EARTH STATIONS IN SMALLER PACKAGES

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Why are small aperture earth stations so popular? - economics and ease of location. What can a small aperture earth station provide to the cable operator? This paper will analyze the performance of earth stations employing antennas with diameters smaller than 9-metre, with emphasis on the 4.5-metre size. Impact of adjacent satellite and terrestrial interference to these smaller antennas and the effect on system G/T is discussed. Economic trade-offs between antenna and low noise amplifier are presented. Carrier-to-noise ratio of the system as it relates to receiver threshold is also discussed.

Declaratory Ruling 76-1169, issued by the FCC in January of 1977, permitted the use of smaller aperture antennas to provide TV to cable operators. Antennas as "small as 4.5 metres" (15 ft.) were considered capable of delivering acceptable quality performance in certain areas of the Continental United States. The use of smaller aperture antennas for satellite communication to the United States is not new, however, with this ruling. Four-and-one-half-metre antennas have been providing single-channel-per-carrier transmit and receive service in the Gulf of Mexico on an oil platform, and in the "Bush" of Alaska. Also Canada, who shares the same satellite orbit space with the United States, has in service 8-metre (26 ft.), 4.5-metre (15 ft.) and 3.7-metre (12 ft.) antennas.

Concern over the use of small aperture earth station antennas centered around two areas - adjacent satellite interference and terrestrial interference. With satellites spaced just 4° apart in orbit, there was concern that smaller antennas, with their broader beams and lower gain, would permit unwanted signals from adjacent satellites to "get into" the antenna and interfere with the wanted signal. Also, since the 4 GHz downlink satellite band is the same as used by terrestrial microwave common carriers, there was concern that interference from these systems would also "get into" the antenna and interfere with the satellite signal. The FCC, therefore, established performance objectives for earth station antennas in Paragraph 25.209 of the FCC Rules and Regulations. Generally, an earth station antenna must have sidelobes

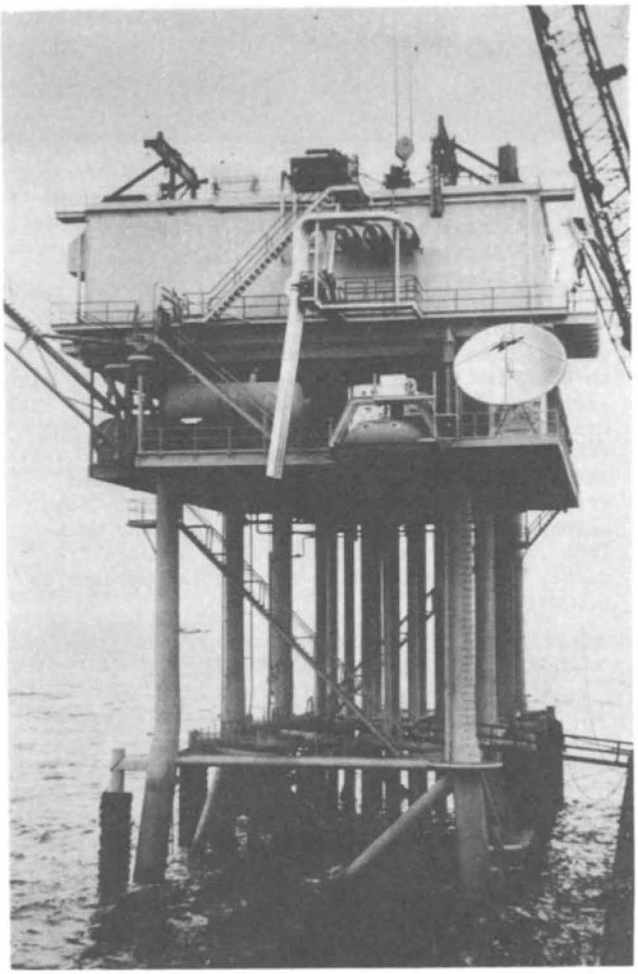

Figure 1

Oil rig in Gulf of Mexico using 4.5-metre earth station antenna

that, when smoothed, fall beneath an envelope defined by 32-25 log θ, where θ is the angle off boresight out to 48 degrees. See Figure 3.

It is assumed that if an antenna meets this criteria, the interfering levels from adjacent satellites and terrestrial interference will be low enough to permit acceptable service. It

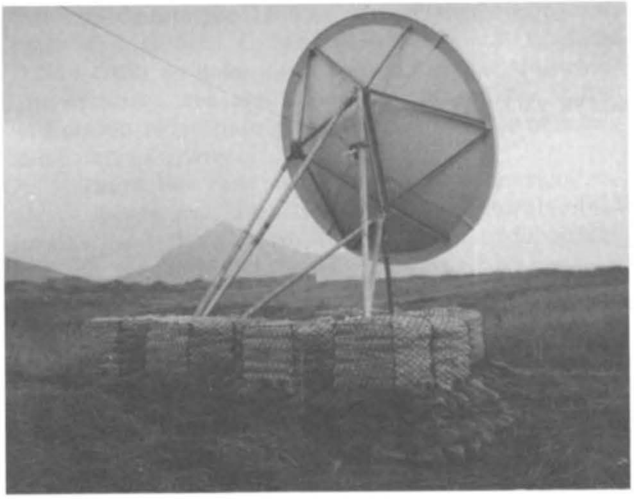

Figure 2

Alaskan "Bush" terminal using
4.5-metre earth station antenna

was also assumed that it took a big antenna to do this. This is not necessarily the case and, with proper design, antennas down to 4.5-metre in size can realize pattern control which provides the required interference protection of the FCC rules. This can be done while retaining much needed efficiency (higher gain) of the antenna. Some antennas also provide improved wide- and back-lobe radiation characteristics to enhance frequency coordination with terrestrial systems in congested areas.

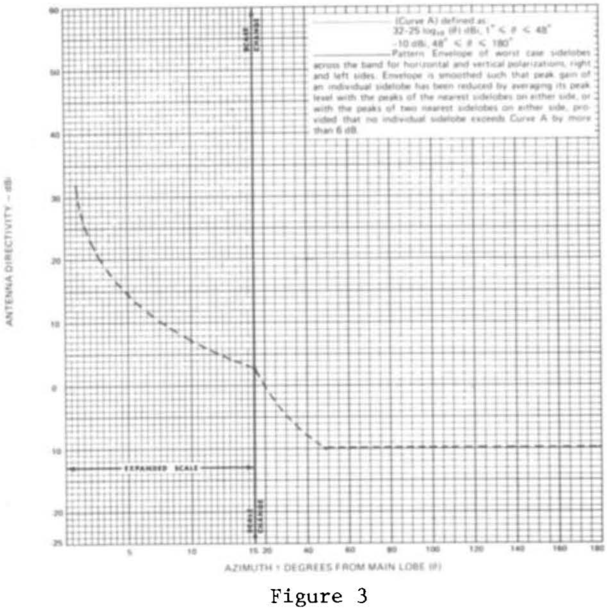

Figure 3

Pattern envelope required by FCC for earth station antennas.

The FCC stated in their Declaratory Ruling that antennas of diameters down to 4.5-metre could meet the interference criteria. This permitted new and interesting possibilities to the cable operator - the most important economic. Not only is the basic cost of the antenna less (approximately 1/4 the cost of a 10-metre antenna), the economics of placing the antenna (transportation, land, foundation, erection) are also less.

But there are other ramifications that must be considered with smaller sized antennas and the FCC has recognized these in their Declaratory Ruling. Smaller antennas have lower gain, and to deliver the required signal level to the receiver requires that the low noise amplifier be properly chosen. The performance capabilities of any receive earth station are determined by the satellite effective isotropic radiated power (EIRP) and the station's figure of merit (G/T). The EIRP for any location is fixed so the cable operator must rely on the station's G/T to provide the proper signal. The earth station's figure of merit is a function of antenna gain and system noise temperature and is defined as:

G/T = Antenna gain -10 log (system temperature)

System noise temperature includes sky noise, antenna noise, and amplifier noise. To produce a better G/T requires reducing the system noise temperature or increasing antenna gain, or both. There are limits to both, however, with antenna gain generally being limited by reflector size and feed configuration. The system noise temperature is generally controlled by the choice of amplifier.

Sky noise is a function of antenna elevation angle. The earth is warmer and, therefore, noisier than the sky. As the antenna elevation angle is lowered, the antenna picks up more of the earth noise, making the system noisier. Antenna elevation angle depends on location and is fixed depending on what satellite the antenna is to look at. System noise temperature is lowered by choosing an amplifier with lower noise temperature.

The cable operator must carefully choose the proper antenna and low noise amplifier combination. The antenna is chosen to maximize gain, while meeting the required pattern envelope, and the amplifier is chosen to reduce noise level. This is shown graphically in Figure 4.

The Appendix to the FCC Declaratory Ruling suggests a 14 dB carrier-to-noise ratio, which would deliver a 52 dB signal-to-noise ratio. A 14 dB C/N would provide a 3 dB margin over an 11 dB receiver threshold.

Assuming a 14 dB C/N is acceptable for pay TV distribution, then the feasibility of achieving such a C/N ratio economically must be reviewed. The C/N available in an earth station terminal is determined by a number of external influences,

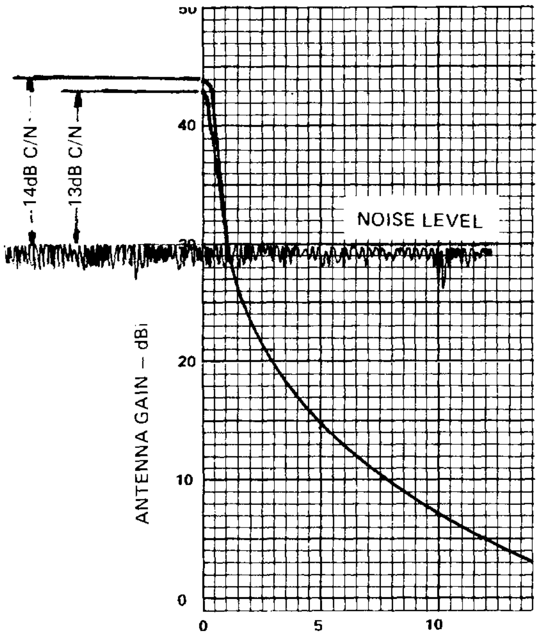

Figure 4

Antenna gain and noise level determine C/N

including carrier-to-noise ratio of the uplink to the satellite $(C/N)_U$, carrier-to-noise ratio of the earth station due to thermal and downlink characteristics $(C/N)_D$, and carrier-to-interference levels caused by adjacent satellites, terrestrial interference, transponder intermodulation, cross polarization, etc. In the Appendix to their Declaratory Ruling, the FCC has assumed an antenna with 43.7 dBi gain satisfying the FCC pattern requirements. Other antenna types are available offering various gain values. Figure 5 shows a tabulation of the parameters used in the Appendix to the FCC Ruling, along with the same calculated values for a 44.0 dBi gain antenna, and a 43.0 dBi gain antenna. Calculations and assumptions are based on the Appendix to the FCC Declaratory Ruling and Order, FCC76-1169. All antennas meet, or are better than, the FCC 32-25 log θ envelope requirement, and calculations are based on 4° satellite spacing. A second set of calculations has been performed assuming a 2 dB margin over receiver threshold of 11 dB for a 13 dB C/N, and is also shown in Figure 5.

The results indicate that in order to achieve a 14 dB $(C/N)_{TOTAL}$, the earth station terminal G/T must be designed to achieve a $(C/N)_D$ of 15.8 dB, or 15.2 dB, or 15.0 dB, depending on antenna gain and pattern performance.

The $(C/N)_D$ is a convenient value to work with as it is determined by the satellite EIRP, noise bandwidth of the receiver, and G/T of the earth station. The relationship between G/T and EIRP has been graphically represented in Figure 6, assumint both 30 MHz and 36 MHz noise bandwidths using the following formula:

$$G/T = (C/N)_D + 10 \log (\text{receiver bandwidth}) - EIRP - 32.4^*$$

*Includes 196.2 dB path loss, Boltzmann's Constant (-228.6 dBw/°K)

The EIRP values for current DOMSATS average 33 to 34 dBw on a nationwide basis. There are, of course, areas which have radiated power significantly above or below these values, depending on transponders used and location. Assuming a receiver IF bandwidth of 30 MHz, and an EIRP of 33 dBw, a $(C/N)_D$ of 15.2 dB can be achieved by using earth station terminals with G/T equal to 24.5 dB/°K. Those areas with higher EIRP for transponders of interest have an advantage of higher performance or lower terminal cost. The reverse follows for those areas with lower EIRP.

There are limits on the G/T that can be achieved by an antenna/LNA system. The limits are determined by antenna gain and systems noise temperature. In order to achieve a G/T of 24.5 dB/°K with a 44 dBi gain antenna, the maximum system noise temperature tolerable would be 90°K. Figure 6 represents graphically the relationship between G/T and noise temperature based on various antenna gains.

The antenna noise temperature is 22°K at 30° elevation, requiring an LNA with a 68°K noise temperature. This is achievable with current parametric amplifiers. With 43 dBi of gain, the maximum system noise temperature tolerable would be 70° K. The antenna noise temperature is 30°K at 30° elevation, requiring a parametric low noise amplifier with 40°K noise temperature. It is important to note that the gain of the antenna directly affects the G/T of the system. Therefore, any increase in gain for a given small aperture terminal can provide a straight-through increase in $(C/N)_D$ which results in either higher fade margins or lower LNA cost.

If the EIRP is 34 dB, and the $(C/N)_{TOTAL}$ reduced to 13 dBi (2 dB margin over 11 dB threshold), then $(C/N)_D$ would be 14.4, 13.9, or 13.8 for the three 4.5-metre antennas being considered. Figure 5 indicates the system G/T must be 22.5 dB assuming 30 MHz IF bandwidth. Systems noise temperature would have to be 140°K for a 44 dBi gain antenna and 113°K for a 43 dB antenna. LNA temperatures would have to be 118°K and 83°K, respectively.

It is recognized that changes in modulation technique and threshold extension receivers may alter minimum performance characteristics of small earth station terminals. However, the performance characteristics should be specified in a format which clearly identifies the operating margins of the system (i.e., $(C/N)_{TOTAL}$, G/T, and EIRP of the actual location of the terminal).

In the past, video signal-to-noise ratio was used to specify systems performance. This procedure was certainly valid for terminals operating well above threshold or impulse noise levels. However, for the small earth station terminals, fade margin above threshold is critical. Therefore, performance criteria should be established based on components that determine the system G/T; namely, $(C/N)_D$ and fade margin.

CONCLUSION

The Federal Communications Commission has released Declaratory Ruling and Order, FCC76-1169, authorizing the use of 4.5-metre earth station antennas for TV receive-only applications, providing the applicant submits certain supplemental information with his filing. This supplemental information includes detailed calculations of the expected station performance. The Ruling indicates that the calculations should consider EIRP, carrier-to-interference, and carrier-to-noise. It is clear that the FCC intends good engineering practice be incorporated in the design of 4.5-metre earth station terminals to assure good delivered signal quality. This paper concludes that improved antenna gain delivers similar improvement to carrier-to-noise level with resultant improvement in delivered signal-to-noise ratio or increased fade margin. An increase of 1 dB in antenna gain yields a similar increase in carrier-to-noise ratio, making it easier to achieve the FCC objectives.

Antenna	FCC Case 32 – 25 Log θ	Andrew HP 4.5M ESA	4.5M Prime Focus
Gain	43.7	44.0	43.0
Elevation Angle	30°	30°	30°
T_A @ 30°	30°K	23°K	30°K
G_A 4° (avg. dBi)	16.94	12.10	6.10
G_A 8° (avg. dBi)	9.42	4.5	-0.6
G_A 12° (avg. dBi)	5.02	1.0	-6.3
G_A 16° (avg. dBi)	1.89	-7.0	-5.7
$(C/I)_D$	22.1	27.9	32.6
$(C/I)_U$	35.6	35.6	35.6
$(C/I)_{ADJ.\,SAT.}$	21.9	27.2	30.8
$(C/I)_{INT}$	26	26	26
$(C/I)_{TER}$	25	25	25
$(C/I)_{TOTAL}$	19.2	21.2	21.9
$(C/N)_U$	27.2	27.2	27.2
$(C/N)_D$ for $(C/N)_{TOTAL} = 14$	15.8	15.2	15.0
$(C/N)_D$ for $(C/N)_{TOTAL} = 13$	14.4	13.9	13.8

$$(C/N)_{TOTAL} = (C/N)_U \boxplus (C/N)_D \boxplus (C/I)_{TOTAL}$$

$$(C/I)_{TOTAL} = (C/I)_{ADJ\,SAT} \boxplus (C/I)_{TER} \boxplus (C/I)_{INT}$$

$$(C/I)_{ADJ\,SAT} = (C/I)_U \boxplus (C/I)_D$$

where:

T_A = antenna noise temperature including sky noise

G_A = antenna gain at 4° satellite spacing

$(C/I)_D$ = carrier to interference on downlink due to adjacent satellite interference

$(C/I)_U$ = carrier to interference on uplink due to adjacent satellite interference

$(C/I)_{ADJ\,SAT}$ = carrier to interference due to uplink and downlink adjacent satellite interference

$(C/I)_{INT}$ = satellite internal interference

$(C/I)_{TER}$ = terrestrial interference

$(C/I)_{TOTAL}$ = total carrier to interference level due to adjacent satellite interference, internal satellite interference and terrestrial interference (objective $\geqslant$ 18 dB)

$(C/N)_U$ = uplink carrier to noise (thermal)

$(C/N)_D$ = downlink carrier to noise (thermal)

$(C/N)_{TOTAL}$ = total carrier to noise level due to uplink and downlink thermal carrier to noise and total carrier to interference (system design objective $\geqslant$ 13 or 14 dB)

FIGURE 5

Table of calculated carrier-to-noise ratios for three 4.5-metre antennas

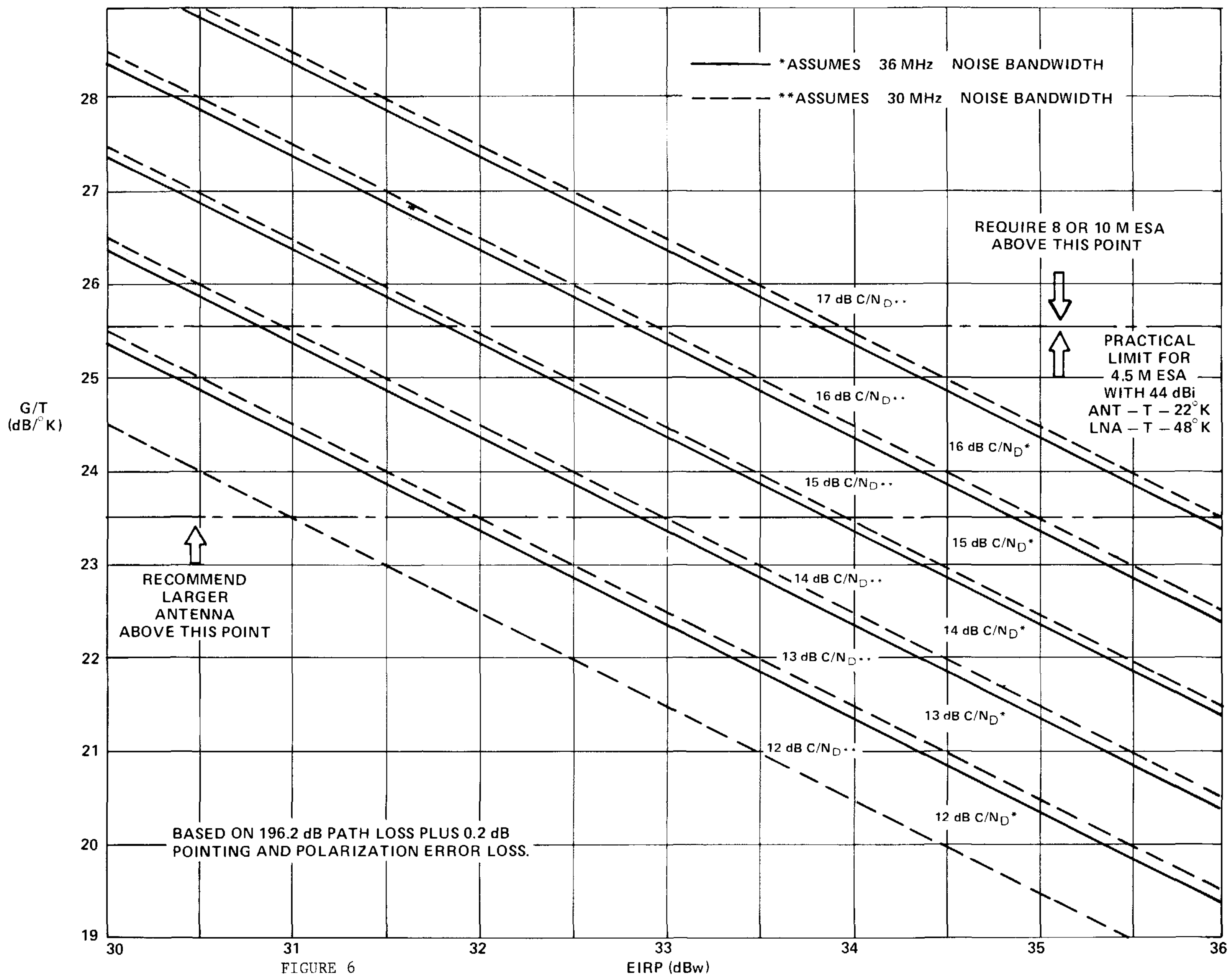

FIGURE 6

Graphic representation of G/T vs satellite EIRP

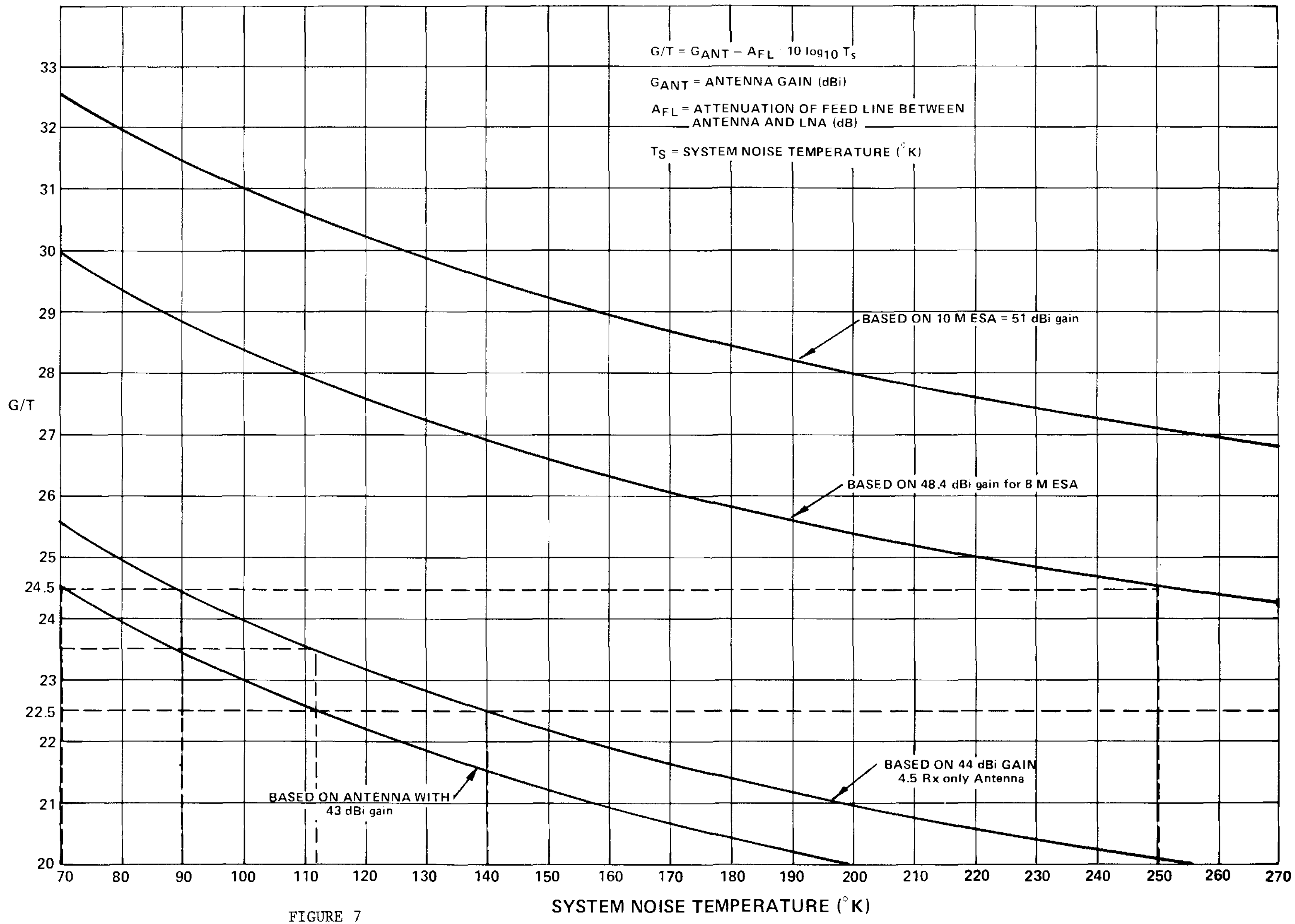

FIGURE 7

Graphic representation of G/T
to system noise temperature