Comparison of Performance Criteria of Five and Ten Meter Earth Terminals.

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Abstract

Geostationary satellite communications links have found wide use in CATV during the past two years. Until recently, only 10 meter diameter antennas have been employed for domestic video receive terminals. Careful study and consideration of all requirements of the communications industry has now shown that smaller diameter antennas of 4.5 and 5 meters will satisfy requirements for a percentage of the 48 contiguous states. Consequently, the FCC has stated that they will approve those terminals which employ smaller antennas if the applicant outlines his requirements and gives adequate proof that those requirements are met. This paper is a comparative analysis of 5 and 10 meter antenna receive terminals and shows tradeoffs which must be considered for various locations in the 48 contiguous states.

1.0 Introduction

This paper is a presentation of operational characteristics of 5 and 10 meter earth terminals in graphic form. Supporting derivations are given where it was felt that a greater depth of understanding the data would result. Certain assumptions were made on characteristics which have negligible effects on the results. These assumptions are carefully outlined in each section. The last sections deal with the summation of the earth terminal degradation and that due to the CATV system. The overall performance of the headend and distribution system is the important aspect for cable operators. The paper is developed in a sequence which should be easy to follow step by step. Taking information out of context without understanding the foundation presented in previous sections is not recommended in this case.

2.0 Overall Considerations

Basically the requirement of an overall link is a quality picture at the final destination - the viewers home. Many factors affect the ultimate picture quality. Generally, the downlink and CATV distribution system have the greatest impact on signal quality. This, of course, assumes that the studio quality is adequate. The purpose of this paper is not to analyze link degradations but to compare typical 5 and 10 meter receive terminals and their performance in a complete system. To accomplish this task without getting deeply involved in system analysis, a set of degradation allowances which are presently under consideration by the FCC and others will be utilized. Figure 1 is a summary of these allowances. First, the downlink is analyzed under clear sky conditions. The basic allowance of 3.65 dB is then subtracted from the main IF carrier-to-noise ratio (C/N), and the result is considered a worse case condition. This worse case condition will be accepted if the C/N falls equal to or above the receiver objective threshold (threshold being defined as the point where S/N ratio is worse by 1 dB than the projected asymptote at high C/N). This allowance and its prescribed use is not to be considered final and is subject to change, but it provides a convenient method for this comparison.

FCC Recommended Satellite Link Degradations

Parameter	Nominal (dB)	Random (dB)
EIRP	0	0.15
Satellite Degradation	0.4	0.4
Atmospheric Absorption	0.1	0.1
Polarization Loss	0.1	0.1
Rain Attenuation	0	0.2(1)
Pointing Error	0.3	0
Wind	0	0.4
Antenna Gain	0	0.2
Earth Station Degradation	0	0.35
Interference	1.0	0 (2)
FM Threshold Margin	1.0	0
	2.9	0.75(3)

(1) Or as appropriate for given location
(2) Or Calculation
(3) Combined on a Root Sum Square basis

Figure 1

3.0 Downlink Considerations

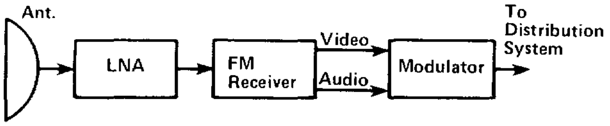
3.1 System Noise Temperature

Figure 2a is a simplified block diagram of a receive terminal. Figure 2b assigns gain and noise temperature quantities to each contributing element of the terminal.

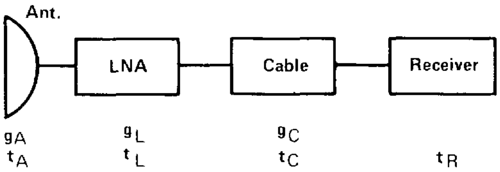
System noise temperature at the antenna flange is given by:

$$t_S = t_A + t_L + t_C/g_L + t_R/(g_L g_C)$$

where
t_S = System noise temperature at antenna flange °K
t_A = Antenna noise temperature °K
t_L = LNA noise temperature °K
t_C = LNA to receiver cable noise temperature °K
t_R = Receiver noise temperature °K
g_L = LNA gain ratio
g_C = Cable gain ratio



Receive-Only Earth Terminal
Figure 2A



Gain-Noise Temperature Diagram
Figure 2B

Figure 3a presents the system noise temperature of a Scientific-Atlanta 5 meter system versus LNA noise figure. The following typical variables were assumed:

Cable Loss = 6 dB (200 feet)
LNA Gain = 47 dB (Minimum)
Receiver NF = 12 dB
Antenna t_A = 20°K (30° Elevation)

Figure 3b is the same data for a 10 meter system assuming:

Cable Loss = 6 dB
LNA Gain = 47 dB
Receiver NF = 12 dB
Antenna t_A = 28°K

The overall noise temperature is affected only a very small amount by variations in these assumed quantities at different sites, and the preamplifier is the dominate factor.

The small difference in the 5 and 10 meter cases is due to the type feed utilized and the sidelobe patterns of the two antennas.

The 10 meter antenna utilizes a focal-point feed to achieve a superior sidelobe pattern at the expense of greater loss in the waveguide run to the feed. Optimization for interference rejection is desirable because, as will be shown, gain in the 10 meter case is available for tradeoff.

3.2 Receive System G/T
The receive system G/T is given by:

$$G/T = G_A - 10 \log t_S$$

where G/T = Receive system Gain/Noise Temp in dB/°K
G_A = Antenna gain at flange in dB
t_S = Flange system noise temperature in °K

Figures 4a and 4b show the G/T curves for the 5 and 10 meter case versus LNA noise figure. Assumptions in addition to those in Section 3.1 were:

G_A = 44.5 dB (5 Meter)
G_A = 50.2 dB (10 Meter)

Due to nearly equivalent noise temperatures for the two antennas, the G/T difference is almost entirely related to the gain difference.

G/T is a quality factor which is directly related to performance and cost of video earth terminals.

3.3 Main IF Carrier-to-Noise Ratio
The next important parameter is the receiver IF carrier-to-noise ratio (C/N). Noise of an FM link can be divided into two categories for understanding the process even though both are derived from the same source - thermal noise.

First, there is carrier power to noise power density given by:

$$(C/N_O) = EIRP - Lp + G/T - K$$

where EIRP = Effective isotropic radiated power dBw
Lp = Path loss in dB
G/T = System G/T in dB/°K
K = Boltzmanns constant (-168.6 dBw/MHz/°K)

This (C/N_O) affects (S/N)v on a one-for-one basis when the link is operated well above threshold, and

$$(C/N) = (C/N_O) - 10 \log b_{IF}$$

where b_{IF} = Effective main IF noise bandwidth in MHz

This (C/N) determines the threshold of the receiver.

Path loss is given approximately by:

$$Lp = 96.6 + 20 \log f + 20 \log d$$

where f = Frequency in GHz
d = Distance in miles

Secondly, when an FM system is operated near or below threshold, the peaks of noise reduce the instantaneous sum of signal-plus-noise to near zero. Under these conditions, the FM discriminator becomes unable to determine the instantaneous phase of the carrier, and impulse noise appears in the detected signal. This results in a greater than one-for-one variation in S/N and the characteristics of this impulse noise is different than that of the previously demodulated thermal noise. The impulse noise appears very rapidly below threshold, and it causes serious degradation to picture and audio quality. For this reason, it is necessary to operate FM systems above threshold for quality performance.

Figures 5a and 5b give the C/N ratio for a clear sky. Assumptions in addition to those in Sections 3.1 and 3.2 were:

L_p = 196.0 dB
b_{IF} = 39 MHz

The IF filter is an INTELSAT 36 MHz type. An improvement in the margin against threshold of 0.8 dB can be obtained for those marginal cases by utilization of an INTELSAT 30 MHz filter; however, no benefit in the ultimate S/N results in this move since S/N ratio is not a function of IF bandwidth when operating above threshold as will be later shown.

Figures 6a and 6b show the C/N ratios including the 3.65 dB degradation of Figure 1. Two threshold lines are shown. The upper line represents a standard Scientific-Atlanta 414 receiver. The lower line is the same receiver with threshold extension included. Again it must be remembered that threshold extension does not improve the ultimate S/N ratio except when operating down near and below threshold. This will be shown in later S/N curves.

3.4 Threshold

Figures 7a and 7b give the threshold characteristics of a Scientific-Atlanta 414 receiver with and without threshold extension. In each case, threshold is defined as the C/N where the S/N curve departs 1 dB from the high C/N asymptote. Note that this occurs at 9.3 dB for no extension and 7.3 dB with extension. Also note that S/N at these points are 47 dB and 45 dB respectively.

Threshold extension has carried threshold to such a low C/N that S/N ratio is becoming the limiting factor. Most CATV systems are operated with headend S/N of greater than 45 dB; therefore further improvement in C/N performance by reducing bandwidth must be done keeping in mind that the 45 dB S/N will drop even lower. This may or may not be desirable for a particular CATV cascade. Curves to follow will aid in making this decision.

3.5 Video Signal-to-Noise Ratio

The video signal-to-noise ratio (S/N)v is given by:

$$(S/N)_v = \frac{C}{N_o}\left[\frac{12(\Delta Fs)^2}{b_n^3}\right]$$

where C = Carrier power in watts

N_o = Noise power density at that point in the receiver where C is measured

= $K\ t_s$ in Watts/MHz

K = Boltzmann's constant (1.3806×10^{-17} W/MHz/°K)

t_s = System operating noise temperature referred to that point in the system where C is measured in°K

ΔF_s = Half the peak-to-peak deviation produced by that part of the video waveform defined to be the signal in MHz

b_n = Noise bandwidth of the baseband filter function representing the combination of the de-emphasis network, measurement bandlimiting filter, and weighting network with respect to triangular noise in MHz

= 1.574 MHz for CCIR weighted

Figures 8a and 8b give the $(S/N)_v$ for the 5 and 10 meter cases clear sky. The assumptions are as previously stated in addition to:

$$\Delta F_s = (.714)\ (10.75\text{ MHz}) = 7.68\text{ MHz}$$

Video systems presently in use in this country are using this deviation. Note that two curves exist on Figure 8A. The dotted case shows the effect of threshold extension. Note that no change occurs above threshold. It is true, however, that the small change which does occur near threshold is of extreme importance since impulse noise is removed. Threshold extension has no use in the 10 meter case under these assumed conditions as shown in Figure 8b.

Figures 9a and 9b give the $(S/N)_v$ after application of the 3.65 dB degrading factor to C/N. Note that above threshold the curves have simply moved down by 3.65 dB, but at and below threshold the effect is much greater due to impulse noise. In these curves the advantage of threshold extension can be seen even in the 10 meter case to a small degree.

3.6 Audio Threshold

Figure 10 gives the audio threshold characteristics of the Scientific-Atlanta 414 receiver. The unweighted audio $(S/N)_A$ is shown versus main IF C/N. Note that audio threshold occurs at about 7.6 dB (C/N). Assumptions are:

Subcarrier on Carrier Deviation = 2 MHz Peak
1 kHz Test Tone on Subcarrier = 75 kHz Peak

It is important to note that the deviations of video and audio are well chosen since audio thresholds at a near equal C/N as video with threshold extension. Any reduction in the audio deviation rules out any use of threshold extension since it has little effect upon audio threshold in this case.

3.7 Audio Signal-to-Noise

Figures 11a and 11b give $(S/N)_A$ for the 5 and 10 meter cases. These curves were derived from Figures 5 and 10.

Figures 12a and 12b give $(S/N)_A$ for the 5 and 10 meter cases including the 3.65 degrading factor. These curves were derived from Figures 6 and 10. No mention is made of threshold extension since it has been shown that it affects $(S/N)_A$ very little.

3.8 Overall CATV System Video Performance

This section deals with the heart of the matter. What counts is the result at the home. The earth terminal and CATV system share in the overall degradation.

How is the CCIR (S/N)v at the output of the headend FM receiver related to the NCTA (S/N) which would produce the same quality picture if the noise source were thermal noise in the distribution system? The best thing to say is that they are essentially equivalent. However, if we are considering an objective CCIR measurement at the output of an ideal home receiver (or in the case treated by Straus[2]) and are concerned about tenths of a dB, the answer is that

Equivalent NCTA = Headend $(S/N)_v$ + 0.3 dB

because as shown by Straus

Equivalent NCTA = Home Rcvr CCIR $(S/N)_v$ + 0.2 dB,

and

Home Rcvr CCIR $(S/N)_v$ = Headend $(S/N)_v$ + 0.1 dB

The latter relation results from the effect of the rolloff of the Nyquist filter in the ideal home receiver on de-emphasized triangular noise between 4 and 4.2 MHz.

Figure 13a shows the combined noise of the headend receiver and the distribution white noise. It is important to note again that receiver baseband S/N of 45 dB (which results at threshold with threshold extension) will have an impact on most CATV systems - especially those which are operating at NCTA (S/N) of 45 dB and better.

3.9 Overall CATV System Audio Performance

Figure 13b gives a curve similar to 13a for the overall audio performance. The earth terminal noise was power added to the CATV distribution system noise contribution to obtain the overall result. The audio (S/N) for the CATV system is given by:

$$(S/N)_A = \frac{C}{N_o}\left[\frac{3}{2}\ \frac{\Delta F_A{}^2}{b_{NA}{}^3}\right]$$

where C = audio subcarrier power in watts

N_o = noise power density in watts/MHz

ΔF_A = half the audio peak-to-peak deviation in MHz

b_{NA} = triangular noise bandwidth of baseband response function for 75 μs de-emphasis with 1 kHz crossover with ideal rectangular 15 kHz bandlimiting filter

= 5.82×10^{-3} MHz*

The assumption for Figure 13b was:

$$\Delta F_A = .025\text{ MHz}$$

*This noise bandwidth corresponds to a de-emphasis advantage of:

30 log (15 kHz/5.82 kHz) = 12.3 dB

The figure of 13.2 dB often cited for 75μs pre-emphasis is for unity pre-emphasis gain at dc. It must be reduced by the 0.9 dB insertion loss necessary to put the pre-emphasis corssover at 1 kHz.

Also it was assumed that the aural subcarrier was run at -15 dB with respect to the video carrier on the CATV system.

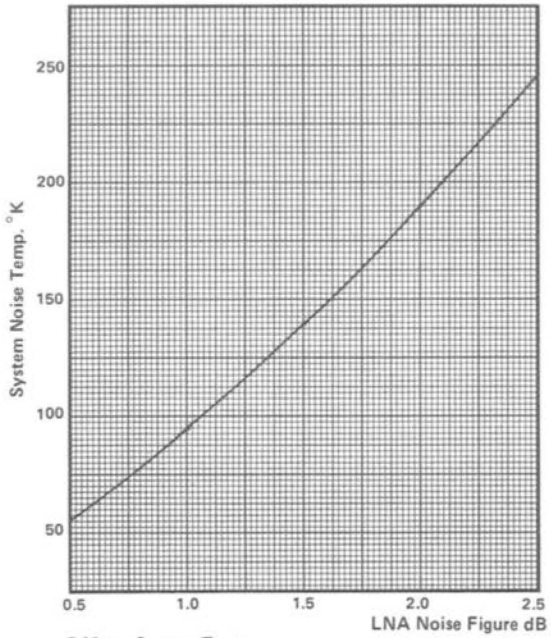
It can be noted in Figure 13b that almost all the degradation of audio occurs in the satellite link, but the quality is still quite good.

4.0 Conclusion

The quality of a video link by satellite is governed by many factors. It is important for the individual operator to consider his requirement and buy the system best suited for his needs. Careful consideration must be given to threshold and the overall performance desired. Other considerations such as terestrial interference must be looked at on an individual basis.

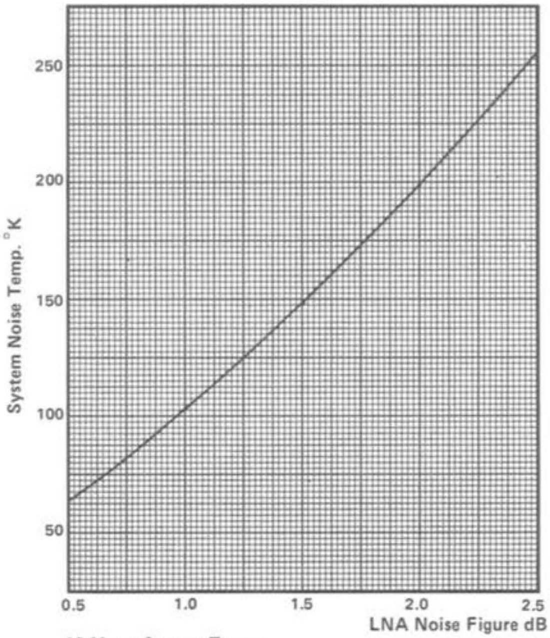
5.0 Acknowledgment

My sincere appreciation is expressed to Dr. Larry Clayton, Heinz Wegener, and Elias Livaditis for their invaluable support in writing this paper.



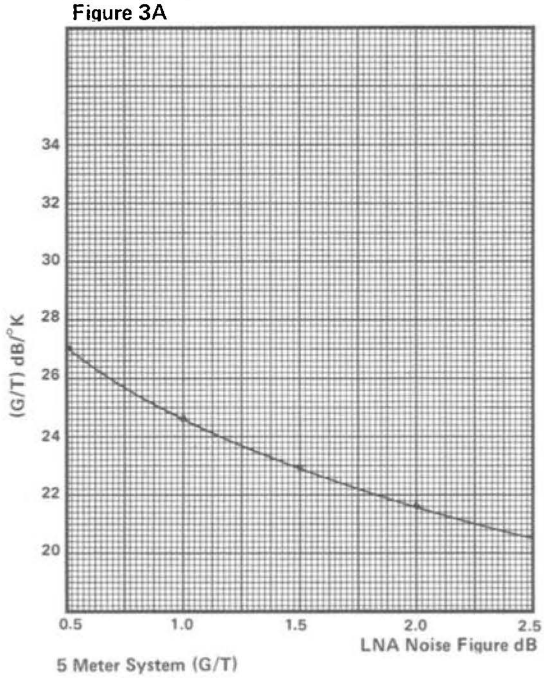
5 Meter System Temp

Figure 3A



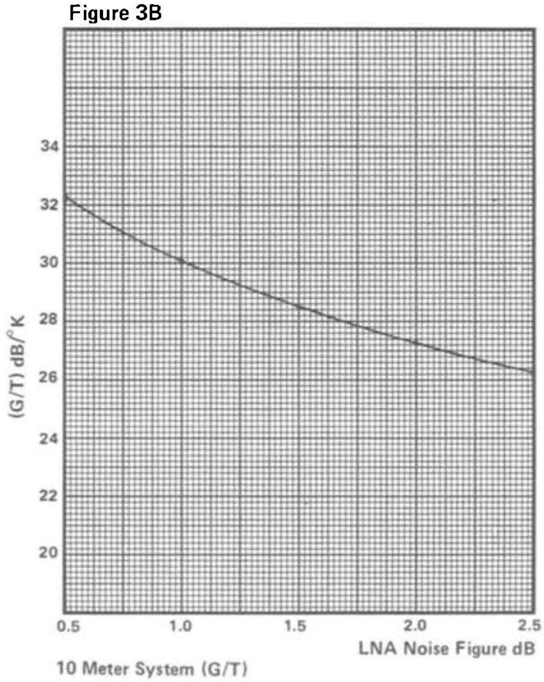
10 Meter System Temp.

Figure 3B



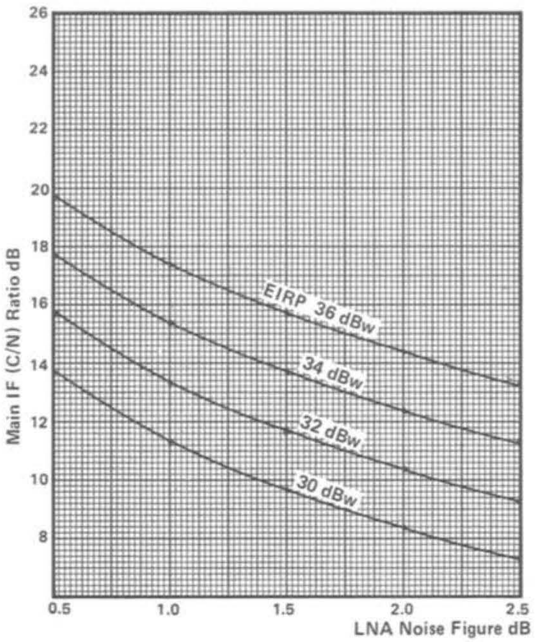
5 Meter System (G/T)

Figure 4A

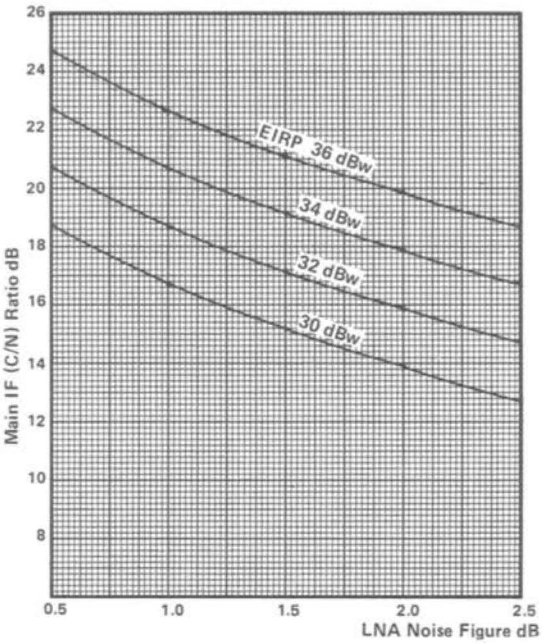


10 Meter System (G/T)

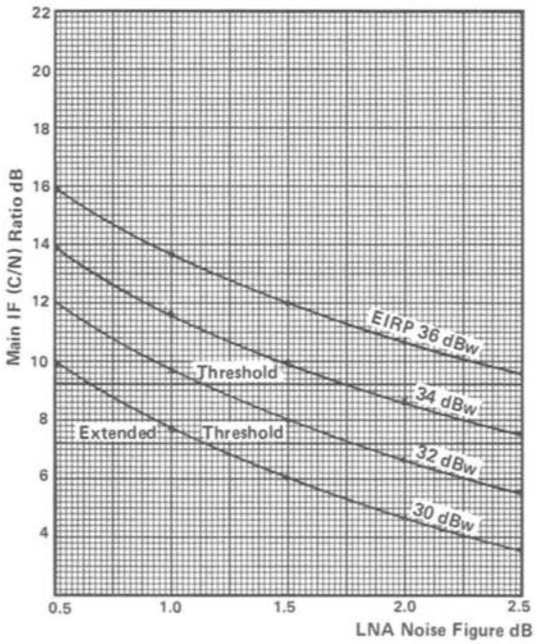
Figure 4B



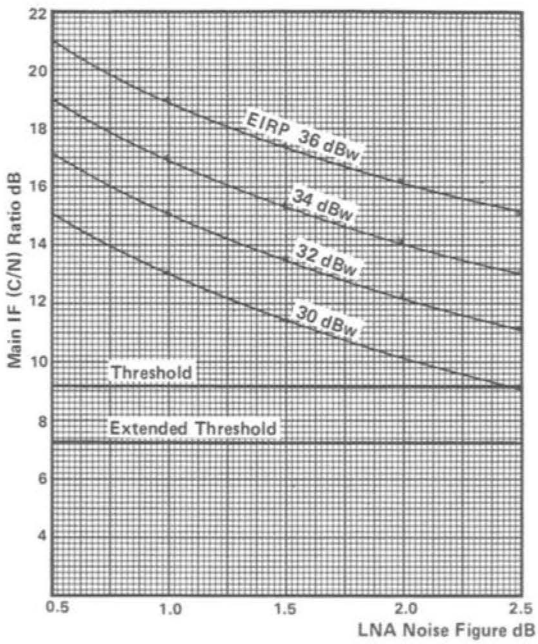
5 Meter System Clear Sky (C/N)
Figure 5A



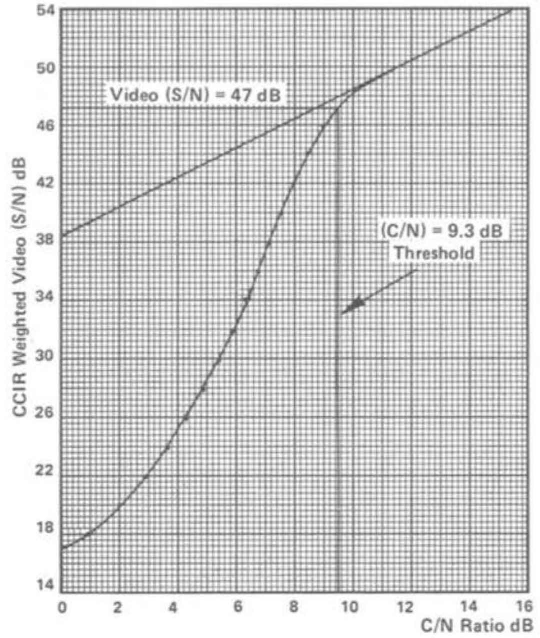
10 Meter System Clear Sky (C/N)
Figure 5B



5 Meter System Degraded (C/N)
Figure 6A

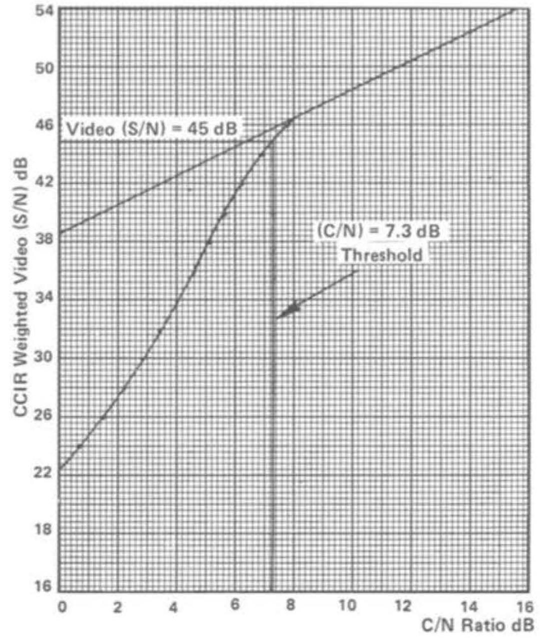


10 Meter System Degraded (C/N)
Figure 6B



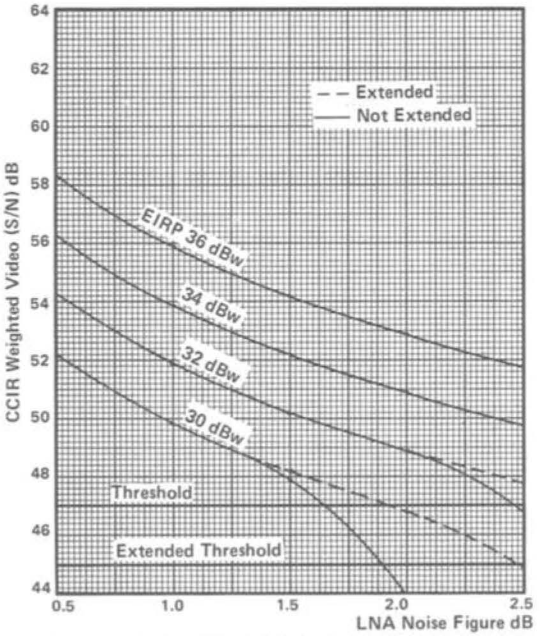
Video (S/N) vs. Main IF (C/N)
Without Threshold Extension
Scientific-Atlanta 414

Figure 7A



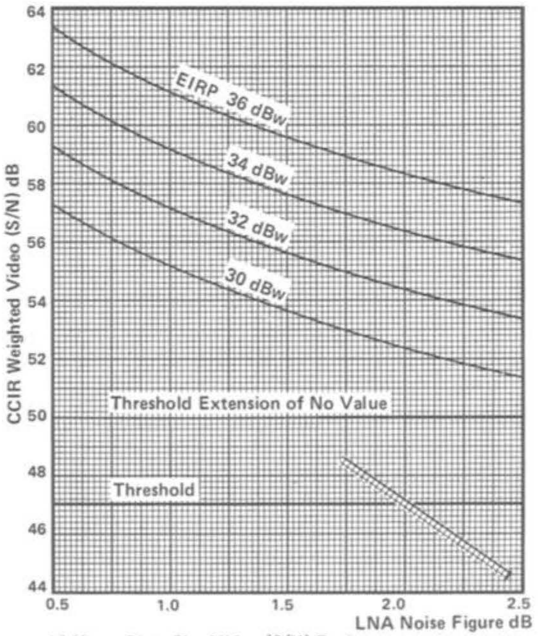
Video (S/N) vs. Main IF (C/N)
With Threshold Extension
Scientific-Atlanta 414

Figure 7B



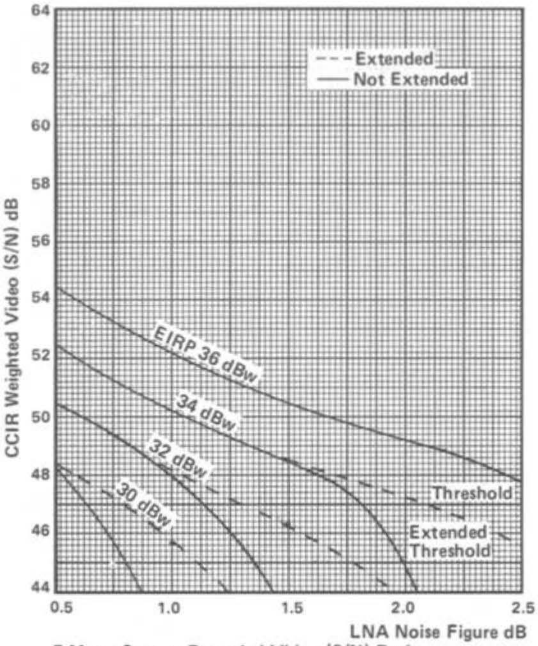
5 Meter Clear Sky Video (S/N) Ratio

Figure 8A



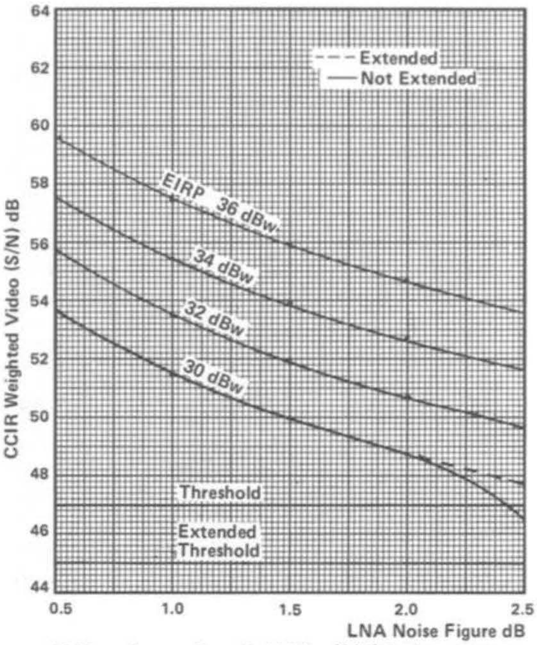
10 Meter Clear Sky Video (S/N) Ratio

Figure 8B



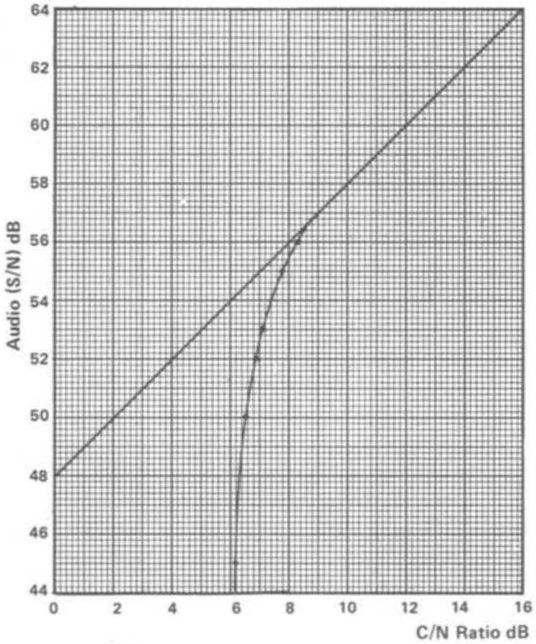
5 Meter System Degraded Video (S/N) Ratio

Figure 9A



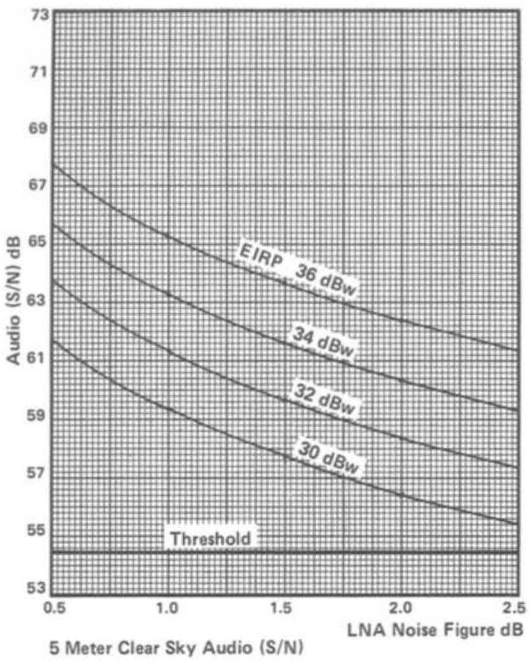
10 Meter System Degraded Video (S/N) Ratio

Figure 9B



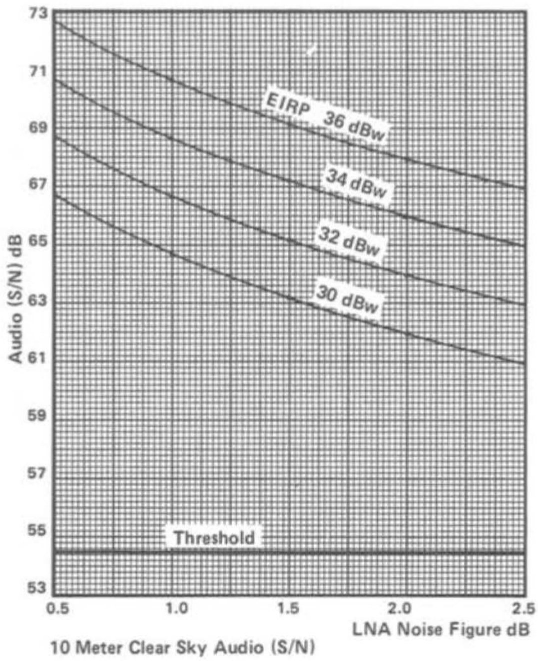
Audio (S/N) vs. Main IF (C/N)
Scientific-Atlanta 414

Figure 10



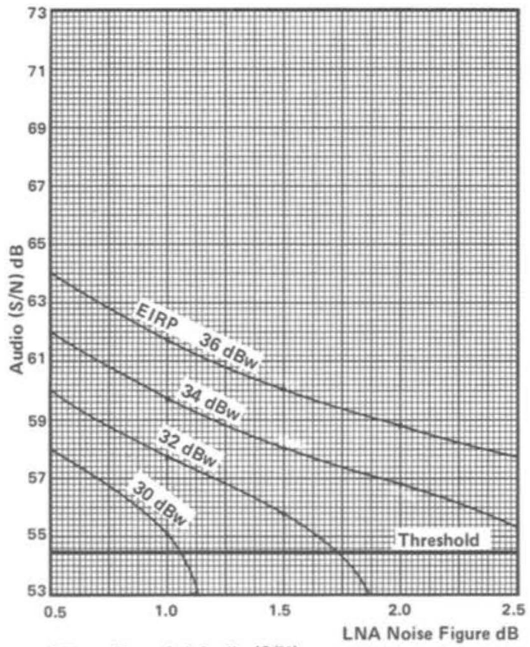
5 Meter Clear Sky Audio (S/N)

Figure 11A



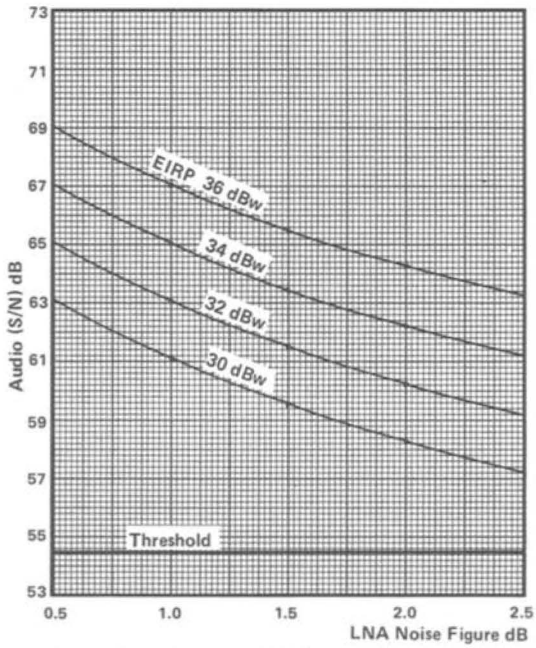
10 Meter Clear Sky Audio (S/N)

Figure 11B



5 Meter Degraded Audio (S/N)

Figure 12A



10 Meter Degraded Audio (S/N)

Figure 12B

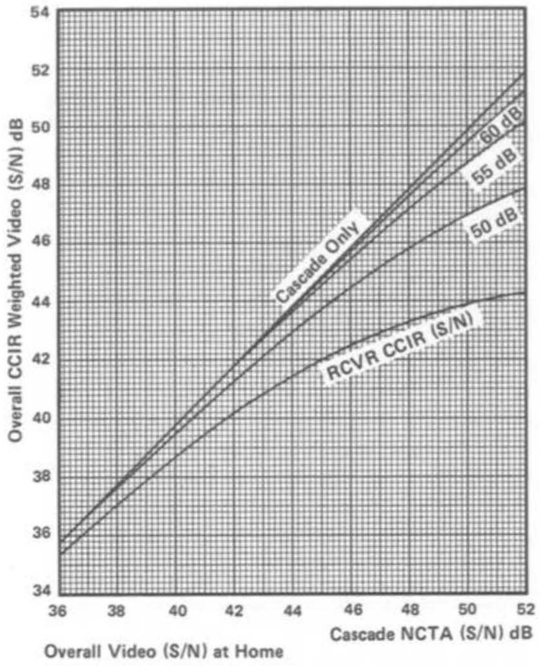


Figure 13A

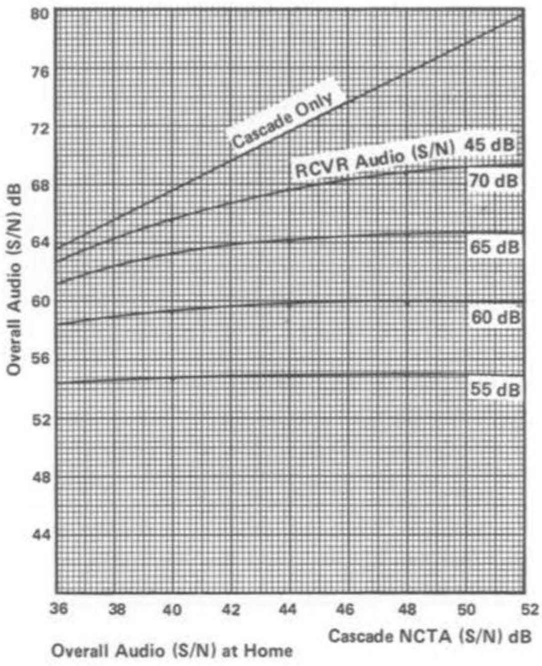


Figure 13B

References

1. L. Clayton, "FM Television Signal-to-Noise Ratio" IEEE Transactions on Cable Television, October 1976, p. 25-30.
2. T.M. Straus, "The Relationship Between the NCTA, EIA, and CCIR Definitions of Signal-to-Noise Ratio" NCTA 1974, p. 58-63.