig. 10 as a passive repeater except the $\pi r^2$ area of the parabola used is multiplied by 55 percent efficiency, and $\theta/2$ is zero degrees. It is important to ensure a good impedance match between the two antennas; failure to do this can lead to frequency-dependent performance.

The beam width of the flat billboard passive reflector repeater is given by:

$$\gamma = \frac{58.7}{fL} \qquad [15]$$

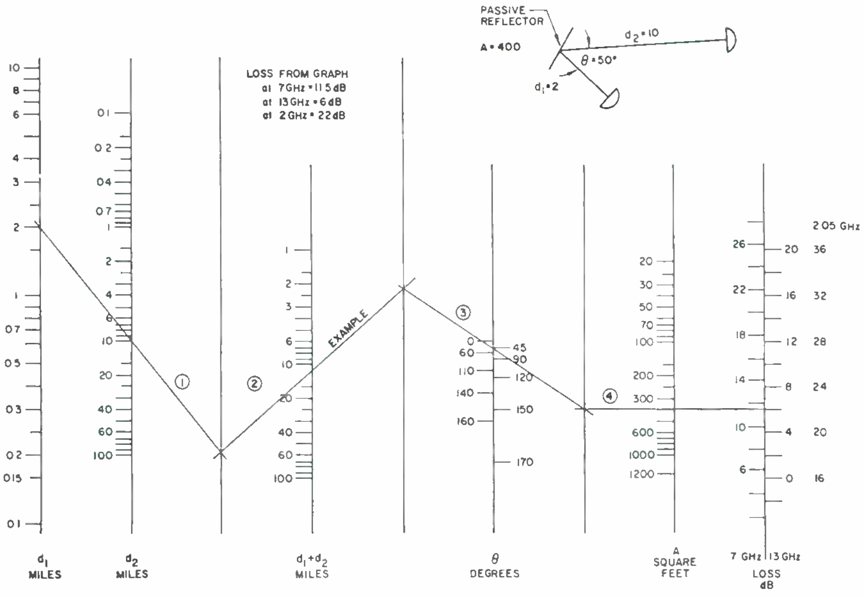


Fig. 10. Passive repeater loss relative to direct transmission over $D_1 + D_2$

Where:
$\gamma$ = Beam angle in degrees
$f$ = Frequency in GHz
$L$ = Projected length of a side in feet

$$(\text{width} \times \cos \frac{\gamma}{2})$$

Because the passive repeater does not require maintenance or operating costs, its use should not be overlooked when designing microwave systems. Passive repeaters are available in a wide range of areas from about 8 × 10 to 40 × 60 feet.

## RADIO CONSIDERATIONS

Transmission of video and audio signals over the last 40 years has been almost exclusively carried out by frequency modulation of the microwave carriers by an analog signal (i.e. the exact waveform to be transmitted rather than a sampled and coded version of that waveform).

Since the broadcast television transmitter uses the analog signal it is probable that analog video transmission will predominate for at least another decade. Audio information also is usually frequency modulated onto a subcarrier, though digital modulation in the sync period or on a subcarrier is also used.

The microwave transmitter terminal thus comprises a baseband processor and frequency modulator (directly to microwave or via an intermediate frequency). The receiver terminal comprises a down-convertor, frequency demodulation (invariably at intermediate frequency) and baseband processing.

### Repeaters

In a multi-hop system, two approaches can be taken at the intermediate repeater sites:

The received signal may be demodulated to baseband using a conventional terminal receiver and then this baseband applied to a conventional terminal transmitter thus regenerating the microwave signal at the desired output level. This is the remodulation approach. The second approach is to take the 70 MHz IF off the receiver and apply this to a transmitter, where it is mixed with a local oscillator 70 MHz away from the desired RF output. The correct side band is extracted by filtering, amplified at microwave and forms the desired repeater output signal. This is the heterodyne approach. The basic advantage to a remodulating system is cost. The heterodyne approach involves both microwave power amplifiers and tight RF (microwave) filters to reject the upconversion LO and unwanted sideband. Both these items are costly.

Heterodyne systems have a significant advantage in preserving the purity of the video signal. Because the video is not demodulated and remodulated, no extra low-frequency corners are added to the video path. This improves the tilt and bounce performance, particularly over a large number of hops. Another feature is video gain stability. Since the signal is never demodulated and remodulated, the 4 MHz peak deviation is invarient over any number of hops. This directly translates to video gain stability. Only the modems at the terminal transmitter and receiver affect the video gain.

In summary, in long-haul microwave systems, heterodyne repeaters are a necessity to keep end-to-end video degradation down to reasonable levels. In short-haul systems, the remodulating system offers comparable performance at a lower cost and with greater flexibility. For systems up to 8 to 10 hops, the remodulating system is normally used, while for longer systems, heterodyne equipment is normally used. Detailed descriptions of remodulating and heterodyne transmitters and receivers are presented below.

## Transmitters

The basic remodulating transmitter consists of a video amplifier (with preemphasis), an oscillator which can be modulated, a crystal referenced AFC loop, a power amplifier and frequency multipliers when required to reach the desired output frequency as shown in Fig. 11. Various optional items are available to extend the usefulness of the transmitter. These include: Off-air demodulators to monitor quality of output at antenna feeder input; audio subcarrier modulators for transmitting program audio channels; a switch for rapidly changing frequency to different channels covering 5% or more of the output carrier frequency; output filters (wideband or channel width) to further reduce spurious outputs and operate with diplexers and duplexers; weatherproof housing for portable equipment; and ruggedized packaging for vehicular mobile equipment.

The baseband amplifier is wideband (10 MHz or so) for best linearity and incorporates liberal feedback for stability. A 13 dB preemphasis is used which together with the receiver deemphasis improves the overall signal to noise performance. Provision is also made for combining one or more audio program subcarrier modulators with the video before frequency modulating the voltage-controlled oscillator. The gain of the video amplifier is matched to the modulation sensitivity of the oscillator so that 8 MHz peak-to-peak deviation is produced on the RF carrier for a 1-volt peak-to-peak input video signal. The low-frequency response of the amplifier extends below 1 Hz as required for tilt performance.

The transistorized VCO (voltage controlled oscillator) typically runs at 2 GHz where transistors are available with enough power capacity to produce an adequate transmitter output level. As new transistors are developed, the trend will result in higher output power and greater power conversion efficiency (lower dc input power). A number of solid-state devices are available which operate directly at the output carrier frequency. The output power of the oscillator may be up to several watts, but it is usually lower followed by an amplifier.

The power amplifier consists of one or more broadband stages to provide a gain of 25 to 30 dB at a power output of 8 to 10 watts at 2 GHz falling to 1 watt or less at 13 GHz. As with other transmitter components, the mark of quality is linearity, wide bandwidth (10% or more of the operating frequency) and long-term stability. The amplifier should operate on any assigned frequency channel in the band without retuning.

Present generation solid-state equipments at 7 and 13 GHz use frequency multipliers and the degree of multiplication used depends upon the output operating frequency. This is typically x3 or x4 for 7 Ghz, and x6 for 13 GHz. These multipliers consist of varactors, impedance matching

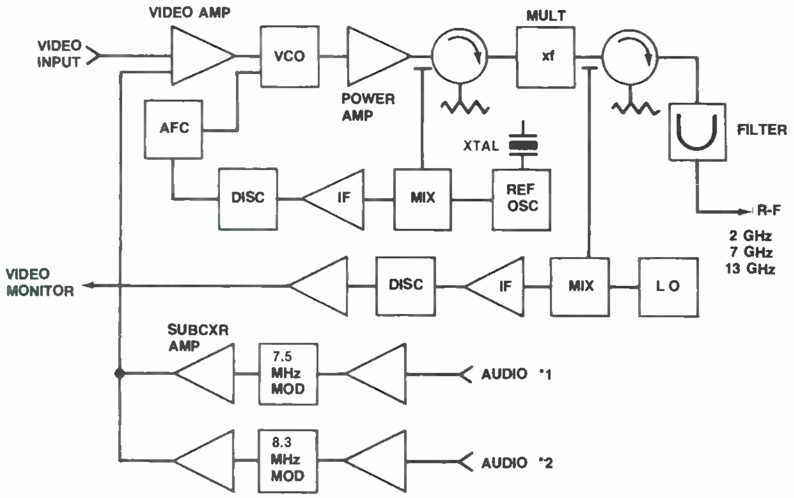


Fig. 11. Remodulating transmitter block diagram.

circuits, cavities, and filters to efficiently operate over a wide band of frequencies with minimum spurious output signals. No tuning is required to cover up to 10 assigned frequency channels in one of the three operating bands. Typical power output from the varactor multiplier is 1 to 2 watts at 7 GHz and 0.8 watts at 13 GHz. At the present time, operating frequencies of solid-state components are increasing so that the need for frequency multipliers will not exist for any frequency band in the near future, as they are not now required at 2 GHz.

Two approaches for AFC are common: Fig. 11 illustrates a crystal-controlled source which feeds one side of a mixer. The other side of the mixer is fed with a sample of the transmitter frequency. The mixer output is an IF signal which is amplified and demodulated by a temperature compensated discriminator. The dc output from the discriminator is the carrier frequency error voltage which, when applied through a dc amplifier to the VCO, keeps it on its assigned frequency. A more state-of-art approach uses a phase-locked oscillator as the microwave source. Here a microwave IC divider samples the oscillator output directly at 2 GHz. The output of the divider is at a frequency where standard PLL IC's and techniques can be used to lock the oscillator to a crystal reference. The phaselock approach involves less hardware and is thus less expensive.

The off-air monitor is essentially a microwave receiver which demodulates a sample of the transmitter output signal for monitoring. To be of maximum value as a transmitter test tool, the monitor signal should be of high quality even though this approach is slightly more expensive than slope detectors and other lower cost devices which are sometimes used.

The frequency switcher shifts the operating bias on the oscillator to change its frequency and, when AFC is used, switches crystals in the reference oscillator. Since all circuits are wideband, no tuning is necessary when frequency is changed.

The transmitter output filter is used when the transmitter is diplexed with another transmitter or duplexed with a receiver, or to reduce spurious levels. The filter may be broadband covering 5% or more of the spectrum, or narrow band covering a single assigned channel.

For portable applications, a weatherproof housing is required which is easily fitted, with an antenna, to a tripod. If remote control is used, special wiring and a connector are installed for mating with the remote control cable.

Equipment for mobile applications must be packaged in a rugged manner to withstand the high degree of shock and vibration experienced in most vehicles. Also size and weight become more important so special precautions must be taken to keep the high density packaged components from overheating.

To prevent interference to or from broadcast microwave equipment, special precautions must be taken for RFI filtering and shielding. The total unit is usually enclosed in an RFI resistant case with critical circuitry completely shielded. Additionally, all input and output electrical connections must be RFI filtered. Without these precautions, considerable difficulty can be expected, since broadcast microwave equipment often operates in close proximity to high powered transmitters.

### *Receivers*

All TV microwave receivers are typically superheterodyne with a 70 MHz IF amplifier as shown in Fig. 12. For broadcast work, the local oscillator and mixer should be broadband to eliminate the need for tuning when switching to a variety of different frequencies.

Mixers are usually balanced mixers and often double balanced. If no low-noise amplifier (LNA) is used, the mixer determines the noise figure of the receiver which is in turn largely dependent on the diodes used. Noise figures of 8 dB at 2 GHz rising to 9 dB at 13 GHz are common. The mixer function is to produce an IF frequency by generating the difference between the local oscillator frequency and the received carrier frequency.

For superior noise performance and fade margin, a low-noise amplifier may be added to the receiver design (as in the figure). Using a LNA, receiver noise figures of 1.5 dB at 2 Ghz rising to 3 dB at 13 GHz are achieveable. Modern LNA designs are based on Ga-As (Gallium Arsenide) FETS. Previously, tunnel diode designs were used at 7 and 13 GHz while bipolar transistors were used at 2 GHz. The gain of these LNA's is typically 15 to 20 dB.

LNA's are also available separately for use outside the receiver. In this case, they are often mounted near the antenna and are provided with a weatherproof housing. In this case, the loss of the transmission line is eliminated and the system improvement is further increased. Another potential application of the low noise amplifier is between two back-to-back dishes operating as an active repeater. FCC action on this configuration is imminent. The low noise amplifier is a useful tool to the microwave design engineer, and its use in the system should not be overlooked.

The local oscillator carrier is usually crystal controlled to 0.005% or better of the output frequency. This eliminates the need for receiver AFC. Fundamental oscillators are usually used, but lower frequency oscillators followed by multipliers are occasionally used as well. For frequency agile equipment, up to 10 switch-selectable

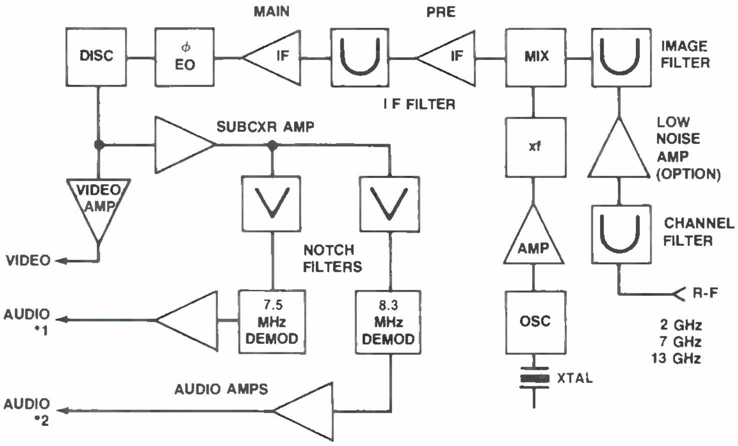


Fig. 12. Receiver block diagram.

crystal references may be used, or a suitable synthesizer employed.

The 70 MHz IF preamplifier is often mechanically integrated with the mixer to achieve best overall noise figure of the receiver. The preamplifier typically has 25 dB gain and is 50 to 60 MHz wide.

Optimum receiver noise performance is achieved when the minimum necessary bandwidth is used. This is typically 30 MHz to the 3 dB points for TV transmission. However in many metropolitan areas, frequency congestion is pushing usage to 20 MHz wide IF band widths. Since the basic IF amplifier circuits are 50 to 60 MHz or more wide, a lumped constant filter located between the preamplifier and the main IF is employed to reduce the noise bandwidth of the receiver to 30 MHz. The characteristics of this filter must be carefully controlled for good phase and amplitude linearity.

The main IF amp follows the filter and provides typically 65 dB of gain. In both pre and main IFs, discrete common-base transistor design had previously been used. This effectively isolates the transistor characteristics from the overall amplifier performance characteristics which are determined primarily by the interstage coupling circuits. With this design approach, the receiver characteristics are essentially independent of the transistor characteristics which may vary widely with temperature. However, current approach is to use special purpose IC's or RF modules to provide IF gain. The output level of the IF is typically +5 dBm. The input microwave level to a typical receiver may vary from −25 to −80 dBm during fading conditions. Since +5 dBm output is required, the gain needed varies from 30 dB to 85 dB. In order to keep the output constant, 60 dB of AGC is typically used to regulate the 90 dB gain in the two IF amplifiers between 40 and 90 dB. Since portable and mobile equipment operate over wide ranges of distance, it is important that receivers have at least 60 dB of AGC.

The limiters are an essential part of an FM receiver because they effectively eliminate the effects of AM variations on threshold performance. Typically 20 dB of limiting is used.

The discriminator demodulates the FM signal back to video. In a wideband TV system, it is important to keep the discriminator linear over a wide bandwidth, typically ±5 MHz or more about the center 70 MHz IF frequency. Nonlinearity will produce distortion and noise on the signal by increasing intermodulation between various components of the TV signal.

The video amplifier brings the discriminator output signal back up to one volt. It also includes a deemphasis network which is exactly matched to the transmitter preemphasis network so that an overall flat frequency response is achieved through the system. The video amplifier includes a low pass filter to reduce the level of the audio subcarriers at the video output. While the degree of audio subcarrier rejection is not extremely important in TV microwave signals, it is typically 30 to 40 dB below peak video levels. A high degree of feedback is used in the video amplifier to achieve maximum stability.

The preselect filter at the receiver input is used to improve selectively, prevent local oscillator radiation, and suppress image frequencies. It typically consists of five or more filter selections designed and tuned to cover several channels in switch tunable systems or a single channel in fixed signals. The passband characteristics must be closely controlled to avoid phase non-linearities in the system.

The same comments made for the transmitter regarding portable and vehicular applications apply to the receiver.

### *Basic Heterodyne TV Microwave*

The receiver in a heterodyne system is almost identical to the remodulating receiver already discussed, the only difference being that the output is taken at 70 MHz from the IF amplifier and connected to the heterodyne transmitter. A second IF output may be used to feed an optional 70 MHz demodulator (limiter, discriminator and video amplifier) if a video drop is desired at the hop.

The heterodyne transmitter block diagram is shown in Fig. 13. It consists of an IF amplifier and a microwave source both of which feed an up converter mixer. The source is similar to that used in the remodulating transmitter except it need not be modulated. The mixer heterodynes the 70 MHz IF input signal up to a microwave signal ±70 MHz different from the source frequency depending upon the sideband selected. The sideband select filter passes the desired sideband while rejecting the undesired sideband and source frequency.

A microwave power amplifier is then used to restore the level of the signal to its desired value. Impatt diode (Avalanche diode) reflection amplifiers have been the norm and are still being produced, but the current move appears to be to GaAs FET power amplifiers.

At a repeater the 70 MHz IF input to the transmitter comes from the receiver IF output at a level of +5 dBm. If the heterodyne transmitter is used at a terminal station, the video signal first modulates a 70 MHz FM transmitter (modulator) which then feeds the transmitter.

### *Power Supplies*

Whether remodulating or heterodyne, microwave equipment uses several different voltages to power the various active circuit components. These are usually low voltages in the 12 to 35 range that must be highly regulated and filtered for best performance. The power supply function is to convert the ac or dc main supply voltage to those required in the equipment.

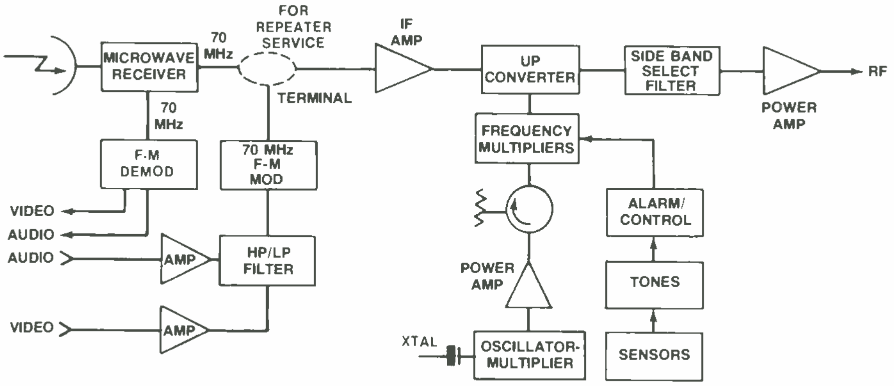


Fig. 13. Heterodyne transmitter block diagram.

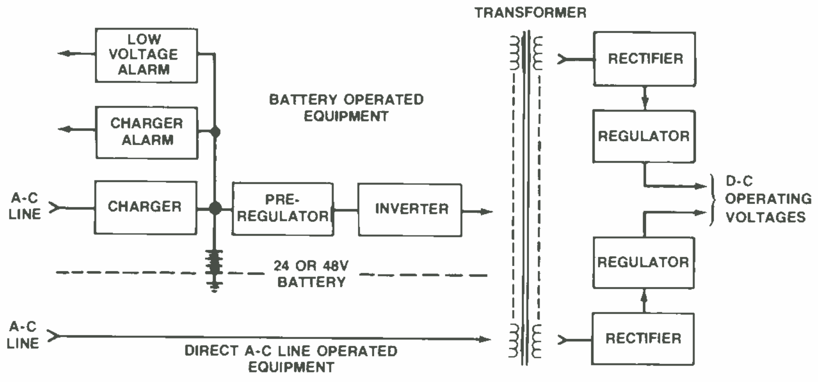


Fig. 14. Power supply block diagram.

Fig. 14 is a block diagram of a typical power supply system. AC units consist of a transformer and rectifiers to obtain the unregulated operating voltages. Various types of transistor regulators are used to keep the operating voltages within a narrow range of variation. In dc units, the battery voltage is first converted to ac by a chopper or inverter after which operation is similar to the ac. Good designs usually employ protection circuits on both input and outputs to protect the power supply from surges, load short circuits, and lightning. The power supply may be separate from the transmitter or receiver or it may be built in.

## Subcarriers

In addition to carrying the video traffic, a microwave link can carry additional information above the video portion of the baseband. As the NTSC video bandwidth extends to 4.2 to 4.5 MHz, the area above 4.5 MHz, after allowing a suitable guard band, is available for other use. Four different uses are made of this baseband spectrum: Program audio subcarriers (multiple); engineering order wire; supervisory signals (alarms); and continuity pilot. In all uses, the deviation is generally 20 dB below the peak video deviation of 4 MHz.

The program audio subcarriers are generally modulated 75 kHz peak deviation at a 1 kHz test tone. Maximum audio bandwidth is almost universally 15 kHz. From Carson's rule the information bandwidth is thus 180 kHz. To allow adequate filtering of one subcarrier from the next, subcarriers are generally spaced at least 600 kHz apart (though occasionally a 400 kHz spacing is used.) Moreover, successive subcarriers are spaced at successively larger distances apart. This avoids a multiple difference beat of 600 kHz in the video baseband.

Up to four audio subcarriers are commonly used. But the more subcarriers used, the greater receiver bandwidth required, with its trade-offs. When 25 MHz wide channels (7 and 13 GHz bands), the four subcarriers are often located at 6.2, 6.8, 7.5 and 8.3 MHz. If 17 MHz wide channels are used, (2 GHz band) the four subcarriers might be located at 5.8, 6.2, 6.8 and 7.5 MHz. However, such a four subcarrier system in a 17 MHz bandwidth will show compromises in audio and video quality. Occasionally a subcarrier at 4.83 MHz will be used. However, this generally requires more severe video filtering, and the resultant degradation of video performance. The 4.83 MHz subcarrier is generally used in ENG systems (see Section 6), where a narrow IF filter is desirable due to transmitter power limitations and band congestion.

Often a single-side-band suppressed-carrier supervisory and control system is added to the baseband. If less than four subcarriers are used, this SSB system might be located at one of the above mentioned subcarrier frequencies. In four subcarrier systems, the SSB system might be located at 8.59 or 9.023 MHz. The supervisory and control system can include both an engineer's order wire and remote repeater alarming. The order wire allows two way communication among the terminals and the repeaters. The alarming allows automated fault reporting from these unattended repeater locations. The requirements for "partyline" transmission from multiple sites forces the use of a suppressed carrier, avoiding carrier beats which would otherwise occur.

In addition, a continuity pilot may be included in the baseband spectrum. Generally the pilot is the highest frequency in the baseband; 8.59 and 9.023 MHz are commonly used.

Descriptions of program audio modulators and demodulators are next presented. Note that depending on manufacturers and model, the program audio modulator and demodulator might be packaged separately or be integral to the microwave transmitter or receiver.

The subcarrier modulator is actually an FM transmitter operating in the range of 4.83 to 8.3 MHz. The subcarrier oscillator is generally frequency stabilized. Previous techniques had included AFC for the oscillator using a built-in FM discriminator as the frequency reference. Current practice is to phase lock the oscillator to a crystal reference using IC phase-lock components. Usually 75 μs preemphasis is employed in the audio circuit.

The subcarrier demodulator is similarly a FM receiver operating in the range of 4.83 to 8.3 MHz. These demodulators are available fixed tuned to one subcarrier frequency (analogous to a TRF receiver) or frequency agile, able to be tuned to several subcarrier frequencies (the superheterodyne approach). In either case, the "RF" or "IF" filters must be sharp enough to reject adjacent subcarriers as well as the 20 dB stronger video signal.

Due to residual non-linearity in the microwave modulator and demodulator, as well as in the path, sometimes cross modulation of the video appears on the demodulated audio. The most annoying characteristic is a 15.7 kHz buzz caused by the video horizontal scanning frequency. Subcarrier demodulator manufacturers often include a 15.7 kHz notch in their audio processing circuitry to suppress this tone. This notch requirement is difficult, as little attenuation at 15.0 kHz (top of the audio band) is allowed. In addition, 75 μs deemphasis and perhaps, noise low-pass filtering above 15 kHz is included in the audio circuitry.

Audio output level is generally +9 to +18 dBm, at a balanced 600 ohms; for multiple outputs a low-impedance option is sometimes available.

## POWER PLANTS

### Primary Power and Back-up

With improvements in equipment and systems engineering, the reliability of the main power source becomes more important. With solid state equipment which requires low power and voltages, batteries are the most popular form of standby power. If prolonged commercial power failures are anticipated, engine-generator sets are used to recharge the batteries. In some remote areas, gas fueled thermoelectric generators are used and solar power is now becoming an economic alternative except in the most northerly states where the necessary standby battery capacity becomes prohibitive.

Industrial lead-acid batteries are most often used. To give strength to the plate structure the lead is alloyed with calcium, antimony or selenium, and this gives each cell certain advantages or disadvantages depending on application.

Currently, industrial lead-calcium or lead-antimony acid batteries are most often used. Both types are reliable and the choice is often one of personal preference. The one advantage of lead calcium is that equalizing charges are not required which reduces maintenance. The float charge voltage is 2.15 volts per cell for lead-antimony, 2.2 volts per cell for lead-calcium, and 2.23 volts per cell for lead-selenium. Batteries should be installed in well-ventilated areas to reduce the possibility of explosion from escaping hydrogen gas. Battery banks usually consist of 12 to 24 cells (24 to 48 volts) and the positive terminal is grounded. Cell voltage typically varies over a range of 1.75 to 2.35 volts when completely discharged and when at maximum charging rate. The communication equipment must be capable of accepting this variation. Battery size is usually selected for a minimum 8-hour capacity with 24-hour capacity being about the economic limit. To arrive at the minimum ampere-hour capacity ($AH$) for a given standby period, the average station load ($A$) should be multiplied by the hours of standby required ($H$), typically 8-12.

To arrive at the minimum charger capacity ($C$) to recharge in $R$ hours, the average station load should be multiplied by the factor:

$$\frac{A + H \times A \times 1.1}{R} = C \text{ amperes} \qquad [16]$$

When $H = 8$ and $R = 24$ this factor is 1.37. $R$ should not be less than 2.5 times $H$.

Since charger failure would lead to station failure after $H$ hours, a key repeater could require a duplicated charger for full protection. In this case each charger need only have a capacity equal to the station load A rather than $C$ as derived above.

Present day batteries are quite reliable and require little attention for many years. Batteries are also effective filters to protect solid state equipment from power line surges, and act as a very large capacitor, so reducing ripple from the charger.

Battery chargers operate from standard commercial power and actually provide the power to the equipment with the battery floating as a standby device. Good chargers should incorporate protective devices to limit charging current and to protect against line surges and duplicated chargers should be designed to share the load. Alarms for charger and line voltage failure should also be available. Purchase of batteries and chargers from the same source of supply is recommended to insure compatibility.

Batteries and charges are sound investments which will add many hours of operating time to the average microwave system.

When diesel generators are the primary source of power they should not be run at less than 75% of rated load (after allowing for any de-rating

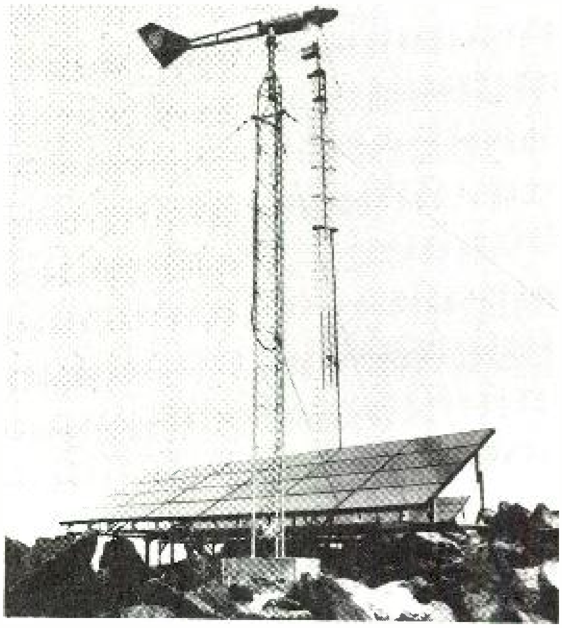


**Fig. 16. A fixed solar powered TV station in Oman with a wind-powered generator. (Courtesy of Solarex Corporation)**

due to altitude). This prevents oiling-up of the engines.

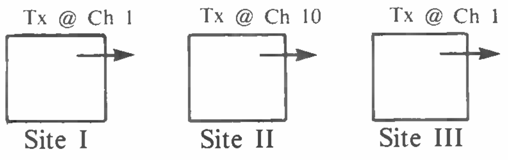
Solar power using photo-voltaic cells is attractive as there are no moving parts requiring maintenance. However the batteries required to maintain the supply during periods of darkness or heavily-clouded weather (which could be several days in some areas) can be the most expensive item in a solar installation. It may pay to have a small generator which can be cut in after 48 hours rather than a battery to give, say, six days standby when that capacity may only be required once or twice a year. The small generator can also power lighting and test gear during a maintenance visit to the site.

## FREQUENCY PLANNING

Frequency coordination has been primarily a local case-by-case selection process through cooperation of the respective chief engineers. Most areas, through the local chapter of the Society of Broadcast Engineers (SBE), maintain an up-to-date log of existing licences.

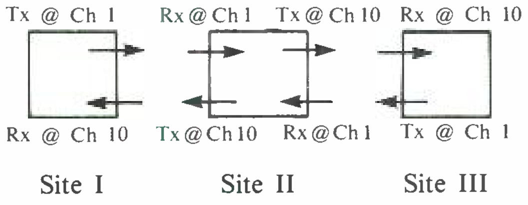
Ideally, frequency planning for future growth should follow the following basic parameters:

A. Multi-Hop System: High-Low Plan



Simplex System—One Way

B. Multi-Hop System: Duplex—Two Way



Future growth allows a second channel addition, diplexed on the same antenna system, with alternate channel selections.

With the High/Low Plan, channel additions can expand up from low end and down from high end.

Basic rules with standard transmitter and receiver designs sharing the same antenna network are:

Diplex—Channel Expansion—Same Direction—Alternate Channels

Duplex—Channel Expansion—Two Directions—Minimum two clear channels between transmitter and receiver at same end. When more than one transmitter is multiplexed onto a feeder, any receiver on that feeder must avoid 2A-B intermodulation products; this can be done by using even channels for transmitters and odd channels for receivers.

Cross polarization can be employed to interleave the channel plan, but care must be exercized in controlling the respective bandwidths through modulation control and RF/IF response.

### Frequency Re-Use

Microwave antenna discrimination provides a degree of isolation that very often allows the re-use of the same channel as the same or a nearby site a number of times.

The EIA Interference Criteria, "Telecommunications Systems Bulletin 10D," specifies a carrier to interference (C/I) ratio of 60 dB. This is ideal, but in many cases very difficult to realize. Acceptance of a lesser C/I ratio has worked successfully in many cases.

Lowering the C/I ratio will raise the effective noise level and hence reduce the fade margin. Given a threshold of −80 dBm, say, the noise level will be appropriately −90 dBm and interference at −90 dBm will raise the threshold to −77 dBm. This may be acceptable in many cases.

Assume a well-designed path from Site A to Site B has, by design, a 40 dB fade margin from normal receive carrier level to Threshold—defined as 37 dB Video S/N. If another co-channel (same frequency) transmitter with same power output and antenna size is located at Site A, but aimed in another direction and the side lobe of the new antenna is only 50 dB down, relative to main beam, a 3 dB increase in the noise floor of the original receiver would be expected and undesirable. If, however, the side lobe can be made greater than 50 dB down, a lesser noise floor increase would be expected. Antenna patterns typically describe a worst-case peak envelope and in practice, the nulls can be well below the envelope and provide essentially no contribution to the original system noise floor. Many systems have been successfully built along this line. Fading over respective paths would be identical and the two systems could exist on the same frequency.

Same site re-use of receiver frequency can be considered in the same fashion with care exercized relative to fading differential.

# FCC LICENSING

## FCC Application

All broadcast microwave systems, portable or in fixed station operation, must be licensed through the FCC. The application is filed on FCC Form 313, with the pertinent characteristics and Type Acceptance Identification Number provided by the respective manufacturer.

Frequency coordination for clearance of the applied for frequency is the responsibility of the local area engineers. In contrast, licensing by Common Carriers, Industrial Service and CARS Band operators is supported by formal frequency coordination studies. The applicant provides detail analysis of use of the applied for frequency in the area with supporting technical details as to the acceptance of the use.

Broadcast engineers should be aware and careful when applying for channels in the 12.7 to 13.25 GHz Band. This band is shared with CARS—Cable TV Operations, and is in wide service in most areas.

The details in Form 313 are straight forward. However, some confusion may arise on Item 8 treating transmitter output. Subsection 8.B.1 is the typical output of the specific transmitter. Subsection 8.B.2 is the antenna input power and represents the actual typical power expected to reach the transmitting antenna after subtracting the losses expected from the length of connecting coaxial or waveguide transmission line. Subsection 8.B.3 is the Effective Radiated Power (ERP) actually transmitted and is the input power raised by the antenna gain. Subsection 8.C is the Emission Designator, 17,000 F9 at 2 GHz and 25,000 F9 at 7 and 13 GHz.

Portable frequency agile transmitters are typically licensed for all the channels that they can provide. For example, at 2 GHz, all seven channels are submitted on the single license applications.

Broadcasters and others using this Handbook should refer to the FCC Rules and Regulations and to their attorneys for complete, up-to-date information.

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# 4.3

# Satellite Earth Stations

James Fitzgerald
*Vice President,*
*Earth Station Services*
*Comsearch, Inc.*
*Reston, Virginia*

## INTRODUCTION

In less than a decade, satellites have become an essential part of the broadcasting industry. The rapid fall in the cost of satellite transmission has made satellites the vehicle of choice for program distribution. As the cost of satellite transmission continues to fall, we are fast approaching a time when many broadcasters will not only receive but also transmit programming by satellite as a natural extension of their role as communication centers. The local broadcaster may on a "shared use" basis transmit teleconferences for local corporations, distribute programming for LPTV networks or distribute its own "superstation" program material.

There are at this time two major developments that are changing the nature of satellite broadcasting. One is the introduction of the 14/12 GHz transmission, which provides channels with less interference from terrestrial microwave systems. The other is the introduction of 2° satellite spacing in the 14/12 GHz band and eventually in the 6/4 GHz band as well.

Satellite communication still has two primary advantages over terrestrial distribution—communication cost is independent of distance and many points can be served with a relatively small investment in terminal equipment. These characteristics make satellites an ideal means for delivery of broadcast programming over vast areas, such as the United States.

## SYSTEM DESCRIPTION

A satellite communication system consists of a transmitting earth station, a satellite, (with a receive antenna, transponder and transmit antenna,) and a receiving earth station (Fig. 1 and 2). Since the characteristics of the satellite components determine the requirements of the earth systems, the analysis must begin with the satellite.

### Satellite Frequencies, Channeling and Polarization

Satellites used for broadcast program relay are in an orbit 22,282 miles above the equator. In this orbit a satellite travels around the earth in exactly 24 hours, so that it appears stationary at a fixed point over the earth **(geosynchronous)**.

Like a microwave relay on earth, the satellite receives and transmits at different frequencies to prevent interference between incoming and outgoing signals. Current broadcast satellites operate in the C band (also known as the 6/4 or 4/6 GHz band) or the Ku band (also known as the 12/14 or 14/12 GHz band). C band uses uplinks from 5.925 to 6.425 GHz and downlinks from 3.7-4.2 GHz. Ku band uses uplinks from 14.0-14.5 GHz and downlinks from 11.7-12.2 GHz.

The satellite bandwidth is divided into channels. In the C band, 36 MHz channels have been standard (with two 2-MHz guard bands, so that

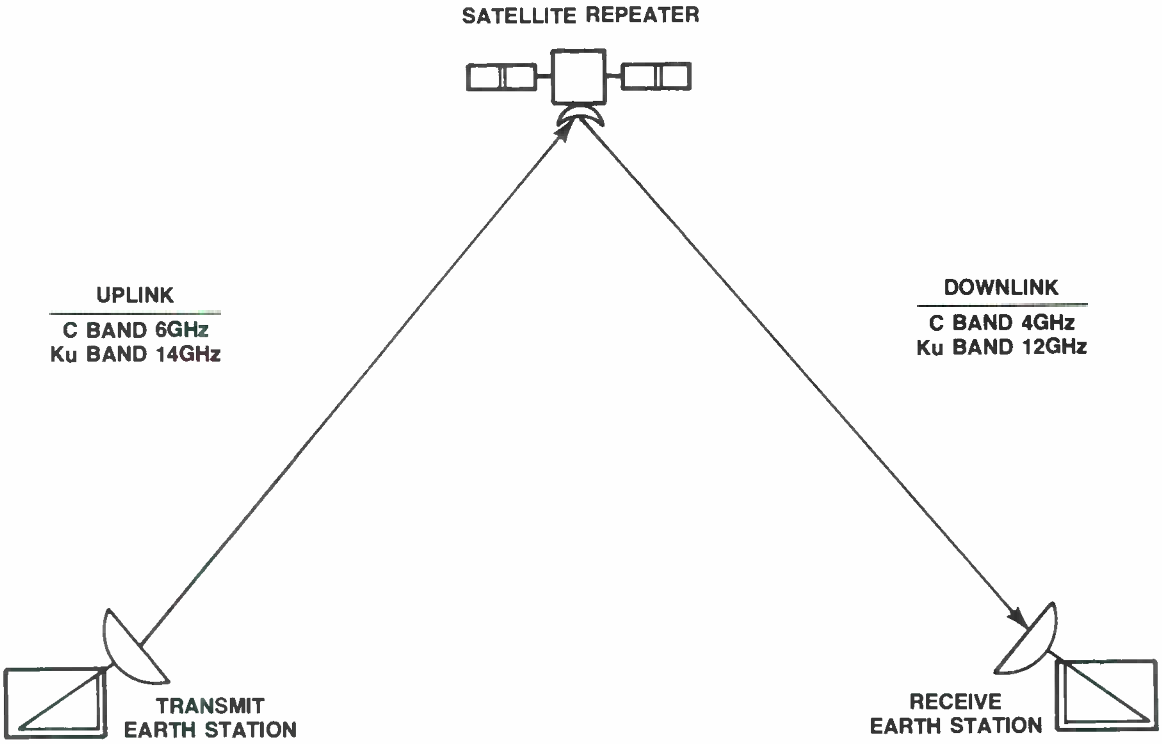

**Fig. 1. Two hop satellite communication link.**

channels are spaced 40 MHz apart). The 36 MHz bandwidth carries one standard FM modulated broadcast color television signal with sound (the 6 MHz signal used for broadcast has to be spread over 36 MHz to maintain a reasonable S/N in the received signal.) In the Ku band, channels of various bandwidths (such as 43, 54 and 72 MHz) permit combinations of broadcast quality video and other forms of communication.

Most satellites double their capacity by using two polarized channels in the same frequency range. In the typical C band scheme, alternate 36 MHz channels of opposite polarization are spaced 20 MHz apart.

Each channel on a satellite is served by its own transponder. The transponder receives the signal from the earth, converts it to the retransmission frequency, amplifies it and retransmits it.

## Satellite Link Analysis

Satellite link analysis is the process of determining what characteristics of the transmitting and receiving station are needed to achieve specified system performance. For most systems used in broadcasting, the primary system performance specification is a signal-to-noise ratio (S/N). For digital systems, such as digital radio transmission, performance is specified as a bit error rate (BER).

Due to the importance of atmospheric conditions in satellite transmission, another significant specification for a satellite system is its performance over time. A system that exceeds a given S/N 99.99% of the time is a system that on average experiences an hour of degraded performance per year.

Once a system specification is established, the analysis generally proceeds in two steps. First is the analysis of system carrier-to-noise ratio (C/N) from transmitting earth station to satellite and from satellite to receiving earth station. The C/N ratio is independent of the type of signal to be carried. To simplify further, carrier-to-noise is referenced to a 1 Hz bandwidth ($C/N_0$) then converted to a full bandwidth figure.

The second step is to compute S/N or BER, taking into account the characteristics of the modulated signal.

The analysis of a C/N is dominated by the effects of transmitting a signal over vast distances and the limited power available for retransmission from the satellite. Thus the requirements for a transmitting earth station are set by the performance of the satellite's receiving system (measured by a figure called "G/T", explained below). The requirements for a receiving earth station are set by the transponder's EIRP (effective radiated power relative to an isotropic anten-

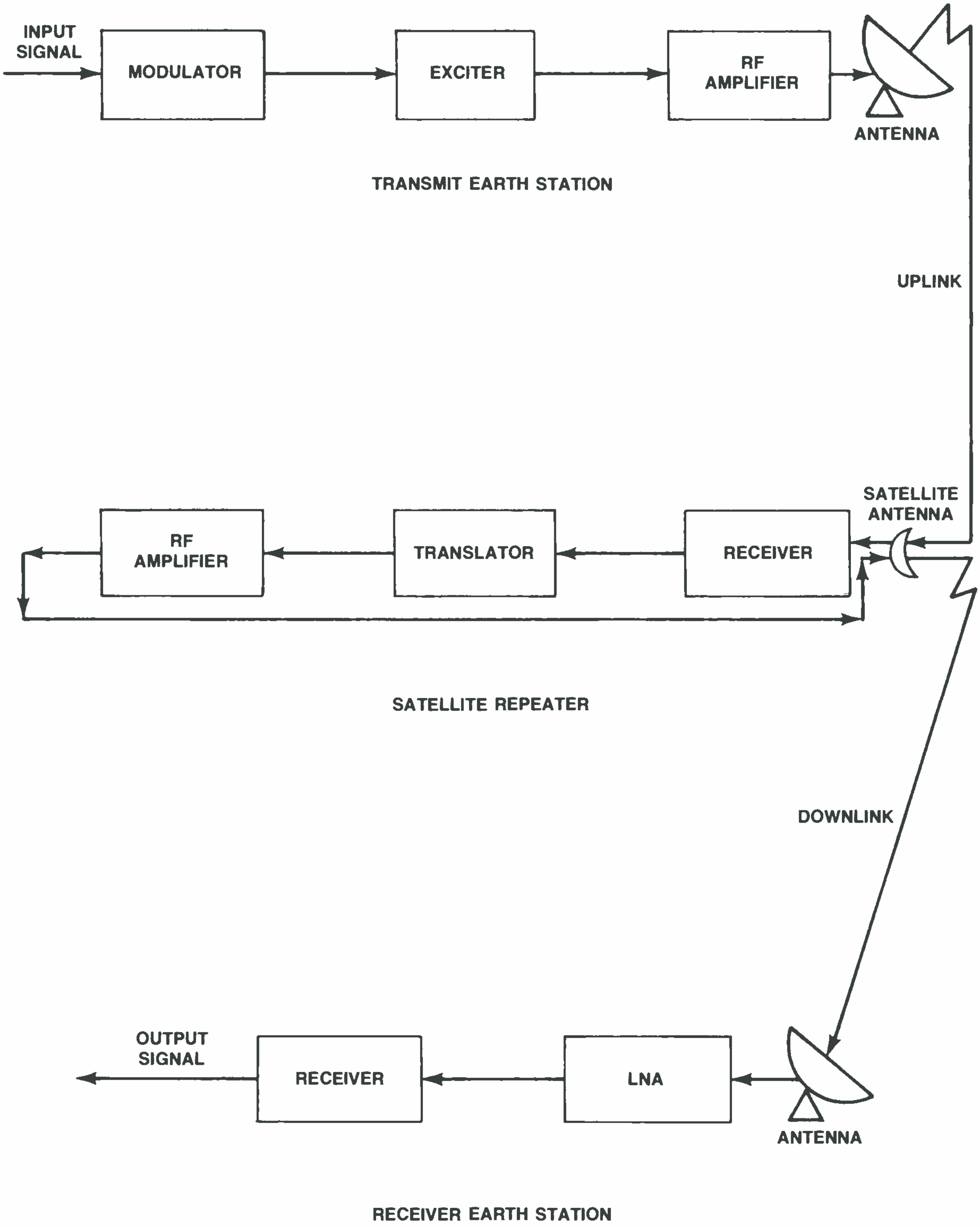

Fig. 2. Simplified block diagram satellite communication system.

na.) The G/T and the EIRP levels vary by location. "Footprint" maps (Fig. 3) show the contours of G/T and effective EIRP. These footprints vary by satellite and by transponder.

For either an unplink or a downlink, $C/N_0$ is computed using an equation like the following:

$$(C/N_0) = EIRP + (G/T) + 228.6 - L_{fs} - L_a \qquad [1]$$

Where:

$EIRP$ = effective isotropic radiated power from the transmitter (dBw)
$G/T$ = figure of merit (see below) (dB)
228.6 = Boltzmann's constant (dBw-Hz)
$L_{fs}$ = Free space loss (dB)
$L_a$ = Atmospheric loss (dB)

Of these figures, EIRP is the sum of antenna power and antenna again. Power at the antenna is a specification of the amplifier feeding the antenna. In the case of the earth station, amplifier power is on the order of 500 W (27 dBW) from a high-powered amplifier (HPA) for video services. The satellite power, supplied by solar panels, is limited to 5-10 W (7 to 10 dBW). Gain depends on the efficiency of the antenna and is proportional to the square of the frequency of transmission and the aperture area of the antenna. The larger the antenna, the larger the gain. EIRP is easily computed for a transmitting station given the power at the feed flange and antenna gain (from the manufacturer). Satellite EIRP is available from a footprint map.

G/T, also called "figure of merit", is a measure of the ability of a receiving system to amplify very weak signals, such as those of a transmitter 22,300 miles away, over background noise. The "G" is antenna gain. The "T" is a noise temperature, which is specified in degrees Kelvin for equipment used in satellite communications. For purposes of satellite link analysis, all noise is referred to an equivalent level of thermal noise, that is, the noise caused by random motion of electrons. As noted above, a footprint map of G/T for the satellite transponder supplies the figure used in calculating uplinks.

For downlinks, the gain figure is obtained from manufacturing specifications. The noise temperature, T, of the receiving earth station is the sum of antenna noise temperature and the noise temperature of the system's electronics, as shown in the following equation:

$$T_s = T_a + T_{lna} / G_{\text{feed}} + T_{\text{receiver}} / G_{\text{feed}} \times G_{lna} \qquad [2]$$

Where:

$T_s$ = total system noise temperature (°K)
$T_a$ = antenna noise temperature (°K)
$T_{lna}$ = noise temperature of the LNA (°K)
$T_{\text{receiver}}$ = noise temperature of the receiver (°K)
$G_{\text{feed}}$ = gain of the device coupling feed to LNA (dB)
$G_{lna}$ = gain of the LNA (dB)

Antenna noise temperature, $T_a$, depends on the elevation of the antenna, since an antenna pointing to cold space faces less noise than one angled

**Fig. 3. Footprint showing assumed satellite EIRP in dBW at 4 GHz. (Figure actually shows average EIRP of RCA SATCOM f-1 at 135°W for transponders 3, 7, 11, 15, 19 and 23) (Courtesy J. Searcy Hollis, Scientific Atlanta, Inc.)**

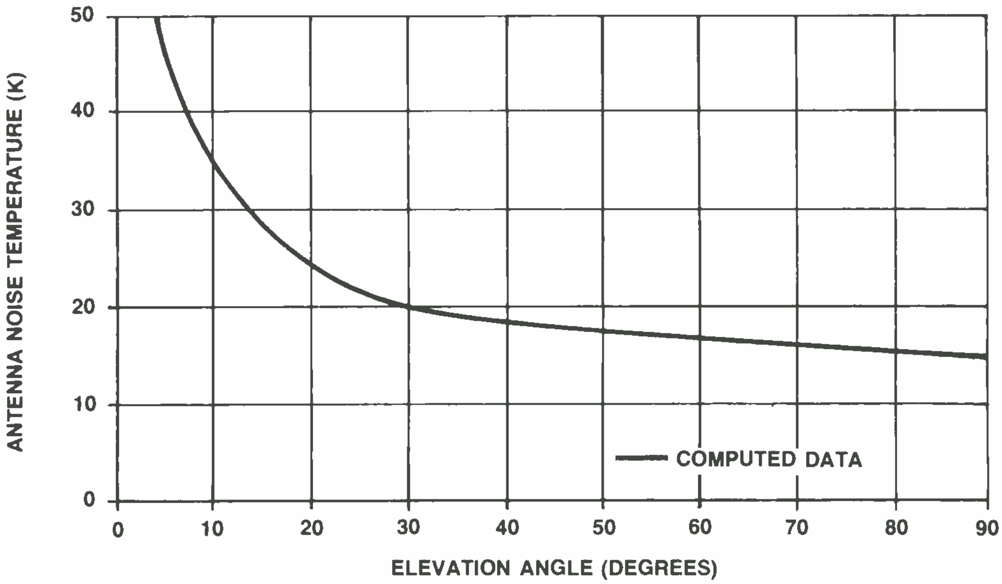

**Fig. 4. Typical variation of the noise temperature of a satellite antenna as a function of elevation angle. (Courtesy J. Searcy Hollis, Scientific Atlanta, Inc.)**

closer to the warm earth. Fig. 4 shows a typical relationship between antenna noise temperature and elevation angle.

Of the remaining terms in equation [2], only $T_{lna}$ should make a difference. An LNA should be selected with a gain sufficient to overcome effects of noise temperature in the components that follow it.

The constant 228.6 in equation [1] is Boltzmann's constant ($1.38 \times 10^{-23}$ W/°K-Hz) expressed in decibels. This universal constant relates the noise temperature in G/T to power.

Free space loss, Lfs, can be expressed (in watts) as:

$$Lfs = (4 \times \pi \times f \times D / C)^2$$

Where:

$f$ = frequency, Hertz
$D$ = distance traveled, meters
$C$ = the speed of light ($2.99 \times 10^8$ meters/second)

The final term in equation [1] refers to atmospheric loss. This term can be neglected under most circumstances, particularly with C-band (6/4 GHz) systems. Ku band (14/12 GHz) systems are more likely to be affected by intense rain and heavy clouds. Atmospheric loss for all bands also increases with lower elevation of the earth station, since the station must look through more of the atmosphere.

Equation [1] calculates a single link from earth to satellite or from satellite to earth. To compute a two-hop link (earth to satellite to earth), the individual hops are calculated, then the two figures are combined by power addition. For power addition, decibel figures are converted back to ratios and then summed using the formula:

$$C/N_o = \frac{1}{\dfrac{1}{C/N_{ou}} + \dfrac{1}{C/N_{od}}}$$

The result is then reconverted to decibels. In this type of summation, the resulting noise level is higher than either of the links considered alone.

## Types of Signals Carried

There are a number of types of signals that a broadcaster will encounter on satellite:

***Full transponder FM video.*** This is a standard broadcast signal, including color and sync tips, using 36 MHz of bandwidth, in C-band systems.

***Half transponder FM video*** is a video signal that uses 18 MHz bandwidth (whether or not the transponder actually has a 36 MHz bandwidth). Both the terms full and half transponder video are misleading, since not all existing or planned satellite transponders use 36 MHz. Half transponder video is used by Intelsat (the international satellite consortium) to transmit news video. It is not a broadcast-quality signal, but is used mainly for news programming.

***Audio subcarrier*** is an FM signal modulated onto the video baseband. Audio subcarriers contain the program audio for video signals. In addition, audio subcarriers are used to distribute radio programming.

***Other subcarrier uses.*** Subcarriers can also be used to transmit slow scan video (still photographs), teletext or other data.

***Frequency Division Multiplexed/FM (FDM/FM)*** is a system by which a large number of limited bandwidth signals (such as voice-grade 4 kHz signals) modulate a carrier of much higher frequency. Using FDM/FM a transponder with 36 MHz bandwidth can carry 1200 telephone conversations.

***Single-channel-per-carrier (SCPC)*** is an alternative to FDM/FM for sharing transponder bandwidth. SCPC transponder frequencies are divided up and assigned to various users, all of which can be transmitting at the same time. By contrast, in FDM/FM all the signals have to be modulated together and sent on a single carrier from a single transmitting station at any one time. SCPC links use more bandwidth per signal (for example: 50 kHz to 200 kHz for a standard radio signal), but they permit higher power on transmission and thus allow smaller, cheaper receiving antennas. News services are using SCPC to transmit audio feeds to radio stations using small antennas.

***Digital radio*** The use of digital, time division multiplexing (TDM) techniques permits more efficient use of satellite transponders than analog techniques, because analog signals can not be compressed as well as digital signals without distortion. Current technology permits twenty 15 kHz audio channels where analog techniques would allow just 16 with very high quality and 15 dB more dynamic range than analog transmission. Digital signals can be sent by SCPC or as a subcarrier.

***Data on blanking interval*** uses the vertical blanking interval in a television signal to send a burst of high-speed data.

## SATELLITE EARTH STATION COMPONENTS

### Antenna

The purpose of the earth station antenna is to concentrate the energy from a satellite signal at a single point. The critical characteristics of an antenna are its ability to increase the signal and its ability to exclude signals off the "main beam."

Gain is a measure of signal increase. Gain is typically given in dBi (decibels relative to isotropic). The gain of an antenna is dependent upon antenna size, frequency and its efficiency. In a given frequency range, the gain of the antenna increases by the square of the area. Thus the larger the antenna, the greater the gain, other things being equal.

The beamwidth of an antenna measures its ability to exclude signals in any direction other than where it is pointed. It is sometimes specified by the radius at which it radiates at 3 dB and 15 dB down from the main beam gain. Other times it is presented graphically by showing gain across a plane that includes the antenna's main beam.

The licensing of a transmit/receive earth station facility requires that the antenna beamwidth pattern must satisfy Paragraph 25.209 of the FCC regulations pertaining to sidelobe performance, to prevent a transmitter from interfering with adjacent satellites. While this performance is not required of receive-only earth stations, some consideration of beamwidth and sidelobe performance should be made, especially since the FCC has authorized closer spacing of satellites in the popular C band.

What follows is a brief description of antenna types used in satellite broadcasting.

### *Prime-Focus Antenna*

A prime-focus antenna (Fig. 5) consists of a main reflector that reflects the signal energy to a single point, known as the focal point. The antenna feed and amplifiers are located at the focal point. At this point the transmission line is connected to carry the signal to the electronic processing components.

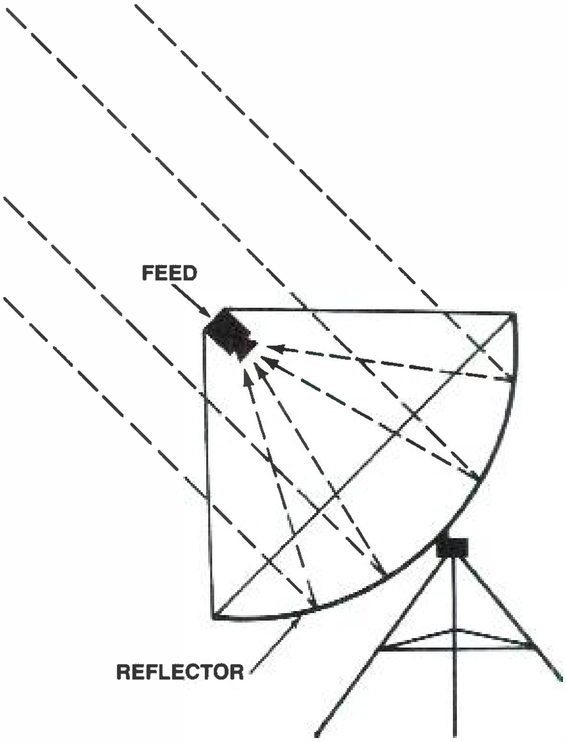

**Fig. 5. Prime focus antenna.**

Prime-focus antennas are generally used for receive-only services. Benefits of a prime-focus antenna are ease of construction and the fact that pressurization is not required because its design prevents rain and moisture from entering the amplifier. The major drawback of a prime-focus antenna is that the amplifier is located at the focal point and thus repair and maintenance are difficult. In addition, the electronics are exposed to the elements.

### *Cassegrain Antenna*

The cassegrain or dual reflector antenna uses a convex and a concave reflector to direct signal energy to a feed horn. The system is shown in Fig. 6.

Dual reflector antennas like the cassegrain have distinct advantages. The most significant benefit is higher gain than that of a prime-focus antenna of equal aperture. In addition, the electronics can be located behind the antenna in a sealed housing.

The gain is slightly higher due to the fact that signal energy is being concentrated twice. The gain of a cassegrain is typically .5 - 1.0 dB higher than the gain of an equal size prime-focus antenna.

The disadvantage of a cassegrain system is the potential for sidelobe degradation and the need for system pressurization. Sidelobe degradation can occur because the subreflector lies in the main beam of the antenna. This potential problem is usually minimized by optimizing subreflector design and by achieving high manufacturing tolerances.

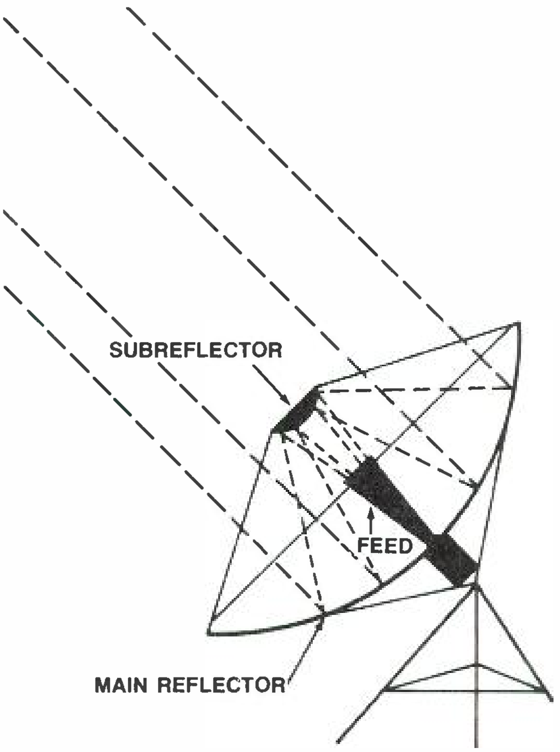

Fig. 6. Cassegrain antenna.

Cassegrain antennas require pressurization to keep moisture out of the system, since the feed horn is facing upward—exposed to the elements. The system is pressurized by a dry air pump regulated to maintain specific pressure within the feed assembly.

### *Offset Feed Antenna*

Another earth station antenna design is the offset feed. The major benefit of this system is its excellent sidelobe characteristics, due to the fact that no obstruction of the beam occurs between the satellite and the focal point of the antenna. The path from the antenna feed to satellite is clear of subreflector, antenna parts or other support structures. This antenna design is becoming more widely used as a result of the FCC's recent decision to reduce the spacing between adjacent satellites. Its drawback is increased cost due to its nonsymmetrical shape, requiring demanding tooling to achieve its required performance.

### *Horn Antennas*

Horn antennas similar in appearance to the type used in telephone microwave systems (Fig. 7) are sometimes used for satellite communication. They are extremely efficient and exhibit excellent sidelobe performance. However, they are large, expensive and difficult to mount. As a result they are only used in environments with exceptional interference problems.

### *Multiple Beam Antennas*

Multiple beam antennas allow simultaneous communication with more than one satellite. These antennas are a variation on either the prime-focus or offset-feed designs. The advantage is the ability to receive signals from more than one satellite without installing an additional earth station. They are, however, more difficult to align, and the prime-focus types have to be carefully designed to minimize sidelobe degradation.

## Orthogonal Mode Transducer (OMT)

As noted above, many satellites transmit frequencies with both horizontal and vertical polarization. To be able to receive both types of signals, an antenna must be equipped with an orthogonal mode transducer (OMT). The OMT is bolted to the feed coming out of the antenna. A system using an OMT will need two LNAs and cable runs, since signals will be on overlapping frequencies.

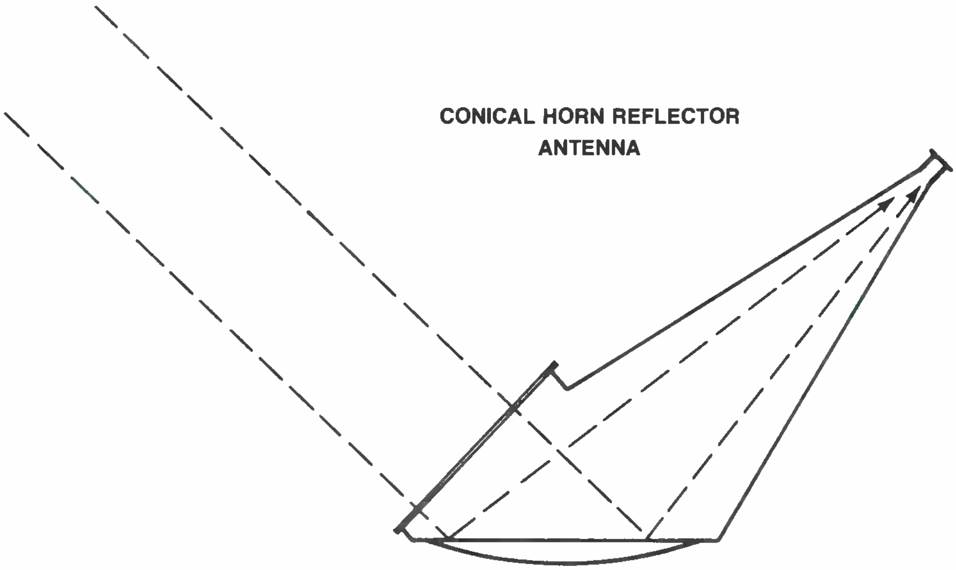

Fig. 7. Conical horn reflector antenna.

## Low Noise Amplifier (LNA)

The low noise amplifier (LNA) amplifies the signal at the output of the earth station antenna. The most commonly used LNAs use gallium arsenide field effect transistors (GaAsFETs). Typical noise temperatures for this amplifier range from 75 °K to 120 °K. A thermoelectrically cooled amplifier reduces the noise temperature further, but at significantly higher cost. The selection of an appropriate LNA depends on antenna size and overall system losses.

There is a basic tradeoff between LNA noise temperature and antenna size (that is, gain), expressed by the system figure of merit G/T. Smaller antennas require a cooler LNA for equivalent system performance. A larger antenna allows use of an LNA with a higher noise temperature and lower cost.

The LNA is powered either by dc or ac current. A dc powered LNA can be supplied power through the output signal cable from the receiver or through a separate cable.

The LNA is a weatherized unit that provides sufficient gain to transport the signal from the antenna to the receiver. The LNA usually has waveguide input to connect the antenna feed assembly and a coaxial output.

## Low Noise Converter

The low noise converter (LNC) combines the functions of an LNA and a down converter. It is usually located at the antenna which feeds the receiver. The low noise converter changes one channel of the 3.7 to 4.2 GHz frequency to an intermediate frequency. By downconverting first the LNC allows the use of low loss coaxial cable rather than waveguides to connect the LNC to the satellite receiver. However, local oscillator phase noise is introduced by the LNC, which makes it more difficult to maintain a broadcast quality signal. This along with the higher cost of an LNC means that LNAs tend to be the preferred choice for broadcasters.

# SITE SELECTION

There are many factors that must be considered in the selection of a site for a transmit/receive or receive-only earth station. These considerations include:

- A clear view of the satellite arc
- Future building plans in the area
- Interference considerations
- Soil conditions
- Zoning, building codes and related regulatory issues
- Connection with ultimate destination of signals

The domestic satellite arc runs from 65° to 145° west longitude. For all practical purposes, an earth station used for broadcasting should have a clear view of the entire satellite arc, even if it may be receiving signals only from one or a few of the satellites now in use, to be able to make the most of the earth station in the future. No trees, buildings, terrain or other obstacles should obstruct the view. Even minor blockage can significantly reduce or obliterate the very weak signal coming from a satellite.

When selecting the earth station location, future building plans near the earth station site should be researched and taken into consideration.

Rooftop locations are rarely desirable for a satellite earth station. The reduction in atmospheric attenuation is negligible and the station is not significantly closer to the satellite. The rooftop antenna faces a far greater likelihood of interference from terrestrial microwave systems which use the same 4 GHz and 6 GHz bands. Obviously, it also costs more to survey, plan, get permits for and construct a rooftop earth station.

Perhaps the most important consideration for a site after its unobstructed view of the satellite arc is its shielding from other signal sources. This issue is discussed in detail in the following section.

An additional consideration in site selection is its accessibility for maintenance and repair. It is desirable to have access by standard transportation at all times during the year.

A review of the local planning, zoning, environmental and building requirements should be made early in the evaluation process.

Finally, if a remote site turns out to be the only feasible alternative, consider the availability and reliability of electrical and telephone service from the site.

## INTERFERENCE

Interference is a significant enough problem for satellite system operating in the C band to merit separate consideration. The C band is shared between satellite service and common carrier terrestrial microwave (telephone companies). The FCC requires new transmitters in the band to notify current users within a *coordination contour* defined by FCC rule and provide them with technical data on their proposed operation. The current users make an independent study of interference potential and report their objections, if any. The applicant must respond and get the objector's agreement—in writing—that no interference will result or if interference does result, it will be acceptable. After this process, called *frequency coordination* is complete, the new transmitter can apply for an FCC license.

For a receive-only earth station no prior frequency coordination is required. However, the interference potential affects receive stations as well as transmitters. The C band user has the right to license his receive-only earth station and thus the right to be heard when new microwave links are proposed.

The FCC will accept license application for transmit antennas of nine meters or greater for broadband (video) applications. For narrowband transmission (for instance, SCPC or digital radio), there is no limit on antenna size. Receive stations of any size may be licensed, although antennas smaller than 4.5 meters are only protected to the extent that a 4.5 meter antenna would require.

The 4 GHz band used for signals from satellite to earth is shared primarily with AT&T and the former Bell operating companies. They use horn reflector antennas with very good radiation characteristics, and thus only present a problem when they are nearby or if the receive station is directly under a path. Unfortunately, that happens fairly often, due to the number of paths involved.

The situation is more complicated for the transmitting stations at 6 GHz. Non-Bell common carriers and earth stations on this band generally use less discriminating antennas that allow more gain off the main beam of the antenna. In addition, there are more paths and the margin of protection for the terrestrial system is 10-16 dB greater than for an earth station.

Fundamental to an interference analysis is knowledge of how new and existing antennas emit and accept radiation off their "main beam." This information is available from the antenna manufacturer or standard FCC specifications are substituted. For any computation involving satellite earth stations, the analysis must take into account the fact that the antenna will be rotated to view a number of satellites and the fact that, unlike a terrestrial system, the earth station main beam usually points well above the horizon. The basic antenna gain chart in Part 25 of the FCC Rules is used as a basis for developing a horizon gain curve taking these factors into account.

Interference propagates along great circle paths. On unobstructed paths, free space loss is the primary factor reducing the interference level. If the path is blocked, diffraction or tropospheric scatter means that some interfering energy will nevertheless reach the antenna. The basic equation for calculating interference level is:

$$P_r = P_t + G_t - L + G_r$$

Where:

$P_r$ = received signal power (dBw)
$P_t$ = transmitted power (dBw)
$G_t$ = gain of the transmitter in the direction of the earth station (dBi)
$L$ = basic transmission loss (free space loss or loss from diffraction and tropospheric scatter effects) (dB)
$G_r$ = gain of the earth station antenna in the direction of the transmitter (dBi)

This same equation determines interference caused by a transmitting earth station, with the role of transmitter and earth station reversed.

FCC rules establish the criteria that determine which microwave stations must be included in frequency coordination for a transmitting earth station. Similar criteria can be used to identify potential interference sources for a receive-only station.

Licensing for a transmitting or receiving earth station involves three steps. First, before coordination begins, the broadcaster conducts his own study of the interference environment. This can most easily be done using a computer study from one of the frequency coordination services with a data base of existing and approved microwave and earth station licenses. This study will include some consideration of terrain and may be augmented by field testing.

Second, once the user has satisfied himself that the station will operate without interference, he (or his frequency coordinator) issues the coordination notice. Then he responds to the objections of existing users.

Finally, once all parties agree on interference considerations, an FCC license application can be filed.

Often more than just an office study is needed to clear a proposed site, because many of the figures used in calculating expected interference are conservative estimates and because topographic map data usually underestimates isolation provided by buildings and trees. A field test will often clear a case showing marginal interference. For receive-only stations, the field test directly evaluates interfering signals. For a transmitting station, the test measures the isolation between the site and existing transmitters.

Field measurements are taken with a test antenna and a spectrum analyzer. The test antenna is scanned 360° in both vertical and horizontal polarizations, while the spectrum analyzer is set to display the full 500 MHz of either the 4 GHz or 6 GHz bands. Typically a daytime and a nighttime test is made and statistical models are used to estimate the results in the worst season and under the worst short-term conditions.

There are a number of things that can be done to prevent interference. Natural shielding remains the best and cheapest solution. If there is a choice between a hilltop site and a valley site with a view of the satellite arc, choose the valley. Trees can also reduce interference, but remember to take into account the loss of leaves.

Diffraction fences of hardware cloth, expanded metal or chain link fence with metal strips inserted in the mesh can also be used to shield. Prefab shielding material is also available for this purpose. It is often difficult to calculate in advance the precise effect of diffraction fences close to the antenna, since the fence must be considered as part of the antenna itself.

Pit shielding (building earthen mounds around the earth station) can provide more than 25 dB of additional isolation. Drainage should be provided if the pit completely surrounds the antenna.

A higher-performance (more directive) antenna can sometimes solve interference problems.

Because of the differences in channeling between terrestrial microwave and satellite systems, a good notch filter 10 MHz above or below the center of the desired receive frequency will sometimes resolve interference. This approach is only available for receive-only stations and only applies to interference from FDM/FM sources. It will not resolve interference from digital, single-sideband or FM video.

Finally, there is the option of choosing a completely different location for the earth station.

Early in the planning stages for an earth station, it is possible to obtain an interference intensity map. This shows expected worst-case interference levels at a number of equally-spaced locations within a large target area. This map can be used as a guide in finding a location with the right topography, zoning and price. The chosen site will still require detailed interference analysis, but the potential for unpleasant surprises is substantially reduced.

## FCC LICENSE

The FCC requires licensing of transmitting earth stations and permits licensing of receive-only earth stations. It is desirable for a broadcaster to license a receive-only station, since licensing protects the station from future interference from domestic microwave systems.

The receive-only application is relatively simple. It is a narrative (there is no standard form) with the following information:

1. The nature of the proposed service.
2. A statement of public interest.
3. The name of a person to receive correspondence (usually includes a technical contact and counsel).
4. The applicant's technical qualifications.
5. A paragraph identifying that the application is a "minor" action for environmental considerations. Generally, the action is minor if the antenna dish is less than 30 feet in diameter and is not located in certain specific areas (e.g. historic districts, scenic areas, floodplains and some others listed in 47 CFR 1.1305(a)(6)).
6. Description of the site (plot plan) and its availability. This should include the eleva-

tion of the antenna base above sea level and the maximum antenna height above the base.

7. A functional block diagram of the system.
8. Description of the antenna mounting and range.
9. A statement of compliance with the requirements for antenna sidelobe performance.
10. A statement of FAA clearance, if required (the same rules apply as for any antenna).
11. The report of frequency coordination and interference analysis.
12. A technical showing that the antenna meets the performance criteria for a 4.5 meter antenna, if the antenna is less than 4.5 meters.
13. A completed FCC Form 403.
14. A technical summary of the proposed station including a description of the equipment to be used, major structures, the type of communication being received, the space segment being accessed, frequencies and polarities received, satellites and transponders being used.
15. A statement that the applicant will only receive program material for which it has obtained rights.
16. The applicant's certification.
17. The technical certification by a technically qualified person that the engineering data is complete and accurate.

These same items are required for transmitting stations, although naturally some of the items will be more involved (such as frequency coordination and technical description of the system). There are a few additional requirements for transmitting stations:

1. A completed FCC Form 430 (legal and financial qualification). This form is required if common carrier status is sought.
2. A statement of compliance with regulations for the protection of employees and the general public against excessive radiation.
3. A statement of compliance with FCC regulations regarding quiet zones.

## INSTALLATION

This section consists of a checklist of considerations in constructing a satellite earth station.

### *Foundation*

In selecting the precise location for the antenna, it is important to choose a level site, well drained and free from underground obstructions that might interfere with foundation construction. The foundation for the antenna will be substantial to maintain the pointing angle of the antenna despite substantial wind loading and possible ice loading. An evaluation of soil type and frost penetration is necessary to establish the foundation required.

There are two common types of foundation. In the mat footing, the load is borne by a single, large reinforced concrete mat. The alternative, a drilled pier footing, requires much less concrete and are more cost-effective if soil conditions permit their use. Further economies can be achieved with earth anchors supplementing concrete piers. Pier kits are available for smaller earth stations.

The mat foundation may be required if the ground is too rocky or the soil too loose for drilling holes for piers. Sometimes it is too expensive to transport pier drilling equipment to the proposed site. In some areas small contractors may be able to build a mat foundation at less cost.

As mentioned above, rooftop locations are not recommended for earth stations. If a rooftop location is required, it is necessary to construct a load frame to connect the antenna mount to the building columns. As height increases, expected wind load increases and the design of the antenna mount needs to be adjusted accordingly.

Note that a professional engineer may be required to approve a foundation design in some states.

Finally, before the foundation is poured, be sure that provision has been made for supplying ac power and RF interfacing, if it will pass through the foundation.

### *Mounting*

There are a number of systems for mounting and pointing earth stations, some with two moving axes, some with one. As might be expected, the one-axis systems sacrifice some accuracy in the interest of simplicity.

The two-axis systems are elevation-over-azimuth (with one axis of rotation perpendicular to the plane of the horizon), X-Y (with one axis parallel to the ground) and polar (with one axis parallel to the earth's axis of rotation). Elevation-over-azimuth is an extremely flexible system, and initial mounting is not critical. It is more complicated than the other systems. X-Y requires that careful attention be given to the initial heading angle of the antenna.

The polar system has the advantage that it can maintain pointing at any point in the sky simply by rotating about its vertical axis. For this reason, the polar mount is the basis for the single-axis mounting systems. In a simple single-axis system, the vertical mount is exactly parallel to the earth's axis of rotation. In a declination-corrected polar mount system, a slight correction is made to account for the fact that the antenna is not in the same plane as the satellite arc (that is, the plane of the equator). In most parts of the continental U.S., a declination-corrected polar mount antenna can be made to point to any satellite between 70° and 135° west longitude with negligible error.

### *Heading*

Accurate heading of the antenna center line is often essential for finding the desired satellites. With some mounting systems, an inaccurate foundation heading may require reconstruction, and the foundation contractor should be made aware of the importance of maintaining a surveyed heading. A competent surveyor can establish the proper heading by reference to known survey lines, by pole star observation or by compass. The last should take into account magnetic declination from true north and, in any case, should not be used near large metal structures or strong electrical fields.

### *Shelters*

For receive-only earth stations in remote locations, the necessary electronics can often be located in a simple equipment shelter (8′ × 8′). Since the equipment generally does not generate a large amount of heat, it may be possible to avoid air conditioning.

Shelter requirements become significant for a transmitting earth station. Each HPA is about 2′ wide, 3′ deep and 7′ high, and a typical station will have redundant HPAs for reliability. Control equipment will occupy two standard 19″ racks. Sufficient space is needed for waveguides and cable runs. A 10′ × 18′ shelter is probably the minimum for accommodating the necessary equipment.

Any shelter should be as close to the earth station as possible to avoid long cable runs. If long runs cannot be avoided, additional amplifiers will be needed along the run.

### *Power*

Power requirements for a receive-only station are modest, probably less than 1 kW for the LNAs, receiver and control equipment. Motorized antenna positioning would require additional power. For transmitting stations, HPAs demand large amounts of power, perhaps 12 kW of three-phase power for a 3 kW video amplifier. A hot backup HPA requires a doubling of the load. Antenna deicing represents the other major power requirement, with 3 kW for feed and subreflector deicing (sufficient in milder areas) up to 51 kW for full reflector deicing. Air conditioning is an additional power consumer.

Two kinds of backup power should be considered. Short outages can be bridged with an uninterruptible power system (UPS), a battery-based system. It is impractical for a UPS to protect anything but the electronics of the system. An engine and generator is needed for longer outages. This system should be sufficient to operate the entire system, with provision for enough fuel to maintain operation when conditions may hamper refueling.

### *Pressurization*

A pressurization unit must be installed to keep moisture out of certain earth station antennas, notably cassegrains. Pressure may also be required for air dielectric cabling.

## OPERATION

Operating an earth station antenna is above all a matter of correct pointing. The process should be one of pointing to the correct azimuth and elevation of the desired satellite and then fine tuning, first with the meters of the satellite receiver and then with a video monitor.

For a transmitting station, a scenario for starting transmission might follow these lines:

1. Position antenna on satellite (can use receivers to insure accurate pointing).
2. Check null on adjacent transponders to verify polarization angle.
3. Tune exciter, HPA and Receiver to the transponder frequency.
4. Check power levels with a dummy load.
5. Call the satellite technical operations center to initiate transmission.
6. Transmit low-power CW to check polarization.
7. Operations center clears full-power transmission.
8. Increase power.
9. Add modulation (test tone).
10. Check for interference on adjacent transponders.
11. Add source.
12. At the end of transmission, call operations center to inform them.

## MAINTENANCE

Maintenance will usually be specified by equipment manufacturers. There are few moving parts or sensitive equipment with a receive-only station, so maintenance will not be a major item. Antenna bolts should be checked and tightened periodically. Waveguides should be checked for leaks and kinks. Antenna motors should be checked and lubricated as required. Weekly inspection should identify impending problems.

For a transmitting station, HPAs require daily inspection. The klystron tube in an HPA will need to be rebuilt every two to three years, so that a redundant system with two HPAs will require 3 klystrons, two operating and one in repair.

A rule of thumb for maintenance is 3% to 5% of system cost per year.

# 4.4

# Fiber Optic Video Transmission Systems

Pete Mountanos
*Grass Valley Group*
*Grass Valley, California*

## INTRODUCTION TO FIBER OPTICS

Fiber optic technology is a dramatic step in the evolution of telecommunications. The heart of fiber optic communications is an optical fiber or waveguide, made of glass or plastic, through which light is transmitted. Light, being a part of the electromagnetic spectrum, follows the same principles we have employed in designing microwave, television and radio transmitters. The most common use of fiber is as a transmission link connecting the two electronic circuits of a transmitter and receiver. The central part of the transmitter is the optical source, either an LED or laser diode, which converts electrical signals into light signals. The source is modulated by a driver, which may, for example, convert a digital or frequency modulated voltage signal into a current source appropriate to drive an optical device. The receiver contains some form of a photodiode, which in turn converts light back into electrical signals, and an output circuit which amplifies and reconstructs the signal into its original form. Fig. 1 is a simple block diagram of such a link.

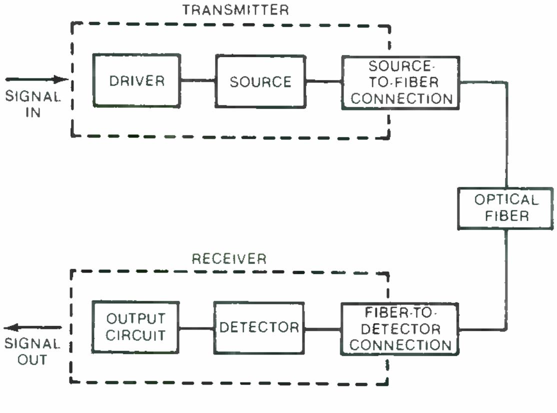

Fig. 1. Basic fiber-optic link.

As compared with discrete wire, twisted pair, coaxial cable, and even in some cases, over-the-air microwave and satellite transmission, fiber optic systems offer significant advantages for transmitting signals.

### Advantages

The advantages of fiber optic systems warrant considerable attention from the communications industry. Among the most important are the following:

1. ***Bandwidth.*** Information carrying capacity of a carrier increases with the elevation of the carrier frequency. Since the signal is light with fiber optics, the carrier frequency is several orders of magnitude higher than the highest radio frequencies. (Fig. 2) Today's fiber optic systems easily surpass the information carrying capacity of more conventional methods and its future carrying capacity has only begun to be utilized. Fibers have bandwidths in excess of several GHz per kilometer, which allow high speed transfer of most types of informa-

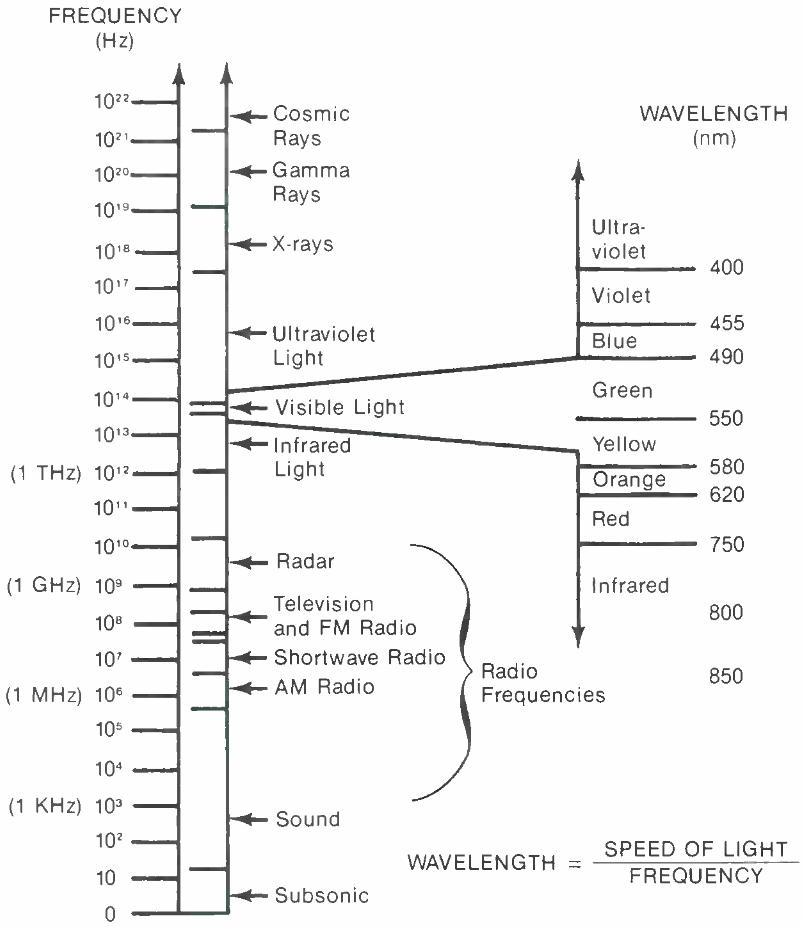

Fig. 2. Electromagnetic spectrum.

tion. With multiplexing, many signals can be sent over a single fiber. For example, the phone industry now transmits thousands of voice channels simultaneously over a single optical waveguide.

2. ***Low Loss.*** Fibers provide substantially lower attenuation than copper wires and require no equalization. In premium cables attenuation can be below .5 dB/km for certain wavelengths.
3. ***Electrical Isolation.*** Since the fiber cable is essentially dielectric material it is inherently isolated electrically. There is no spark hazard, and no risk of EMI emmissions. Fiber cable is a natural in hazardous environments, and its electrical isolation precludes ground loop problems. Fiber optic systems are immune to outside electrical noise as well.
4. ***Size and Weight.*** In general, the optical waveguide is the size of a human hair. As a result an equivalent copper cable is always much larger, stiffer and heavier than an equivalent fiber cable. Thus, installation costs, ducting, handling costs and the like are typically much lower for a fiber installation than for a similar coaxial system. This factor alone accounts for much of the rapid acceptance of fiber.

## Disadvantages

Optical fiber as a transmission medium does have disadvantages, some of which are strictly due to the relative infancy of the technology. A major disadvantage is lack of fiber optic standards from industry organizations such as EIA. This lack of standards in both specifications and testing procedures makes comparison of various manufacturers' products difficult. It is expected that these problems will be addressed in the near future. Another drawback, most significant to the broadcast industry, is the difficulty of adapting fiber optics to existing systems. Most interconnections rely on linear analog amplifiers such as distribution amplifiers. Fiber optics is not suited for such implementation as it is preferable to operate in a serial pulsed fashion. As the cost of fiber optic components declines, and the use of digital components in television increases, the technology will become increasingly appropriate.

## Economics

The economics of using fiber optic systems is a complex discussion. Direct comparisons between copper based, microwave or satellite based systems are difficult and open to debate. Each evaluation must be based on the user's needs. It is clear that widespread application of any technology depends upon providing superior performance at a lower cost to competing technologies. That fiber optics can meet such a criteria has been established by the telephony industry. As is the case with most new technologies, costs are rapidly dropping while more mature technologies continue to increase. As a result, fiber optics becomes more attractive every day.

# LIGHT AND FIBER CHARACTERISTICS

Light is similar to radio waves, x-rays, and gamma rays in that it is a part of the electromagnetic spectrum. In general the frequencies of light used in fiber optic transmission are in the region of 300-400 terrahertz (10×E14), or several orders of magnitude higher on the electromagnetic spectrum than the highest frequency radio waves. Light waves are more generally described in terms of wavelength rather than frequency (Fig. 2). The region extending from 800-1600 nanometers is of greatest interest because today's fibers propagate these wavelengths most efficiently.

What we refer to as "the speed of light" (300,000 km/sec) is the velocity of any electromagnetic energy in free space or a vacuum. Light travels slower in all other media, and different wavelengths travel at different speeds in any single medium. When an electromagnetic wave crosses a boundary from one medium to the next it changes speed which results in a change of path called refraction.

The index of refraction, *n*. is a dimensionless number expressing the ratio of the velocity of light in free space, *c*. to its velocity in a specific medium. Thus:

$$n = c/v$$

Refraction of a ray of light as it passes from one material to the next depends on the refractive index of the material. When discussing refraction three terms are used. The normal is the line perpendicular to the interface of the materials. The angle of incidence is the angle between the incoming ray and normal. The angle of refraction is the angle between normal and the refracted ray.

When light passes from a high index of refraction medium to a lower one the light is refracted toward the normal. Fig. 3 shows that as the angle of incidence increases, the angle of refraction approaches 90 degrees with normal. This is called the critical angle. If the angle is increased past the critical the light is totally internally reflected.

## Optical Fibers

A basic optical fiber consists of two concentric layers. The inner layer, the core, has a refractive index higher than the outer layer, the cladding. Light injected into the core and hitting the boundary at an angle greater than critical is reflected into the core. Light striking the interface at less than the critical angle is passed into the cladding and lost. This total internal reflection forms the basis for light propagation in optical fibers. The exact characteristics of light propagation depend on fiber size, construction and composition. Maxwell's equations show that light does not travel randomly through a fiber; but rather that it is channeled into modes. A mode is a possible path through a fiber.

## Types of Fibers

There are many ways to classify fibers, however the most informative are by refractive index profile and number of modes supported. The two

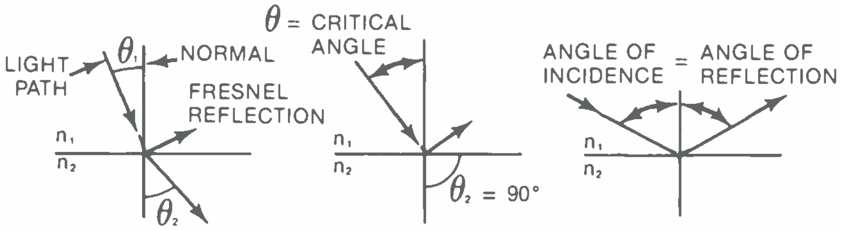

Fig. 3. When the refractive index, of the first medium ($n_1$) is greater than that of the second, ($n_2$) light is refracted away from the normal. If the angle of incidence is greater than the critical, the light is totally reflected.

main types of index profiles are step and graded. In a step index fiber, the core has a uniform index with a sharp change at the boundary of the cladding. In graded index fiber, the core's index is not uniform; it is highest at the center and decreases until it matches the cladding. There is no sharp break. Fig. 4 shows the paths and propagation characteristics of such fibers.

### Multimode, Step Index

A multimode step index fiber typically has a core diameter in the 500-1000 micron range. The large core permits many modes of propagation. Since light will reflect differently for different modes some rays follow longer paths than others. The lowest order mode travels down the center while higher modes strike the core-cladding interface at angles near the critical angle and as a result, follow longer paths through the fiber. As a result, a narrow pulse of light spreads out as it travels through this type of fiber. This "spreading" is called modal dispersion.

### Single or Mono Mode, Step Index

A way to limit modal dispersion is to make the fiber core sufficiently small to insure the fiber propagates only one mode efficiently. A single mode fiber has a core diameter small enough that the fiber propagates only one mode, efficiently. A single mode fiber has a core diameter of the order of 5-10 microns. This is of the order of 1/6th the diameter of a human hair. Its small size makes it very difficult to work with, however it is very efficient and suitable for high speed, long distance transmission.

### Multimode Graded Index

A graded index fiber also limits modal dispersion. Its core is essentially a series of concentric rings, each with a lower refractive index. Since light travels faster in a lower index medium, light farther out from the axis travel faster. Since high order modes have a faster average velocity than low order modes, all modes tend to arrive at a point at nearly the same time. Rays of light are not sharply reflected by the core-cladding interface, they are refracted successively by different layers in the core.

### Dispersion

Dispersion relates to the spreading of a light pulse as it travels down a fiber. A pulse measured at the output will be wider than it was at the input. This limits a fiber's bandwidth or information carrying capacity. Pulse rates must be slow enough that dispersion will not cause adjacent pulses to overlap. Consider the pulse shown in Fig. 5. Two trains of pulses, one faster than the other are injected into the same fiber. In both cases, the pulses are spread by dispersion. For

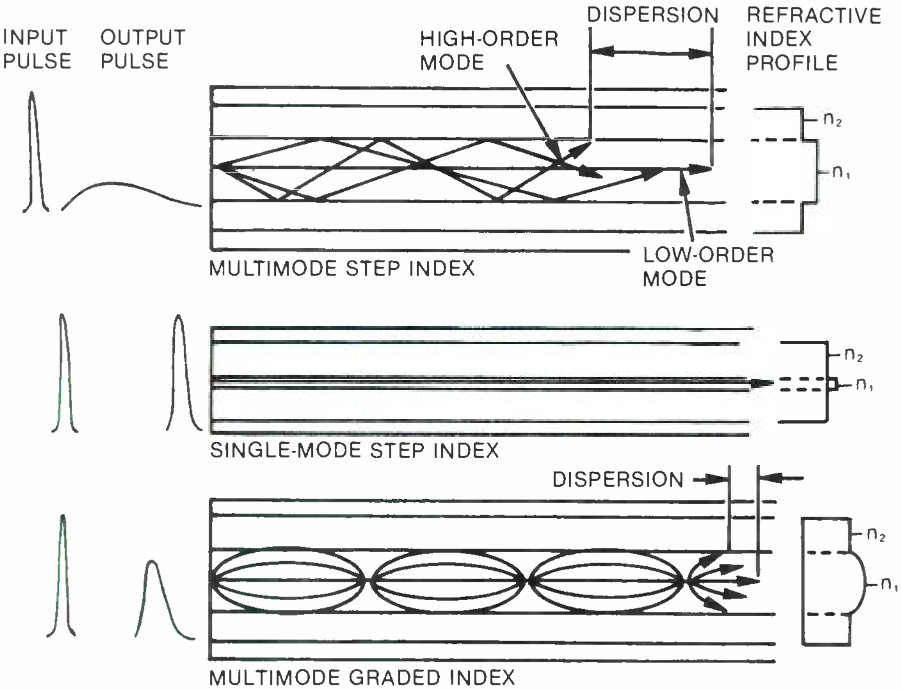

Fig. 4. The core size and refractive index determine the light propagation characteristics of the fiber.

Fig. 5. Dispersion limits signal frequency.

the slower train, the interval between pulses is sufficient to allow each pulse to be distinguished. In the faster train, however, the interval is so short that individual pulses merge into one long indistinguishable pulse. Dispersion, which can be related to pulse rise and fall times as in copper cable, therefore is the limiting factor in determining a fiber's bandwidth.

There are basically two types of dispersion: modal, resulting from differing path lengths already discussed; and material, arising from differing velocities of different wavelengths in the signal. In a single mode fiber there is no modal dispersion, only material dispersion limits its capacity for carrying information.

Material Dispersion is generally limited by either operating at lower frequencies, or using very narrow optical spectrum devices such as lasers.

### Attenuation or Loss

Attenuation is loss of power. During transit some of the light is absorbed into the fiber or scattered by impurities. Attenuation for a fiber is usually specified in decibels per kilometer or dB/km. For commercially available fibers, attenuation ranges from around .5 dB/km for premium fibers to 100 dB/km for large core plastic fibers. It is important to remember that since we are measuring optical power, a 3 db loss represents ½ rather than the 6 dB we have become used to in dealing with voltages.

Fiber attenuation is closely related to light wavelength. Most fibers have a medium loss region in the 800-900 nm range (3-5 dB/km), a low loss region in the 1150-1350 nm range (.6-1.5 dB/km), and a very low loss region (less than .5 dB/km) in the 1550 nm area. As a result best performance is achieved by careful balancing of fiber, device and distance requirements.

## OPTICAL DEVICE CHARACTERISTICS

### Sources

An optical source is generally either a light emitting diode (LED) or an injection laser diode. The LED is an incoherent source, which when compared with a laser, provides less power and operates at slower speeds, but also costs considerably less. It is however, quite suitable for most applications requiring transmission less than 10 km and speeds less than 100 Mbits per second. A laser requires more electronics to operate, is more powerful, and costs more, however it can be used to transmit distances over 100 km before amplifiers are required. In general, an optical source must be evaluated to insure its speed is suitable to the bandwidth required, and that it provides enough optical power at a wavelength suitable to meet the distance requirement. Another important consideration is the fact that optical devices do not turn on with the linear characteristics we are accustomed to with electrical devices. Fig. 6 and Fig. 7 illustrate examples of characteristics for lasers and LED's. As a result, modulation techniques that rely on the linearity of the device are generally not suitable for fiber optic applications.

### Detectors

A detector performs a complimentary function to the source: it converts incident optical energy back to electrical energy. Common detectors used in fiber optics are semiconductor photodiodes, including PIN and avalanche photodiodes.

The performance of a fiber optic system is generally limited by dispersion or attenuation. When a link is limited by attenuation distance, the detector must respond to weak incoming signals and its sensitivity will determine link performance.

In an ideal PIN diode, each incident photon creates an electron-hole pair in the semiconductor lattice. This in turn sets one electron flowing in the external circuit. If the received light is weak, the generated current may not be strong enough to overcome noise inherent in the diode and receiver circuit. In such cases, it is desireable to increase the detector output before amplification by the receiver. Such gain is inherent in an avalanche photo diode or APD. A reverse bias provides several electron volts of energy increase to each liberated electron, providing inherent amplification of the received signal. Once again, such amplification is not linear with received levels.

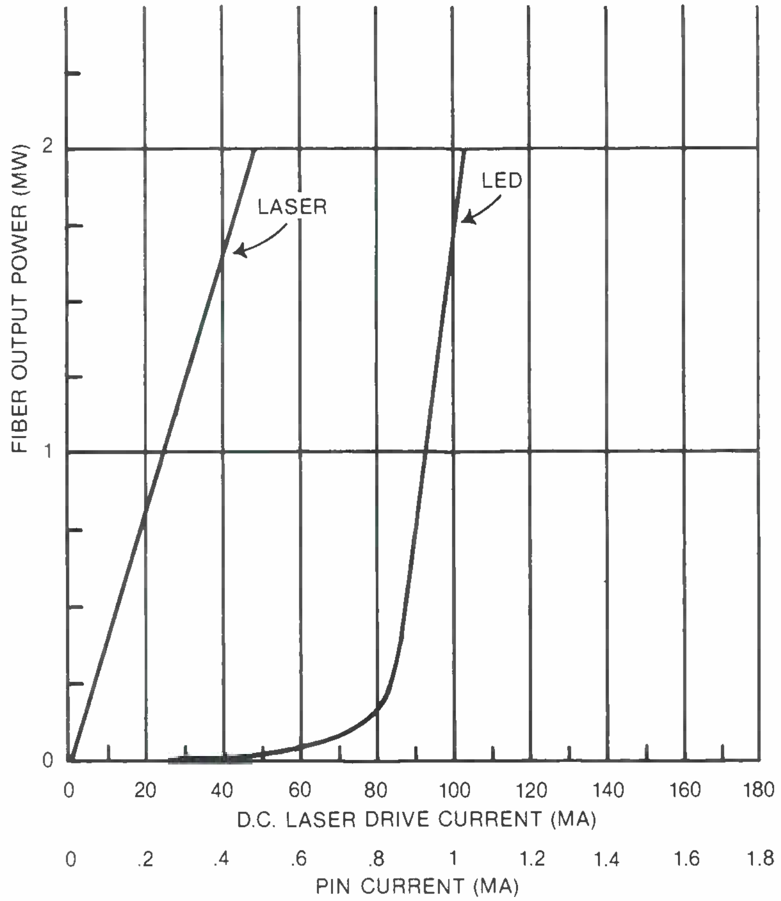

Fig. 6. Semiconductor laser turn-on characteristics.

## VIDEO AND AUDIO TRANSMISSION TECHNIQUES

### Modulation Techniques

In general there are three basic ways to modulate information onto an optical carrier. These are intensity modulation (light amplitude carries the information), frequency modulation (pulse speeds directly correspond to input signal levels), and digital pulse code modulation.

### Intensity Modulation

Intensity Modulation (referred to as IM or AM) is the simplest form of modulation. Here an incoming signal such as video is used to directly drive an optical device. Thus, maximum amplitude of video being "white", would result in the most output light and bottom of sync the least. Unfortunately, as shown in Figs. 6 and 7, optical devices do not turn on in a linear fashion. As a result, linear distortions are introduced to the video signal when such modulation techniques are implemented. In addition, the signal-to-noise ratio of the signal is directly correlated to the optical power. As a result, attenuation in a system lowers signal to noise directly. Further, since most optical devices do not completely "turn off" (particularly lasers) there is always an optical noise floor present. For broadcast applications (EIA RS-250-B) such systems are not widely used.

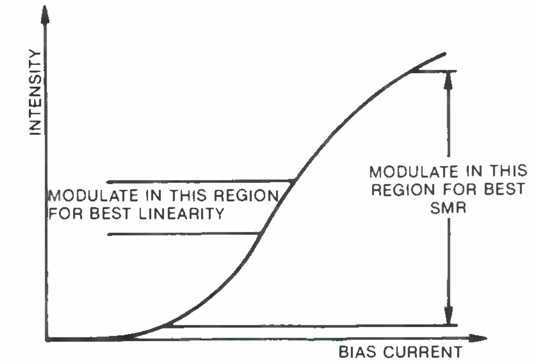

Fig. 7. Typical LED characteristics.

## Frequency Modulation

Frequency modulation devices are often used to help overcome the limitations of optical devices. In general, an FM approach is more complicated and costly but removes the problems of signal quality from the optical domain to the electrical domain. Here an input signal (video or audio) is frequency modulated prior to driving an optical device. All problems related to required SNR or linearity are solved by proper design of the frequency modulator. The desired output being a square pulse train where the input signal information is carried in the time domain as pulse spacing. Audio information is generally contained as FM subcarriers added to the video; then the entire signal is remodulated to avoid non linearities in the devices.

## PCM or Digital

As mentioned earlier, fiber optics is a technology intended to be operated in a pulsed mode, thus it is particularly suited to FM and digital approaches. In telephony applications, the relatively narrow bandwidth of a single voice channel can be digitized and multiplexed with thousands of other similar channels. Video on the other hand, is a much higher bandwidth signal and results in very high bit rates. In evaluating digital systems a user must keep in mind analog performance requirements. As a result, digital systems are generally evaluated end to end on the basis of the specific application. Two major factors affect digital systems performance: sampling rate and number of bits per sample. The Society of Motion Picture and Television Engineers (SMPTE) has done a very thorough job in correlating bits per sample (quantizing error) to equivalent signal to noise ratio. It is perhaps, worthwhile to provide a quick review.

In general, it has been shown that 8-bit sampling can provide excellent television pictures. This will generally result in bit rates (depending on sampling frequency) of up to 115 Mbits. However, this results in an equivalent signal-to-noise ratio of 56 dB. In general, most analog systems have allocations of performance to various portions of transmission that can require up to 67 db SNR. Unless the user can insure an entire digital transmission, higher sampling rates should be used. As a guide (again based on SMPTE digital publications), 9 bit sampling systems should be used where 60 dB SNR is required and 10 bit systems where 67 dB SNR is required. Such systems result in bit rates in excess of 150 Mbits per second.

## Performance Requirements

In general, fiber optic transmission requirements must continue to meet the needs of existing transmission parameters. The EIA RS-250-B standard has served the industry well and continues to be the bench mark by which transmission systems are measured. It is a very comprehensive document but in general requires short haul systems (most fiber optic systems today) to deliver 67 DB SNR with 2% diff. gain and .5 degrees differential phase error. In applications for teleconferencing and CATV obviously lower specifications apply and cost-effective solutions exist for virtually all performance requirements.

## Multiple Video Transmission

Because of the large information carrying capacity of fiber optic systems, they are frequently asked to send multiple video signals over a single optical fiber. Where required, there are several methods for accomplishing this. These are Wavelength Division Multiplexing (putting different wavelengths of light onto a single fiber), Frequency Division Multiplexing (putting multiple FM subcarriers through a single optical device), and Digital Multiplexing.

## Wavelength Division Multiplexing

This multiplexing technique is primarily used to reduce the number of optical fibers required to meet a specific transmission requirement. Basically it requires two or more complete fiber optic transmission systems operating at different optical wavelengths. Utilizing a passive optical multiplexer (basically a prism) multiple optical wavelengths may be placed onto an optical fiber and then removed. Similar techniques can be used to accomplish bidirectional transmission. Several considerations are important in designing such systems.

First, adequate separation (measured in dB of each optical channel is required. Optical crosstalk between channels results in lowering the effec-

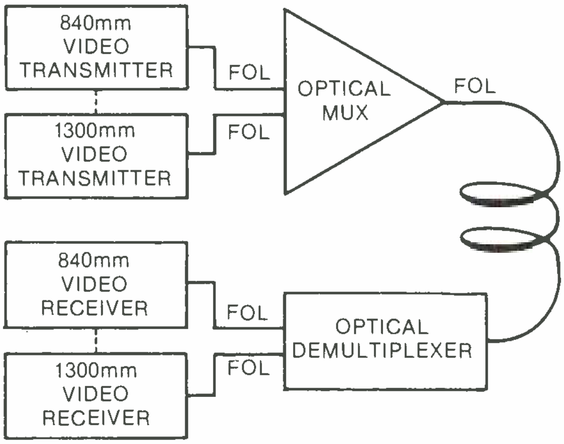

Fig. 8. Typical WDM configuration (FOL = fiber-optic link).

tive SNR of the link. Secondly, passive devices result in some optical attenuation when used (1-5 dB per device). As a result, effective transmission distances must be reduced when attempting to use WDM techniques. Lastly, most optical devices change output wavelength over temperature and the band pass of such WDM devices must be wide enough to accommodate the range. In general, fiber costs have dropped sufficiently that WDM is only cost effective when used to add capacity to existing installations. Furthermore, since optical separations are relatively poor, WDM techniques are only appropriate for FM and digital systems whose carrier-to-noise requirements are equivalent to or less than the WDM components.

### Digital Multiplexing

As mentioned earlier, digital transmission rates for video are very high, particularly with regard to short haul requirements in an analog domain. However, even rates of 180 Mbits (243 for serial digital components) are less than current telephony rates. Serial transmission of 565 Mbits are now commonplace with demonstrations in the gigabit range occuring by numerous manufacturers. As a result such high speed transmission offers the promise of low cost high bandwidth channels. As these systems are proliferated it is increasingly obvious that multiple high quality video transmission will be most cost effective over fiber optics systems. In general, multiplexing applies equally to ancillary signals. Audio and data channels are similarly multiplexed together or with video using one or more of the above multiplexing techniques.

## INSTALLATION CONSIDERATIONS

Installation of fiber optic systems is rapidly increasing. System design of each system requires numerous considerations, the following represents a guide to implementing a system.

### Performance Requirements

First, the system engineer must determine what end to end performance requirements are needed. For video this can range from a very high performance entrance link to a low performance security camera. Determining performance requirements first can expedite equipment evaluation and insure the most cost-effective solution.

Once system performance of a link is determined, optical loss budgeting must occur. This is governed by the distance required and the manufacturer's specifications. In general, fiber optic systems specify an optical loss budget at a given wavelength. Subtracting from this number connector losses, splice losses, fiber losses, and future margins for additional splices and/or WDM components, will determine whether a particular system is acceptable and whether repeaters are required.

Optical loss affects the performance of a fiber optic system. Thus, it is worthwhile to minimize these wherever possible. In general, the optical loss of a link should always be measured to insure it meets calculations. There are basically two methods. First, an instrument called an Optical Time Domain Reflectometer (OTDR) is frequently used to measure attenuation or look for breaks in the fiber. It operates on the principle of sending a pulse of light and evaluating back scattered or reflected light in the time domain. This instrument provides a graphical representation of the fiber as a function of distance. It can literally pinpoint a break in a fiber to approximately a meter even over 10's of kilometers.

A simpler method is to use a simple optical meter and the system being installed. First, the user measures output power of the transmitter or launch power. This should be done with a patch cord to account for the first connector interface. Then, at the end of the fiber, received power is measured to insure it meets expectations. Once this is accomplished, the fiber optic system installation can be completed.

### Frequency Division Multiplexing

This technique involves multiple FM modulators operating at different carrier frequencies and then summation of the signals. This is a widely used technique in coaxial cable distribution. Unfortunately, in optical systems the non-linearity of the optical devices results in large intermodulation distortions. As a result, wide spacing of carriers has been required in systems built to date. Further, insufficient experience has been gained regarding changes in device characteristcs with time that could result in long term increases in intermodulation distortions. This technique requires operation of the optical devices in an intensity modulation mode, which as discussed earlier, is not a desired application in fiber optics. This however, may turn out to be suitable for lower quality transmission requirements in the future such as CATV or teleconferencing.

### Cable Specifications

In general, specifying cable for transmission applications is relatively easy. Step index fibers cost the same as higher performance multimode or single mode fibers but do not offer bandwidth. As a result, single mode or multimode fibers are chosen. They are comparably priced and the selection criteria is based on other factors. Because multimode fibers are larger in core diameter they are easier to splice and connectorize. However, they have higher attenuation and lower bandwidth. As a result, in very long distance transmission (greater than approximately 25 Km), single mode is generally used. In shorter distances, (with the exception of telephony which is such a large user) standardization and large bandwidths lends itself to single mode) multimode cables are generally selected. In choosing a cable, numerous factors should be considered.

1. ***Attenuation.*** This will determine distance. It is specified in terms of dB/km. Thus if a cable has a specified attenuation of 3 dB/km, 4 kilometers will attenuate 12 dB of light. Remember attenuation is a function of wavelength. Short wavelength (800-900 nm) is used for short distance and vice versa.
2. ***Bandwidth.*** This only applies to multimode cables. It is generally specified in terms of MHz-km. Thus a cable specified as 800 MHz-km would have 80 MHz bandwidth end to end over 10 kilometers. There is a factor called concatenation which results in actual bandwidths greater than predicted by a specification. Cable manufacturers can provide additional specifications. In general the bandwidth requirements are only a consideration in FM and digital systems. With FM it is desirable to have sufficient bandwidth to pass the upper end of the FM modulators deviation including sidebands. Of course, in digital you must pass the bit rate.
3. ***Construction.*** Specific applications require specific types of cable. For example, for an aerial hang, UV resistant jackets are required. Similarly, for direct burial, rodent-proof jackets are required. In general, cables for every application and environment are available, however a user must insure he selects the correct cable for the application.

## FIBER OPTIC SYSTEM PLANNING

In general, implementing a fiber optic system is in many ways similar to a coaxial system. After becoming familiar with connectors and cables, users find installations are actually simpler and easier. Several areas to consider are:

### Loss Budgeting

THIS IS THE MOST IMPORTANT PART OF DESIGNING A FIBER OPTIC SYSTEM. In general, development of a loss budget is critical in installing a system that will meet the performance expectations of the user. It is a very simple process designed to insure that adequate light is received by the receiver to meet the performance requirements. First, it is important to learn to think of distance in dB. This is because of the number of variables that can attenuate light in a system. Light attenuation is a function of many factors thus manufacturers are loathe to guarantee a certain distance specification, but rather base their specifications on received light levels. Thus loss budgeting is a process of adding up all the known losses plus contingency and insuring the equipment being selected is compatible. Thus, such a process consists of:

Determining the launch power of the transmitter in dBm. From this value the following losses are subtracted.

a. Connector losses
b. Cable splice losses
c. Cable attenuation (This is dB/km and is wavelength dependent.)
d. Margin for future cable splices
e. Margin for future devices as couplers of multiplexers to be inserted. (This is generally important where future use of wavelength division multiplexing is anticipated.)

When all of the above values have been quantified in dB, they are simply added to obtain the worst loss likely to be incurred. This value is then subtracted from the launch power to determine the worst expected optical receive power expressed in dBm. This value is measured against manufacturer specifications to determine if system performance will be acceptable. If a specific system is weak on optical power, then light amplifiers can be employed to increase the total loss budget for a system.

### Patching

Virtually all fiber optic connector manufacturers make "barrels" compatible with their connectors. Generally connectors which are used to terminate cables are "males"; barrels and device mount housings are "females". Bulkhead mount barrel connectors are used to construct patch panels for mass termination of fiber optic cables. Small, highly flexible patch cords are available to provide patching flexibility to large fiber optic installations. This is the generally used technique within common carriers to provide maximum flexibility. Virtually all connectors manufactured provide consistent performance even after hundreds of matings. As a general rule, after selecting a fiber optic connector, the manufacturer is the best source of information on such options.

## Switching

No ideal optical switching solution has yet come out of the laboratory and found general acceptance. Optical switches are available which provide mechanical switching between fibers, however because of the mechanical nature of such a switch, and the extremely tight tolerances required, some optical losses are incurred.

Semiconductor switches are currently being evaluated as a preferred alternative. These devices promise switching directly analogous to semiconductor crosspoints used in today's electrical routing systems. Virtually all routing switching today is accomodated in the electrical domain by either decoding the fiber optic signals back to their baseband signals or more simply using an RF or Digital routing switcher. These latter approaches provide multiple passes without substantial signal degradation. Most major fiber optic systems manufacturers also provide compatible routing switcher equipment for large installations. When such installations are being considered, it becomes important to consider the electro-optic interfaces and insure compatibility between switching and transmission systems.

## Cables

There are literally hundreds of types of fiber optic cables for virtually every application. The construction of the core glass or fiber is virtually identical in most cables (especially since there are only a few manufacturers of fiber), all of the variations result in differences in cable design. Cables come with many different characteristics, some of which are:

1. All dielectric construction
2. 1-144 fibers in cable
3. Suitable for direct burial with rodent proofings
4. Aerial hanging cable with U.V. resistant jackets
5. High moisture or underwater application
6. High pulling strength
7. Special cable for long vertical runs (glass does not support its own weight)
8. Hybrid cables with both copper and fiber capabilities

As a result it is important to work with a manufacturer in selecting a cable. Most installation problems result from cables being used in applications for which they were not designed. This problem is easily prevented by thorough discussions with cable and system suppliers.

In multiple fiber cables it is necessary to break out individual fibers with a "breakout kit". This is a simple junction technique generally done with a fusion splicer to break out individual fibers into individual cable for termination. Again, all cable suppliers provide simple solutions to such problems.

## Installation

Installation of fiber cables is generally simpler and less costly than equivalent coaxial cables. Design of cables has reached the point where they have bending radii as small as an inch and can accept pulling loads of several hundred pounds. Because these cables are small and light for their information capacity, they come in very long lengths. As a general rule cables 2 km long are readily available with custom cables up to 5 km. Installation practices based on existing cable practices have been found quite acceptable. Again, working with a cable supplier can help point out the difference.

## Connector Installation

Installation of fiber optic connectors has advanced to the point where it is a relatively simple process depending on the connector. Generally the installation of a connector consists of:

1. Cable preparation
2. Crimp or glueing of connector
3. Polishing
4. Final preparation

Specific installation instructions for a connector are available from all connector manufacturers. Generally, installation is accomplished with a connector kit available from the connector manufacturer. Once a cable is properly terminated, it is ready for connection to transmission equipment.

## Test Equipment and Troubleshooting a Fiber Optic Link

There are many types of test equipment used in fiber optic systems evaluation and troubleshooting. Most of these pertain to ascertaining the optical performance of the link. Some of these equipment types are:

1. ***Optical Power Meter.*** Reads received optical power in dBm (preferably). Generally comes with connector adapters to permit direct connection to a fiber optic cable. These units are relatively inexpensive ($500-2000) and very easy to use. They are mandatory for any fiber optic user. Applications include verifying that received power matches manufacturers specifications, confirmation of calculated loss budgets, continuity verification; if no light is being received, the fiber may be broken.

2. ***Optical Time Domain Reflectometer.*** An instrument that measures the backscattered light down a fiber and based on its time after origination determines distance. These are used to precisely locate discontinuities in a fiber, evaluate the quality of splices and connections as well as characterize newly installed fibers. Such instruments provide a hard copy record of an individual fiber's characteristics which can be later remeasured to evaluate changes in performance. Generally this instrument is required by large volume users and installers. Priced in the $20,000 range, it is also available on a rental or service basis from many vendors.
3. ***Optical Attenuator.*** This is a variable attenuator capable of varying the amount of light through a fiber. It is generally used by equipment manufacturers to measure the range over which their receiver will operate. Fixed value versions are used in the field to "pad down" received light to meet manufacturers specifications.
4. ***Bandwidth Tester.*** This instrument is used to measure the bandwidth performance of individual fibers. Not required on single mode systems today and generally only needed by cable manufacturers to measure cable performance for grading.
5. ***Optical Spectrum Analyzer.*** Another rather expensive instrument used to quantify the spectral width of optical devices. Important for manufacturers of such devices but certainly not needed by a system installer or user.

As a general rule, we recommend a power meter as a mandatory tool for any use. It is inexpensive and easy to use and can provide useful information during installation. Again, before any receiver is connected a power meter should be used to verify received power is as expected.

### Troubleshooting

There are many areas to look for problems if they occur, however the following procedures apply to virtually every case.

1. *Assume no or low received light level.* There is probably a squelch or alarm indication at receiver. First step is to check transmitter for launch light at appropriate level. If light out of transmitter is low then problem is in transmit card. If however, launch power is correct, then problem exists in fiber optic link.
2. *Verify received optical power level using a power meter.* If level is acceptable, then most likely problem is on the receive card. In some systems, it is possible that the transmitter can put out light with no modulation. Verify that receive card operates by direct connection to a transmitter, if not operating trouble shoot the receive card.
3. *In general, an OTDR is required at this point to measure performance of link and pinpoint trouble spots.* However, most problems (barring a backhoe digging up a cable) tend to occur very near the ends of cables. Patch cords get pulled on, connectors are bad, etc. Thus, the first place to look is the connections near the equipment before necessarily needing an OTDR. Failing this, an OTDR provides easy test of the link and will pinpoint the problem.

## SUMMARY

In general, fiber optic systems and equipment have become very easy to use. The requisite test equipment is available and the technology has reached the point that newcomers can handle most installations. All vendors provide consulting service (generally free) and a large successful installed base of experience already exists.

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2. P. Mountanos "How to Choose an Analog Video Fiber Optic System", Broadcast Engineering, June 1984.
3. "Digital Video" SMPTE publication, March 1977.

## 4.5

# Aural Broadcast Studio Transmitter and Intercity Relay Service

John E. Leonard, Jr.
*President*
*Gentner RF Products*
*San Jose, California*

## INTRODUCTION

The Federal Communications Commission (FCC) has defined an aural studio-to-transmitter link (STL) as a fixed station used to transmit the aural program material between a studio and transmitter of a broadcast station. Intercity relay service (ICR) is used for the transmission of aural programming between broadcast stations. In other words, an STL or ICR is a radio link used between two fixed points whose primary purpose is to carry program audio. In this chapter, STL and ICR will be used interchangeably, with emphasis on the STL application. The STL offers an alternative to the use of leased telephone circuits to the station with studio and transmitter at separate locations. The STL permits other signals to be carried in addition to the program material.

Currently, the radio links or microwave systems for this service use frequency modulation (FM) and operate in a band of channels at 950 MHz. Additional frequencies are available at 18 GHz, but at the time of the chapter's preparation the FCC reported that it had not received a single application for a license at these frequencies. For this reason, while 18 GHz will not be overlooked, the 950 MHz band will receive the major attention below.

In this chapter the current FCC requirements and procedures of licensing, as well as the available channels will be covered. Since Rules are subject to change, the information here should be checked with a current set of Rules. Typical equipment, its configuration and uses, and propagation characteristics are presented. At the outset, a review of the reasons for selecting the STL are presented.

## STL SELECTION

The reasons for the selection of an aural STL in many cases are economic. With the deregulation of the telephone industry, the broadcasting industry is seeing major increases in the cost of program-grade circuits. It is anticipated that these costs will continue to rise in the future. There are a number of methods for assessing the economic viability of an STL. One of the simplest is to take the cost of the STL system and divide it by the monthly charges of the leased special access private lines it will replace. The resultant number is the number of months required to pay for an STL system with the money that would have gone for special access private line service. As an example, if the program circuits for a station are $475.00 and an STL system to do the same job will cost $8500.00, the payback period, without considering interest, would be 17.89 months, or just under one and one-half years. Even without adding the cost of financing the STL system or the loss of interest income by not using this $8500.00 for other investments, it can be seen that this would be a good investment for the station.

Another compelling reason for STL selection is the infeasibility of private line facilities. Constructing new lines in an area where there are no utilities and, possibly, no right-of-ways, can be very expensive. Moreover, in some parts of the U.S. program quality circuits are simply not available.

The quality of service is also a factor, as is having the interconnecting circuits totally under station control. With quality, the transient response characteristics of the typical STL system, most noticeably at lower audio frequencies, is a major contributing factor. For many users of STL systems, the factor of the reliability of the STL is of importance.

In summary, the factors favoring the selection an STL system are:

- Quality of Program Transmission
- Higher Reliability
- Total Control of Station Facilities
- Financial Consideration or Savings

## FCC REQUIREMENTS

Aural STL and ICR service is controlled by FCC Rules and Regulations Part 74 Subpart E. No attempt will be made in this Chapter to fully reproduce these Rules, but important segments in effect at the time of writing are included. Under these, only licensed broadcast stations may hold an STL/ICR license. It is to be noted that this service is for AM and FM stations, with television aural only licensed on a secondary basis.

### Available Frequencies

In considering the available frequencies or channels, some history may help in understanding the current situation for this service. The STL/ICR service dates from the early 1950's when, in 1953, there were some 47 licenses authorized. In this era the service had the spectrum from 890 MHz to 952 MHz available for all broadcast stations. Until 1961, TV stations had 41 channels in the 890-911 MHz band, 29 channels for AM stations in the 925-940 MHz band, and there were 23 channels in 940-952 MHz for FM stations. Only the 940-952 MHz spectrum was exclusively broadcast, all others were assigned on a shared or non-interference secondary basis. In 1961 the FCC altered the service such that separation by service was eliminated and the band was set as 942-952 MHz. Then in 1968 the Commission began a rule making that resulted in a reduction of the exclusive band to 947-952 MHz and 9 channels. 942-947 MHz was placed in a "reserved" status, with licenses issued on a secondary basis. The next change to available spectrum on an exclusive basis came late in 1984 when 944 to 947 was returned to STL/ICR service and increased the available channels to 15. New additional spectrum was allocated in 1983 at 18 GHz, but placed in a "hold" mode, until a rechannelization occurred in mid-1984. The 18 GHz channels are not available on an exclusive basis but rather on a co-primary basis with stations in the Point-to-Point Microwave Service operating under Part 21 of the FCC Rules and Regulations and stations in Private-Operational Fixed Service operating under Part 94. On October 31, 1985, the Commission revised the channelization and bandwidth criteria of the aural STL band, 944-952 MHz (MM Docket No. 85-36). The new rules "split" the existing 500 kHz channels into 25 kHz "segments" which can be "stacked" to form channels of varying bandwidths. The Commission also adopted RF bandwidth "criteria" for aural STL operation: 300 kHz for FM stereo stations using subcarriers, 200 kHz for AM stations and the existing 500 kHz bandwidth as a "wideband" criterion.

The fifteen 950 MHz channels available are:

| MHz | | |
|---|---|---|
| 944.5 | 947.0 | 949.5 |
| 945.0 | 947.5 | 950.0 |
| 945.5 | 948.0 | 950.5 |
| 946.0 | 948.5 | 951.0 |
| 946.5 | 949.0 | 951.5 |

Each of these channels is 500 kHz wide, with the use of frequency modulation (FM) required. There is no transmitter power output restriction other than that necessary to render satisfactory service. And, no type approval or acceptance is necessary for the equipment used at these frequencies. These frequencies are for STL and ICR service, and are assigned for a specific path or hop, that is from one point to another. At 18 GHz two spectrum segments are available, 18.64-18.70 GHz and 18.88-18.94 GHz. These two segments are divided into 12 paired channels, each 5 MHz wide. A paired channel has one transmit channel and one receive channel for full duplex service.

The specific frequencies are:

Transmit (or receive)

| MHz | | |
|---|---|---|
| 18,642.5 | 18,662.5 | 18,682.5 |
| 18,647.5 | 18,667.5 | 18,687.5 |
| 18,652.5 | 18,672.5 | 18,692.5 |
| 18,657.5 | 18,677.5 | 18,697.5 |

Receive (or transmit)

| MHz | | |
|---|---|---|
| 18,882.5 | 18,902.5 | 18,922.5 |
| 18,887.5 | 18,907.5 | 18,927.5 |
| 18,892.5 | 18,912.5 | 18,932.5 |
| 18,897.5 | 18,917.5 | 18,937.5 |

A two-way system may be used or an application can be made for only one of the two frequencies making up that paired channel. These frequencies require that they be coordinated, with the users of them governed by Parts 21 and 94, and such coordination should use the procedures required in Parts 21 and 94. It is suggested that if use of these frequencies is being considered that a consulting engineer or others familiar with all the requirements be retained to assist. Section 1, Chapter 4 of this *Handbook* touches on these services. Transmitter power output at 18 GHz is limited to 10 watts and type acceptance of the transmitter is required. It should be noted that at 18 GHz, digital modulation, in addition to frequency modulation (FM), is permitted.

The frequency information presented above is for the continental U.S. and other states and possessions governed by the FCC. In Puerto Rico 942.5, 943.0, 943.5, and 944.0 MHz are available for licensing on a primary basis. Likewise, stations operating in the 942-944 MHz as of November 21, 1984 may continue to operate on a co-equal primary basis. It should be noted that in the Report and Order released January 18, 1985 (FCC 84-557) regarding aural STL spectrum, the Commission stated it would consider on a case-by-case basis a possible waiver for use of frequencies in the 2 GHz region in areas where 944-952 MHz operation is not possible because of the lack of sufficient spectrum.

One additional type of permissable service deserves mention. This is the aural broadcast microwave booster station. The booster station is a station that must receive and amplify the signals of the originating station and re-transmit them on the same frequency without significantly altering them in any way. With a booster, the licensee is responsible for correcting any condition of interference that results from the radiation of radio frequency energy outside the assigned channel. In essence, these Rules permit a repeater station to be created that must function as an on-frequency repeater, or what might be called a beam bender. A license is required for a booster station, and it can operate in conjunction with any STL/ICR system.

## Frequency Selection

As noted above, frequency coordination is specifically required for use of the 18 GHz STL/ICR channels. At 950 MHz the procedure most commonly used is outlined in Section 1, Chapter 3, "Frequency Coordination." Specifically, Aural STL considerations are addressed beginning on Page 1.3-57. In essence, the procedure is to work with a local frequency coordinating committee to find a channel that can be used between the two points involved. As indicated above, consulting engineers or other service firms may also assist in this process. The desired end result is a channel that can be used for the required service and that does not receive interference from another station, or cause interference to any station already licensed.

With only fifteen channels available at 950 MHz and over 10,000 radio (AM & FM) stations in the country, great care must be taken in most cities to successfully use an STL or ICR system. This involves correct engineering of the system at the beginning and proper maintenance of it over time.

One technique used in many areas to make multiple use of channels is the cross polarization of antenna systems. With one system operating with horizontal polarization and the other vertically polarized, some 20 dB isolation is obtained in practice. Differences in the vectors of the actual paths and topography will also permit channel re-use or sharing.

## Antenna Requirements

The Rules and Regulations place minimum directive requirements on the STL/ICR antenna at 950 MHz and both transmitting and receiving antenna minimums at 18 GHz. At 950 MHz, the current requirement is that a directional antenna is required. No specific parameters are placed on this antenna, but the requirement of narrower beamwidths and reduced sidelobe radiation in congested areas or to resolve an interference problem is contained in the Rules. See Section 1, Chapter 3, page 1.3-58, paragraph 6 for comments developed by one frequency coordinating committee.

At 18 GHz the requirements of the Rules and Regulations are more specific. First, the directivity requirement applies to both transmit and receive antennas. There is first a division based upon whether frequency congestion exists in the area the STL will operate. Ignoring this point for the moment, a minimum gain of 38 dB over an isotropic antenna is required for all antennas. The values presented in the two divisions below represent the suppression required in the horizontal plane without regard for the polarization plane of intended operation.

For areas not requiring frequency coordination, and without frequency congestion, the following "Standard B" applies:

| Angle from Center of Main Lobe | Minimum Radiation Suppression (dB) |
|---|---|
| 5 degrees up to, not including 10 degrees | 20 |
| 10 degrees up to, not including 15 degrees | 24 |
| 15 degrees up to, not including 20 degrees | 28 |
| 20 degrees up to, not including 30 degrees | 32 |
| 30 degrees up to, not including 100 degree | 35 |
| 100 degrees up to, including 180 degrees | 36 |

It must be noted that the Rules give the Commission the right to require replacement, at the licensee's expense, of a Standard B antenna with a Standard A antenna if there is an interference problem or the likelihood of interference.

The Standard A antenna requirements apply to areas with frequency congestion and as noted above. The "Standard A" is:

| Angle from Center of Main Lobe | Minimum Radiation Suppression (dB) |
|---|---|
| 5 degrees up to, not including 10 degrees | 25 |
| 10 degrees up to, not including 15 degrees | 29 |
| 15 degrees up to, not including 20 degrees | 33 |
| 20 degrees up to, not including 30 degrees | 36 |
| 30 degrees up to, not including 100 degrees | 42 |
| 100 degrees up to, including 180 degrees | 55 |

### Licensing

To license an aural STL/ICR, the filing of a FCC Form 313 is required. It is noted that the Rules and Regulations at this writing permit operation of an STL/ICR transmitter for up to 720 hours without a license. This is to permit operation while an application is being processed. As a normal procedure, a Special Temporary Authorization will not be issued for this service. Completion of this Form is aided by the companion instructions.

## STL EQUIPMENT

At 950 MHz there are currently two basic configurations of STL/ICR equipment being commercially manufactured for this service. These are:

A. Systems utilizing conventional inputs and outputs, but with two types:
   - Monaural
   - Composite

B. Systems utilizing conventional inputs and RF-type outputs.

An STL/ICR system is made up of a transmitter and receiver. In the 950 MHz service they must use frequency modulation (FM). At 18 GHz, FM or digital modulation techniques are permitted. Fig. 3 and 4 present block diagrams of several different systems.

### Monaural STL/ICR Systems

As the name implies, this type of system accommodates monaural program audio, that is, it has a program or baseband frequency response in the range of 50 Hz to 15 kHz. All STL systems available today have the capability of relaying more information than the program audio. As will be seen below in more detail, an STL transmitter, much like an FM broadcast transmitter, will convey programming and subcarriers with a variety of information. Most systems available have the capability of several subcarriers. One configuration uses two monaural systems for stereo. Most monaural systems utilize pre-emphasis in the transmitter and de-emphasis in the receiver to obtain the FM benefit. This must be taken into consideration when setting audio levels.

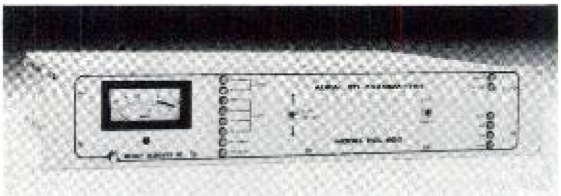


Fig. 1. Typical STL transmitter. (Courtesy Moseley Associates, Inc.)

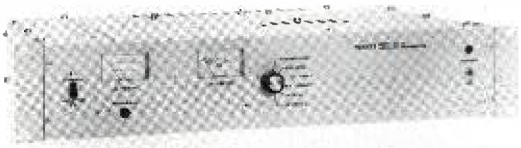


Fig. 2. Typical STL receiver. (Courtesy Marti Electronics, Inc.)

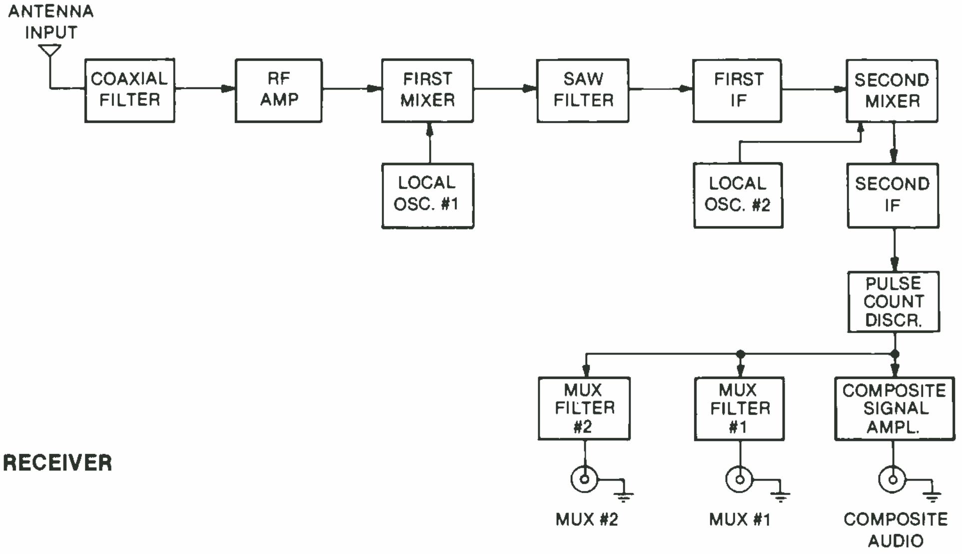


**Fig. 3. Block diagram—composite STL system transmitter and receiver. (Courtesy Broadcast Engineering)**

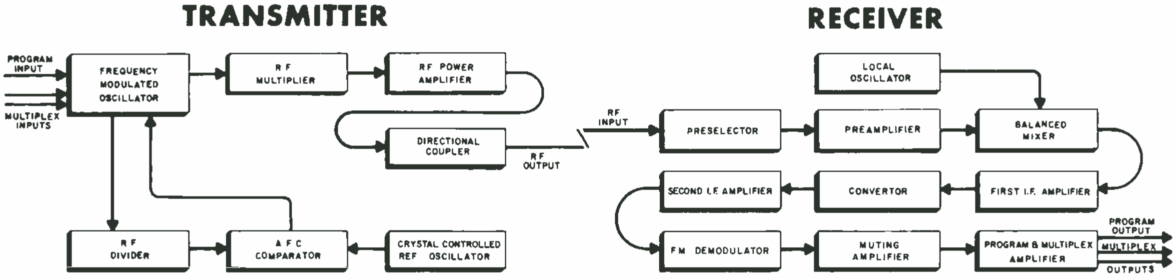


**Fig. 4. Block diagram—monaural STL system transmitter and receiver. (Courtesy Broadcast Engineering)**

## Composite STL/ICR Systems

The composite system conveys the FM stereo waveform on one STL carrier. With this system, the baseband or program input and output has a frequency response of 20 Hz to 75 kHz, or slightly above. Some manufacturers offer composite systems with response through approximately 100 kHz. A number of subcarriers can be conveyed above the programming present in the baseband. As this is a wide band system, it does not utilize pre-emphasis or de-emphasis.

### Transmitter

While there are differences between manufacturers on the exact techniques of transmitter design, there is a common theme. The input circuitry functions to provide proper level and impedance matching as well as any filtering necessary. As a general rule, STL transmitters do not include any audio processing. The modulator operates at a frequency less than the output frequency. For frequency control the use of phase-locked loops is common, referenced to a crystal oscillator. The transmitters manufactured today easily exceed the frequency tolerance required in the Rules. The modulator or modulated oscillator is then multiplied, mixed with another oscillator, or IF modulated to reach the final operating frequency. A final RF power amplifier stage then serves as the output. STL transmitters typically have an RF power output in the 7 to 20 watt range. Many contain a reflectometer permitting the measurement of forward and reflected power.

There are two basic types of STL transmitters, monaural and composite. With some manufacturers the differences lie more with the filtering in the receiver than in differences in the transmitter. This filtering is used to separate program audio from subcarriers. Some monaural transmitters contain a 15 kHz low-pass filter to prevent audio excursions into the spectrum occupied by subcarriers. Composite transmitters have typically not contained filtering.

### Receiver

As with the transmitters, there are common areas in STL receivers. Most employ several intermediate frequency (IF) amplifier stages. Double and triple conversion receivers are common. It is the receiver in the STL system that is the principal determinate of overall performance. As can be seen from the prior discussion on available frequencies, only 15 channels available at 950 MHz, extensive use of channel sharing has become the norm in many areas. It is the receiver that must perform to the utmost. Use of adjustable RF input attenuators, advanced techniques for obtaining selectivity such as surface acoustic filters (SAW), and high performance demodulation techniques are employed in many STL receivers. It is in two areas that the major differences between monaural and composite receivers will be found. These are the IF selectivity and the audio sections. In the audio sections, the filtering and amplification differs with the frequency responses necessary. With a monaural receiver, program audio is typically passed through a 15 kHz low-pass filter. This rejects any subcarriers that may be in use on the system. These subcarriers are in the 26 kHz to 100 kHz range. With a composite receiver, the program or baseband response is through 75 kHz, or as an alternative with some manufacturers through 100 kHz. Subcarriers are above this and normally have not been above 185 kHz.

### STL Maintenance

With the advantages of the STL come responsibilities that include maintenance of the equipment. Routine maintenance is an important part of insuring proper and trouble-free operation of the system. Depending upon the equipment selected, this maintenance can be the simple observation of operating parameters and an occasional cleaning dictated by the environment of the transmitter and receiver. As with most electronic equipment, heat, or excess heat, is the major concern.

Test equipment should be kept at hand and in working order to take care of a failure if it should occur. Test equipment requirements are determined by the equipment in use, but a volt-ohm meter (VTVM or DVM) is the basic measurement equipment needed for observation of dc operating parameters, including power supplies, a principal source of failures. Should the transmitter not have a built-in VSWR bridge, a directional wattmeter will prove useful. Such an inline wattmeter is helpful for locating transmission line and connector problems. An oscilloscope is needed for audio and similar troubleshooting. For more information on audio testing please see Section 7, Chapter 9 of this *Handbook*. A frequency counter is needed for verification of operating frequency, but can be supplemented by a frequency measuring service. One item of test equipment that is viewed by some as mandatory is an RF spectrum analyzer. While it may be necessary in making certain types of repairs, it is not needed for satisfactory daily operation on an STL. On those occasions where a spectrum analyzer is required, one may be rented or borrowed.

## STL EQUIPMENT CONFIGURATIONS

There are a multitude of ways that STL systems can be used to solve the interconnection requirements of the typical aural broadcast station. This section will explore various configurations. To enlarge or enhance the capabilities of an STL system, subcarriers are multiplexed on the carrier. This is the same process as multiplexing an SCA on an FM broadcast transmitter. Please see Section 3, Chapter 4 for a thorough presentation on the multiplexing of subcarriers on an FM carrier. The information presented there is directly applicable to the STL system, as to the characteristics of a frequency modulated carrier conveying subcarriers. In STL systems, frequency modulated subcarriers have been the most commonly used modulation technique. Amplitude modulated subcarriers have potential application but have not received wide use.

For the following sections, only the use of FM subcarriers will be discussed. The modulation technique used for the subcarrier determines the number of subcarriers possible and their frequency. Consideration must be given to the radio frequency bandwidth of the carrier in selecting the uppermost subcarrier frequency. STL channels are assigned a bandwidth of 500 kHz. To comply with bandwidth requirements, manufacturers use peak deviations of 40 kHz to 60 kHz and recommend the highest subcarrier center frequency to be 185 kHz.

### Monaural System

The monaural STL is used as implied by its name, to relay the monaural programming for an AM or FM station. Fig. 5 shows the monaural system. This system has the capability of conveying two subcarriers. These subcarriers can be put to many uses, usually carrying the command information from broadcast transmitter remote control system and feeding secondary audio, such

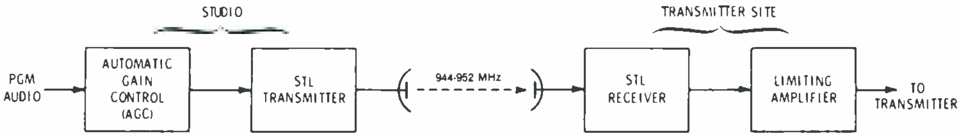


Fig. 5. Block diagram—monaural STL system, overview. Note portion of audio processing equipment. (Courtesy Broadcast Engineering)

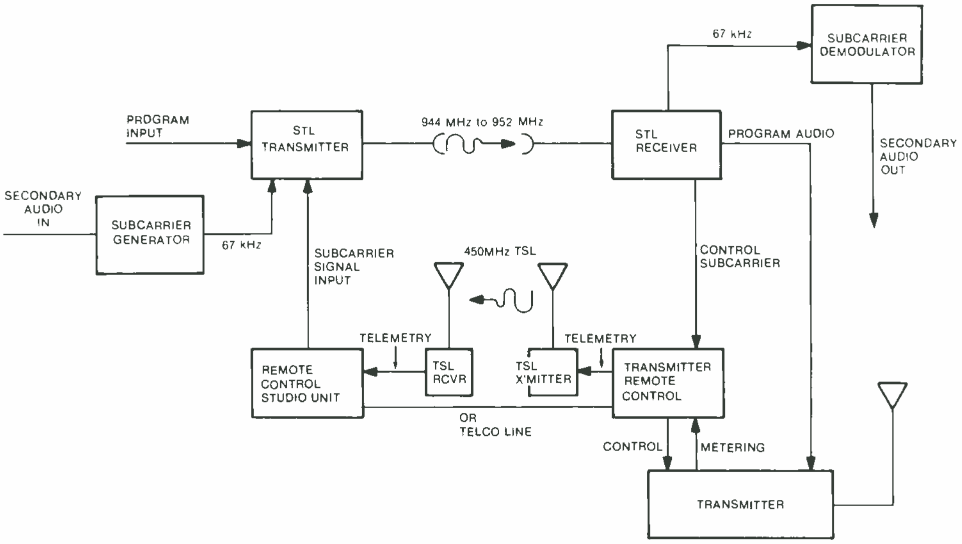


Fig. 6. Block diagram - monaural STL system, depicting use of subcarriers for command information of remote control system and second subcarrier for additional audio or other information feed. (Courtesy Broadcast Engineering)

as subsidiary program audio, data or intercom audio.

The subcarrier frequency used for the first subcarrier is in the 20 kHz to 30 kHz region, and the second subcarrier between 40 kHz to 70 kHz.

In Fig. 6, the first subcarrier is used to carry the command information for the remote control system to the transmitter site. For this remote control system, an SCA channel on the broadcast signal is then used to return the metering information. This would be representative of an STL system for FM use. The second subcarrier is carrying secondary audio, which in this example could be the SCA programming.

In using the monaural STL system it is important to verify if pre-emphasis and de-emphasis are employed. If this is the case, the same precautions that would be taken with an FM broadcast transmitter must be taken to prevent over-modulation from occurring. This is typically done by reducing the audio level feed to the STL transmitter by 10 dB, or placing all transmitter audio processing at the input of the STL rather than the input of the transmitter.

## Stereo STL Systems

For stereo applications, there are three types of systems in use. These are:

- Dual Monaural
- Composite
- RF Output

### *Dual STL*

The dual STL configuration consists of two monaural systems. Both systems are established on RF operating frequencies that enable them to operate within one 500 kHz STL channel. Given a channel center frequency of 950.0 MHz, with a dual system one system may operate on 950.125 MHz and the other on 949.875 MHz. This represents an offset from channel center of 125 kHz.

Fig. 7 depicts a possible dual STL configuration. This block diagram shows two transmitting antennas; however a transmitter combiner can be used to couple the two transmitters to a single antenna. A transmitter-to-transmitter isolation of at least 70 dB is desirable (see Section 1, Chapter 3, page 1.3-56).

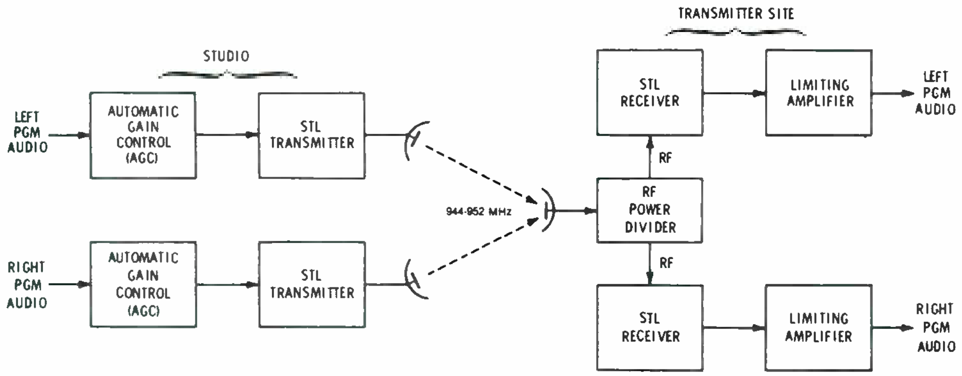


**Fig. 7. Block diagram - dual Stereo STL configuration. Separate transmitting antennas are shown, with an RF power divider used to permit a single receiver antenna. (Courtesy Broadcast Engineering)**

Because of the differences in STL transmitters, it is suggested that the manufacturer of the system be contacted for recommendations. A ferrite transmitter combiner is best suited for this use, because of the isolation provided between transmitters and the transmitter-to-antenna isolation. The subcarrier capability of most dual systems is that of two monaural systems. Because the dual STL consists of two monaural STLs, it permits switching to monaural transmission in the event of failure in one channel.

### *Composite STL*

The composite STL system is designed to convey the FM stereo waveform on a single carrier. That is, the complete composite baseband that makes up the stereo signal. Attention is directed to Section 3, Chapter 4 for a complete definition of composite baseband, and specifically to Fig. 1 on page 3.4-115. The program or baseband frequency response of most composite STL systems commercially produced have the capability of accommodating, with acceptable phase and amplitude characteristics, frequencies through 75 kHz. This permits the composite STL to convey the stereophonic waveform and one subcarrier from the studio to the transmitter. Some STL manufacturers offer expansion of this response to 100 kHz permitting the system to convey stereo and two or more subcarriers.

The advantages of the composite system are that only one RF carrier is used to transmit stereo, and the stereo generation equipment can be located at the studio. This single site location of stereo generator and all associated audio processing equipment can simplify servicing and audio set up. Although some feel that the sound of a composite system is superior because of the elimination of additional audio sections, pre and deemphasis, and filtering found in the monaural systems that make up the dual configuration, there is disagreement. Selection of a dual or composite component system should be based on a careful review of equipment specifications and costs in light of station requirements. Discussions with users of both types of systems may also be useful.

The composite system can convey additional subcarriers above the program or baseband information which makes bandwidth excessive. Fig. 8 presents a typical configuration. In this configuration one subcarrier is used for remote control command information and the other for secondary audio. Except for the specific subcarrier frequencies employed, the configuration for these subcarriers is identical to that shown for the monaural system.

AM stereo must be mentioned in regard to the composite STL system. Due to the nature of AM stereo (see Section 3, Chapter 2 for specific AM stereo information) a composite STL cannot be used for direct transmission of AM stereo. An RF output system, as described below for FM, could perform in the manner of a composite system. This leaves the dual configuration above or use of a composite configuration as shown in Fig. 9 for AM stereo applications.

### *RF Output System*

Fig. 10 shows a system, where the transmitter is a conventional composite transmitter as described above, but the receiver is unique. This receiver functions as an FM exciter. The receiver output can be used to directly drive the IPA stage of the FM broadcast transmitter. As the block diagram shows, this receiver uses a phase-locked loop (PLL) that is tied to a TXO reference oscillator for the frequency control. This reference is used as the last conversion oscillator. At this writing the FCC is licensing this approach on a temporary authorization basis only. The system represents a unique approach, but system engi-

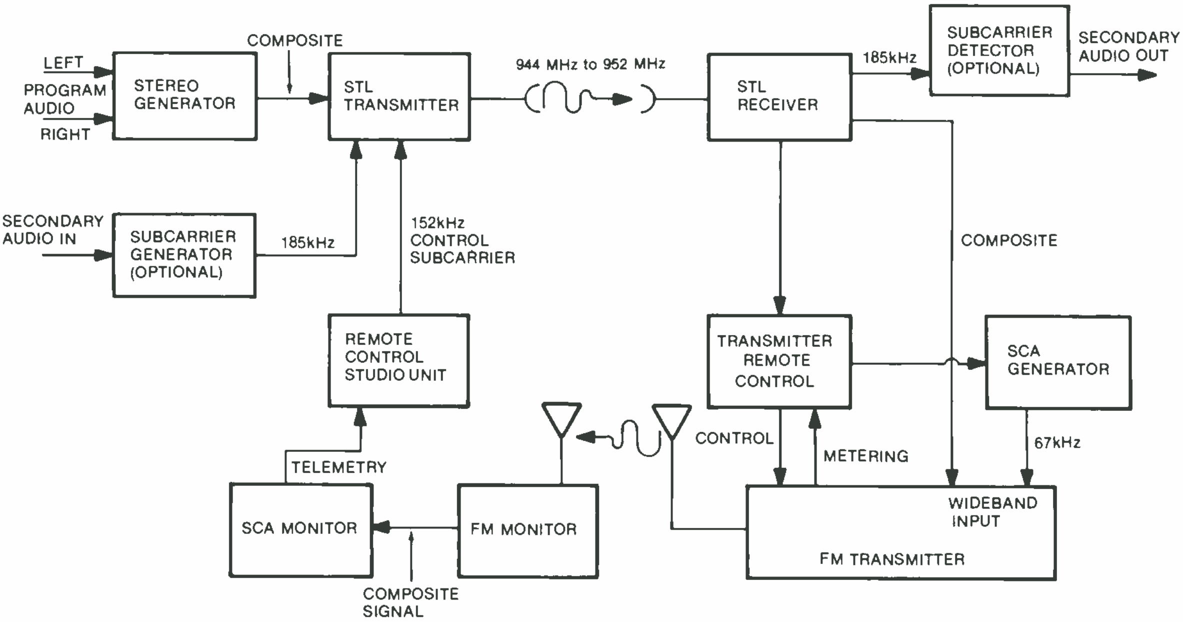


**Fig. 8. Block diagram - composite Stereo STL configuration. While this depicts an SCA generator at the transmitter, it is shown for the return of metering information from the transmitter remote control system. An SCA generator operating at 67 kHz could be located at the studio and directly transmitted by the FM transmitter. (Courtesy Broadcast Engineering)**

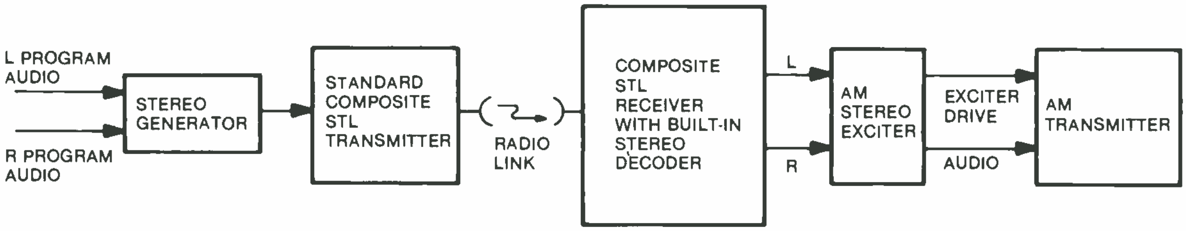


**Fig. 9. A basic AM stereo STL configuration utilizing the FM composite STL. By converting the left and right audio channels to the FM composite waveform and then decoding them at the transmitter site, the FM stereo system is used as a multiplex scheme. (Courtesy Broadcast Engineering)**

neering requirements go beyond the scope of this Chapter and consultation with the manufacturer is recommended if use of this system configuration is considered.

## SYSTEM PLANNING

In the implementation of an STL or ICR system the most important thing to insure reliable and correct operation is the planning that is done at the start of the project. As stated in the introduction to this chapter, major attention will be given to the 950 MHz band. If 18 GHz operation is being considered the reader is referred to Section 4, Chapter 2, "Microwave Engineering for the Broadcaster" for information on path studies and considerations. While the information presented below can be applied to 18 GHz, it is directed mainly to the lower band. To evaluate a potential path the services of a consulting engineer may be employed or the user should perform an evaluation using the information presented below.

### Path Evaluation

When planning the STL, the first point of consideration is the ability of a system to operate between the studio and the transmitter site: an acceptable path must be available for the system to function. This normally is interpreted to mean that a clear line of sight must exist between the two sites. If it is found that a line of sight does not exist between the studio and transmitter site, a repeater station may have to be used or the use

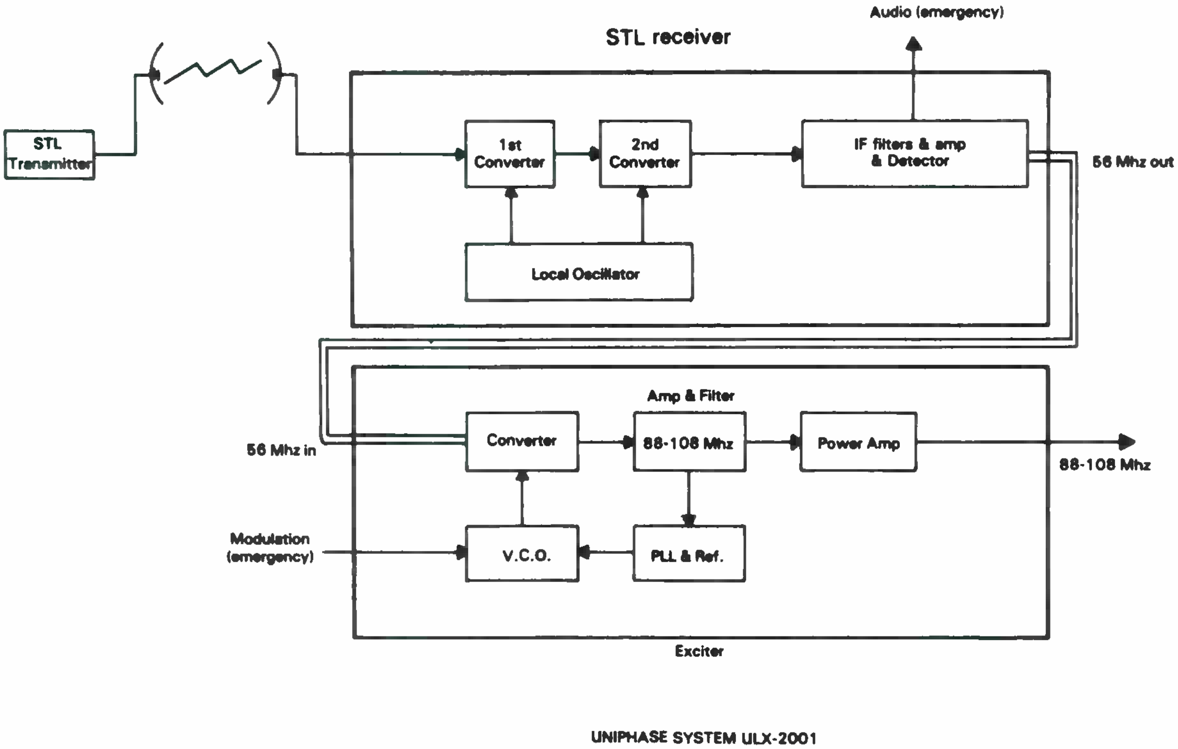


Fig. 10. Block diagram—RF output STL system. Micro Controls ULX-2001 system. (Courtesy Broadcast Engineering)

of an STL abandoned. While unusual propagation conditions can result in the operation of an STL system over a path that is blocked, it cannot be considered as being reliable over time. Exceptions to this are paths of short length over terrain that will not change. In this case, "short" means a distance of a few miles or less. When considering such a path, the opinion and recommendation of an engineer experienced in path evaluation at these frequencies should be obtained or an in-place test conducted.

### *Path Profile*

To begin the evaluation, topographic maps showing the studio and transmitter locations and all terrain between these points are needed. After locating the two sites, a straight line is drawn on the map between these two points. From this information a chart is prepared that is a profile of the path on graph paper. The end result will look much like Fig. 11. The particular graph paper must be the type used for these purposes, and it can be obtained from engineering supply firms or from some equipment manufacturers. This graph paper reflects the curvature of the earth in a given way, as discussed below, and is referred to as K factor.

Following completion of the profile, the available heights above ground at each end of the path should be drawn on the graph. A straight line is then drawn between these two points to represent the center of radiation between the STL transmitting antenna and STL receiving antenna. For required antenna heights, see the discussion below on Fresnel zones.

### *K Factor*

The relative curvature of the surface of the earth and the relation of propagation of an STL signal along that surface are considered in the creation of a K factor. The STL signal must be viewed as radiating in a straight line. Changes in temperature and water vapor cause the index of refraction to change. This can cause the signal path to curve toward the surface. The result is as if the earth had been "flattened" by increasing the radius by a certain amount (the K-factor). See also Section 4, Chapter 2, "Microwave Engineering for the Broadcaster," page 4.2-61 of this *Handbook.*

For this use the norm is to either use a K factor equal to the earth's radius (K = 1.0) or one that views the earth as slightly flatter (K = 1.33 or sometimes written as 4/3). When graph paper is produced using these factors they are referred to as true earth graph paper, where K = 1.0 and 4/3 graph paper, where K = 1.33.

The true earth paper can be viewed as being a pessimistic presentation with the 4/3 paper being optimistic. That is that the 4/3 paper antici-

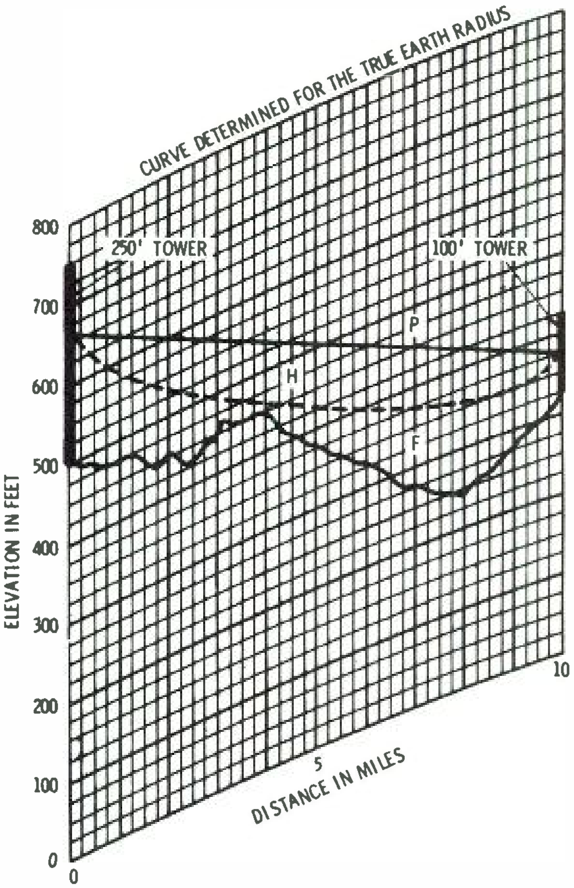


Fig. 11. Typical STL path profile drawn on true earth (K = 1.0) graph paper. P represents the center of radiation between transmit and receive antennas. The dotted line F depicts 0.6 First Fresnel zone. (Courtesy Broadcast Engineering)

pates that some positive refraction of the signal will occur.

*Fresnel Zones*

The Fresnel-Kirchoff theory was developed to explain the diffraction of light as obstructed by a diaphragm and the effects of transmission through an aperture of various characteristics. Light is an RF waveform of a high frequency, and thus these theories can be applied for microwave and STL purposes. As it will be used here, Fresnel zones can be viewed as various zones about the center of radiation, with the odd numbered zones possibly being additive and the even numbered being out-of-phase, and thus could be subtractive. It is the first fresnel zone that is of interest, and then only 60% (0.6) of that zone as it contains the energy that must be recovered.

All of this produces a formula that can be used to calculate the clearance needed above possible obstructions in an STL path. In fact, if viewed from the end, remember that the number produced is a radius from the center of radiation, and thus can be used to check clearance by objects that may be to either side, above or below the path center, such as a building.

This formula is:

$$H \text{ or } FR = 1316 \sqrt{\frac{d_1\ d_2}{f\ (d_1 + d_2)}}$$

In Fig. 13. note that $d_1$ is the distance from one end of the path to a possible obstruction in miles,

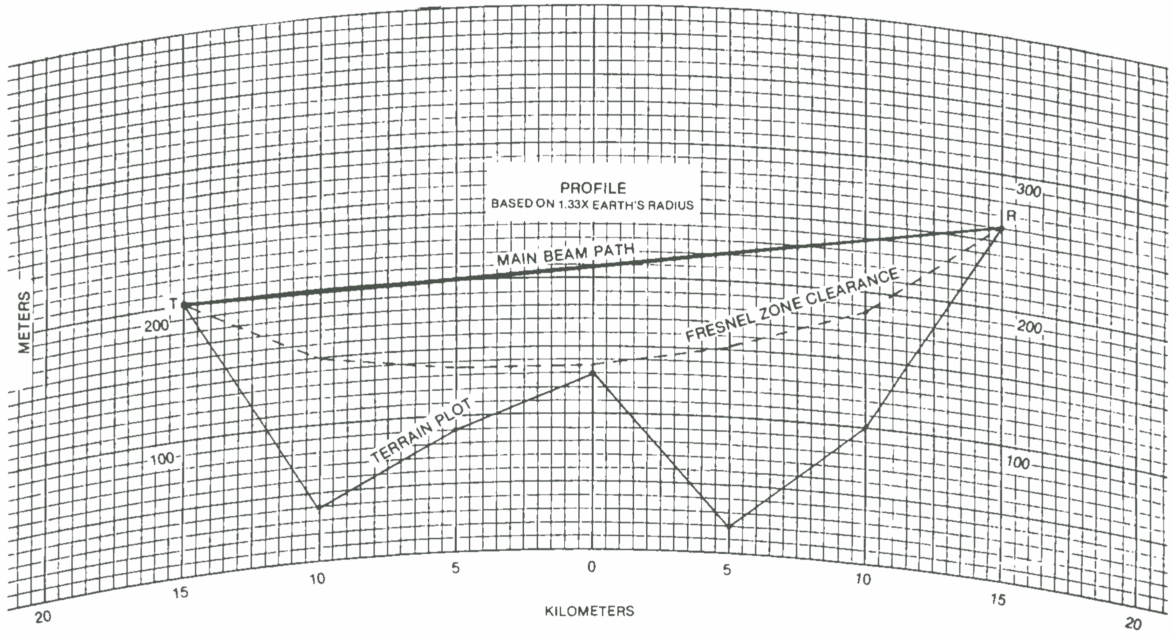


Fig. 12. Typical path profile using 4/3 or 1.33 profile paper. (Courtesy Broadcast Engineering)

and $d_2$ is the distance from that point to the other end of the path in miles. The $f$ in the formula is the operating frequency in MHz. The resultant, $H$, is the radius of 0.6 of the first Fresnel zone in feet. It should be noted that this dimension is greatest at the center of any path, no matter what the path length. Also if plotted accurately, it is elliptical in shape. This formula can be used to check for minimum clearance above, or around any possible solid obstruction in a path. Thus this formula as applied to the path profile, will assist in determining the minimum height of the transmit and receive antennas for the STL system. It should be remembered that too much height can lead to unwanted reflected signals arriving at the receiving antenna, thus the desire is to have antenna heights that will produce a clearance equal to but not much greater than 0.6 first Fresnel zone over the entire path. Such unwanted reflections would come from even-numbered Fresnel zones that, after reflection, will change phase and reduce the signal.

It is advisable to calculate 0.6 first Fresnel zone clearance for any point in the path that is suspect. For many applications this will be no more than calculating this radius or clearance from the center of radiation only for the center of the path. Fresnel zone clearance is also discussed in Section 4, Chapter 2, "Microwave Engineering for the Broadcaster," page 4.2-61.

### *Field Survey*

As the name implies, an actual observation of the potential path in question cannot be overlooked. This will verify that the data for terrain between the studio and transmitter are accurate. Often it is been found that data from topographic maps is in error. It may also be found that a building may be under construction which could block the path.

It is not necessary at typical STL frequencies to go to elaborate means to verify accuracy. A simple sighting of the proposed path will suffice. Existing obstruction lights on a tower can be useful for this purpose. Field glasses and a light source will do the job in most cases. The desire is, for the typical path of 20 miles or less, to verify that a clear line of sight exists, and to estimate clearance above or beside any possible obstruction. This permits verification of the profile prepared on paper.

## Path Calculations

In the path evaluation above, the existence of a path was explored as well as the probable antenna heights necessary to obtain acceptable clearance over the path. In this segment the requirements of the antenna and transmission line will be determined.

Both antenna gain and transmission line loss must be viewed as controlled variables in designing an STL system. Only the loss between the transmitting and receiving antenna is fixed by the distance or length of the path.

### *Path Calculation Form*

Before exploring the various aspects of a system path calculation, the following form should be reviewed.

LOSS

1. Path ( ___ miles / ___ km) – _____ dB
2. Transmission Line (total- ____ feet / ____ m) – _____ dB
3. Connectors (total) – _____ dB
4. Others ________________ – _____ dB

TOTAL SYSTEM LOSSES (Sum of 1-4) – _____ dB

5. Transmitter Power Output (_____W) + _____ dBm
6. Transmit Antenna + _____ dBi
7. Receive Antenna + _____ dBi
8. Others ________________ + _____ dBm

TOTAL SYSTEM GAINS (Sum of 5-8) + _____ dB

Subtract System Losses from System Gains

TOTAL SYSTEM GAINS + _____ dB

TOTAL SYSTEM LOSSES – _____ dB

Expected Received Signal Strength ( ____ $\mu$V) – _____ dBm

Desired Signal Level ( ____ $\mu$V for ____ SNR) – _____ dBm

Fade Margin (Subtract desired signal from receiving signal line) _____ dB

### *Path Loss*

Path loss is the atmospheric attenuation between the transmit and receive antennas of an STL system. For the purpose of this evaluation, free space loss will be used for these calculations.

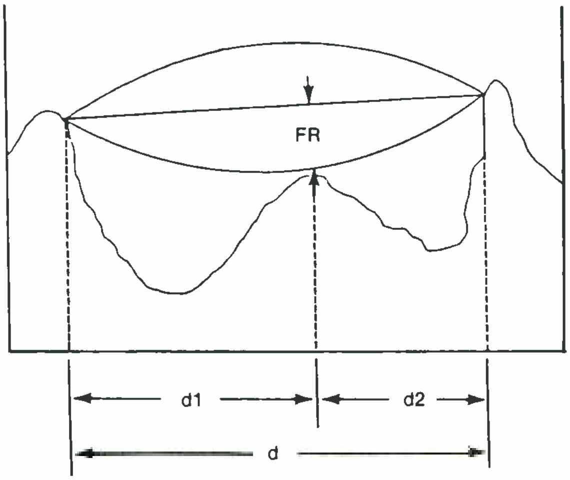


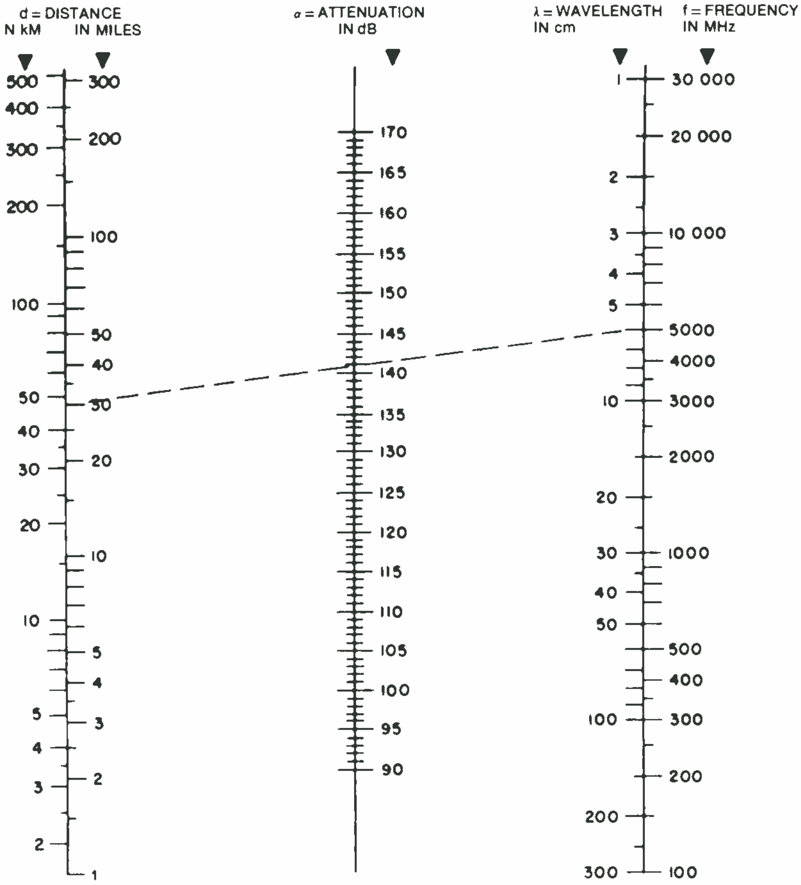
**Fig. 13. First Fresnel zone radius, FR, depicts minimum desired clearance above obstructions. Note maximum clearance is required at the center of the path. (Courtesy Broadcast Engineering)**

The nomograph in Fig. 14 provides an easy way of determining this loss as well as a formula that can be used to calculate this figure.

In some situations a clear line of sight path having 0.6 first Fresnel zone clearance may not be obtainable. If the obstruction is reasonably sharp in form, it can be anticipated that some refraction of the desired signal will occur over this obstruction. Fig. 15 provides a means of estimating this diffraction loss, and would be entered on the above form under Other Losses. This diffraction is referred to as knife-edging. As most obstructions are not sharp in form, it is advisable to add some additional loss possibly as much as 10 or 15 dB, to that obtained from this chart.

### *Transmission Line Loss*

From the Fresnel zone calculations above, the needed height above ground at the studio for the transmitting antenna and the height above ground for the receiving antenna at the transmitter site have been determined. This in turn provides the



$\alpha = 36.6 + 20\log f(\text{MHz}) + 20\log d(\text{MILES})$

**Fig. 14. Monograph for determining free space loss of an STL path. For distances under 2 miles, use formula shown. (Courtesy Broadcast Engineering)**

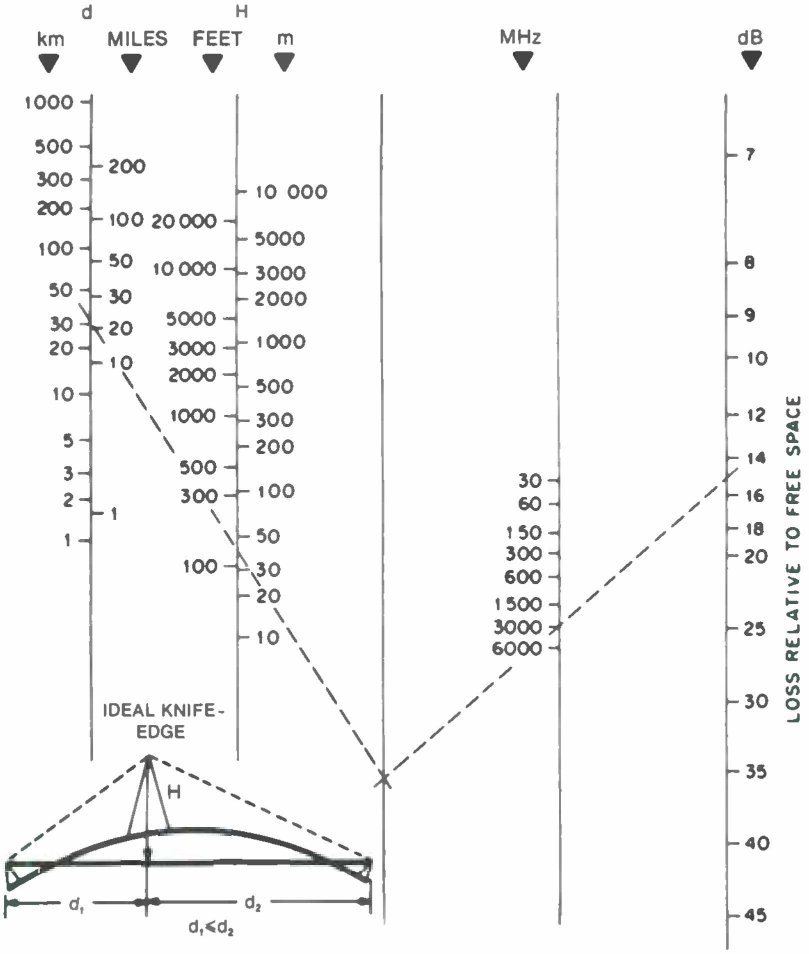


**Fig. 15. Knife-edge diffusion loss can be estimated with above chart. (Courtesy Broadcast Engineering)**

needed lengths of transmission line at both locations.

The transmission lines used for STL systems are half-inch or larger foam or air dielectric cables. These cables, while flexible, can be considered semi-rigid. In some installations rigid air dielectric transmission has been used to reduce this loss.

In designing an STL system there are three variables used in the path calculations to obtain an acceptable system. The loss in the path is a fixed parameter that cannot be changed. Transmission line losses are within the control of the system designer, by the transmission line selected. Fig. 16 gives typical losses for various transmission lines at 950 MHz. By the selection of transmission line, this loss can be controlled.

*Connector Loss*

This parameter is one that can be argued as being unnecessary. The designers of RF connectors state that connectors, when properly designed

| TYPE | Loss per 100 feet (dB) |
|---|---|
| **Standard Foam Dielectric Transmission Line** | |
| 1/2 inch diameter | 3.0 |
| 7/8 inch diameter | 2.0 |
| 1-5/8 inch diameter | 1.4 |
| **Low-loss Foam Dielectric Transmission Line** | |
| 1/2 inch diameter | 2.4 |
| 7/8 inch diameter | 1.4 |
| **Air Dielectric Transmission Line** | |
| 1/2 inch diameter | 2.7 |
| 7/8 inch diameter | 1.4 |
| 1-5/8 inch diameter | 0.7 |
| **Standard Coaxial Cable** | |
| RG-8/U type | 8.5 |
| RG-218/U type | 3.8 |

Note-Attenuations shown are typical for line types, at 950 MHz, 50 Ohms.

**Fig. 16. Transmission line attenuation for commonly used transmission lines.**

and properly installed have no loss. From actual observations it has been noted that some losses are typically encountered, and rather than debate, some loss is included here and is referred to as connector loss.

In practice, there are normally short (three feet or less) jumper cables, used between the ends of the transmission line and the STL transmitter and receiver and again between the transmission line and the antennas. These jumper cables are for ease of installation and to prevent connector damage. STL equipment employs Type N connectors. This connector, while correct for these frequencies, can be difficult to handle. The center conductor of the female connector is susceptible to bending and breaking. For this reason jumper cables have been used to make the joining of the connectors easier. Should jumper cables be used, care must be taken to select cables that will not contribute to intermodulation and related problems. To this end, it is recommended that RG-8/U and similar cables not be used, but rather flexible, solid-conductor outer shield cables, such as Andrew Corporation Superflex be used.

For the typical path calculations it can be assumed that approximately 0.5 dB loss will be seen at each end of the system, for a total of 1 dB.

### *Other Losses*

Other losses will be used to account for a variety of possibilities. In areas with a large number of RF carriers it is advisable to use a ferrite isolator to protect the output of the STL transmitter. This device assures a constant impedance to the transmitter while providing isolation from outside influences.

Another loss will be encountered if, as in the dual system, a transmitter combiner is used to permit two STL transmitters to operate on a single antenna. Also in the dual system a power divider is used to feed the two receivers from one antenna. Such a power divider can contribute about 3.5 dB of loss.

In some situations, receivers may require the use of external preselectors or cavity filters for proper operations in congested frequency locations. Such devices have losses that would be accounted for at this point in the calculations.

### *Transmitter Power Output*

This entry is self-explanatory. Fig. 17 provides conversion from watts to dBm power levels. The power output of the STL transmitter is the second area of control over the system design, following transmission line loss. The Rules and Regulations do not place an upper limit on power as is done in other services, but simply say that it should be not be greater than necessary to carry on the service.

**Watts to dBm**

| P. Watts | dBm | P. Watts | dBM |
|---|---|---|---|
| 5.0 | +37 | 18.0 | +42.6 |
| 5.5 | 37.42 | 19.0 | 42.8 |
| 6.0 | 37.79 | 20.0 | 43 |
| 6.5 | 38.12 | 25.0 | 43.9 |
| 7.0 | 38.46 | 30.0 | 44.8 |
| 7.5 | 38.75 | 35.0 | 45.4 |
| 8.0 | 39 | 40.0 | 46.0 |
| 8.5 | 39.3 | 45.0 | 46.5 |
| 9.0 | 39.55 | 50.0 | 47 |
| 9.5 | 39.78 | 55.0 | 47.4 |
| 10.0 | 40.0 | 60.0 | 47.8 |
| 10.5 | 40.2 | 65.0 | 48.1 |
| 11.0 | 40.4 | 70.0 | 48.5 |
| 12.0 | 40.8 | 75.0 | 48.8 |
| 13.0 | 41.1 | 80.0 | 49 |
| 14.0 | 41.5 | 85.0 | 49.3 |
| 15.0 | 41.8 | 90.0 | 49.5 |
| 16.0 | 42.0 | 95.0 | 49.8 |
| 17.0 | 42.3 | 100.0 | 50 |

**Fig. 17. Table for conversion of RF power ouput in Watts to dBm.**

With the advent of land mobile services in the 900 MHz spectrum solid-state power amplifiers exist to the 200-250 watt range, and are commercially available. As neither type approval or type acceptance is required of a 950 MHz STL transmitter, such amplifiers can be licensed for this service.

In considering the use of powers above the normal STL level, care must be taken to insure that undesirable interference does not occur to other users of the same channel (co-channel) or adjacent channels.

### *Transmit/Receive Antennas*

The antennas used by a system represent the area where the most amount of control exists over the end result. Changes in antenna gain by selection of a larger antenna can make substantial changes in the received signal strength. With this goes, potentially, major revisions to the cost of the STL system if large antennas are used. Not only is the cost of the antennas a consideration, but also the cost of the supporting towers or structures.

Parabolic antennas are the most commonly used antennas for this service. Fig. 18 is an antenna that has been widely used in STL systems. In some parts of the country, antennas with a tighter pattern are needed because of the channel sharing that occurs in these areas. See Section 1, Chapter 3, page 1.3-58, paragraphs 5, 6 and 8 for comments on antennas from the viewpoint of frequency coordination. Other antennas that are in common use are both solid and grid full sized parabolic antennas see Fig. 19 and 20. Fig. 21 provides a summary of typical antenna gains.

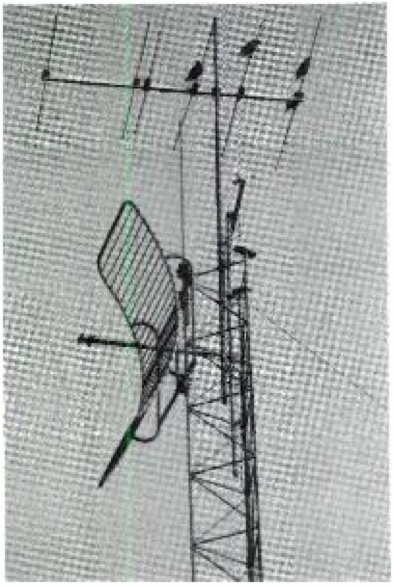


Fig. 18. Scala PR-450U STL antenna. A commonly used STL antenna. Antenna shown is in use at KPDJ-FM Eureka, California. (Courtesy Broadcast Engineering)

Fig. 20. Solid parabolic STL antenna. This type of antenna provides excellent side and back lobe protection and is used in situations involving channel sharing. (Courtesy Andrew Corporation)

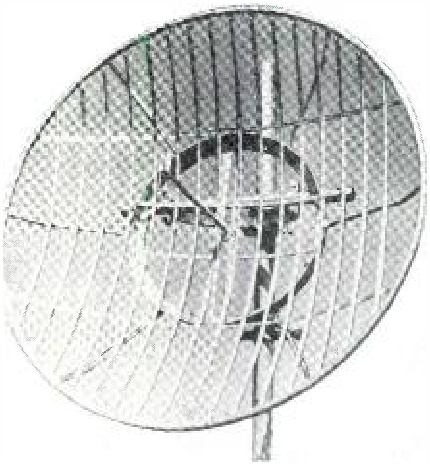


Fig. 19. Typical grid Parabolic STL antenna. Grid antennas provide gain without the wind loading of solid dish antennas. (Courtesy Anixter-Mark)

| TYPE | Forward Gain (dBi) |
|---|---|
| **Grid Parabolic Antenna** | |
| 4 foot diameter | 18.9 |
| 6 foot diameter | 22.0 |
| 8 foot diameter | 25.0 |
| 10 foot diameter | 27.0 |
| 12 foot diameter | 28.5 |
| 15 foot diameter | 30.0 |
| **Solid Parabolic Antenna** | |
| 4 foot diameter | 18.7 |
| 6 foot diameter | 22.3 |
| 8 foot diameter | 24.8 |
| 10 foot diameter | 26.7 |
| 12 foot diameter | 28.3 |
| 15 foot diameter | 30.2 |
| **Parabloic, Single Plane, Grid** | |
| a foot × 6 foot | 20.1 |

Source - Manufacturers data sheets. Data to be considered typical, only.

Fig. 21. Chart of antenna forward gains for commonly used STL antennas.

### *Other Gains*

While not common in many STL systems, there are devices that can be included that will result in further increases in total system gain. These include preamplifiers that may be used ahead of the STL receiver to lower the receiver noise figure and increase its sensitivity, thus adding gain but with a penalty of increased cross and intermodulation. In the dual STL or other situations where more than one receiver is located at the transmitter site, a receiver multicoupler may be used to couple these receivers to one antenna. Some multicouplers contain preamplifiers to compensate for the loss in the power dividers used for this division, and these can contribute gain to the overall system.

### *Expected Received Signal Strength*

This number, expressed in dBm, is the end result of these calculations. It is, as the name implies, the anticipated RF energy entering the receiver RF input connector. As the microvolt ($\mu$V) is the unit of measure more commonly used in this area, the above form provides space to enter the end result in this unit. Fig. 22 provides a table for conversion to μV from dBm.

### *Desired Signal Level*

This parameter expressed in μV and dBm represents a given sensitivity specification for the selected STL receiver. As the desired service of the STL system is to deliver the program audio or signal to the transmitter site, a measurement of program signal-to-noise ratio (SNR) seems more appropriate than a quieting figure or other receiver sensitivity measurement. It is customary to use 60 dB SNR, but with the improving noise floors of program sources, transmitters, and other components of the program chain in FM service this figure may have to be increased to 70 dB. In a situation where there is co-channel sharing of the selected channel, the performance of the receiver to produce the desired SNR under co-channel conditions must be taken into consideration. Such co-channel operation will typically increase the desired signal level. In obtaining this number care must also be exercised to insure that the entire environment the receiver will see, be taken into consideration. This can be a consideration of all signals reaching the front-end of the receiver, levels of undesired signals in adjacent channels, in addition to any co-channel energy.

| MICROVOLTS | DBM | MICROVOLTS | DBM |
|---|---|---|---|
| 0.10 | -127 | 35 | -76 |
| 0.12 | -125.25 | 40 | -74.9 |
| 0.14 | -124 | 45 | -73.9 |
| 0.16 | -122.9 | 50 | -72.9 |
| 0.18 | -121.9 | 60 | -71.25 |
| 0.20 | -120.9 | 70 | -70 |
| 0.25 | -119 | 80 | -68.9 |
| 0.30 | -117.25 | 90 | -67.9 |
| 0.35 | -116 | 100 | -66.9 |
| 0.40 | -115 | 120 | -65.25 |
| 0.45 | -113.9 | 140 | -64 |
| 0.50 | -112.9 | 160 | -62.9 |
| 0.60 | -111.25 | 180 | -61.9 |
| 0.70 | -110 | 200 | -60.9 |
| 0.80 | -108.9 | 250 | -59 |
| 9.90 | -107.9 | 300 | -57.50 |
| 1.0 | -106.9 | 350 | -56 |
| 1.2 | -105.25 | 400 | -54.9 |
| 1.4 | -104 | 450 | -53.9 |
| 1.6 | -102.9 | 500 | -52.9 |
| 1.8 | -101.9 | 600 | -51.25 |
| 2.0 | -100.9 | 700 | -50 |
| 2.5 | -99 | 800 | -49 |
| 3.0 | -97.5 | 900 | -48 |
| 3.5 | -96 | 1,000 | -46.9 |
| 3.0 | -95 | 1,200 | -45.25 |
| 4.5 | -93.9 | 1,400 | -44 |
| 5.0 | -92.9 | 1,600 | -42.9 |
| 6.0 | -91.25 | 1,800 | -41.9 |
| 7.0 | -90 | 2,000 | -40.9 |
| 8.0 | -88.9 | 2,500 | -39 |
| 9.0 | -87.9 | 3,000 | -37.25 |
| 10 | -86.9 | 3,500 | -36 |
| 11 | -86 | 4,000 | -34.9 |
| 12 | -85.25 | 4,500 | -33.9 |
| 14 | -84 | 5,000 | -33 |
| 16 | -82.9 | 6,000 | -31.25 |
| 18 | -81.9 | 7,000 | -30 |
| 20 | -80.9 | 8,000 | -28.9 |
| 25 | -79 | 9,000 | -27.9 |
| 30 | -77.25 | 10,000 | -26.9 |

**Fig. 22. Microvolt to dBm conversion table, at 50 Ohms.**

### *Fade Margin*

The last entry on this form may be the most difficult to determine. This represents the signal level above the acceptable minimum that it is desired to have as normal to the RF input to the receiver. It is this number that the calculations are to produce. By selecting a minimum fade margin, antenna gains and transmission line losses can be selected to meet the desired fade margin.

One way this may be addressed is the amount of time through a year that it would be acceptable for the performance of the system to drop below the established minimum. This may be expressed as a percentage of outage. Fig. 23 provides the relationship of reliability and outage time.

As the numbers imply, when reliability is highest the outages are the shortest. In the Chapter on Frequency Coordination (Section 1, Chapter 3, page 1.3-58, paragraph 4) it is suggested that 30 dB is a workable fade margin. For another point of view on this subject, Fig. 24 presents a nomograph relating distance to desired fade margin. It is the system design engineer's choice as to the level to be used for this entry in the calculations.

### *A Sample of Path Calculations*

Fig. 25 represents a completed, typical path calculation. This theoretical path is some 10 miles in length, and uses parameters common to many situations. Having filled in the various gains and losses, they are totaled on the appropriate line. The Expected Received Signal Strength is obtained from the difference between Total System Loss and Total System Gain. The Fade Margin is the difference between this Expected Signal Level and the Desired Signal Level. It is to be noted that units of measure are not followed as an absolute with a mixing of dB, dBm, and dBi. As these are all relative, the desired end result is produced.

## Repeaters

The above analysis may produce a situation that is not a workable STL configuration. If this is due to a blockage of the path than a repeater may be the solution. The two types of repeaters that may be considered at these frequencies are:

- Active
- Inactive or Passive

| Reliability | Outage Time % | Outage Time per - Year | Month | Day |
|---|---|---|---|---|
| 0 | 100 | 8760 hrs | 720 hrs | 24 hrs |
| 90 | 10 | 876 hrs | 72 hrs | 2.4 hrs |
| 99 | 1 | 88 hrs | 7 hrs | 14.4 minutes |
| 99.99 | 0.01 | 53 minutes | 4.3 minutes | 8.6 seconds |
| 99.999 | 0.001 | 5.3 minutes | 26 seconds | 0.86 seconds |
| 99.999 | 0.0001 | 32 seconds | 2.6 seconds | 0.086 seconds |

**Fig. 23. Reliability vs outage time.**

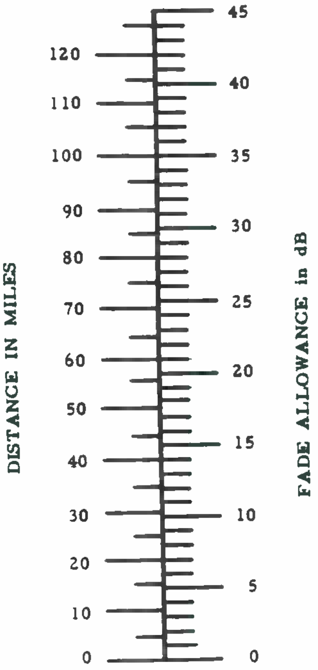


**Fig. 24. Commonly used fade margin requirements versus path length. (Courtesy Broadcast Engineering)**

| | |
|---|---|
| **LOSS** | |
| 1. Path (10 miles/16.1 km) | – 116.0 dB |
| 2. Transmission Line (Total-400 feet/122 m)* | – 5.6 dB |
| 3. Connector (total) | – 1.0 dB |
| 4. Others-none ________ | – ___ dB |
| TOTAL SYSTEM LOSS | – 122.6 dB |
| **GAIN** | |
| 5. Transmitter Power Output (15W) | + 41.8 dBm |
| 6. Transmit Antenna** | + 22.0 dBi |
| 7. Receive Antenna** | + 22.0 dBi |
| 8. Others none ________ | + ___ dB |
| TOTAL SYSTEM GAIN | + 85.8 dB |
| TOTAL SYSTEM LOSS | – 122.6 dB |
| TOTAL SYSTEM GAIN | + 85.8 dB |
| Expected Received Signal Strength (3300 uV) | – 36.8 dBm |
| Desired Signal Level (100 uV for 70 dB SNR) | – 66.9 dBm |
| Fade Margin | + 30.1 dB |

Notes: * -7/8 low-loss foam transmission line
**-6 foot grid parabolic antennas

**Fig. 25. Example of a typical STL path calculation, reflecting a path length of 10 mile.**

### *Active Repeaters*

This type of repeater can be subdivided into two types, that of a booster station and a full power repeater. The booster station is a station that receives and amplifies the signals of the originating station and re-transmits them on the same frequency without significantly altering them in any way. With a booster, the licensee is responsible for correcting any condition of interference that results from the radiation of radio frequency energy outside the assigned channel. In essence, this permits a repeater station to be created that must function as an on-frequency repeater, or what might be called an active beambender. A waiver is required for a booster station, that operates in conjunction with any STL/ICR system.

The second type of repeater is more conventional. This is normally a standard STL receiver feeding an STL transmitter, with different input and output frequencies or channels. For this, an ICR license is needed as it is an additional station. This repeater functions as a baseband repeater, with program output of the receiver feeding the program input of the repeater transmitter. Recently one firm offered a commercial I.F. or intermediate frequency STL repeater, similar to those used in telephony microwave systems. In establishing a two hop system with a repeater, it can treated as two individual paths for purposes of path calculations.

### *Inactive or Passive Repeaters*

At 950 MHz this type of repeater is used, but only under certain conditions. See Section 4, Chapter 2, Microwave Engineering for the Broadcaster, page 4.2-68 for details on true passive repeaters. With the billboard type passive repeater, normally the physical size at 950 MHz is so large making it not physically or financially viable. This is not to imply that the passive repeater should be ignored, as there are situations where it can be the ideal solution. Another passive repeater is back-to-back antennas. In considering the configuration, performance can be calculated as was done above, but using the expected received signal strength from the "receiving" antenna as the transmitter power output for the second hop calculations. From a mathematical viewpoint it will be seen that it will require a very short path for back-to-back antennas to function successfully as a passive repeater.

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