A STUDY OF THE COST/PERFORMANCE TRADEOFFS FOR REGIONAL TELEVISION DISTRIBUTION VIA SATELLITE

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ERRATA

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page		
vi	line 6	"1980" becomes "1985"
1-1	line 10	"1980" becomes "1985"
2-31	line 4	"Table 2-4" becomes "Table 2-5"
5-2	line 4	omit "by"
5-4	line 6	"and second" becomes "and the second"
10-9	line 6	"-48" becomes "-10"
10-19	delete lines 21-25 and insert the following:	"there will essentially be no staggering improvement; assuming operation above FM threshold, the single TV carrier per transponder line can tolerate at least 10 dB more interference relative to the carrier level than that allowable in the two carriers per transponder case."

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FINAL REPORT

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A. Tables of system calculation parameters for the various system models at 4/6 GHz and 12/14 GHz.

B. List of earth station subsystem manufacturers contacted during the mail campaign.

EXECUTIVE SUMMARY

The objective of this study is to "determine the capital and annual operating costs of satellite ground stations for regional television reception satisfying the performance and availability criteria of broadcasting and CATV companies; and using 4/6 GHz and 12/14 GHz satellites which might be launched in the 1978 to ~~1980~~ 1985 timeframe."

During the course of the study Telesat contracted a new satellite utilising twelve transponders at 4/6 GHz of slightly higher EIRP than their existing Aniks and also carrying a transponder configuration operating in the 12/14 GHz band. This configuration provides a satellite transmit pattern of fixed spot beams covering four regions of Canada. Since this satellite is due for launch in 1978 its performance might be used as a bench-mark for comparing the size of earth terminals required to receive various television signal qualities over a range of EIRP's likely to be achieved by this and subsequent satellites.

A "regional television" system for "broadcasters and CATV companies" implies not only a large earth segment but also a requirement for a large number of TV channels. It is therefore appropriate to examine more efficient ways of using available satellite power and bandwidth. The study addresses the constraints and develops system calculations showing the impact on the ground terminals of using the bench-mark

satellite model as a means of delivering signals with:

1. single carrier per transponder
2. two carriers per transponder.

The effect of, and need for up-link power control as a means of improving the high frequency band's vulnerability to fading is discussed and presented - as is the impact of a modest amount of threshold extension.

Since digital transmission offers possible means of improving the transmission efficiency of television, a survey of the "state-of-the-art" in this area was conducted. This survey was based on the literature, discussions with other engineers and some actual involvement in system testing of one of the leading developments (DITEC). Some constraints and advantages of digital transmission techniques are discussed.

Alternative audio transmission techniques are receiving increasing attention for conventional and satellite transmission usage. Such attention appears timely since some of these techniques provide the satellite system planner with means of improving the utilization of satellites for broadcasting. A review of the available techniques and comments on possible satellite utilization are presented.

In order to gain a good cost data base a large number of suppliers were contacted. The results, whilst disappointing to an extent in quantity of information, do provide significant by-product information on the current thrust of system planners and manufacturers.

One by-product was an improved understanding of the development efforts currently being undertaken for near future application. The results are presented in the section "Technology Trends".

As might be expected the cost data on 4 GHz - a mature technology - was easy to come by; it is of interest that equipment costs continue to decline under quantity purchase and value engineering. The cost data collected on the 12 GHz subsystems is sketchy and somewhat dubious. The technology is receiving little attention from manufacturers at this time although interest is growing with the approach of the use of 12 GHz for:

i the Intelsat V Satellite - bids for which are currently under review

ii Satellite Business Systems (Comsat-IBM) - which is currently in the planning stage

iii the Japanese program and European programs - currently under construction

iv the Telesat dual-band satellite

The report also discusses the issues surrounding site selection and presents some ground rules.

It should be stressed that the study is not an attempt to define a system. This can only be done when operational needs are indicated, performance targets defined; number of candidate feeds and locations are identified; candidate configurations and techniques examined and other factors such as financing, marketing and the regulatory aspects considered. The need for such overall planning activity is a major conclusion of the study if satellite technology is to play an increasing role in regional TV distribution systems.

1. INTRODUCTION

For regional television reception in the 1978 to 1985 time frame, regional centres may transmit through satellites to receive-only ground stations located directly on the sites of local television stations or CATV head-ends. This study produces estimates for the capital and operating costs of satellite ground stations for regional television reception satisfying the performance and availability criteria of broadcasters and CATV companies; and using 4/6 GHz and 12/14 GHz communications satellites which might be launched in the 1978 to ~~1980~~ 1985 time frame.

The impact of the following on the design, performance and cost of the receiving terminal are considered:

1. The use of standard FM techniques to transmit one or two TV channels per transponder.

2. The application of over-deviation and threshold extension to enhance FM transmission performance.

3. The possible use of digital encoding and transmission techniques.

4. The impact of varying satellite EIRP and saturating flux density (at 12/14 GHz only) on each of the above.

5. Required performance and threshold fade margins, and the application of up-link power control at 12/14 GHz.

6. Developing technology for TV receive earth stations at 4 GHz and 12 GHz

7. Siting constraints for 4 GHz receive stations.

8. Alternatives for carrying sound channel(s), and the addition of radio program facilities to a receive terminal.

In addition to providing a final set of immediately useable video S/N vs G/T vs earth station cost curves for each of the satellite models considered, the report describes in some detail the underlying system equations and cost data employed. This information clearly identifies the assumptions and methods employed in deriving the results given here and is essential if new satellite or transmission models are to be added.

2. SYSTEM MODELS

This section identifies the satellite models considered and presents the results of system calculations relating video S/N to earth station G/T for single and two carrier per transponder FM/TV systems.

2.1 Network Model

The regional TV network which is the subject of this study is not defined in detail here, nor is this necessary in order to present the relative costs and performance of various TV receive earth stations. However, several assumptions about the network are implicit to the study, and these are stated here:

1. Comparisons between proposed systems consider only TV receive earth station cost (vs quantity) and video S/N performance. Transponder annual charge and transmitting earth station costs are not included, although these might vary from model to model. For a network in which one or two regional centres transmit to a large number of receive terminals, receive earth station costs will dominate total earth segment cost.

   The space segment cost, however, is not negligible, and will increase with increasing transponder EIRP. The results of this study cannot therefore immediately be interpreted as a comparison of the cost-effectiveness of alternative transmission schemes and satellite models to provide a regional TV service. A simple addition of the unknown space segment charge divided by the number of receive locations to the annualized cost per receiving earth station provided here will lead to such a comparison.

2. Both 4/6 GHz and 12/14 GHz satellite models are considered. Fixed parameters have been assumed in both cases, except for EIRP which is allowed to vary over a reasonable range of values. In the 12/14 GHz case only, three saturating flux densities were considered in order to demonstrate the limiting effects of up-link noise and advantage of introducing attenuation following the satellite receiver.

3. Transmission performance measures other than video S/N are not considered explicitly. All FM system calculations are performed assuming the normal Carson's Rule deviation. The effects of excess or "over" deviation on video S/N and other performance parameters are discussed. For moderate amounts of excess deviation the video S/N increases linearly with deviation. Although there may be a slight accompanying increase in the C/N threshold, a dB for dB improvement in obtainable video S/N vs deviation can be reasonably assumed. Therefore the G/T vs S/N results provided here can be considered parametric with respect to a normalized (i.e., relative to Carson's Rule) peak-to-peak video deviation.

4. Audio S/N performance is not computed since it has little impact on the G/T required to provide a given TV (video plus audio) quality. In computing single and two carrier FM peak video deviations according to Carson's Rule, audio subcarriers are assumed at 6.8 MHz and 5.5 MHz respectively having peak deviations of 2 MHz and 1 MHz. This assumption, however, has little impact on the video S/N obtained, and is therefore not critical.

Alternate means of carrying sound program channels are compared briefly from technical and economic standpoints.

5. A homogeneous set of earth stations receiving one or more fixed TV channels is assumed. FM deviations are selected in all cases to make optimum use of RF bandwidth and power, i.e., to minimize the G/T required to receive a given video S/N. In many cases this leads to a power limited design, with operation just a little above threshold. For a non-homogeneous system having a mix of S/N requirements for a common TV signal, the design procedure might have to be modified to ensure that the smallest station could still operate above threshold. This would in turn reduce the FM advantage to the larger stations, and result in higher G/T requirements than those predicted here. Alternatively, the lower G/T station(s) could employ some form of threshold extension such as:

i a reduction in noise bandwidth (i.e., over-deviation into this station) or

ii a phase-lock loop or tracking filter FM demodulator.

6. Energy dispersal (e.d.) is assumed in all cases at both 4/6 GHz and 12/14 GHz. Fixed (i.e., EIRP independent) peak-to-peak deviations of 1.56 MHz (existing Telesat system) and .4 MHz were selected for single and two carrier per transponder operation respectively at both frequency bands. For energy dispersal or, for that matter, audio sub-carrier deviations other than those assumed here, video S/N can be simply adjusted by the relative change in peak video deviation required to maintain the same net peak deviation.

± 1 MHz used in Telesat calculation

It is understood that there is presently no flux density per 4 kHz restriction and corresponding requirement for e.d. at 12/14 GHz, and that removal of e.d. would both increase FM transmission efficiency and lower the TV receiver cost slightly. However, it appears likely that some e.d. will ultimately be required to reduce interference to adjacent satellite systems (it is being considered for the direct broadcasting 12 GHz satellite), and possibly future terrestrial radio systems (12/14 GHz has not been declared an exclusive satellite band by the ~~CCIR~~ ITU).

7. Two carrier per transponder operation has been demonstrated over the Intelsat and Anik satellites, but a complete performance evaluation and final definition of transmission parameters is not available. A brief discussion of some of the features of two carrier operation is included, but this study cannot serve as a definitive statement on technical feasibility or subjective performance for all satellite and earth station models proposed.

2.2 Satellite Parameters

The satellite parameters which have been used in the system calculations at 4/6 GHz and 12/14 GHz for this study are shown in Table 2-1. It is not expected that future 4/6 GHz satellites will differ drastically in satellite parameters from the present series of ANIK satellites because of the need to maintain the present earth station network configuration in the Telesat Canada System. The only change which might be expected is an increase in satellite EIRP due principally to the higher power generating capability of second generation three-axis stabilized satellites (1).

SATELLITE PARAMETER	4/6 GHz	12/14 GHz	UNITS
Transponder Bandwidth	36 (1,2)	72 (2)	MHz
Receive Frequency Band	5.925-6.425	14.0-14.5	GHz
Transmit Frequency Band	3.7-4.2	11.7-12.2	GHz
EIRP per Transponder	34,(1) 37,(2) 40	44,47,(2) 50	dBW
Receive G/T	-6 (1,2)	0 (2)	dB/°K
Sat. Flux Density	-81 (1,2)	-87,-84,(2) -81	dBW/m^2

(1) Present ANIK performance

(2) Possible 4/6-12/14 GHz dual-band satellite specification.

TABLE 2-1

MAJOR SATELLITE PARAMETERS FOR 4/6 AND 12/14 GHz SATELLITES

2.3 FM Transmission Parameters

FM has thus far been used in the transmission of television signals via satellite. The choice of a 36 MHz transponder bandwidth is in fact well suited to 4/6 GHz TV/FM transmission, permitting efficient single carrier per RF channel operation.

Neglecting intrinsic redundancy in the video signal, the single carrier FM mode of television transmission is both efficient and cost effective for the present satellite transponder parameters. Two FM carrier per transponder operation also makes relatively efficient use of satellite power and bandwidth, and has been proposed for lower quality (eg. CATV) TV distribution systems over existing Anik satellites. In addition, multiple TV/FM carriers per transponder and/or multiple TV basebands per carrier(2) could be examined as a means of utilizing proposed wider bandwidth, higher power 12/14 GHz transponders. This study however, does not consider more than two carriers per transponder.

2.3.1 Single Carrier Operation

The single FM carrier per transponder mode of operation has been well proven and the design of such systems is relatively straightforward. Because of its nearly constant amplitude, a bandwidth limited FM carrier undergoes very little distortion or energy spreading due to amplifier non-linearities, and therefore both the earth station transmitter and satellite TWT can be operated at saturation. Although reduced transmission bandwidths can be employed to decrease the G/T required to receive a TV signal, the existing Telesat TV carriers occupy the full 36 MHz channel bandwidth, i.e., this is the receive bandwidth employed (3). The transmitting earth stations (NTV and Heavy Route) are equipped with group delay equalizers which compensate the group delay of the satellite input multiplex filters and reduce differential phase and differential gain distortion.

In addition to providing good signal-to-noise ratio with a minimum of distortion, measurement and analysis has shown that a single carrier TV/FM system is insensitive to edge of band interference of the type produced by adjacent channel TDMA or 2 carrier FDMA systems operating near saturation (4).

2.3.2 Two Carrier Operation

A two carrier FM/FDMA system can operate close to saturation and suffer very little S/N degradation due to intermodulation (IM) noise.

However, substantial and possibly unacceptable levels of interference resulting from 2A-B and higher order IM products generated in the wide band satellite TWT may fall on the adjacent RF channels, thereby indirectly imposing a backoff penalty on the two carrier system.

A -4 dB backoff is proposed here for system calculation purpose*.

It should be noted, however, that this input backoff still results in substantial interference to the adjacent channels, therefore potentially reducing their traffic handling capability.

Other impairments that must be considered carefully in the design of a two carrier system are listed below

1. Intelligible Crosstalk

   Subjectively disturbing crosstalk between the video basebands may occur primarily through the combined effects of RF filter gain slope and AM/PM conversion in the satellite TWT. Linear gain slope equalizers at the transmitting earth station(s) will reduce but not necessarily eliminate these effects.

2. Direct RF interference

   If over-lapping receive noise bandwidths and over-deviation are proposed to make more efficient use of

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* Reducing the input backoff from -1 dB to -4 dB reduces IM product levels by about 3.3 dB with only a 0.5 dB penalty in carrier output power . Further reductions do not give the same degree of relative advantage.

transponder bandwidth, the objective and subjective effects of direct RF interference between the carriers must be considered.

3. Video Distortion

   The effects of edge of band distortion such as group delay and multipath through the adjacent transponder may degrade the performance of a two carrier FM/TV system.

4. Up-Link EIRP Stability

   A two carrier system is much more sensitive than a single carrier system to variations in up-link carrier power (5).

5. Audio Subcarrier

   The audio subcarrier frequency and peak deviation are typically reduced, imposing more stringent requirements on the baseband demultiplex filters.

The effects of interference to the adjacent channels depend on several factors, including

1. Traffic in adjacent channels, in order of increasing sensitivity:
   - no traffic (e.g., channels '0' or '13')
   - single carrier FM/TV
   - TDMA (single carrier CPSK)
   - single carrier 960 channel FM/message
   - thin route (single channel per carrier)
   - FDM/FM/FDMA

2. Two carrier TV system backoff
   - increased backoff reduces the level of IM products but increases earth station G/T requirements.

3. Required TV Carrier bandwidth
   - if less than a full transponder bandwidth is required for the two carriers, freedom in selecting their frequencies can reduce interference (e.g. in C.O.T.C.'s initial FM system, two carriers are backed against the left hand side of channel 1 resulting in the upper 3rd order IM product falling in the guard band between channels 1 and 2).

4. Output multiplex filters
   - the use of a bandwidth limiting filter following the satellite TWT could substantially reduce the levels

of interference to the adjacent RF channels; however, for a variety of reasons, these filters are quite wide and provide little protection (4).

The following table gives a typical two carrier transponder transfer characteristic at three values of input backoff.

2 Carrier TV I/P Backoff Relative to Single Carrier Saturation	O/P Backoff Per Car. Relative to Single Carrier Saturation	IM Product Backoff (including effect of satellite O/P f filter) Relative to Single Carrier Saturation	
		2B-A	3B-2A
-1 dB	-4.8 dB	-16.6 dB	-33.6 dB
-4 dB	-5.3 dB	-19.9 dB	-36.9 dB
-7 dB	-6.6 dB	-23.6 dB	-40.6 dB

TABLE 2-2
TYPICAL TWO CARRIERS PER TRANSPONDER TRANSFER CHARACTERISTIC.

The maximum 2-carrier output power is 1.8 dB less than that for a single carrier and occurs at 1 dB less total input power. This is not simply a loss of power to the IM terms, but is mostly due simply to the impression of a non-linear amplitude transfer characteristic on a multi-carrier input (5).

2.3.3 Over-deviation

The results of measurements performed at Telesat and elsewhere indicate that 3-5 dB of S/N improvement with no subjective degradation can be obtained by increasing the deviation beyond that allowed by Carson's Rule. In general, Carson's Rule may be modified for broadcasting satellite television FM to:

$$B_x = 2\left(\frac{\Delta F_p}{\hat{x}} + f_m\right)$$

where

x = 20 log $\hat{x}$ is the number of dB's of overdeviation

B = Carson's Rule bandwidth

ΔF_p = peak video deviation

f_m = top video baseband frequency

As pointed out in section 2.1, all FM system calculations are performed for x = 0 dB, i.e., normal Carson's Rule deviation, with a transmission bandwidth selected optimally under the constraints of available total bandwidth (bandwidth limitation) and minimum required C/N into the demodulator (threshold limitation). To generalize the results obtained to deviations other than Carson's Rule, we may apply the simple approximation

$$(S/N)_x \simeq (S/N)_o + x$$

for $x \leq 5$ dB

In fact, the relation between $(S/N)_x$ and x becomes progressively non-linear with increasing x for the following reasons:

1. As the receive noise bandwidth is reduced there is some loss of signal as well as noise power. The change in both C/N and S/N for a video signal is therefore not exactly the relative change in IF receive bandwidth.

2. Over-deviation results in further amplitude modulation on the FM/TV carrier at the demodulator input. This A.M. can reduce the performance of the demodulator in the threshold region, and increase the threshold C/N.

The consequences of increased deviation are increased signal distortion - primarily differential gain and differential phase. Furthermore, over-deviation can produce impulsive noise when the picture signal contains high-amplitude, high-frequency components as in highly saturated colour information.

For a sufficient value of over-deviation (typically 5 dB), the S/N of a subcarrier above the TV baseband decreases. This appears to be due to the fact that the main carrier sideband energy represented by the subcarrier is cut off by the IF filter skirts at peak video deviations.

For an NTSC video baseband with at most one audio subcarrier, it appears that up to 4 dB of over-deviation can be reasonably considered. Deviations above this may introduce subjective degradations. The use of multiple subcarriers with any over-deviation must be considered carefully with regard to the possible effects of difference products interfering with the video signal.

2.3.4 FM Threshold and Threshold Extension

In an FM demodulator, as long as the instantaneous peaks of noise at the limiter input remain below the carrier level, normal operation of the demodulator is maintained. That is, for an ideal case, there is a linear relationship between the input carrier-to-noise power ratio (C/N) and the output signal-to-noise ratio (S/N). For a practical system, there is a slight departure from the ideal case as illustrated in Fig. 2-1.

When a significant proportion of the noise peaks are approximately equal to the carrier, a 'threshold' condition is reached where any further decrease in C/N results in a more than proportional decrease in baseband S/N. Threshold has commonly been defined as that point on the curve relating input C/N to output S/N where the measured signal-to-noise ratio departs from a straight line by 1 dB on the S/N axis. For a limiter-discriminator, threshold occurs at a C/N ≃ 10 dB and is depicted as point 'T' in Fig 2-1.

For a TV demodulator, a more realistic definition of threshold is, perhaps, the point at which threshold noise (characterised by dots or lines arriving and decaying on the screen) becomes subjectively noticeable. Using either definition, threshold depends upon the actual demodulator being used and could occur for C/N's between

fm clicks

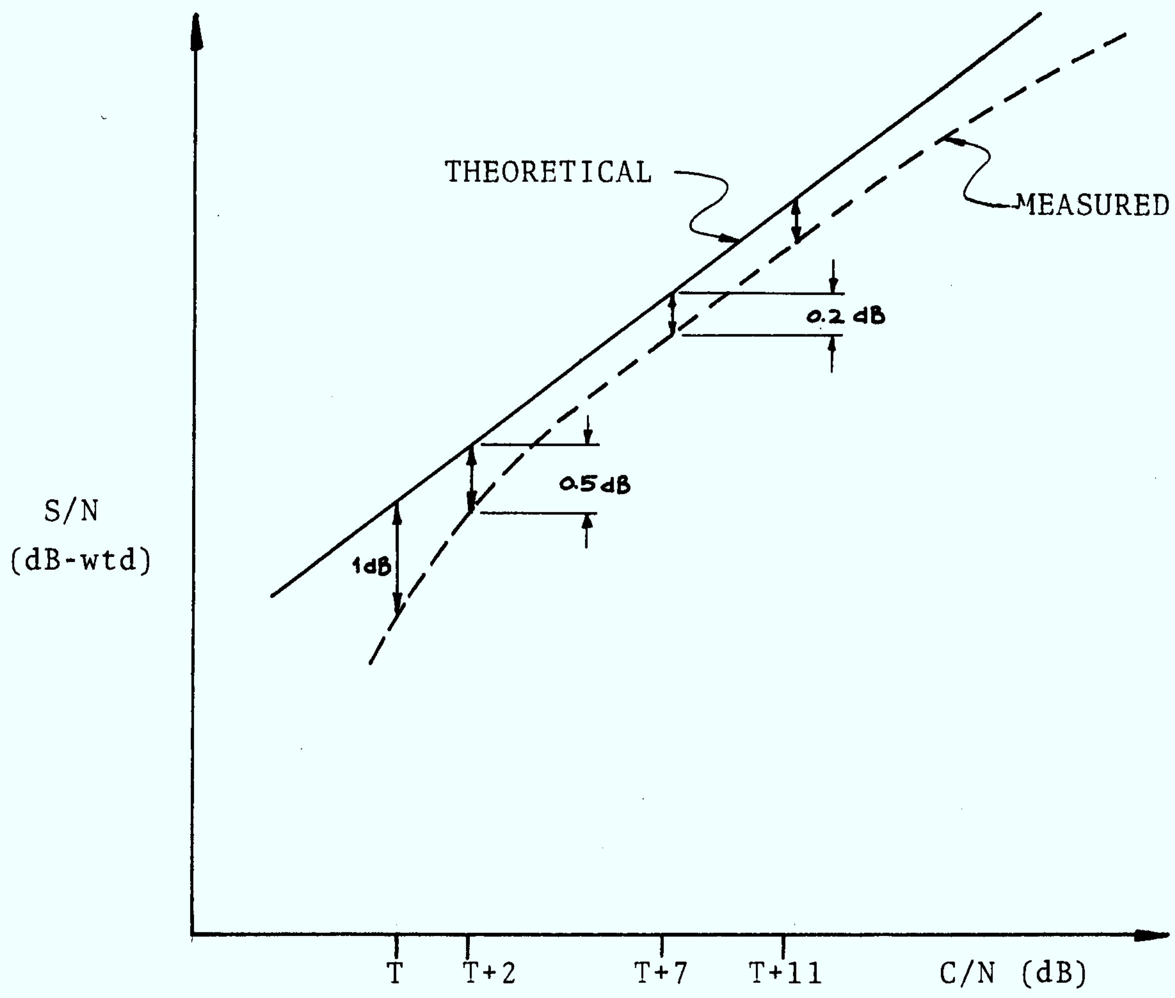

FIGURE 2 - 1

GRAPH OF S/N VERSUS C/N FOR A
TYPICAL LIMITER-DISCRIMINATOR

7 and 12 dB.

By restricting the instantaneous bandwidth of the signal prior to demodulation, it is possible to reduce the noise power reaching the discriminator without significantly distorting the signal. This reduces the C/N at which threshold occurs, and is the principle of threshold extension.

In a large modulation index FM system, the carrier does not occupy all of the Carson's Rule bandwidth on an instantaneous basis; the carrier tracks back and forth in frequency in accordance with the modulating waveform, video in this case. If an ideal bandpass filter whose bandwidth were twice that of the top video baseband frequency were introduced in front of the FM discriminator and could be made to track the instantaneous frequency of the FM wave, then the signal could be demodulated without distortion. (using PLL)

The baseband output of such a demodulator would have the same video S/N above threshold as a conventional demodulator. However, since the total noise power at the input to the discriminator has been reduced by the introduction of the filter, threshold would now occur at a lower value of carrier-to-noise ratio, and hence at a lower value of video signal-to-noise ratio. In other words, the threshold point has been 'extended'.

There are three types of threshold extension demodulators which have been used:

a. the FM Feedback demodulator,

b. the Phase-locked loop demodulator, and

c. the Dynamic-Tracking Filter demodulator.

These threshold extension devices all behave as tracking filters but none of them manage to achieve the degree of threshold extension the simple picture above suggests is possible.

There are a number of reasons for this:

a. the demodulated baseband signal must be used to control the tracking and this signal is both delayed and corrupted by thermal noise and distortion,

b. the tracking filter is in a feedback circuit and usually has to be realized as a single pole filter with limited selectivity, and

c. the static response of the filter will differ from its dynamic response and it will exhibit sluggishness in its tracking

Because of the present limited demand for threshold extension TV demodulators, the cost of these units will be relatively high and the design of a regional TV distribution system using such a demodulator could not be justified.

If, however, a small earth station initially providing thin route service now required television facilities, it might be more cost-effective in such a case to augment the existing equipment with a threshold extension type TV demodulator rather than increase the G/T of the station. This has been the case in the State of Alaska, and California Microwave of Sunnyvale, California, has been active in the development of threshold extension TV demodulators to satisfy the State of Alaska's requirements.

In this study, threshold extension is considered only for single carrier per transponder operation (threshold extension is less attractive in the two carrier case due to the lower FM modulation index). Optimized S/N vs G/T curves with and without threshold extension (a 2 dB advantage is assumed) are presented in order to demonstrate the reduction in required G/T due to threshold extension with deviation optimized in each case. For a fixed deviation, threshold extension reduces the minimum G/T required to receive the signal by more than 2 dB, but offers no advantages at C/N's above the normal threshold.

2.3.5 Propagation Fading Over Satellite Links

A radio signal passing through the atmosphere is subject to various attenuating effects which cause degradation in the received signal strength below that predicted by 'free-space' calculations. In the case of satellite links, this loss effect, generally termed propagation fading, is a function of frequency, elevation angle and climatalogical conditions in the line of sight from the earth station to the satellite. Other causes of fluctuation in received carrier power such as antenna pointing error due to satellite drift and wind deflection, as well as snow buildup and icing on the antenna must also be considered.

Propagation fading can be attributed to such effects as:

a. atmospheric absorption,
b. tropospheric scintillation, and
c. rain and cloud signal attenuation and down-link noise enhancement.

A brief description of each follows:

a. Atmospheric absorption is due primarily to molecular absorption by water and oxygen molecules present in the atmosphere. For a given frequency it is a function of the path length through the atmosphere and hence a function of elevation angle. For 4/6 GHz operation, a value of 0.1 to 0.2 dB is usually allowed for this effect and for 12/14 GHz, a value of 0.6 to 0.8 dB.

b. Tropospheric scintillation is due to the random fluctuations in the refractive index of the troposphere which generally causes signal scattering. This effect is also a function of elevation angle and is only significant at elevation angles below 10 degrees. It ultimately limits communications at very low elevation angles.

c. Rain and cloud attenuation is a sharply increasing function of frequency and is normally the dominant factor at frequencies above 6 GHz. Liquid water droplets in the form of rain contributes the most attenuation but water droplets associated with clouds or rain clouds are also significant when considering performance obtained 'most of the time'. At 4/6 GHz, a rain margin of 3 dB is typically used but at 12/14 GHz, 15 dB or more of attenuation can be encountered at locations subject to heavy rainfall.

A lossy medium such as the atmosphere can be assigned an equivalent noise temperature which depends on the actual loss experienced by a signal, due to molecular absorption and absorption (but not scattering) by rain and cloud, and the actual temperature of the atmosphere. This noise temperature can vary from a few tens of degrees Kelvin up to approximately 290°K, the actual temperature of the atmosphere, under high loss conditions. There is little effect on the up-link signal as the satellite antenna perceives a relatively 'hot' earth at 290°K; this increase in equivalent noise temperature, however, can be significant on the down-link signal since an earth station antenna looks at a relatively cool sky of less than 15°K. The dB degradation in system noise temperature, however, will depend on the noise temperature of the LNA being used - the higher the receiver noise temperature, the smaller the degradation due to atmospheric noise enhancement compared to that of pure signal attenuation. The noise enhancement phenomenon is important when cooled parametric empli-fiers are employed, but can reasonably be neglected for LNA temperatures above 150°K.

The maximum loss in received carrier power which would be experienced by an earth station located at the sub-satellite point due to satellite drift alone is shown in Table 2-3 for operation in the 4/6 GHz and 12/14 GHz frequency bands. Antenna receive gain and half-power beamwidths are calculated for the receive frequencies of 4.0 GHz and 12.0 GHz.

The maximum East-West/North-South satellite drift specification for the present series of ANIK satellites is ±0.1 degrees and it is reasonable to presume that subsequent satellites which may be launched in the 1978 timeframe and beyond will concur with these specifications.

The maximum drift from the nominal satellite position which can therefore be expected is 0.14 degrees.

	RECEIVE FREQUENCY 4.0 GHz			RECEIVE FREQUENCY 12.0 GHz		
ANTENNA DIAMETER	RECEIVE GAIN *	HALF-POWER BEAMWIDTH	MAX. LOSS DUE TO DRIFT	RECEIVE GAIN*	HALF POWER BEAMWIDTH	MAX. LOSS DUE TO DRIFT
FEET	dBi	DEGREES	dB	dBi	DEGREES	dB
3				38.6	1.93	0.06
5				43.1	1.16	0.18
6				44.7	0.96	0.26
8				47.2	0.72	0.46
10	39.5	1.73	0.08	49.1	0.58	0.72
12	41.1	1.44	0.12	50.7	0.48	1.04
15	43.0	1.16	0.18	52.6	0.39	1.58
18	44.6	0.96	0.26	54.2	0.32	2.35
26.5	48.0	0.65	0.57	57.5	0.22	4.97
33	49.9	0.52	0.87	59.4	0.18	7.43

* At Efficiency = 55%

TABLE 2-3

ON-AXIS GAIN DEGRADATION DUE

TO SATELLITE DRIFT

Table 2-4 illustrates the on-axis gain degradation due to the effects of wind and ice loading for some typical Andrew antennas (100 m.p.h. survival) at 4.0 GHz and 12.0 GHz. The figures quoted assume that there is no ice formation on the radiating or reflecting surfaces of the antenna.

LOADING -	4.0 GHz					12.0 GHz				
WIND & ICE	6'	12'	15'	18'	26'	3'	6'	12'	15'	18'
45 m.p.h. + ¼"	0.1	0.2	0.2	0.1	0.1	0.2	0.3	0.3	0.4	0.4
60 m.p.h. + ¼"	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.7
75 m.p.h. + ½"	0.4	0.5	0.8	0.8	0.9	0.6	0.9	1.1	1.5	1.7

TABLE 2-4

ON-AXIS GAIN DEGRADATION (IN DECIBELS)

DUE TO WIND AND ICE LOADING

2.3.6 Fade Margins

For any large scale TV distribution system, such as the regional network being considered in this study, it is desirable that the expected video signal-to-noise performance be obtained for a reasonable percentage of the time, typically better than 98% of the time. Moreover, objectionable performance, characterized by the continual presence of impulse noise, should occur for less that 0.5% of the time.

To satisfy these requirements, it is necessary to assign certain fade margins during the development of the systems equations and it is the aim of this section to present some rationalization of the fade margins used for FM video transmission at 4/6 GHz and 12/14 GHz.

2.3.6.1 Performance Fade Margin

If there is no allowance for fading in the design of a satellite transmission system, desired transmission performance, video signal-to-noise ratio in this case, might only be obtained for a small percentage of the time. A performance fade margin of M_2 dB has been applied in the system calculations to ensure that the desired S/N is in fact realized for better than 98% of the time; this clearly gives more meaning to the S/N quoted.

The values for the performance fade margins used at 4/6 GHz and 12/14 GHz are shown in Table 3-1 (section 3.3).

Higher fade margins must be assigned for the 12/14 GHz cases, firstly to meet the 98% performance availability objective and, secondly to provide some margin above objectionable performance due to random noise* (as opposed to threshold noise considered in section 2.3.4).

2.3.6.2 Threshold Fade Margin

Due to the objectionable effect of impulse noise prevalent below the threshold of a TV FM demodulator, it is essential that such occurences be limited to a small percentage of the time (less than 0.5%). To achieve this, the operating C/N under fairweather conditions is selected to be at least M_3 dB above the threshold point (C/N ≃ 10 dB). M_3 is here referred to as the threshold fade margin, as distinct from the performance fade margin. By stipulating a fairweather C/N

* The point of objectionable performance due to random noise is not as pronounced as in the case of impulse noise. For network quality video, a signal-to-noise ratio less than 38 dB-wtd has been defined as an outage (6), and for our purposes might be considered objectionable.

well above the normal FM threshold, operation below FM threshold will occur for only a small percentage of the time.

In view of the significantly greater propagation fading which occurs at frequencies above 6 GHz, due in particular to rain and cloud attenuation, it is justifiable to consider two modes of operation at 12/14 GHz:

a. with up-link power control, and
b. without up-link power control.

Up-link power control can completely eliminate the effects of up-link fading, resulting in a fixed down-link EIRP from the satellite. If uncompensated, up-link fading is more damaging than down-link fading because fades are typically deeper (due to the higher transmission frequency) and they affect performance into all receive earth terminals. Down-path fading is a function of independent local climatalogical conditions at each receive location, and is therefore less critical in terms of its effect on overall network availability. (The network availability objective will probably exceed the 99.5% receive availability objective, and therefore impose higher up-link fade margin requirements).

Up-link power control implies that some form of closed-loop (incorporating the satellite node) AGC control of the transmit earth station EIRP (7) would be required to compensate for the effects of up-path atmospheric and precipitation attenuation. A larger power HPA would be required, thus increasing the costs of the transmit earth station. However, the reduction in required fade margin leads to a reduction in receive G/T. When a regional TV distribution system consisting of one or two regional transmit earth stations and many low-cost receive earth terminals is being postulated, up-link power control is clearly the economic solution when considering the total earth segment cost. Implementation of up-link power control has been considered previously (8) and is not described further here.

The second mode of operation at 12/14 GHz is to assume no up-link power control. The immediate effect is that a larger fade margin has to be applied to account for up-path and down-path fading* thus increasing the receive G/T which would be required to ensure acceptable performance for a high percentage of time.

It must be emphasized that the fade margins used at 12/14 GHz are by no means absolute and were chosen as possible guideline values that could be used for an operating system, as distinct from an experimental one, with standard service agreements which specify:

a. the percentage of time a desired video signal-to-noise ratio performance must be exceeded (fairweather S/N = S/N (desired) + performance margin) and

b. the percentage of time a non-objectionable video signal is available or conversely, the percentage of time outage i.e. objectionable performance (operation below threshold or video S/N < 38 dB-wtd) occurs.

---

* The 'soft-limiting' characteristic of the satellite transponder TWT offsets the effect of up-path fades on down-path C/N to some extent but not in cases of deep fading on the up-path or when more than one carrier accesses the transponder. Operating the satellite beyond saturation to increase this 'soft-limiting' effect over a wider input power range is not considered desirable due to the possible effect on TWT lifetime and severe non-linear distortion in the over-drive region.

In view of the fact that the degree of propagation fading encountered varies widely with elevation angle and climatalogical statistics (9) (refer to section 2.3.5 and Table 2-5), especially maximum rain rate, it is possible that the down-link fade margin could be reduced to some locations. Without the use of uplink power control, propagation fading would be critically dependent on the fade statistics at the transmitting earth station(s).

The normal approach of an operating company in designing a satellite communications system is to ensure that acceptable performance will be obtainable over the life-time of the satellite for edge-of-beam coverage. It is therefore possible to derive some benefit from the increased EIRP attendant with non-edge-of-beam operation for some receiving earth stations.

Assigning identical fade margins to all receiving earth stations undoubtedly leads to the situation where some stations will be over-designed with respect to others, but until the earth segment can be clearly defined it might be preferable at first to adopt a conservative approach to a new and untried frequency band because of the limited available fade statistics rather than risk implementation of a marginal operational system.*

The approach adopted here has been to use best estimates of up- and down-link fade margins based on a limited analysis using climatalogical statistics for Halifax, N.S. (elevation angle $\simeq 18^{\circ}$), a semi-worse case. Indications are that fade depths here are of the order of 8.5 dB and 6 dB for the up- and down-links respectively for not greater than 0.5% of the time.

The subject of fading is very important in determining the cost effectiveness of a 12 GHz regional TV system and in-depth study is clearly desirable.

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* No operational experience has yet verified the results of limited theoretical and experimental studies of propagation fading at 12/14 GHz although fades in excess of 10 dB can be expected in many areas of the country.

No. of days of rain per year	90
Mean rainfall during year (ins.)	10.3
Max. 5 min. of rainfall (ins.)	0.3
Max. mean wind speed (m.p.h.)	47.9
Maximum wind gusts (m.p.h.)	126

TABLE 2-5

CLIMATALOGICAL STATISTICS FOR HALIFAX, N.S. (9)

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3. FM SYSTEM CALCULATIONS

3.1 FM Equation for Video S/N

Above threshold, the flat unweighted signal to noise ratio of an FM video signal is given by:

$$S/N = \frac{3}{2} (C/N_o)_t \frac{\Delta F_v^2}{f_v^3} \qquad (3\text{-}1)$$

or expressed in dB's:

$$S/N(\text{dB-unwtd}) = 1.76 + (C/N_o)_t + 20 \log \Delta F_v - 30 \log f_v \qquad (3\text{-}2)$$

where S/N = ratio of test-tone power to r.m.s. unweighted noise power

$(C/N_o)_t$ = ratio of the total receive carrier power to the total system noise power density, in dB-Hz

ΔF_v = peak test-tone deviation, in Hz

f_v = top video baseband frequency (equal to 4.2 MHz for the NTSC system),in Hz

To convert equation (3-2) to the CCIR definition of video signal to noise ratio which is the ratio of the peak-to-peak luminance signal to the r.m.s. weighted noise power, a factor of 10 log $(2/0.707)^2$ = 9 dB must be added to convert average test-tone signal power to peak-to-peak signal power. Further, to convert to peak-to-peak luminance signal, 3 dB must be subtracted, giving a net conversion factor of + 6 dB. Adding the CCIR pre-emphasis and weighting improvement factor of 13 dB and substituting for f_v = 4.2 X 10^6Hz, equation (3-2) becomes

$$S/N(\text{dB-wtd}) = (C/N_o)_t + 20 \log \Delta F_v - 177.9 \qquad (3\text{-}3)$$

Including amodem margin of M_1 dB to account for the variance between theoretical performance, as given by equation (3-3), and measured performance, equation (3-3) becomes

$$S/N(\text{dB-wtd}) = (C/N_o)_t + 20 \log \Delta F_v - 177.9 - M_1 \qquad (3\text{-}4)$$

Re-arranging:

$$(C/N_o)_t = S/N - 20 \log \Delta F_v + 177.9 + M_1 \qquad (3\text{-}4a)$$

To ensure that a required S/N is achieved for a reasonable percentage of time, typically greater than 98%, a performance fade margin of M_2dB is added to equation (3-4a), thus

$$(C/N_o)_t = S/N - 20 \log \Delta F_v + 177.9 + M_1 + M_2 \qquad (3\text{-}5)$$

Since this relation is valid only for operation above threshold

(C/N ≈ 10 dB), equation (3-5) is constrained by:

$$(C/N_o)_t - 10 \log B_{IF} \geq 10 \text{ dB} \qquad (3\text{-}6)$$

where B_{IF} is the pre-detection IF noise bandwidth expressed in Hertz.

In addition, since operation of a TV FM demodulator below threshold is extremely undesirable because of the objectionalbe effect of impulsive noise, a threshold margin of M_3dB must be added to the minimum operating C/N to ensure that objectionable performance occurs only for a small percentage of the time (less than 0.5%). Therefore, equation (3-6) becomes

$$(C/N_o)_t - 10 \log B_{IF} \geq 10 + M_3 \text{ dB} \qquad (3\text{-}7)$$

The Carson's Rule bandwidth of a video RF carrier with energy dispersal and an audio subcarrier is:

$$B_{CR} = 2(\Delta F_v + \Delta F_{ED} + \Delta F_{ASC} + f_v)\text{MHz} \qquad (3\text{-}8)$$

where:

ΔF_v = peak video deviation, in MHz

ΔF_{ED} = peak video energy dispersal, in MHz

ΔF_{ASC} = peak audio RF deviation, in MHz

f_v = top video baseband frequency, in MHz

Equation (3-8) however, is a conservative estimate for bandwidth as it is rare that the peaks of modulating waveforms add coherently.

A more realistic estimate would be to assume that the peak deviations of the video and audio modulating waveforms can be represented by randomly varying, non-coherent vectors. It can be shown that the mean-squared value of the vector sum is the root-sum-square (R.S.S.) of the representative vectors.

The deviation of the R.F. carrier due to the energy dispersal triangular waveform has not been included due to its low frequency (30 Hz) and repetitive peaking.

The new estimate of the Carson's Rule bandwidth is, therefore

$$B_{CR} = 2((\Delta F_v^2 + \Delta F_{ASC}^2)^{\frac{1}{2}} + \Delta F_{ED} + f_v)\text{MHz} \qquad (3\text{-}9)$$

Re-arranging to obtain ΔF_v, the peak video deviation:

$$\Delta F_v = ((B_{CR}/2 - \Delta F_{ED} - f_v)^2 - \Delta F_{ASC}^2)^{\frac{1}{2}} \quad \text{MHz-pk} \qquad (3\text{-}9a)$$

Substituting for ΔF_v in equation (5):

$$(C/N_o)_t = S/N - 10 \log ((B_{CR}/2 - \Delta F_{ED} - f_v)^2 - \Delta F_{ASC}^2) + 177.9 + M_1 + M_2 \quad \text{dB-Hz} \qquad (3\text{-}10)$$

For the cases where equation (3-7) is not satisfied, that is,

$$(C/N_o)_t - 10 \log B_{IF} < 10 + M_3 \text{ dB} \qquad (3\text{-}11)$$

then the procedure adopted is to optimize the I.F. noise bandwidth and hence the Carson's Rule Bandwidth, B_{CR}, by iterative calculations such that

$$(C/N_o)_t - 10 \log B_{IF} = 10 + M_3 \text{ dB}$$

or

$$(C/N_o)_t - 10 \log (1.06\ B_{CR})^* = 10 + M_3 \text{ dB} \qquad (3\text{-}12)$$

and equation (3-10) are both satisfied.

3.2 Link Equations

The total receive carrier power to noise power density ratio, $(C/N_o)_t$, is related to the up-link and down-link C/N_o by:

$$(C/N_o)_t^{-1} = (C/N_o)_u^{-1} + (C/N_o)_d^{-1} \quad \text{(in numerics)} \qquad (3\text{-}13)$$

where $(C/N_o)_u$ =up-link carrier power to noise power density ratio

$(C/N_o)_d$ =down-link carrier power to noise power density ratio

---

* Note that the I.F. noise bandwidth and the Carson's Rule bandwidth are related by the approximation: $B_{IF} \simeq 1.06\ B_{CR}$.

Re-arranging equation (3-13)

$$(C/N_o)_d^{-1} = (C/N_o)_t^{-1} - (C/N_o)_u^{-1} \quad \text{(in numerics)} \qquad (3\text{-}13a)$$

The up-link C/N_o is given by the equation:

$$(C/N_o)_u = \phi_s + (G/T)_s - IBO - \text{Gain of } 1m^2 - 10 \log k \quad \text{dB-Hz} \qquad (3\text{-}14)$$

where

ϕ_s = flux density for single carrier saturation of the satellite transponder, in dBW/m^2

$(G/T)_s$ = satellite antenna gain to noise temperature ratio, in $dB/^oK$

IBO = satellite transponder input back-off relative to single carrier saturation, in dB

Gain of $1m^2$ = gain relative to isotropic of a $1m^2$ antenna, in dBi

k = Boltzmann's constant, 1.38×10^{-23} $Joules/^oK$

10 log k = -228.6 $dBW/^oK$

The down-link C/N_o is given by:

$$(C/N_o)_d = EIRP - OBO - FSL_d + G/T - 10 \log k \text{ dB-Hz} \qquad (3\text{-}15)$$

where

EIRP = satellite transmit effective isotropic radiated power, in dBW

OBO = satellite transponder output back-off relative to single carrier saturation, in dB

FSL_d = free-space path loss on down-link for slant range of 25,300 miles (i.e. 10^o elevation angle), in dB

G/T = receive earth station antenna gain to total receive system noise temperature ratio, in $dB/^oK$.

Re-arranging equation (3-15)

$$G/T = (C/N_o)_d + OBO + FSL_d + 10 \log k - EIRP \text{ dB}/^oK \qquad (3\text{-}15a)$$

Summary of System Equations

Summarizing the pertinent system equations:

$$(C/N_o)_t = S/N - 10 \log ((B_{CR}/2 - \Delta F_{ED} - f_v)^2 - \Delta F_{ASC}^2) + 177.9 + M_1 + M_2 \text{ dB-Hz} \quad (3\text{-}10)$$

$$(C/N_o)_t - 10 \log B_{IF} \geq + 10 + M_3 \text{ dB} \quad (3\text{-}7)$$

and for bandwidth optimized operation:

$$\begin{aligned}(C/N_o)_t &= S/N - 10 \log ((B_{CR}/2 - \Delta F_{ED} - f_v)^2 - \Delta F_{ASC}^2) + 177.9 + M_1 + M_2 \text{ dB-Hz} \\ &= 10 \log (1.06\, B_{CR}) + 10 + M_3 \text{ dB-Hz}\end{aligned} \quad (3\text{-}12)$$

$$(C/N_o)_u = \phi_s + (G/T)_s - IBO - \text{Gain of } 1m^2 - 10 \log k \text{ dB-Hz} \quad (3\text{-}14)$$

$$(C/N_o)_d^{-1} = (C/N_o)_t^{-1} - (C/N_o)_u^{-1} \quad \text{(in numerics)} \quad (3\text{-}13a)$$

$$G/T = (C/N_o)_d + OBO + FSL_d + 10 \log k - EIRP \text{ dB}/^oK \quad (3\text{-}15a)$$

While no attempt has been made to combine these equations because of the relative complexity, a relationship between signal to noise ratio and receive G/T is clear.

3.3 Earth Station G/T Versus Video S/N

Presented in this section is the graphical representation of the relationship between earth station G/T and video signal-to-noise ratio for the various system models at 4/6 GHz and 12/14 GHz. The results were obtained by substituting the relevant satellite link and FM transmission parameters (Tables 3-1 and 3-2 respectively) into the system equations derived in section 3.2. The overall design procedure has been to optimize the deviation using Carson's Rule and the constraints of a minimum (threshold) C/N and total available bandwidth.

A tabular summary of the key parameters, from which the graphs are derived, for each system model is presented in Appendix A.

3.3.1 4/6 GHz

3.3.1.1 Single FM Carrier per Transponder

Two cases are presented here:

1. Normal Threshold (Fig. 3-1)
2. 2dB Threshold Extension (Fig. 3-2)

Referring to Fig. 3-1, the straight line relationship between G/T and video S/N occurs in the band-limited region of operation. As the

		4/6 GHz		12/14 GHz			
		SINGLE FM CXR/TPDR	TWO FM CXRS/TPDR	WITH UPLINK POWER CONTROL		WITHOUT UPLINK POWER CONTROL	
PARAMETER	UNITS			SINGLE CXR TPDR	TWO CXRS TPDR	SINGLE CXR TPDR	TWO CXRS TPDR
ϕ_s	dBW/m^2	-81	-81	-87 -84 -81	-87 -84 -81	-87 -84 -81	-87 -84 -81
$(G/T)_s$	$dB/^oK$	-6	-6	0	0	0	0
Gain of $1m^2$ (6.0,14.0 GHz)	dBi	37	37	44.5	44.5	44.5	44.5
IBO	dB	0	7	0	7	0	7
OBO	dB	0	5.3	0	5.3	0	5.3
EIRP	dBW	34 37 40	34 37 40	44 47 50	44 47 50	44 47 50	44 47 50
FSL_d(4.0 GHz, 12.0 GHz)	dB	196.7	196.7	206.2	206.2	206.2	206.2
FM Threshold	dB	10	10	10	10	10	10
Modem margin, M_1	dB	0.5	0.5	0.2	0.2	0.2	0.2
Perf. Fade Margin, M_2	dB	1	1	3	3	5	5
Threshold Margin, M_3	dB	2	2	7	7	11	11
Available Transponder Bandwidth	MHz	36	17	72	34	72	34

TABLE 3-1

SUMMARY OF LINK PARAMETERS FOR THE
4/6 GHz and 12/14 GHz FREQUENCY BANDS.

	PARAMETER	SYMBOL	4/6 GHz	12/14 GHz
	Top video baseband frequency	f_V	4.2 MHz	4.2 MHz
	Peak video deviation	ΔF_V	12.9 MHz	31 MHz
SINGLE FM	Audio subcarrier frequency	--	6.8 MHz	6.8 MHz
VIDEO CARRIER	Peak audio RF deviation	ΔF_{ASC}	2 MHz	2 MHz
PER TRANS-	Receiver I.F. Noise bandwidth	B_{IF}	38 MHz	76.5 MHz
PONDER	Carson's Rule Bandwidth (≈0.94 I.F. Noise B/W)	B_{CR}	36 MHz	72 MHz
	Video Weighting and Pre-emphasis (CCIR-525)		Rec. 421-2 Rec. 405-1	Rec. 421-2 Rec. 405-1
	Peak Video Energy dispersal	ΔF_{ED}	0.78 MHz	0.78 MHz
	Top video baseband frequency	f_V	4.2 MHz	4.2 MHz
	Peak video deviation	ΔF_V	4 MHz	12.6 MHz
TWO FM	Audio subcarrier frequency	--	5.5 MHz	5.5 MHz
VIDEO CARRIERS	Peak audio RF deviation	ΔF_{ASC}	1 MHz	1 MHz
PER TRANS-	Receiver I.F. noise bandwidth	B_{IF}	18 MHz	36 MHz
PONDER	Carson's Rule Bandwidth (≈0.94 I.F. Noise B/W)	B_{CR}	17 MHz	34 MHz
	Video Weighting and Pre-emphasis (CCIR-525)		As above	As above
	Peak video energy dispersal	ΔF_{ED}	0.2 MHz	0.2 MHz

TABLE 3-2

SUMMARY OF TRANSMISSION PARAMETERS FOR THE
4/6 GHz and 12/14 GHz FREQUENCY BANDS.

required video S/N and corresponding G/T decrease, a point of inflexion occurs where the faded operating C/N over the 36 MHz available bandwidth equals the threshold C/N, and subsequent reduction in S/N implies a reduced Carson's Rule Bandwidth.

Below the point of inflexion (S/N = 50.6 dB-wtd), we enter the power-limited region where the Carson's Rule Bandwidth has been optimized such that the carrier-to-noise ratio remains at the operating threshold. (with margin, C/N = 12dB in this case).

For the 2dB Threshold Extension case (Figure 3-2), the threshold point has been decreased by 2 dB to a C/N = 10 dB. Note that in the power-limited region, the G/T required to achieve a particular video S/N has been decreased by approximately 1.6dB but that in the bandwidth-limited region (S/N > 50.6dB-wtd.) no advantage is gained. A G/T vs S/N curve can be generated for any desired satellite EIRP by simply moving one of the curves plotted up or down by the difference in EIRP's. In all cases, earth station G/T and satellite EIRP trade off on a one for one basis, i.e., for a given video S/N a 1dB increase in EIRP results in a 1dB decrease in required G/T.

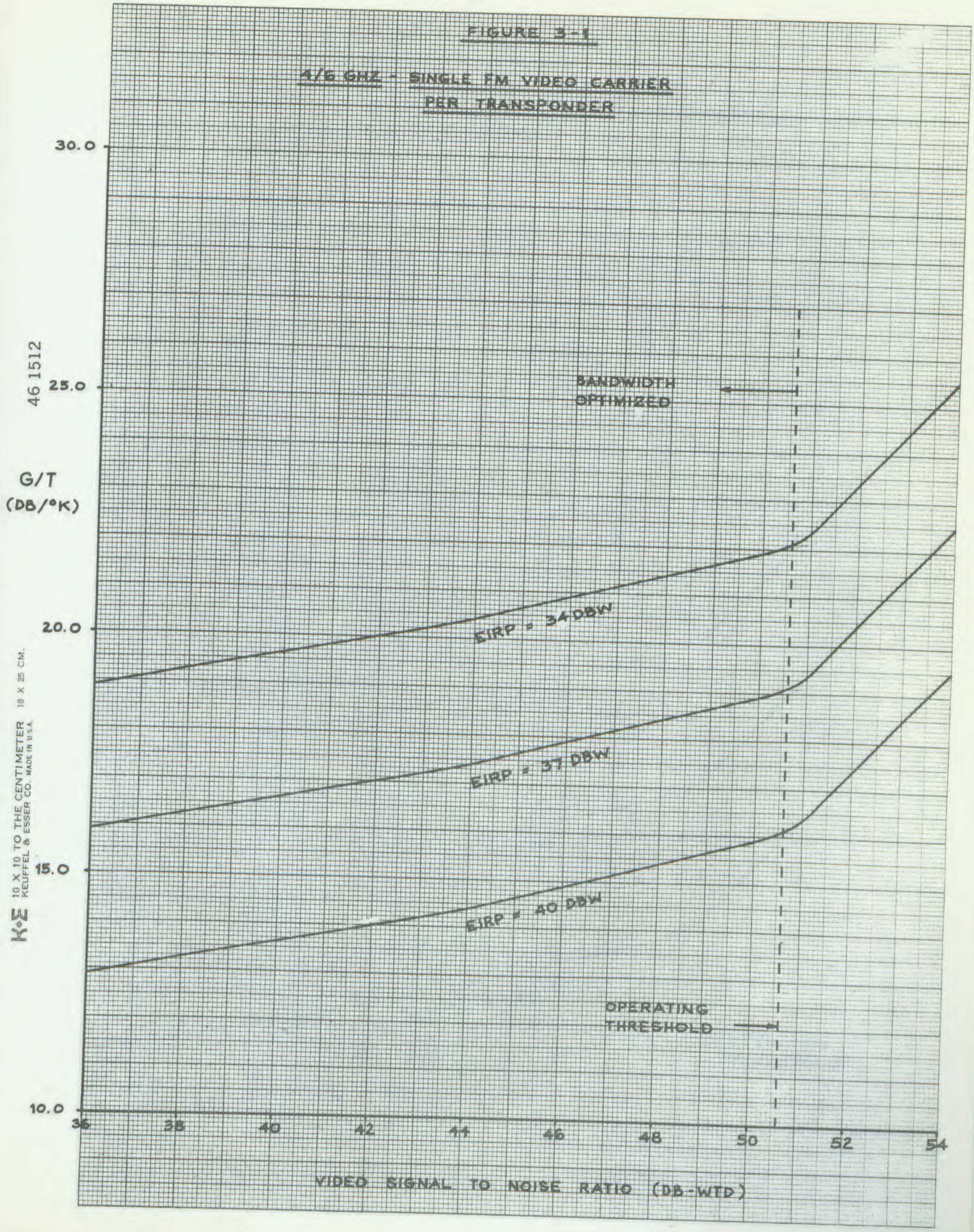


FIGURE 3-1
4/6 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER
G/T (DB/°K)
30.0
25.0
20.0
15.0
10.0
BANDWIDTH OPTIMIZED
EIRP = 34 DBW
EIRP = 37 DBW
EIRP = 40 DBW
OPERATING THRESHOLD
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

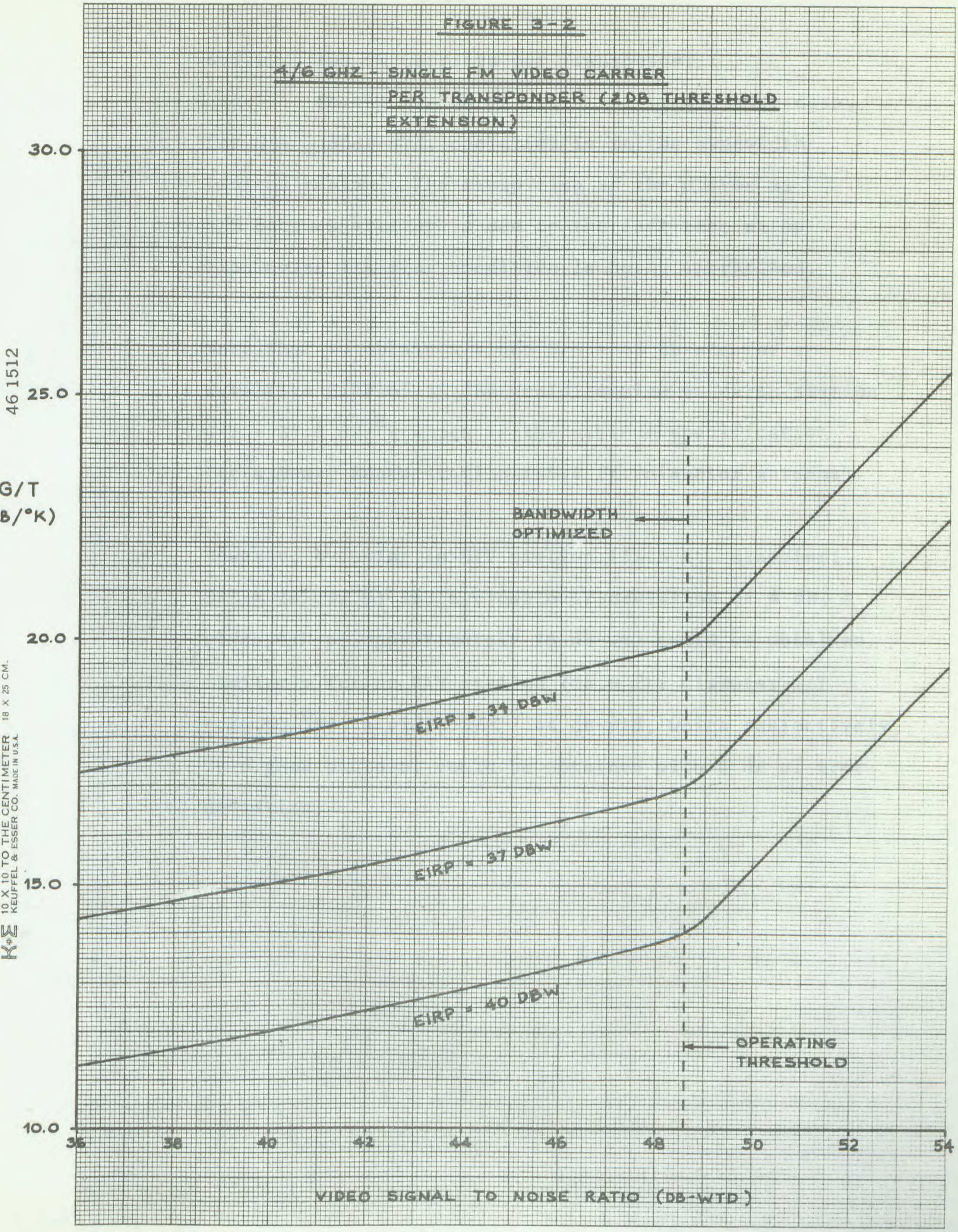


FIGURE 3-2
4/6 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER (2DB THRESHOLD EXTENSION)
G/T (DB/°K)
30.0
25.0
20.0
15.0
10.0
36
38
40
42
44
46
48
50
52
54
EIRP = 34 DBW
EIRP = 37 DBW
EIRP = 40 DBW
BANDWIDTH OPTIMIZED
OPERATING THRESHOLD
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

3.3.1.2 Two FM Carriers per Transponder

In the two FM carriers per transponder case, for S/N > 36dB-wtd, operation is in the bandwidth-limited region. The steep rise of the curves as S/N becomes greater is due to the fact that an up-link noise limiting condition is being approached.

Note that to obtain a video S/N = 48 dB-wtd for a satellite EIRP of 35 dBW would require an earth station G/T = 37.6 dB/^{o}K which is the minimum specification for a Heavy Route station (98.4 ft. diameter antenna).

However, by using an NTV station (33.3 ft. diameter; G/T = 28 dB/^{o}K) and a video over-deviation of 4 dB, a video S/N of approximately 46 dB-wtd could be obtained. Similarly for an RTV station (26.5 ft. diameter G/T = 26 dB/^{o}K), a video S/N $\simeq$ 44 dB-wtd, which subjectively, is a good picture, could be obtained with 4 dB of over-deviation.

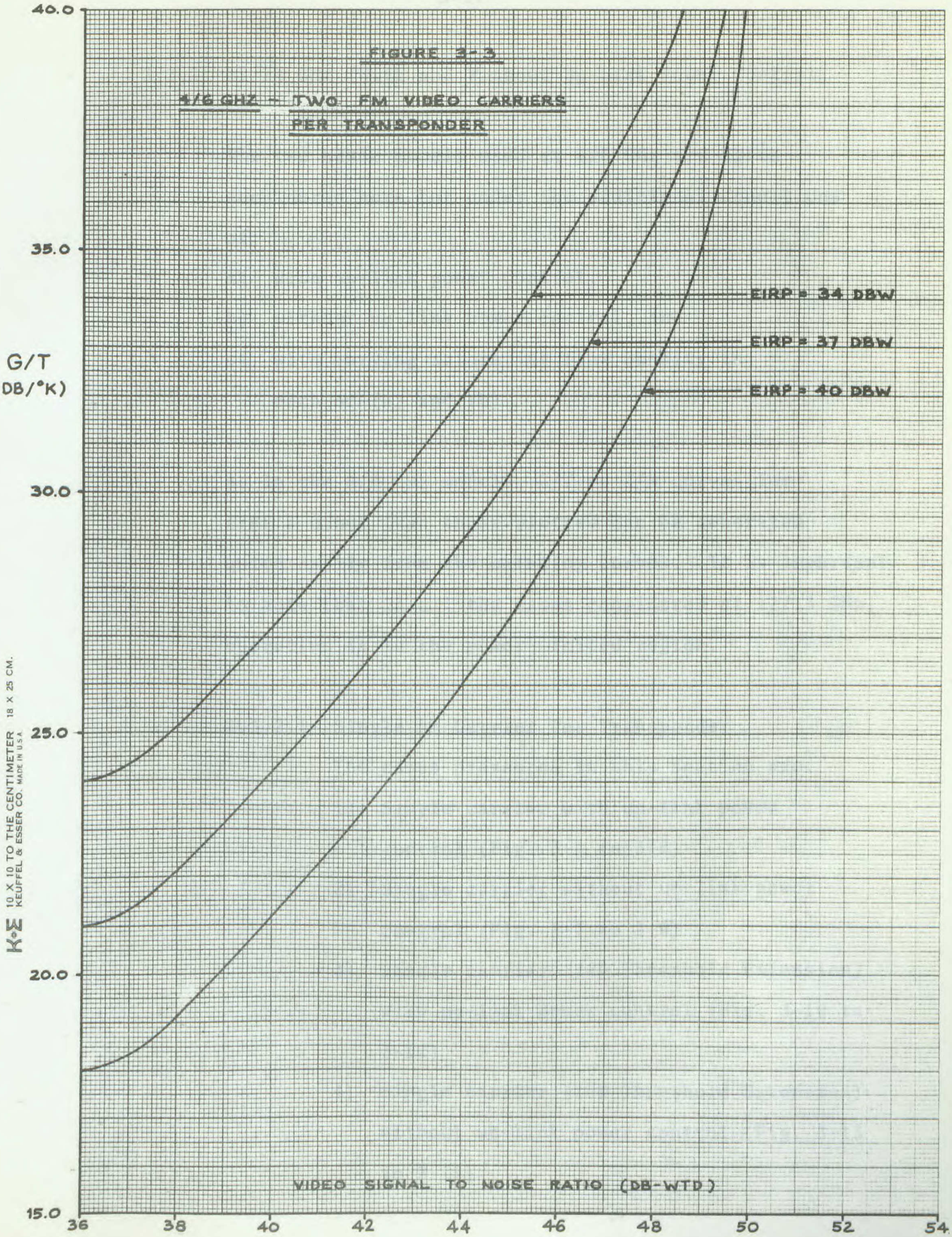


FIGURE 3-3
4/6 GHZ - TWO FM VIDEO CARRIERS PER TRANSPONDER
G/T (DB/°K)
EIRP = 34 DBW
EIRP = 37 DBW
EIRP = 40 DBW
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
40.0
35.0
30.0
25.0
20.0
15.0
36
38
40
42
44
46
48
50
52
54
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

3.3.2 12/14 GHz (With and Without Up-Link Power Control)

The two basic models used at 4/6 GHz are again considered here but under the additional conditions of:

a) with up-link power control,

b) without up-link power control, and

c) with varying saturating flux density in each of (a) and (b)

As in the 4/6 GHz models, G/T vs S/N curves for EIRP's other than those plotted can be generated quite easily from the existing curves. It is important to note that in all the cases considered at 12/14 GHz, operation is in the power-limited region.

3.3.2.1 Single FM Carrier Per Transponder

The cases presented in this section are:

1) Single carrier with up-link power control (Fig. 3-4 to 3-6)

2) Single carrier without up-link power control (Fig. 3-7 to 3-9)

3) Single carrier (2dB Threshold Extension) with up-link power control (Fig. 3-10 to 3-12)

4) Single carrier (2dB Threshold Extension) without up-link power control (Fig. 3-13 to 3-15)

In each of the above cases, three values of saturating flux density are presented to illustrate the effect of what amounts to varying the contribution of up-link noise.

The following features in the graphs should be noted:

(a) in all cases, operation is in the power - limited region thus necessitating bandwidth optimization;

(b) increasing the saturating flux density decreases G/T requirements but more importantly, reduces the dominance of up-link carrier-to-noise density ratio at high video S/N's.

(c) the use of threshold extension results in a lower G/T requirement (power-limited region of operation) for the range of video signal-to-noise ratios considered, and

(d) the use of up-link power control, as against no up-link power control, reduces to a great degree the G/T requirements.

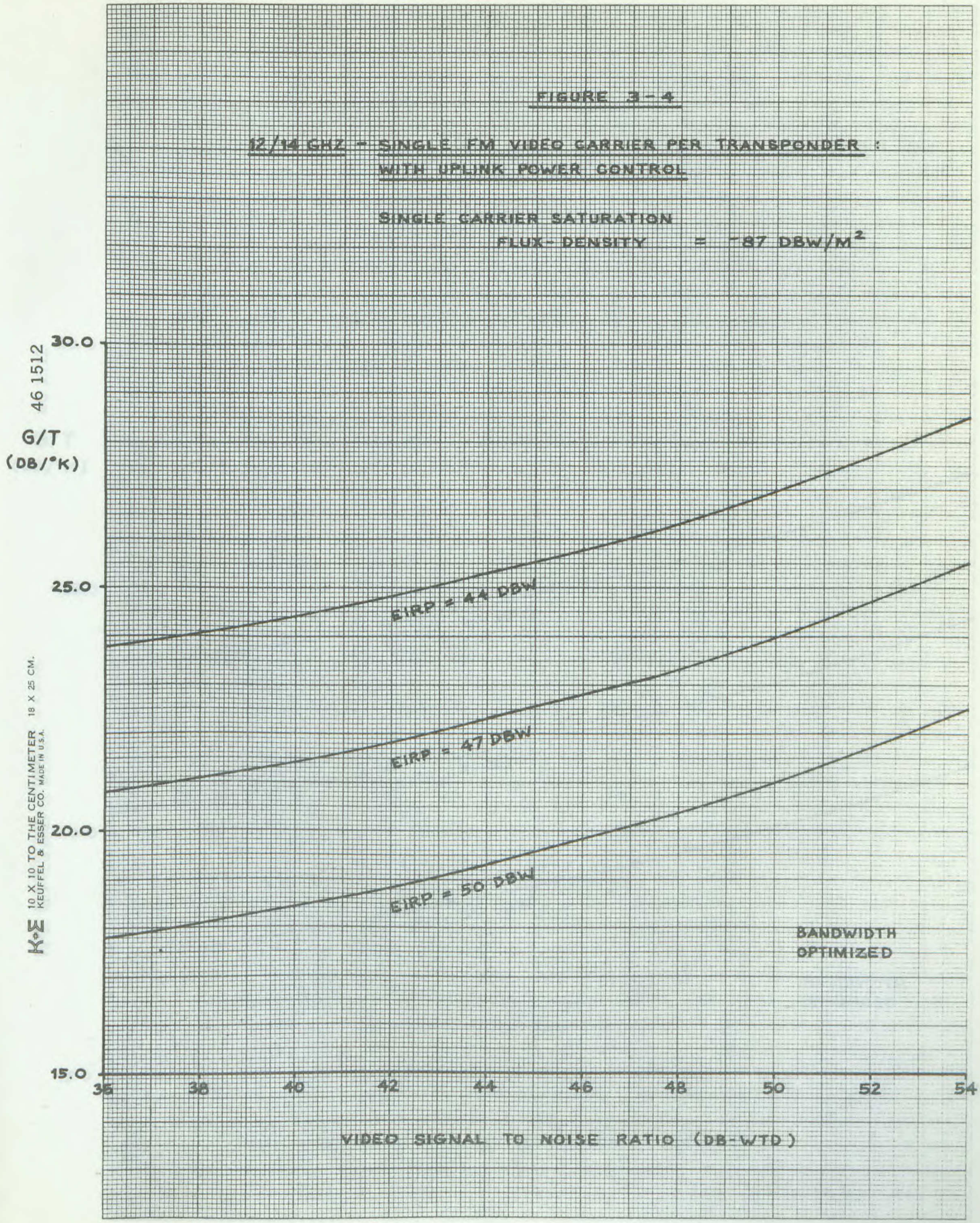


FIGURE 3-4
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER : WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX-DENSITY = -87 DBW/M²
G/T (DB/°K)
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)

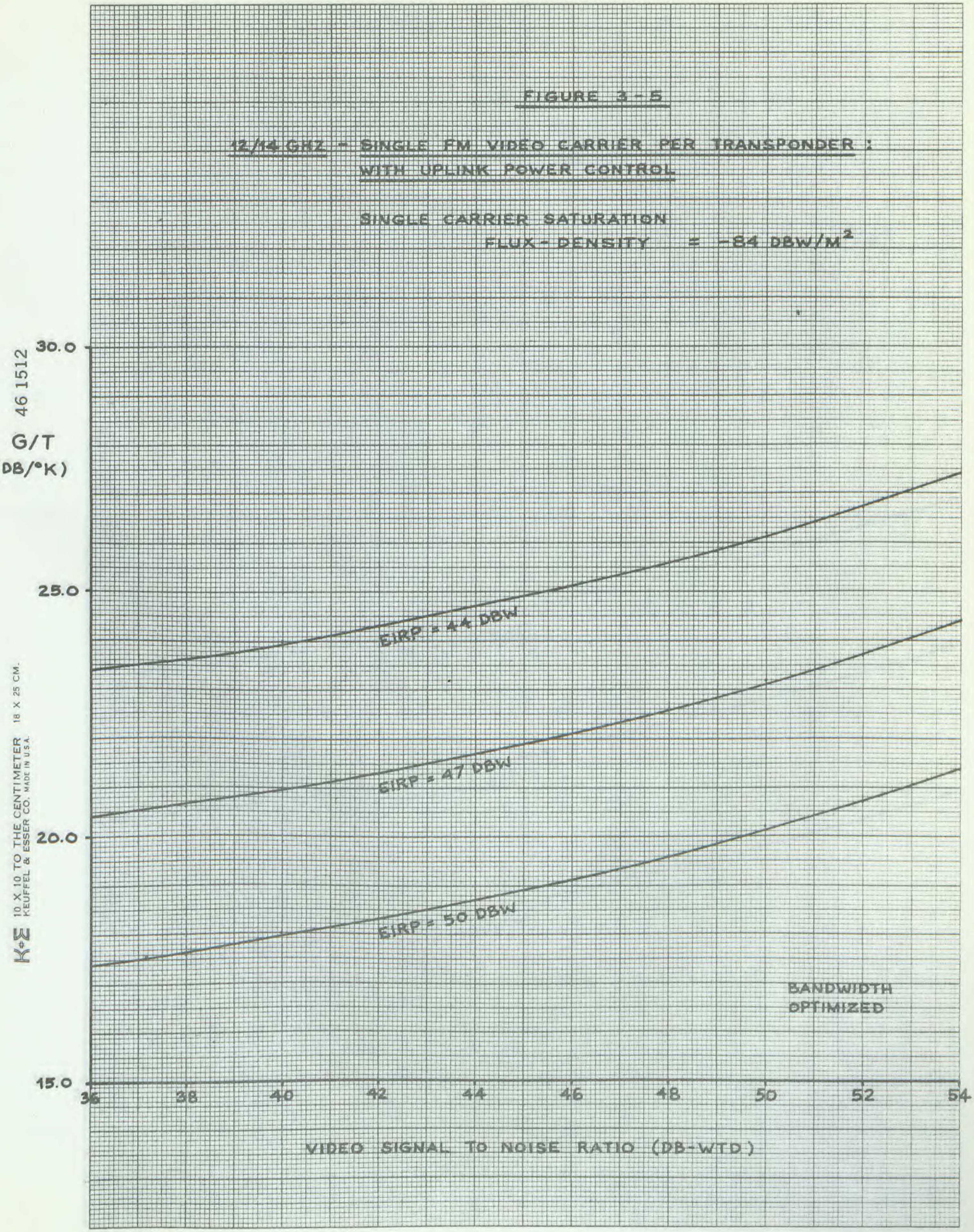


FIGURE 3-5
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER : WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX-DENSITY = -84 DBW/M²
G/T (DB/°K)
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1512

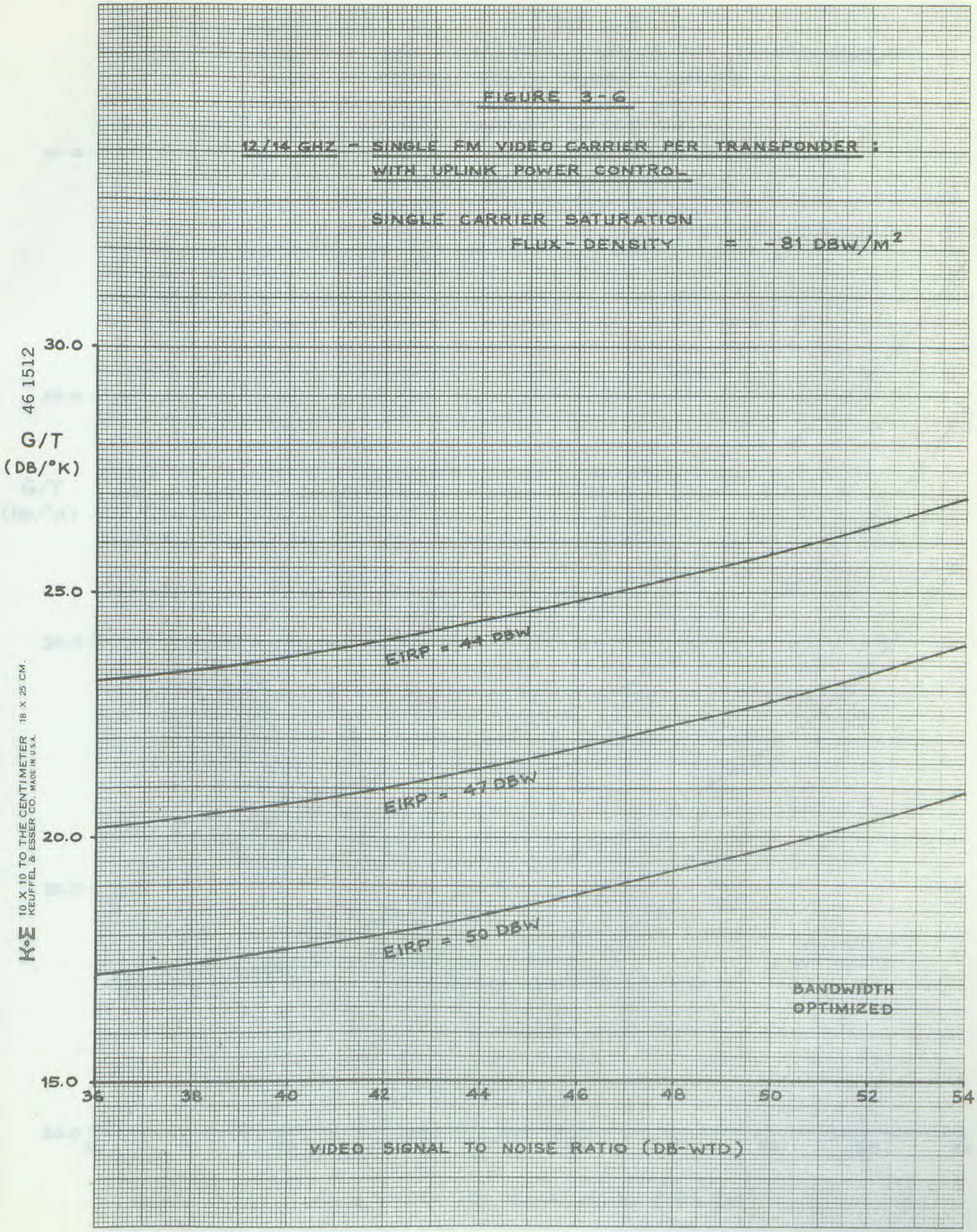


FIGURE 3-6
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER : WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION
FLUX-DENSITY = -81 DBW/M²
G/T (DB/°K)
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1512

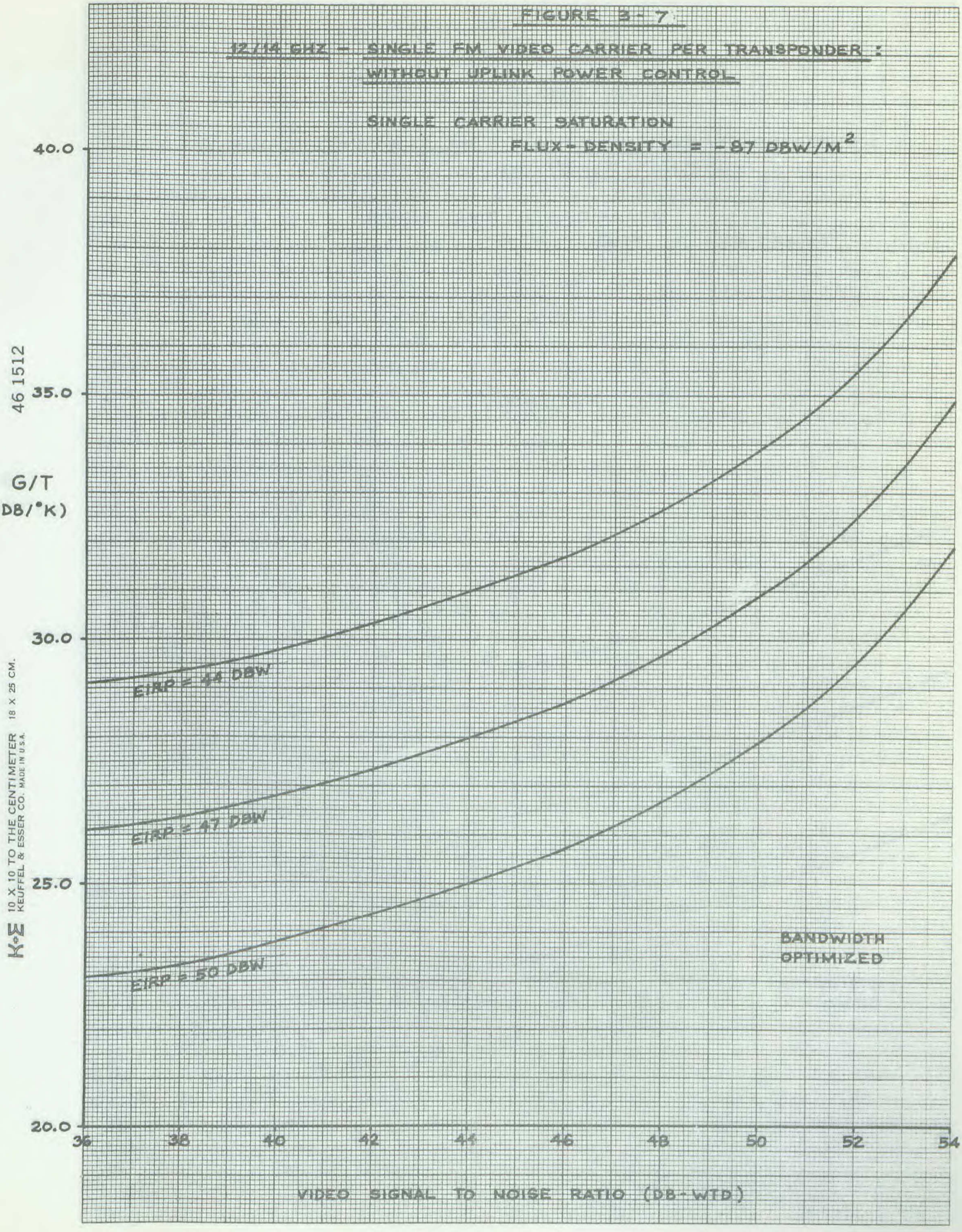
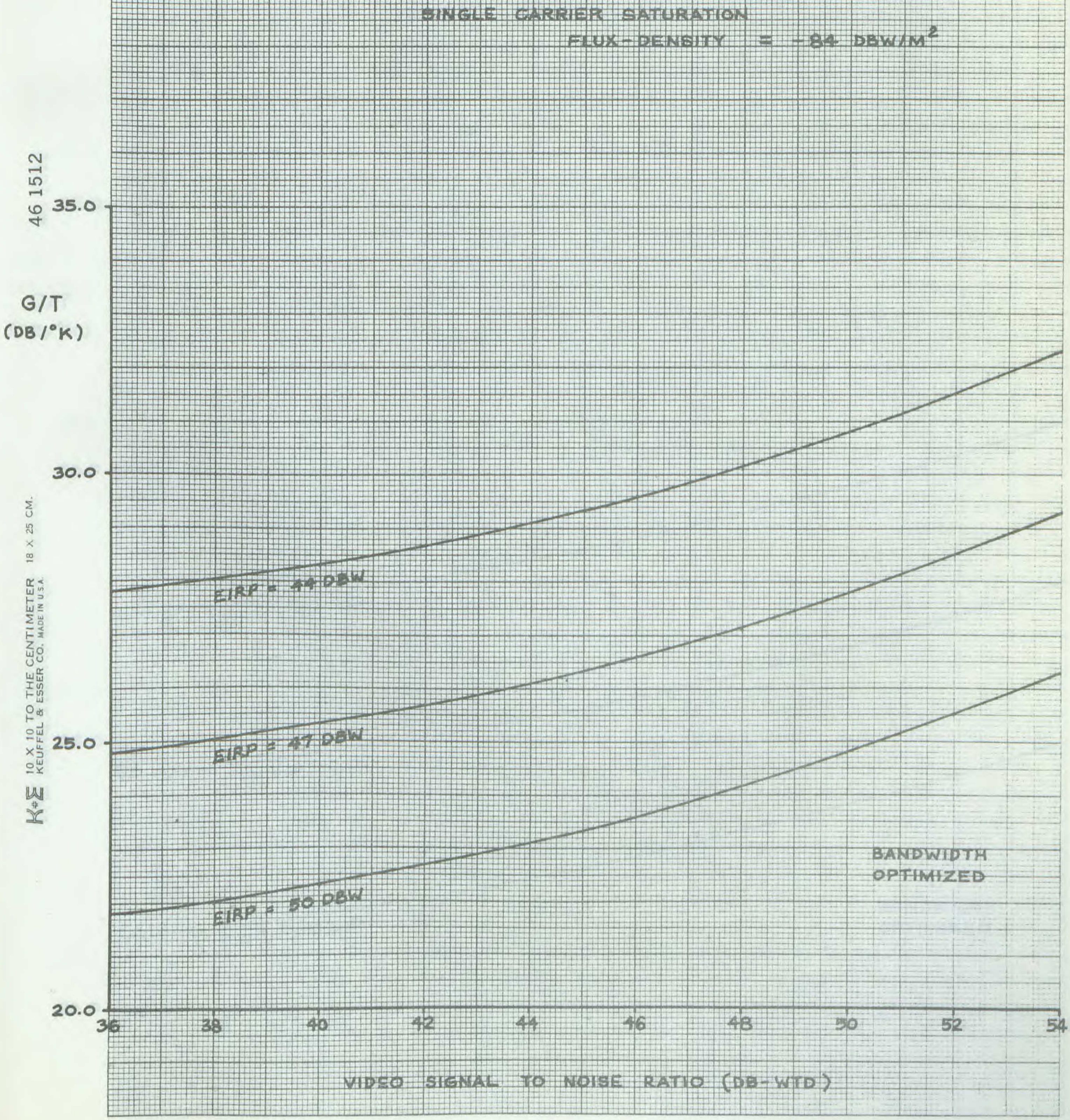


FIGURE 3-7
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER:
WITHOUT UPLINK POWER CONTROL
SINGLE CARRIER SATURATION
FLUX-DENSITY = -87 DBW/M2
G/T
(DB/°K)
40.0
35.0
30.0
25.0
20.0
36
38
40
42
44
46
48
50
52
54
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH
OPTIMIZED
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 3 - 8

12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER : WITHOUT UPLINK POWER CONTROL



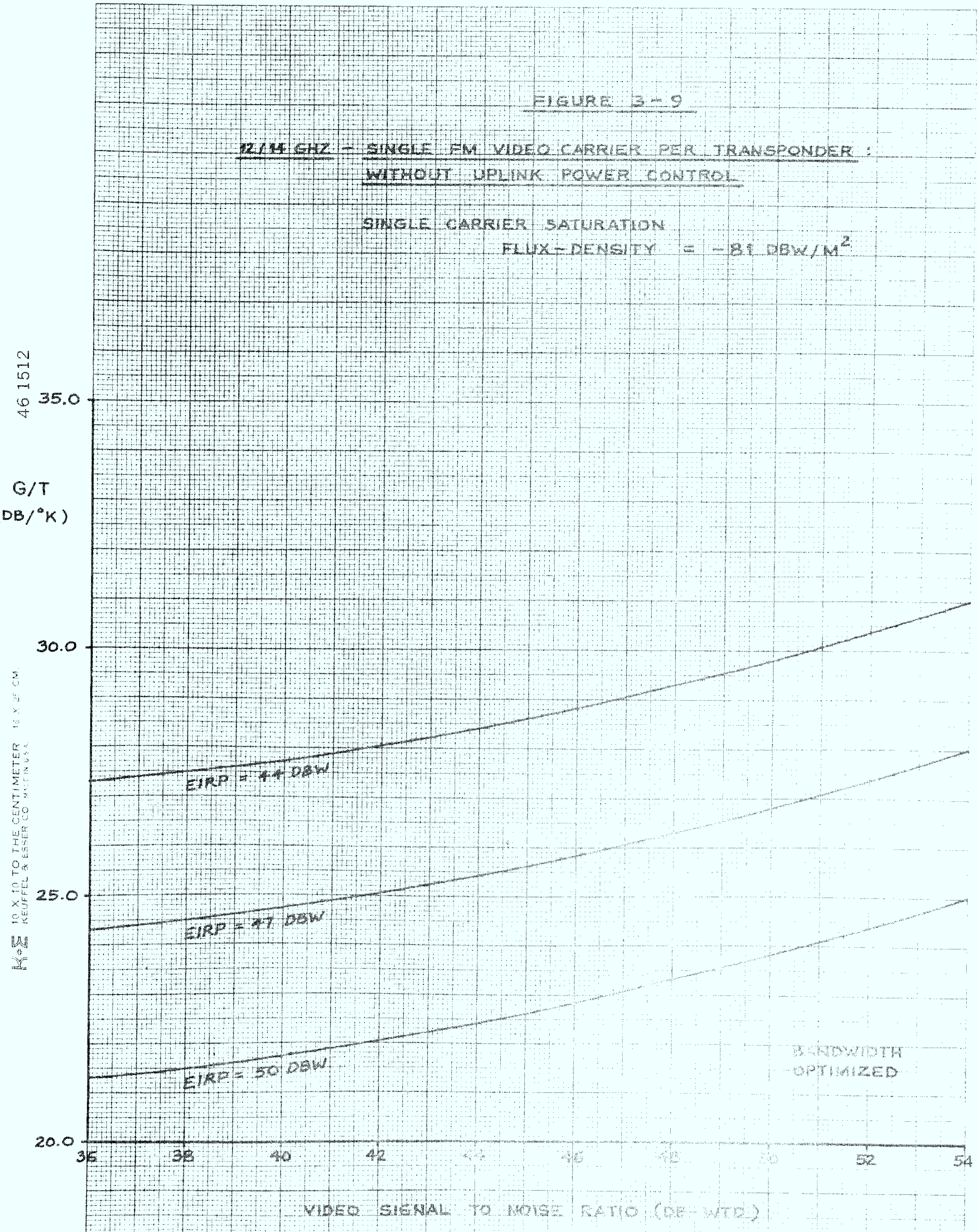


FIGURE 3-9
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER : WITHOUT UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX-DENSITY = -81 DBW/M2
G/T (DB/°K)
35.0
30.0
25.0
20.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

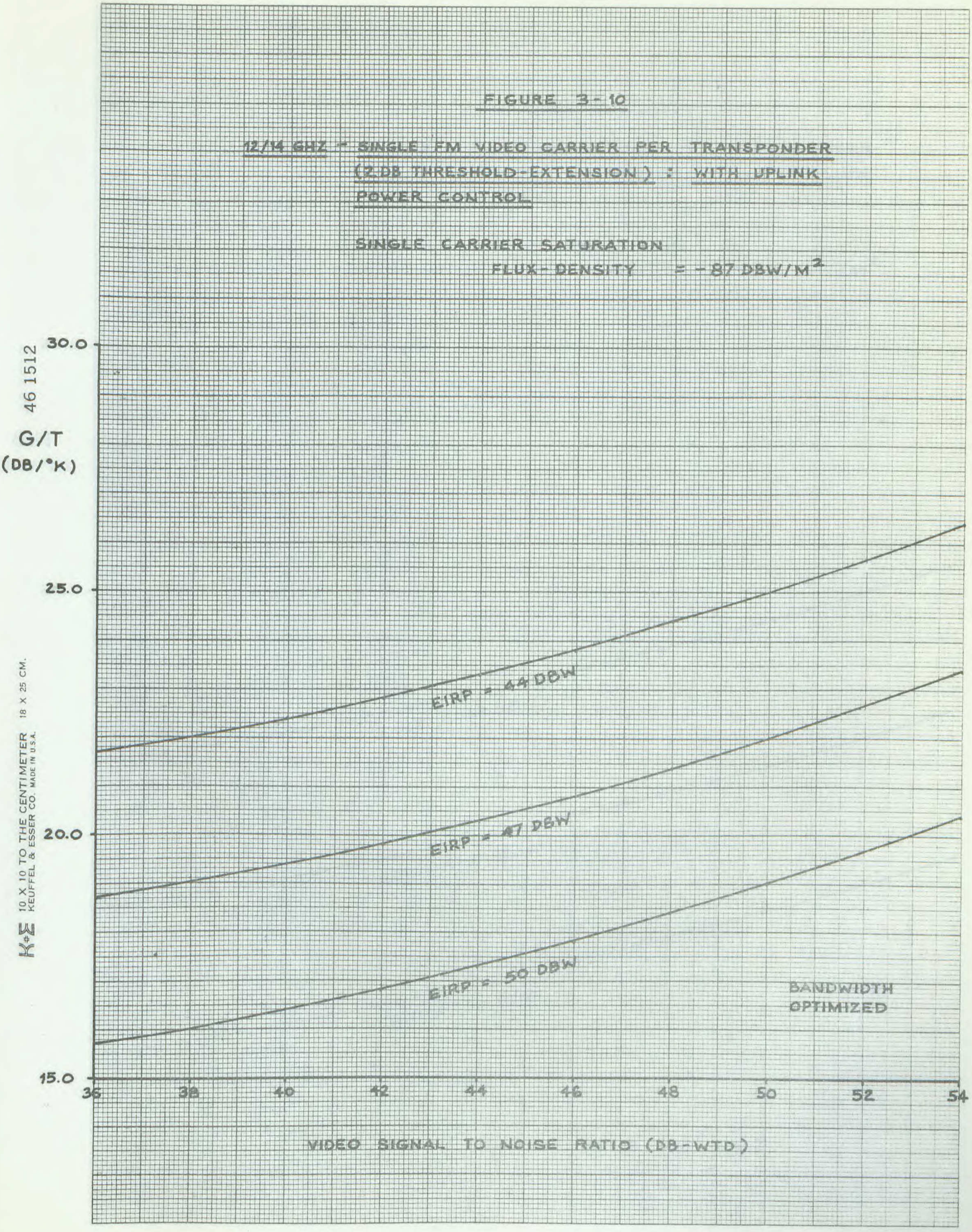


FIGURE 3-10
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER (2 DB THRESHOLD-EXTENSION) : WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX-DENSITY = -87 DBW/M²
G/T (DB/°K)
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

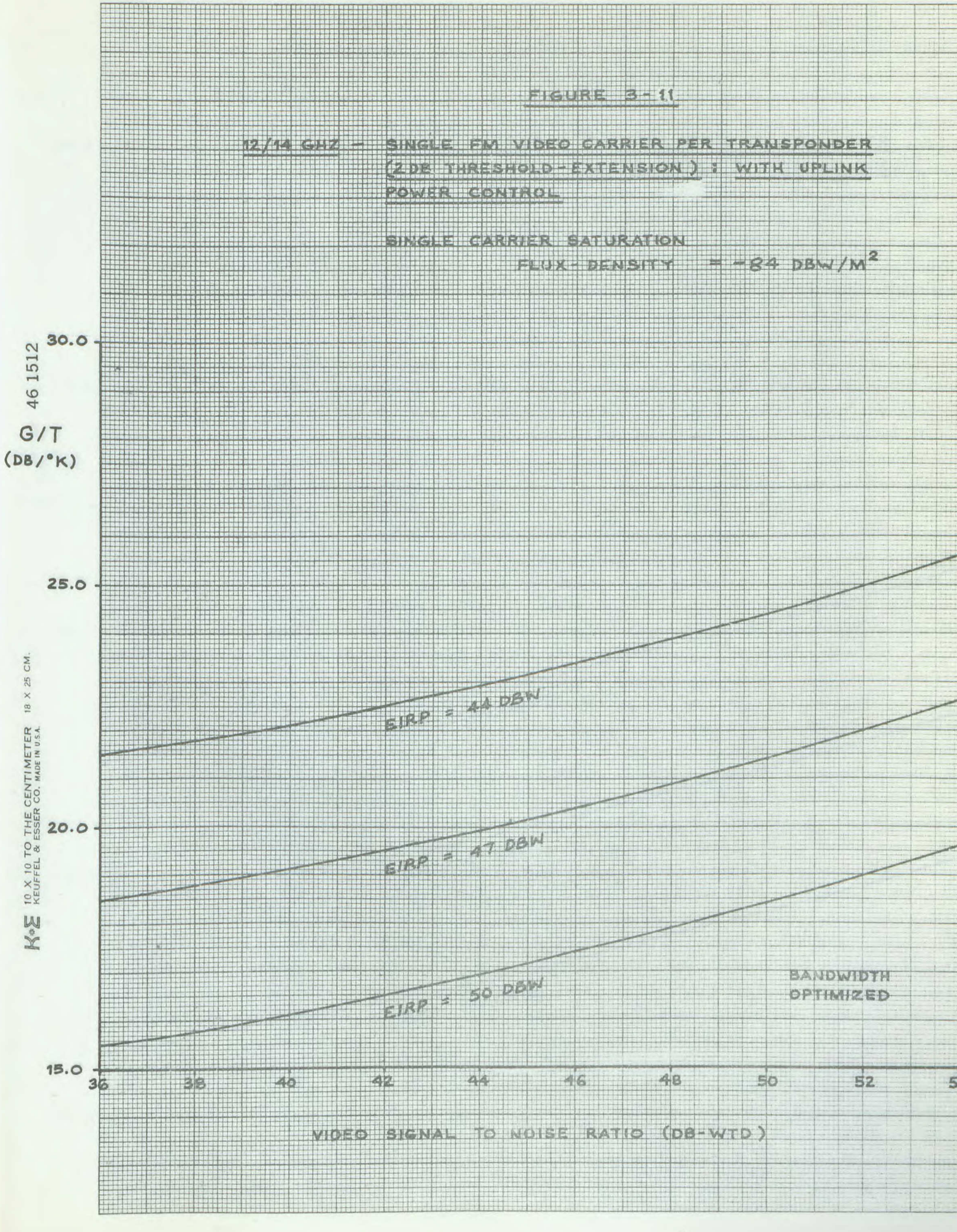


FIGURE 3-11
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER (2 DB THRESHOLD-EXTENSION): WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX-DENSITY = -84 DBW/M²
G/T (DB/°K)
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

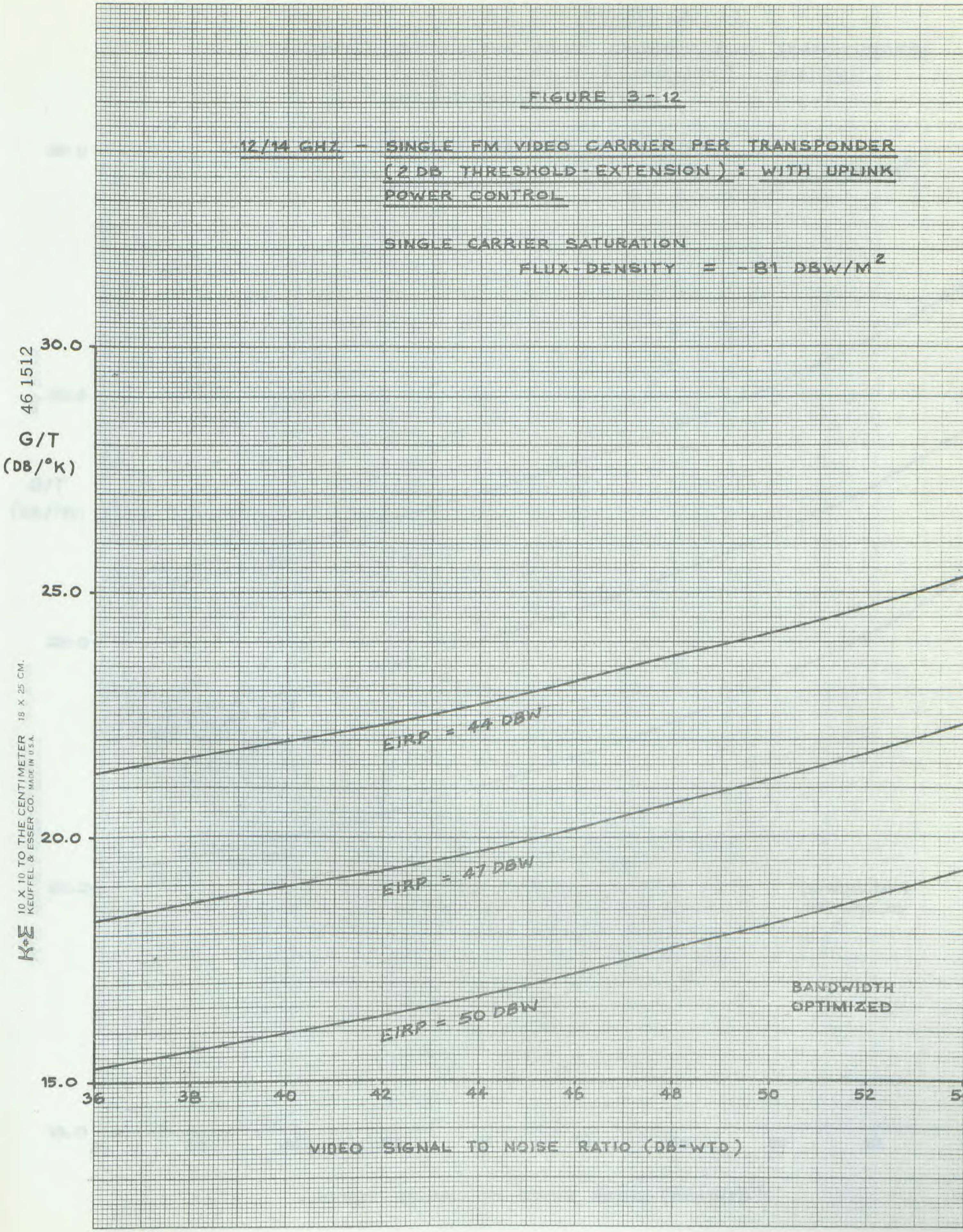


FIGURE 3-12
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER (2 DB THRESHOLD-EXTENSION): WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX-DENSITY = -81 DBW/M2
G/T (DB/°K)
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

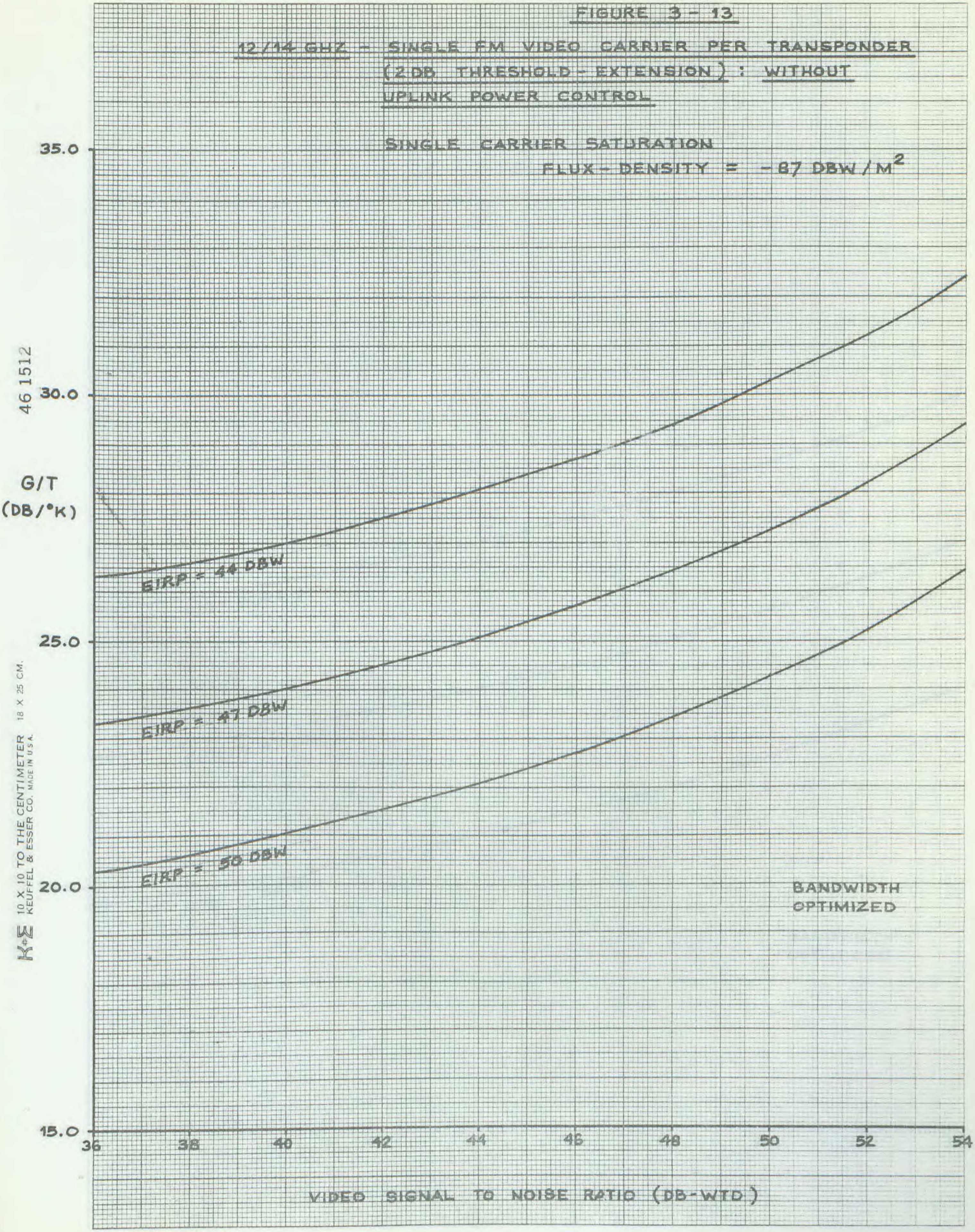


FIGURE 3 - 13
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER (2 DB THRESHOLD - EXTENSION) : WITHOUT UPLINK POWER CONTROL
SINGLE CARRIER SATURATION
FLUX - DENSITY = -87 DBW/M2
G/T (DB/°K)
35.0
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

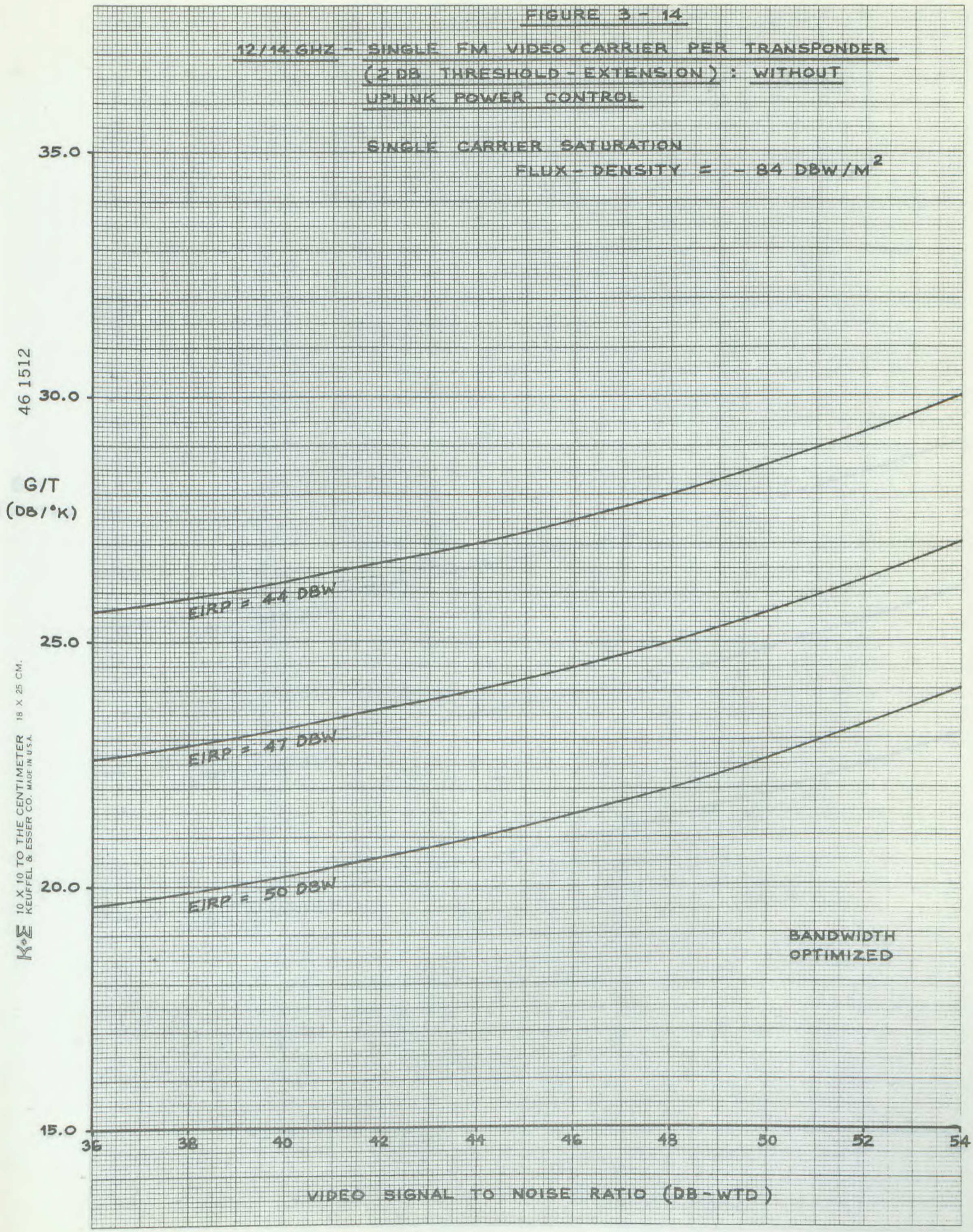


FIGURE 3 - 14
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER (2 DB THRESHOLD - EXTENSION) : WITHOUT UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX - DENSITY = - 84 DBW/M²
G/T (DB/°K)
35.0
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB - WTD)

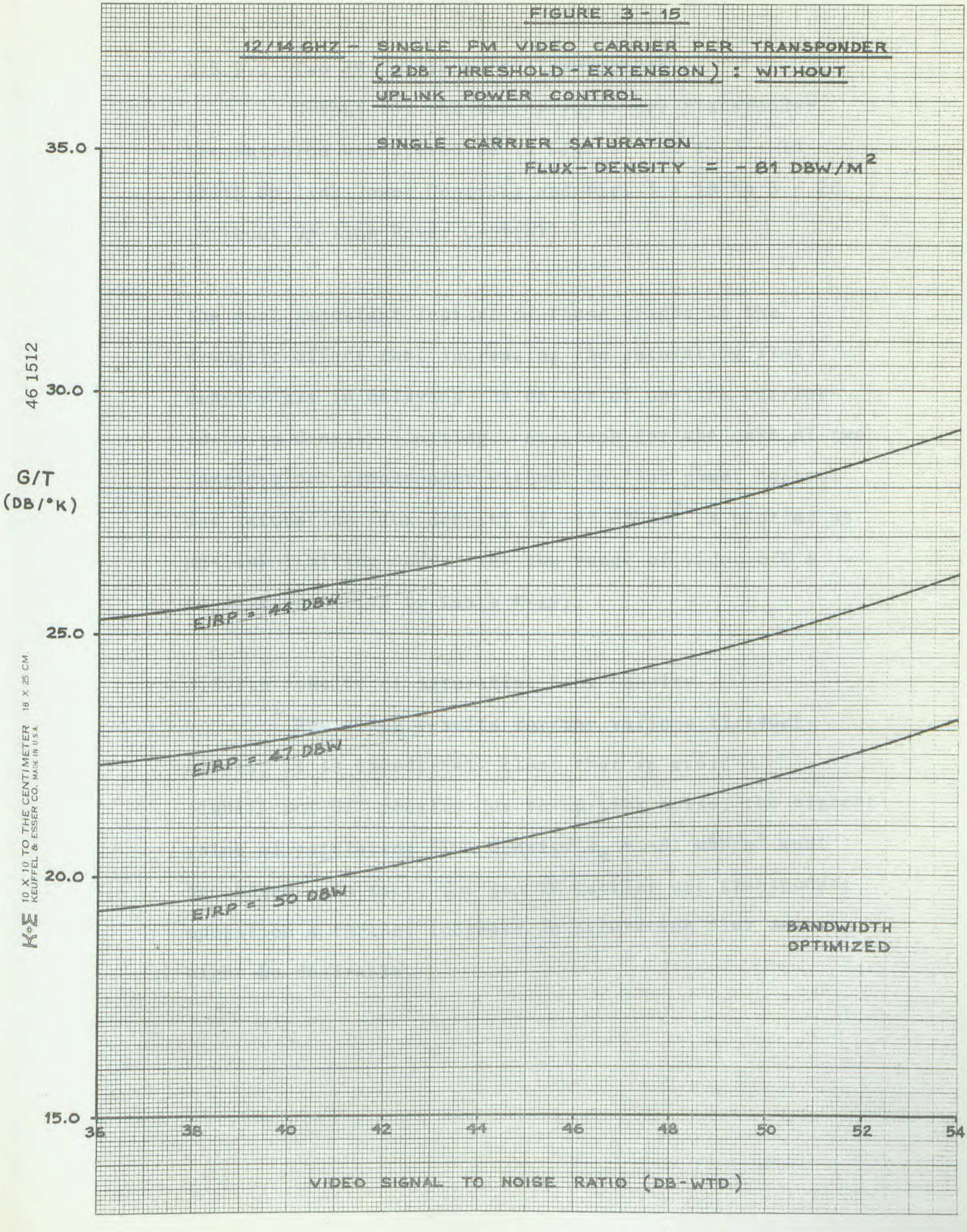


FIGURE 3 - 15
12/14 GHZ - SINGLE FM VIDEO CARRIER PER TRANSPONDER (2 DB THRESHOLD - EXTENSION) : WITHOUT UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX - DENSITY = - 81 DBW/M²
G/T (DB/°K)
35.0
30.0
25.0
20.0
15.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

3.3.2.2 Two FM Carriers Per Transponder

Graphs for the two carriers per transponder transmission are presented in Fig. 3 - 16 to 3 - 18 (With Up-link Power Control) and Fig. 3 - 19 to 3 - 20 (Without Up-link Power Control).

The most important feature of these graphs is the dramatic effect that increasing the saturating flux density has in delaying the on-set of up-link carrier-to-noise density limiting. No graph for the case of two carriers per transponder without up-link power control and saturating flux density of -87 dBW/m^2 is plotted as up-link limiting occurs for the range of video S/N's considered (refer to Table A-19).

3.3.2.3 Choice of Saturating Flux Density

Reviewing results for the various 12/14GHz models, it is immediately clear that to avoid a significant G/T penalty due to up-link noise, the highest value of saturating flux density $\emptyset_s$ = -81 dBW/m^2 must be chosen. In fact, for two TV carrier per transponder operation a further increase in saturating flux density might be desirable.

Although the final parameters of the 12/14 GHz satellite are not known at this stage, it is felt that -81 dBW/m^2 or a value close to it will be achieveable on the flight model.

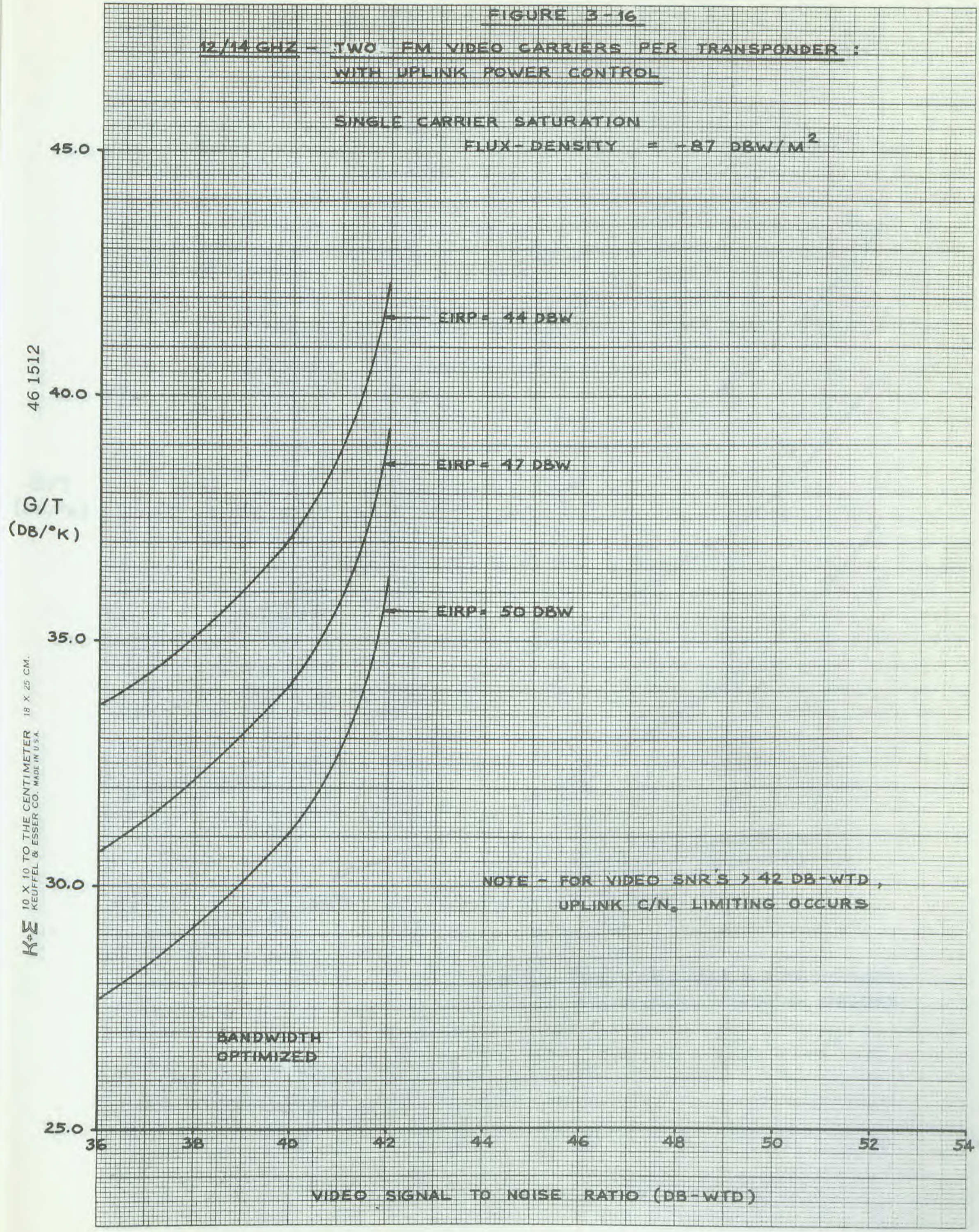


FIGURE 3-16
12/14 GHZ - TWO FM VIDEO CARRIERS PER TRANSPONDER : WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION
FLUX-DENSITY = -87 DBW/M²
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
NOTE - FOR VIDEO SNR'S > 42 DB-WTD, UPLINK C/N₀ LIMITING OCCURS
BANDWIDTH OPTIMIZED
G/T (DB/°K)
45.0
40.0
35.0
30.0
25.0
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

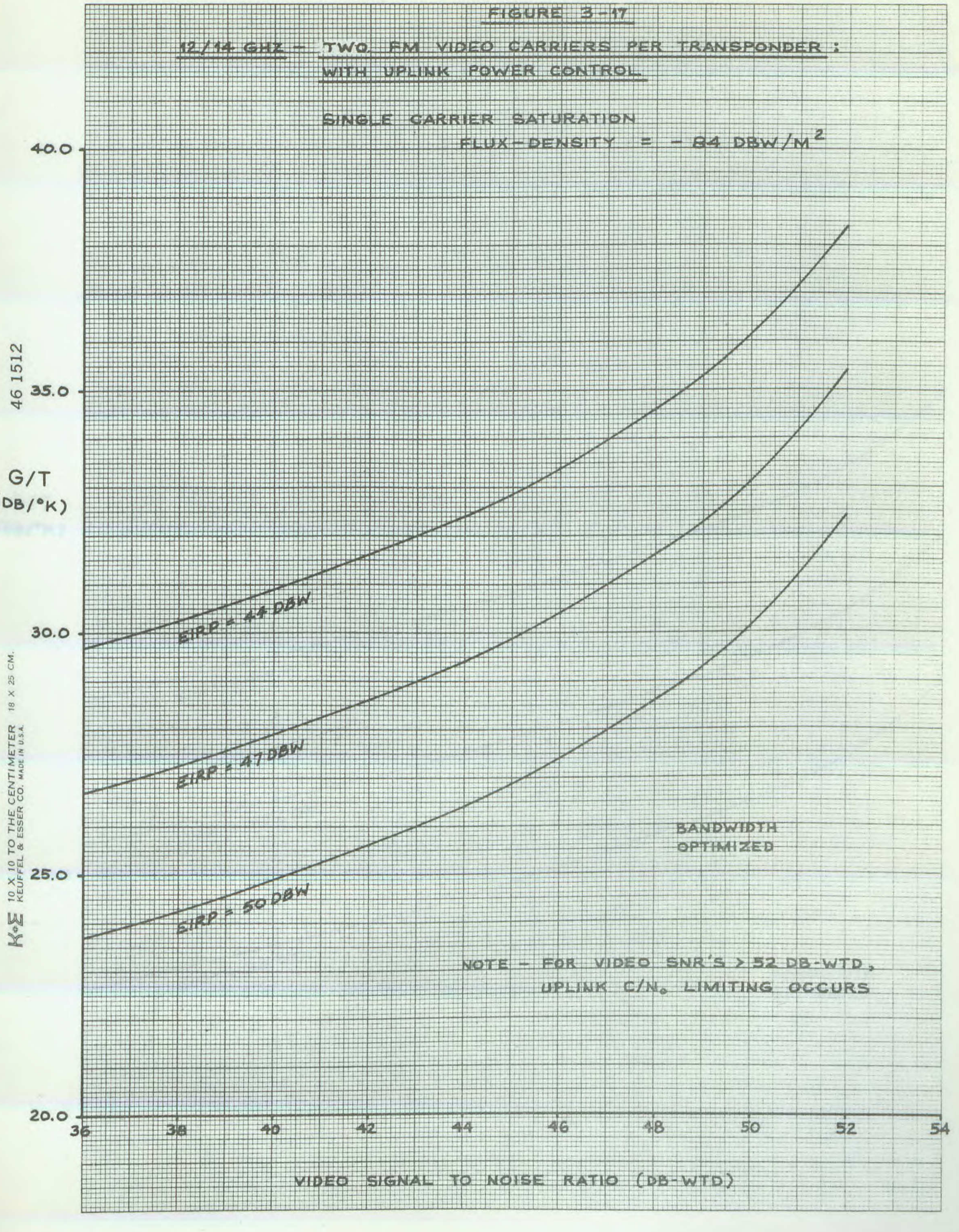


FIGURE 3-17
12/14 GHZ - TWO FM VIDEO CARRIERS PER TRANSPONDER : WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX-DENSITY = -84 DBW/M²
G/T (DB/°K)
40.0
35.0
30.0
25.0
20.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
NOTE - FOR VIDEO SNR'S > 52 DB-WTD, UPLINK C/N₀ LIMITING OCCURS
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

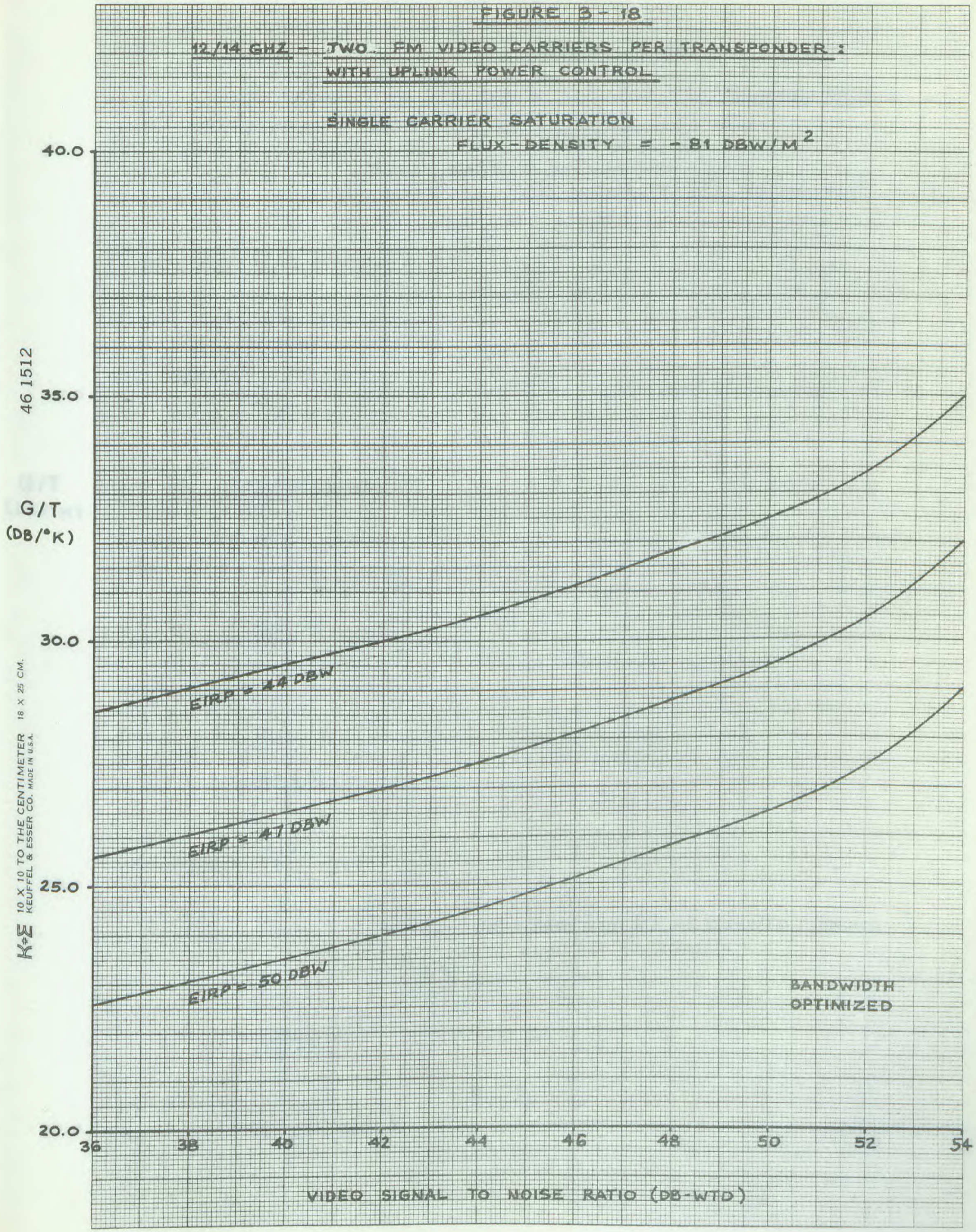


FIGURE 3-18
12/14 GHZ - TWO FM VIDEO CARRIERS PER TRANSPONDER : WITH UPLINK POWER CONTROL
SINGLE CARRIER SATURATION
FLUX-DENSITY = -81 DBW/M2
G/T
(DB/°K)
40.0
35.0
30.0
25.0
20.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH
OPTIMIZED
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

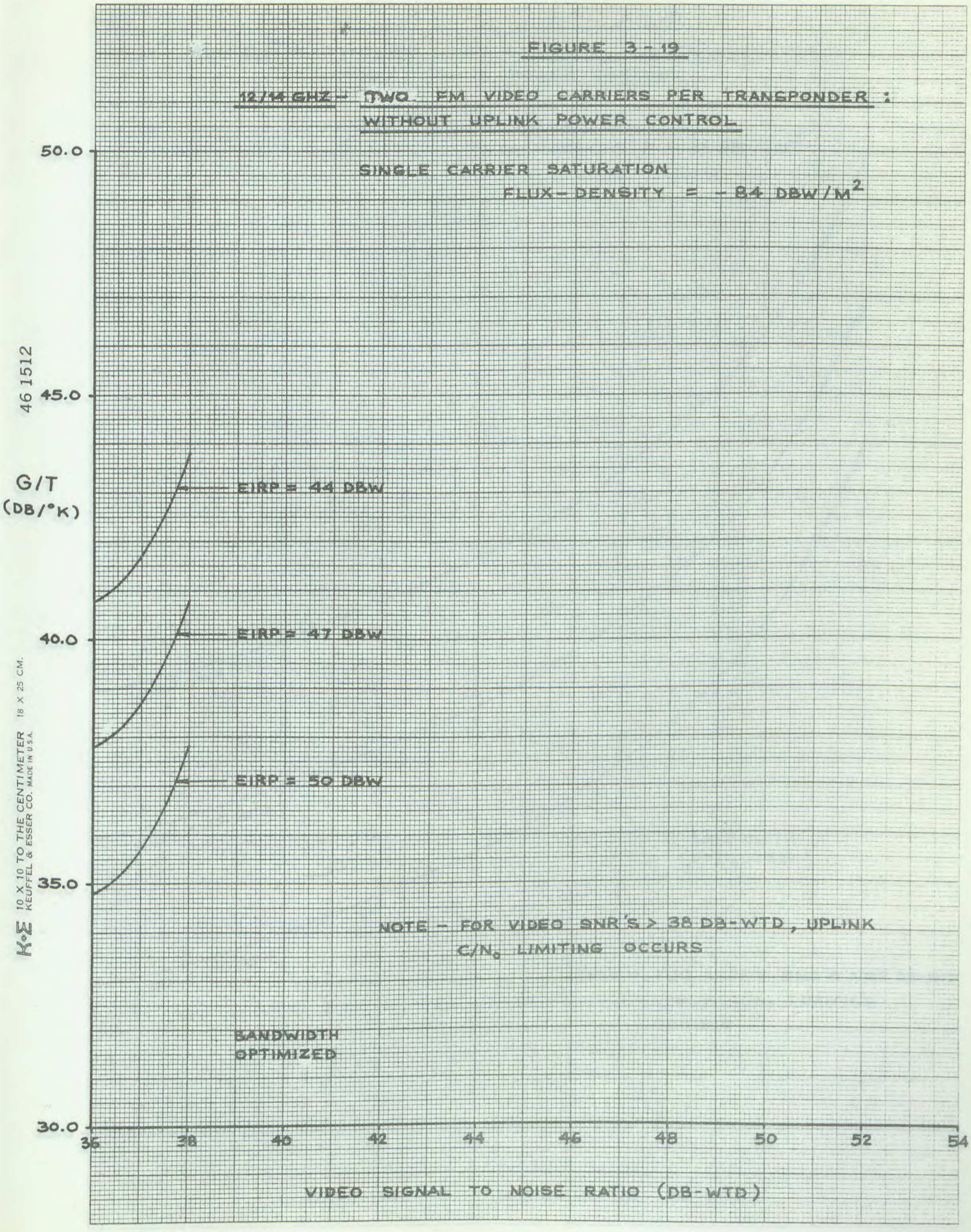


FIGURE 3-19
12/14 GHZ - TWO FM VIDEO CARRIERS PER TRANSPONDER: WITHOUT UPLINK POWER CONTROL
SINGLE CARRIER SATURATION FLUX-DENSITY = -84 DBW/M2
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
NOTE - FOR VIDEO SNR'S > 38 DB-WTD, UPLINK C/No LIMITING OCCURS
BANDWIDTH OPTIMIZED
G/T (DB/°K)
50.0
45.0
40.0
35.0
30.0
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)

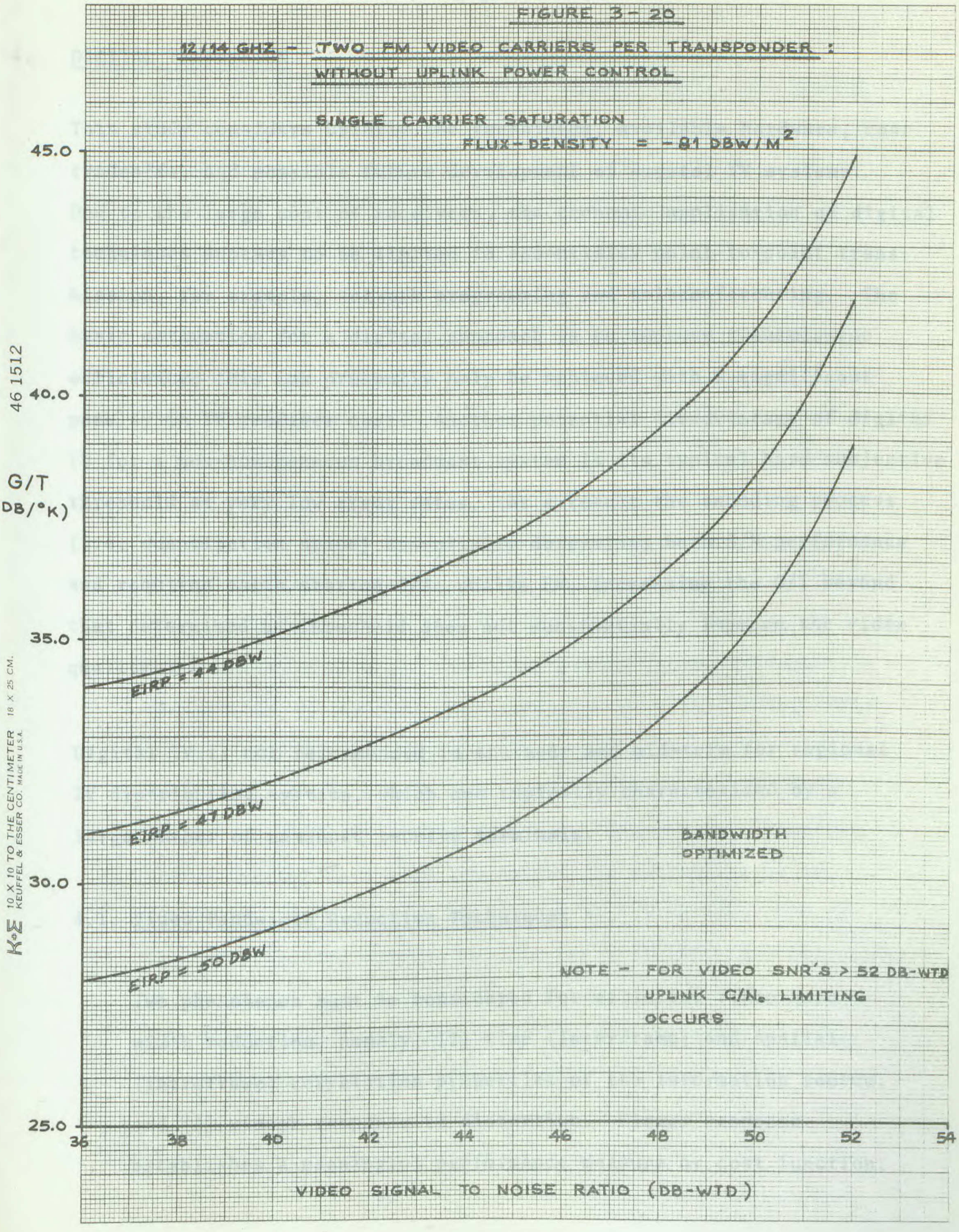


FIGURE 3 - 20
12/14 GHZ - TWO FM VIDEO CARRIERS PER TRANSPONDER : WITHOUT UPLINK POWER CONTROL
SINGLE CARRIER SATURATION
FLUX-DENSITY = -81 DBW/M²
G/T (DB/°K)
45.0
40.0
35.0
30.0
25.0
EIRP = 44 DBW
EIRP = 47 DBW
EIRP = 50 DBW
BANDWIDTH OPTIMIZED
NOTE - FOR VIDEO SNR'S > 52 DB-WTD UPLINK C/N₀ LIMITING OCCURS
36
38
40
42
44
46
48
50
52
54
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

4. DIGITAL TELEVISION

This study considers briefly the techniques, available hardware, cost tradeoffs, and possible future development of digital TV systems. Due to the large cost of receivers, the economic application of digital techniques appears to be limited to essentially point-to-point transmission, for example, network programming and teleconferencing. The basic motivation for a digital approach is to improve transmission efficiency; this can presently only be achieved with a significant penalty in TV receiver cost. Another potential disadvantage of digital TV for a non-homogeneous broadcast system is its typical hard subjective threshold at very low error rates. As a result the encoding process (i.e. quantization noise) essentially determines both S/N performance and required earth station G/T; unlike FM, increasing the G/T beyond that determined by threshold does not substantially improve the video quality.

Digital TV is not recommended in the near and mid-term for regional TV distribution systems, which are typically characterized by a large number of unmanned receive terminals.

4.1 Video Bandwidth Reduction Techniques

Two phenomenon must be considered for efficient video bandwidth reduction, namely, (1) time (interframe) and spatial (intraframe) correlation properties of the information source, and (2) viewer response to distortion. Viewer response establishes a meaningful performance measure or cost function;

given the statistics of the video source, an optimum encoder maximizes the performance measure for a specified available transmission bit rate (the classical information theory approach), or minimizes the rate for a given required performance (the rate distortion theory approach).

A major problem is to establish simple yet representative models for the 'typical' video information source and viewer. Evidently the overwhelming portion of the power in a video signal is in the low frequencies. These provide the information about the brightness levels of large stationary areas. Although the power at high frequencies is small, the high frequencies are essential if the processed image is to have clean sharp edges. One of the most important aspects of human perception to picture coder design is the differential sensitivity of the eye. Any variation of visual sensitivity can be exploited by adapting the encoding accuracy to the variation. Picture-dependent sensitivity decreases with increasing picture detail, luminance, and motion. There is also a decreasing visual sensitivity to increasing noise frequency. It should be noted that all techniques that reduce the required channel capacity by anticipating a redundancy in the signal have a limitation, in that signals which do not contain the expected redundancy cannot be transmitted unless some alternative is provided for them.

Until recently, most of the theoretical emphasis has been on the removal of intra-frame redundancy. The schemes can generally be classified as either spatial domain or transform domain source - encoding schemes. Both classes operate on the spatial correlation of the imagery data; however, spatial source-encoding techniques are typically interpolation or prediction schemes or they utilize the difference between one or more adjacent pixels (picture elements). On the other hand, transform source-encoding techniques utilize various unitary transform of the elements to compact the spatial energy.

Walsh and Hadamard transforms have been proposed to achieve an orthogonal decomposition of the frame information. Bandwidth compression is achieved by truncating or removing the least significant terms in the series. The more terms removed the greater the compression, and corresponding distortion. Application of transform domain source-encoding techniques has been demonstrated in stationary image processing. Very large compression ratios may be achieved with very little reduction in fidelity, and adaptive operation, in which the source statistics can be learned, is also possible.

The spatial source-encoding schemes chronologically preceded the transform schemes in order of application to imagery redundancy reduction. To minimize storage requirements they operate on the horizontal spatial correlation of one or more scan lines either ignoring vertical correlation completely or using only the previous line (eg. DITEC). The primary advantage of these schemes is that they are relatively simple to implement, but in most cases they are limited in redundancy reduction performance and provide no inherent channel noise immunity. Statistical encoding is a type of spatial source encoding that takes advantage of the distribution of differences of adjacent samples to generate an exact code that reproduces the picture to the same quality, but uses a fewer number of bits.

Statistical encoding depends on the differential statistics of the number of level changes between level samples. The level change that occurs the most is assigned a short binary code and level changes which occur seldom are assigned longer codes (according to a Huffman coding tree). Implementation of statistical coding necessitates the use of buffers to accommodate variations in the number of bits per frame; a companded differential quantizer will achieve the same average compression advantage without the requirement for buffering. Statistical encoding is an example of entropy (information)-preserving encoding. Other entropy-preserving techniques, namely run length and bit plane encoding, have also been proposed. The principal entropy-reducing source-encoding schemes are well-known differential PCM (DPCM) and delta modulation and the prediction and interpolation schemes.

The use of source-encoding for redundancy reduction increases the sensitivity of the imagery data to channel noise (i.e., bit errors). A portion of the advantages of redundancy reduction can thus be lost by the need to reduce transmission error. The eye is fairly sensitive to the "salt and pepper" effect of channel noise error on the transmission of spatial source encoded imagery samples. Transform image encoding, on a frame by frame basis on the other hand, provides a degree of immunity to channel noise error. This results from the fact that error in the received transform domain samples is distributed over the entire frame when the image is reconstructed by performing the inverse transform. When transform encoding is applied to small areas of a picture much better compressions are achieved but sensitivity to bit errors increases.

Quantization contours can produce unacceptable granularity in the image. Additive noise (or dither) added to the signal before quantizing eliminates the objectionable contours in flat areas of the picture at the expense of a small increase in overall noise in the picture. The probability density function of the noise should be rectangular and have an amplitude equal to the step size of the quantizer. Study has indicated that better performance can in fact be achieved using signal correlated dither.

Several methods of exploiting the frame-to-frame redundance of video signals have been studied. Until recently, using interframe correlation to improve efficiency required complex and costly equipment; but now, with low-cost memories and integrated circuits, it is becoming economically more attractive.

Successive frames of a video signal usually differ only slightly from each other; moreover, when major changes of image occur, the subjective sensitivity to the details of the image is substantially reduced until the eye is adapted to the new scene.* In other words, intra-frame and inter-frame information requirements tend to be inversely proportional to each other; this makes inter-frame redundancy removal very attractive.

A typical feature of some frame-to-frame redundancy reduction methods is the transmission of the difference in brightness of two corresponding picture elements in adjacent frames. Due to the high correlation, these differences are usually very small, relative to the amplitude of the signal, so that they can be quantized with few levels without degrading the quality of the image too much. The signal is then reconstructed by adding the differences successively transmitted.

However, when reproduced objects or the camera move, the information content of the image remains practically the same, but the brightness of corresponding picture elements are practically independent, thereby rendering useless any differential method for the transmission of the image.

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* Unfortunately this is not true for slow panning or zooming actions in which substantial frame to frame changes occur but do not reduce the viewer's ability to perceive detail.

If a correspondence is established between elements of the displaced images, the correlation may be nearly one. Obviously some zones will not have a correspondent in the previous frame; however, this part of the image can be transmitted with higher distortion since the eye, as observed before, will not be able to detect the finer details immediately. An efficient interframe bandwidth compression scheme should take account of the high frame-to-frame correlation even during rapid movements of objects and/or the camera.

In conclusion, in a number of laboratories, many efforts have been and are currently being aimed at reducing the bandwidth requirements for television transmission. The available analytical methods have been refined considerably, but practical bandwidth reduction schemes implemented thus far have been devised mostly by ad hoc methods. The image processing technology is not well developed and much improved schemes from both efficiency and cost standpoints are anticipated.

4.2 Video Codecs

This section provides performance specifications and estimated receiver costs for several NTSC digital TV systems presently under development.

4.2.1 DITEC (Comsat)

The DITEC system [2] is an integrated TV codec/modem developed to permit the transmission of two network quality video signals in one 36 MHz satellite transponder. The luminance and chrominance video signals are encoded separately using differential PCM (DPCM), and the audio is digitally encoded and inserted in line and field blanking intervals. Rate 7/8 forward error correcting coding is employed to reduce the bit error rate to a required 10^{-8}. Performance specifications for a DITEC system are as follows:

PARAMETERS	SAMPLING FREQUENCY (MHz)	NO. OF BITS/SAMPLE
Video Signal		
Y Channel	6.02	5
I Channel	1.77	4
Q Channel	0.678	12
Audio Program Signal 15.75 kHz		

System Information Bit Rate	29.4 Mbps
System Channel Bit Rate	33.6 Mbps
Threshold Error Rate	10^{-8}

Modem	4-phase CPSK
Required Carrier-to-Noise Ratio	14.4 dB
Required RF Bandwidth	16.8 MHz

The DITEC-1 System is designed to satisfy CCIR performance specifications as given in CCIR Report 486*

Estimated Receiver (FEC decoder, 2 Video and associated Audio Synthesizers) Cost in Qty >50 = $20,000.

Allowing a 3 dB fade margin, an unfaded C/N_o of 92.7 dB is required to receive two TV channels. The corresponding minimum G/T vs satellite EIRP at 4/6 and 12/14 GHz are given in Tables 4-5 to 4-7. In June 1974 satisfactory DITEC performance was demonstrated over Anik 1 into Riviere Rouge (G/T = 28 dB/^{o}K).

DITEC is presently an experimental prototype and has not undergone large scale integration or been leased for manufacture. The receiver costs quoted here are estimated from a leading U.S. manufacturer of high speed digital equipment. It appears doubtful that DITEC in its present form will ever appear in the domestic satellite communications market.

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* The quoted weighted video S/N of 56 dB is not measured directly but determined by subjective comparison.

4.2.2 NETEC (Nippon Electric Co.)

Japanese manufacturers in general and NEC in particular have made the most significant advances in developing cost-effective digital video codecs suitable for low and medium quality TV distribution. The NETEC system [3] employs inter-frame coding and adaptive interpolation to achieve NTSC colour TV transmission rates of 6 Mbps (conference use) or 16 Mbps (possibly medium quality TV. A digital encoded voice signal or some data signals (maximum 500 kbps) can be multiplexed into the sync interval.

The inter-frame coding used for both luminance and time-compressed chrominance signals is based on frame differential coding with conditional replenishment, in which only the picture elements which have changed significantly since the previous frames are transmitted. Since the significant picture segments are transmitted in clusters, the frame differences of them are transmitted along with address words defining the position in the picture.

A similar approach is used in the 1.544 Mbps codec developed by Bell Labs for picture-phone applications.

The adaptive interpolation is made as follows: The significant frame difference is compared with the average of two neighbouring significant differences. If the frame difference is near the average within a predetermined threshold level, the picture element is replenished with the average value and is not sent as a significant element. At the decoder, positions of the interpolated picture elements are decided from the position-code pattern of significant picture elements in the block. The threshold level for the adaptive interpolation is also controlled depending on the buffer occupancy. By adopting the adaptive interpolation, aliasing effects on slowly moving edges is avoided.

Encoded picture quality for the 16 Mbps NETEC system varies with picture character and operating modes, indicated as follows:

i When there is no significant change for more than refreshing cycle, a weighted video S/N of more than 61 dB is obtained.

ii With the coder operating under minimum interpolation threshold, a weighted S/N of 54 dB is obtained.

iii Further degradations around moving parts of the picture occur during rapid movement (weighted S/N >47 dB). These appear to be subjectively acceptable.

iv With rapid change of the entire picture, buffer occupancy is further increased, and field repeating must be applied. This results in momentary jerkiness and edge aliasing. In continuous moving pictures, this occurs infrequently.

The NETEC system was demonstrated at the 3rd Digital Satellite Communications Conference last November in Japan. The response of untrained views to the limited program material presented was quite enthusiastic. It is premature to say, however, that the NETEC 16 Mbps system can provide an acceptable standard of subjective performance for a regional TV distribution system.

Note that an inter-frame coding scheme with replenishment is very sensitive to bit errors, especially in address words. Therefore, error protection is essential. The NETEC system presently employs a rate 239/255 double error correction BCH code, which can reduce a random demodulated error rate of 10^{-5} to a decoded error rate of 10^{-11}.

NEC are pressing hard to develop a commercial product, and further improvements and cost reductions are likely. The price of a complete NETEC decoder (1 video plus 2 sound channels) in quantities greater than 50 is estimated at $20,000.

Note that by utilizing a single common buffer for a digital multiplex of statistically independent video channels, further reduction in the per channel bit rate and/or improvement in subjective performance can be obtained.

4.2.3 HO-DPCM (Nippon Electric Company)

The NEC "higher order differential PCM" intra-frame codec development was initiated prior to the NETEC development program, and proceeded in parallel with it. Main features of the system are high efficiency (22 to 44 Mbps), high colour fidelity, and simple hardware configurations. Specifications are provided for both composite (system B) and separated (system A) NTSC video encoders.

		S/N		RISE TIME	
RATE	TYPE	GRANULAR (WEIGHTED)	EDGE (UNWEIGHTED)	0.7T	0.35T
44 Mbps	A	> 56 dB	35 dB	< 0.2	< 0.2
44 Mbps	B	56 dB	32 dB	0.3	0.2
32 Mbps	A	54 dB	32 dB	0.3	0.2
32 Mbps	B	52 dB	32 dB	0.35	0.25
32 Mbps	A	50 dB	32 dB	0.35	0.25

TABLE 4-1

SPECIFICATIONS FOR THE NEC HO-DPCM SYSTEM A AND SYSTEM B NTSC VIDEO ENCODERS

The A system obviously offers better efficiency; however, terminal costs are increased by the requirement for separation and combining of the Y, I and Q video components.

4.2.4 Fujitsu

Fujitsu have done some development of a DPCM video codec similar to DITEC. The parameters of the 34 and 21.6 Mbps systems first proposed in 1973 are indicated below:

SIGNAL	SAMPLING FREQ (MHz)	NUMBER OF BITS PER SAMPLE	BANDWIDTH COMPRESSION	BIT RATE FOR SIGNAL (MHz)
Y	5.9	4	0.84	19.8
I	2.8	3	0.84	7.1
Q	1	3	0.84	2.5
PROGRAM	0.0315	12	----	0.4
TOTAL				29.8
ERROR CORRECTION CODING			8/7	34.0

TABLE 4-2

PARAMETERS FOR THE FUJITSU 34 Mbps DPCM VIDEO SYSTEM (S/N = 50 dB)

SIGNAL	SAMPLING FREQ (MHz)	NUMBER OF BITS PER SAMPLE	BANDWIDTH COMPRESSION	BIT RATE FOR SIGNAL (MHz)
Y	8	4	0.84X0.5	13.4
I	3	3	0.84X0.5	3.8
Q	1	3	0.84X0.5	1.3
PROGRAM	0.0315	12		0.4
TOTAL				18.9
ERROR CORRECTION CODING			8/7	21.6

TABLE 4-3

PARAMETERS FOR THE FUJITSU 21.6 Mbps DPCM VIDEO SYSTEM (S/N = 49 dB)

4.2.5 OKI Electric

OKI Electric of Japan have done experimental work on both differential and Hadamard transform PCM video encoding [4]. They do not appear to be presently marketing a commercial product.

4.2.6 KDD

KDD is a communications carrier in Japan which does not manufacture. Its strong interest in digital TV indicates an intention to ultimately test a digital system. KDD has recently completed a simulation laboratory for television band compression techniques, which it is currently using to compare encoding techniques.

4.2.7 European Development

The European Space Research Organization (ESRO), the British Post Office (BPO) and the German Ministry for Research and Technology (BMRT) have all sponsored studies on digital TV transmission. An experimental ESRO satellite is planned for launch in 1977 to be followed by the first operational satellite in 1980. In addition to satisfying the future needs of CEPT (Conference of European Postal and Telecommunications Administrations), this satellite will serve the EBU (European Broadcasting

Union). Since digital TDMA transmission of telephony is anticipated, there is an additional incentive to employ digital TV transmission, thereby realizing an all-digital network. A final decision between analog and digital transmission, however, will only be settled after field trials.

European developments may have little relevance to Canadian requirements in the near and mid-terms for the following reasons:

1. The European motivation appears primarily to permit the use of planned digital facilities rather than to improve transmission efficiency. There is therefore less emphasis on video redundancy removal.

2. The satellite application is to interconnect countries rather than reach remote users (e.g. European Broadcasting Union). Therefore, performance requirements are usually high and receiver costs not dominant.

3. The European TV signal (SECAM or PAL) has 625 lines per frame and a 50 Hz repetition rate; therefore codecs developed to meet European requirements are not compatible with the North Americal NTSC signal format.

4. Cost-competitive commercial hardware will not be available within the near future.

4.2.8 Other

This survey of digital TV includes only products currently under development which might be headed for commercial application in the near or mid-term. Many other research institutions and communications carriers and manufacturers are funding research and development programs in digital video processing. Most of these have not progressed or are not sufficiently ambitious as to merit consideration here. Possibly some have been kept under wraps and will arrive as competitive commercial hardware.

4.3 System Calculations

System calculations are performed here for what might be a serious digital contender for regional TV distribution, namely the NETEC system.* The optimum input backoff for single carrier coherent PSK transmission depends on the characteristics of the modem employed, satellite G/T and TWT transfer characteristics and typically lies between -2 and -6 dB. A further reduction in backoff increases slightly the operating carrier-to-noise ratio at the expense of a substantial increase in envelope clipping and phase distortion caused by AM/PM conversion, the net effect of which is an increase in error rate. Capacities are based on the assumption of single carrier per transponder operation at a 4 dB input backoff (1), either CPSK/TDMA (multiple transmit locations) or TDM/CPSK (single transmit location). Table 4-4 summarizes the systems parameters for operation at 4/6 GHz and 12/14 GHz.

Using the link equations developed in section 3.2, the necessary equations can be summarized as:

$$(C/N_o)_d^{-1} = (C/N_o)_t^{-1} - (\emptyset_s - \text{IBO} + (G/T)_s - \text{Gain of } 1\text{m}^2 - 10 \log k)^{-1} \quad \text{(in numerics)} \qquad (4\text{-}1)$$

---

* It must be emphasized that additional development is required before any of the proposed digital schemes can be considered competitive.

		4/6 GHz	12/14 GHz	
PARAMETER	UNITS		WITH UPLINK POWER CONTROL	WITHOUT UPLINK POWER CONTROL
ϕ_s	dBW/m^2	-81	-87 -84 -81	-87 -84 -81
$(G/T)_s$	$dB/^oK$	-6	0	0
IBO	dB	4	4	4
OBO	dB	1	1	1
EIRP	dBW	34 37 40	44 47 50	44 47 50
FSL_d	dB	196.7	206.2	206.2
Fade Margin to threshold	dB	2	7	11
Implementation Margin	dB	3.5	3.5	3.5
Per Channel Bit Rate (Rule 7/8 coded)	Mbs	16	16	16
Threshold Demodulated BER		10^{-4}	10^{-4}	10^{-4}
Frame Efficiency (TDM or TDMA)	%	95	95	95
Available Transponder Bandwidth	MHz	36	72	72

TABLE 4-4

SUMMARY OF SYSTEM PARAMETERS

FOR DIGITAL TV TRANSMISSION

and

$$G/T = (C/N_o)_d - EIRP + OBO + FSL_d + 10 \log k \quad dB/^oK \qquad (4\text{-}2)$$

For the NETEC system (4-phase CPSK):

Per channel bit rate (coded) = 16 Mbps

(TDM or TDMA) Frame Efficiency = 95%

∴ Effective per channel bit rate = 16.84 Mbps

= 72.3 dB

Theoretical E_b/N_o at threshold (BER = 10^{-4}) = 8.4 dB

∴ Theoretical $(C/N_o)_t$ ~~for~~ 1 channel = 80.7 dB-Hz

The required $(C/N_o)_t$ for 1 channel

= 80.7 + Implementation margin + Threshold Fade Margin dB-Hz (4-3)

Required $(C/N_o)_t$ for 2 channels = $(C/N_o)_t$ for 1 channel + 3 dB-Hz (4-4)

Required $(C/N_o)_t$ for 3 channels = $(C/N_o)_t$ for 1 channel + 4.8 dB-Hz (4-5)

Required $(C/N_o)_t$ for 4 channels = $(C/N_o)_t$ for 1 channel + 6 dB-Hz (4-6)

4.3.1 4/6 GHz

Using equations (4-1) to (4-6) and substituting for the various parameters from Table 4-4, the values of earth station G/T required to receive from 1 to 4 digital TV channels for better than 99.5% of the time can be summarized as shown in Table 4-5.

NO. OF TV CHANNELS		OCCUPIED B/W	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T dB/°K		
						EIRP=34	EIRP=37	EIRP=40
DITEC	NETEC	MHz	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
	1	9	86.2	100.6	86.4	21.5	18.5	15.5
1	2	18	89.2	100.6	89.5	24.6	21.6	18.6
	3	27	91.0	100.6	91.5	26.6	23.6	20.6
2	4	36	92.2	100.6	92.9	28.0	25.0	22.0

TABLE 4-5

SUMMARY OF G/T REQUIRED TO RECEIVE

DIGITAL TV AT 4/6 GHz.

Groupe Agriculture
Décision arbitrale

C'est tout à fait par hasard que l'Institut a eu connaissance de la correspondance échangée entre la Commission de lutte contre l'inflation et le Conseil du Trésor visant à ne pas accepter la décision arbitrale pour ce groupe. Il semble que le Conseil du Trésor a soumis la décision à la CLI, laquelle a décidé que certaines réductions devraient être faites Toutefois, aucun des deux organismes n'a jugé bon de prévenir l'Institut ou les employés du groupe sur ce qui se passait. Une demande de copies des documents concernés, qui auraient permis à l'Institut de présenter des observations s'il l'avait voulu, a été refusée."

L'Institut est exaspéré de voir la CLI agir dans le plus grand secret et considère cette situation comme scandaleuse. Nous sommes également préoccupés par la légèreté avec laquelle la CLI et le Conseil du Trésor se jouent des directives en arrivant à une "rémunération totale".

L'Institut ne cesse de prétendre que la CLI n'a pas qualité pour faire obstacle à une décision arbitrale; il nous faut donc continuer à combattre cette soi-disant justice, par tous les moyens disponibles dans la presse, au Parlement et devant les tribunaux.

Comité du Fonds de Prévoyance

Le rapport provisoire du Comité du fonds de prévoyance sera publié dans le numéro de juillet-septembre du Journal.

Groupe Bibliothéconomie

Les membres du groupe LS ont récemment tenu un vote de représentation. Le groupe se compose d'environ 400 employés, et sur les 334 bulletins de vote, 277 se sont prononcés pour être représentés par l'AFPC et 57 pour demeurer à l'Institut. La décision finale concernant l'accréditation d'un agent de négociation pour le groupe LS doit maintenant être prise par la Commission des relations de travail dans la Fonction publique.

Assemblée générale annuelle

L'Assemblée Générale Annuelle de l'Institut Professionnel aura lieu les 26 et 27 novembre 1976 à l'Hôtel Chateau Laurier à Ottawa.

QUESTIONNAIRE

L'Institut doit faire face à une importante augmentation de ses frais de production et d'affranchissement pour les "COMMUNICATIONS" et lettres de nouvelles, lesquelles sont envoyées aux membres par courrier première classe. Le gouvernement vient de proposer une augmentation de 50% des tarifs postaux (2¢ cet automne et 2¢ le printemps prochain); de plus le coût du papier enregistre lui aussi une augmentation. Nous ne pouvons rien contre ces frais supplémentaires; aussi, nous essayons de communiquer le plus de renseignements possibles à nos membres pour les sommes engagées

La publication "COMMUNICATIONS" est actuellement bilingue et afin de ne pas dépasser les limites des tarifs postaux minimums, les 17,000 exemplaires ont "COMMUNICATIONS", nous pourrions publier un numéro de 4 pages dans chaque langue, au même coût que pour l'actuel bulletin de 2 pages publié dans les 2 langues. Nous avons à vrai dire déjà reçu de nombreuses demandes en ce sens, par exemple pour les lettres de nouvelles.

Il va sans dire que ce nouveau système entraînerait certaines difficultés. Il n'est pas possible d'identifier les francophones et anglophones d'après leur nom; il nous faudrait donc envoyer un questionnaire sur lequel les membres indiqueraient dans quelle langue ils désirent recevoir les "COMMUNICATIONS" et les lettres de nouvelles; cependant, ce genre de questionnaire fait rarement l'objet d'un grand intérêt. Une fois les réponses reçues, il faudrait un certain temps pour modifier notre liste d'adresses en conséquence, et

1) Augmentation des tarifs postaux de 50% d'ici un an.

2) Augmentation encore inconnue du coût du papier.

3) Désir de certains membres de recevoir les "COMMUNICATIONS" et lettres de nouvelles dans une seule langue.

4) Envoi d'un plus grand nombre de nouvelles au même coût, en imprimant séparément les éditions française et anglaise.

Tous les membres sont priés de remplir le bulletin ci-dessous, en indiquant s'ils désirent recevoir les "COMMUNICATIONS" et lettres de nouvelles uniquement dans la langue de leur choix, et en précisant celle-ci. Une décision sera prise sur la mise en application de ce système en fonction du nombre et de la nature des réponses. Précisons toutefois que l'Institut continuera de publier toutes ses publications

Agriculture Group Arbitral Award

Quite by accident the Institute learned of correspondence between the Anti-Inflation Board and Treasury Board purporting to roll back the Arbitration Award for this group.

The Treasury Board apparently referred the award to the AIB which ruled that certain reductions should be made. However, neither body saw fit to inform the Institute or employees in the Group of what was transpiring. A request for copies of the documentation concerned which would give the Institute an opportunity to make representations if it so desired, was refused.

The Institute is incensed that the AIB is acting in such complete secrecy, and considers it a scandalous situation. We are also concerned about the manner in which the AIB and Treasury Board are interpreting the guidelines in arriving at "total compensation".

Finally, the Institute maintains its stand that the AIB has no jurisdiction to interfere with an arbitral award, and we shall continue to fight this form of so-called justice by every means at our disposal - in the media, in Parliament and in the courts.

Contingency Fund Committee Interim Report

We would advise members that the interim report of the Contingency Fund Committee will appear in the July-September issue of the Journal.

Official Institute Spokesmen

Professional Institute By-Law 26.3 gives the President the sole authority to speak for the Institute as a whole. This authority may be delegated to another individual only by the Board of Directors.

Members who wish to write letters to their M.P.s or to newspaper editors, are of course free to express their own opinions, but if their connection with the Professional Institute is mentioned, it should be clearly indicated that the views being stated are personal ones.

Members who write to M.P.s or for publication in the press, should not do so in any capacity they may hold as officials of the Professional Institute, unless this has been cleared with the President.

QUESTIONNAIRE

The Institute is being faced with a serious increase in the costs of production and mailing of "COMMUNICATIONS" and Newsletters, both of which are distributed to members by first class mail. As members will be aware, the government proposes to raise postal rates by 50% (2¢ this fall and a further 2¢ next spring). We are also facing an increase in the cost of paper. Since we have no control over these additional costs, we are trying to ensure that we get the greatest amount of information to our members for the money involved.

At present, "COMMUNICATIONS" is a bilingual publication, and in order to stay within the minimum postal rate limits, all 17,000 copies contain two pages in English and two in French. This restricts the amount of language, for the same cost that we now produce a 2-page (2 language) bulletin. In fact, we have frequently received requests to do so - these requests include Group Newsletters.

There are difficulties that would be involved in switching over to such a system; Francophones and anglophones cannot be identified simply by name. We would have to send out a questionnaire asking every member to indicate in which language he or she would prefer to receive "COMMUNICATIONS" and Group newsletters, and such questionnaires rarely attract a satisfactory response. Even after we have received replies, it may take some time to adjust our mailing list to accommodate this system, and we would have to ask members

rates within the next year

2) An unknown increase in the cost of paper.

3) The desire of certain members to receive "COMMUNICATIONS" and Group Newsletters in one language only.

4) The advantage of getting out more information for the same cost by printing separate English and French editions.

We are therefore asking <u>all</u> members to fill in the coupon below, indicating whether they would like to receive "COMMUNICATIONS" and Group Newsletters in the language of their choice only, and what that language is. Depending on the size and nature of your response, a decision will be made whether or not this idea should be implemented. It should be stressed that the Institute will continue its policy of

4.3.2 12/14 GHz

Similarly for 12/14 GHz operation with and without up-link power control, by substituting the relevant parameters from Table 4-4 into equations (4-1) to (4-6), the values of G/T required to receive from 1 to 4 digital TV channels can be derived and are shown summarized in Tables 4-6 (With Up-link Power Control) and 4-7 (Without Up-link Power Control).

	NO. OF TV CHANNELS		OCCUPIED B/W	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T dB/°K EIRP=44	EIRP=47	EIRP=50
	DITEC	NETEC	MHz	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
ϕ_s = -87 dBW/m²		1	9	91.2	93.1	95.7	30.3	27.3	24.3
	1	2	18	94.2	93.1	*			
		3	27	96.0	93.1	*			
	2	4	36	97.2	93.1	*			
ϕ_s = -84 dBW/m²		1	9	91.2	96.1	92.9	27.5	24.5	21.5
	1	2	18	94.2	96.1	98.7	33.3	30.3	27.3
		3	27	96.0	96.1	112.4	47.0	44.0	41.0
	2	4	36	97.2	96.1	*			
ϕ_s = -81 dBW/m²		1	9	91.2	99.1	92.0	26.6	23.6	20.6
	1	2	18	94.2	99.1	95.9	30.5	27.5	24.5
		3	27	96.0	99.1	98.9	33.5	30.5	27.5
	2	4	36	97.2	99.1	101.7	36.3	33.3	30.3

* Uplink C/N_o limited

TABLE 4-6

SUMMARY OF G/T REQUIRED TO RECEIVE DIGITAL TV AT 12/14 GHz (WITH UPLINK POWER CONTROL).

	NO. OF TV CHANNELS		OCCUPIED B/W	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T dB/°K		
							EIRP=44	EIRP=47	EIRP=50
	DITEC	NETEC	MHz	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
ϕ_s = -87 dBW/m²		1	9	95.2	93.1	*			
	1	2	18	98.2	93.1	*			
		3	27	100.0	93.1	*			
	2	4	36	101.2	93.1	*			
ϕ_s = -84 dBW/m²		1	9	95.2	96.1	102.5	37.1	34.1	31.1
	1	2	18	98.2	96.1	*			
		3	27	100.0	96.1	*			
	2	4	36	101.2	96.1	*			
ϕ_s = -81 dBW/m²		1	9	95.2	99.1	97.5	32.1	29.1	26.1
	1	2	18	98.2	99.1	105.5	40.1	37.1	34.1
		3	27	100.0	99.1	*			
	2	4	36	101.2	99.1	*			

* Uplink C/N_o limited

TABLE 4-7

SUMMARY OF G/T REQUIRED TO RECEIVE DIGITAL TV AT 12/14 GHz (WITHOUT UPLINK POWER CONTROL)

REFERENCES

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2. Golding, L.,"DITEC - A Digital Television Communications System for Satellite Links", 2nd International Digital Satellite Communications Conference, Paris, Nov. 1972, pp. 384-397.

3. Ishiguro, T. et al,"NETEC System: Interframe Encoder for NTSC Colour Television Signal", 3rd International Digital Satellite Communications Conference, Kyoto, Nov. 1975, pp. 309-314.

4. Ohira, T. et al,"Comparison of Hadamard Transform Coding and DPCM based on Difference Error Signals from Original Pictures", ICC 1973, Washington.

5. TELEVISION ASSOCIATED AUDIO TRANSMISSION METHODS

5.1 Introduction

Present television-associated audio transmission systems can be assigned to three broad categories:

a. those which utilize an audio subcarrier in the video baseband at a frequency above the video signal,

b. those which time-multiplex the program audio channel(s) into the video line signal format, and

c. those which utilize a separate RF carrier for the audio program channel(s)

Program audio transmissions by the audio subcarrier technique have been in wide-spread use by common carrier and satellite systems in North America. Similar systems have been proposed for domestic satellite systems in Indonesia and Africa.

As the need for increased audio capacity, high quality audio programs and simultaneous multi-lingual audio transmissions grows, both in North America and in Europe, the trend has been towards the use of time division multiplexing techniques to fulfill these needs.

INTELSAT, with the inception of two video carrier per transponder transmissions, has been dissatisfied with audio transmission arrangements whereby the television-associated audio programs are accommodated ~~by~~ either

a. via 24 channel program audio carriers in the SPADE/SCPC transponder, or

b. via spare in-band 4 kHz VF channels in existing telephony carrier basebands.

As a consequence, COMSAT, as Management Services Contractor to INTELSAT, has been actively investigating alternative audio transmission techniques with specific interest in time division multiplexing methods.

5.2 Audio Subcarrier Methods

In the audio subcarrier configuration, the subcarrier is located above the video baseband spectrum between the top video baseband frequency (4.2 MHz for the 525/60 NTSC system) and the second harmonic of the colour subcarrier frequency (1).

On the audio subcarrier are frequency division multiplexed the program channel(s), a cue/control and a pilot. Fig. 5-1 illustrates the typical configuration used for video transmissions on the Anik satellites.

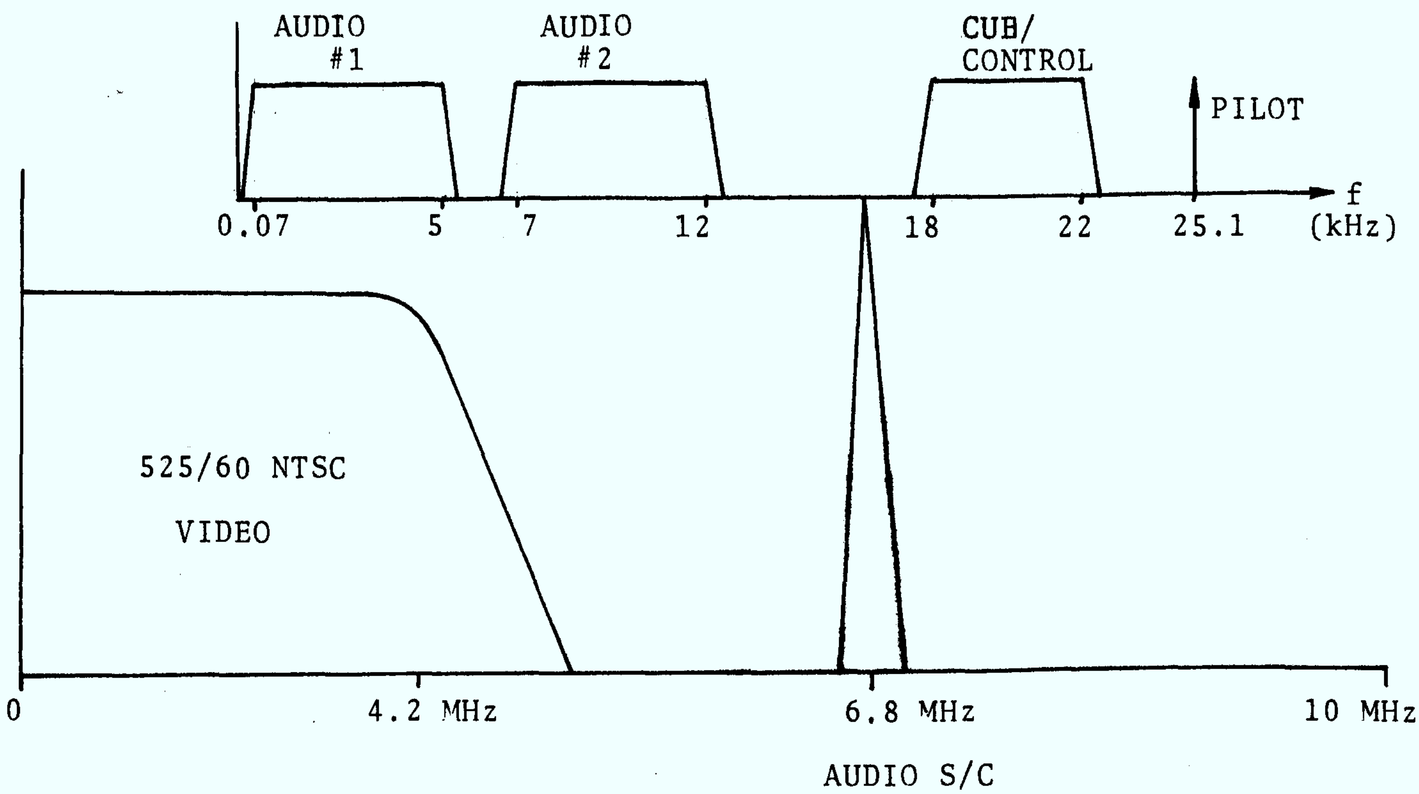

FIGURE 5-1

COMPOSITE VIDEO AND AUDIO BASEBAND CONFIGURATION

AS USED ON THE ANIK SATELLITES

Several investigations have been conducted to determine the optimum subcarrier frequency for best noise performance. These studies and practical experience indicate that there is typically less than 3 dB difference in subcarrier noise performance when the subcarrier is placed between 0.5 MHz above the nominal video cut-off frequency and the second harmonic of the color subcarrier. In general the lower the subcarrier frequency the better the overall system performance (2).

As a practical matter, the lowest usable subcarrier frequency is determined by the characteristics of the video low pass or notch filter. Sharp cut-off video filters usually introduce unacceptable video pulse overshoot and ringing. Therefore, 6.8 MHz is the most common subcarrier frequency for high performance PAL and NTSC color video systems although a subcarrier frequency of 5.8 MHz is used on some NTSC systems.

The advantages of the audio subcarrier configuration are:

a. a single link can accomodate the composite video and audio information at a nominal cost in terminal equipment,

b. the audio subcarrier may be added or removed (using a simple roofing filter) without processing of the basic video information, and

c. a number of single sideband program channels can be multiplexed onto the subcarrier without great effect on the required receive IF bandwidth while avoiding the possibility of intermodulation occuring as in the use of multiple subcarriers.

The disadvantages are that:

a. it requires two stages of de-multiplexing in order to recover the audio program(s), and

b. the RF deviation due to audio subcarrier detracts from useful video deviation (this is of some significance when the two video carriers per transponder mode is being considered).

Another approach is to use multiple subcarriers above the video baseband (2). The advantages of this method are:

a. lower cost per channel (no SSB/AM multiplexing required)

b. less complicated equipment, and

c. each channel is independent and may be demodulated without first demodulating a main subcarrier.

The disadvantages of this method, however, are that:

a. there is the possibility of intermodulation products between the subcarriers interfering with the video, and

b. multiple subcarriers require even more RF deviation than for a single subcarrier thus reducing the useful video deviation further.

5.3 Audio Time Division Multiplexing Methods

A number of systems using time division techniques to multiplex audio programs into the video line format have been proposed but, as far as is known, only the PYE "Sound-In-Sync" version has been marketed as a standard product line for use with either the 525/60 NTSC or 625/50 PAL television frame standards. Dual standard models are being considered.

The PYE "Sound-In-Sync" equipment has been widely used on European terrestrial microwave systems and has undergone tests on the INTELSAT satellite for possible integration into their video transmissions, especially half-transponder TV transmissions.

Approximately one hundred units of the PYE equipment have been installed and are now being used on Bell Canada's microwave facilities.

The approximate costs (for equipment only) to implement the PYE system are as follows:

Encoder	$ 6,700
Decoder	8,300
Back Porch Clamper Amplifier	1,200
Monitor Decoder	900
(U.S.)	$17,100

Dual standard models are expected to cost approximately 20% more than the existing production models.

S.E.L. AG (Standard Elektrik Lorenz Aktiengesellschaft), an ITT associate, of Stuttgart, Germany, will probably have production models of their system available in the near future. The SEL system (3) has been tested on the radio relay links of the Deutsche Bundepost and at Raisting Earth Station via Symphonie I and INTELSAT IV with very successful results being reported by S.E.L. AG.

Digital Communications Corporation (DCC) have produced the DATE (Digital Audio for Television) system for the Public Broadcasting Service in the United States. DATE has so far undergone successful tests by the PBS on AT & T video facilities but its present status is not known.

A brief description of the various systems which have been proposed, follows.

5.3.1 PYE 'Sound-In-Sync'

The PYE 'sound-in-sync' system is essentially a form of time-division-multiplex in which the circuit is available to the sound signal for a period of 3.8 microseconds within each 4.7 microseconds line synchronizing interval, and the vision signal occupies the circuit during the remainder of the time; these 3.8 microsecond periods are symmetrically disposed with respect to the leading and trailing edges of the line synchronizing pulse. The leading edges of the line synchronizing pulses are preserved during transmission.

The sound signal is sampled in the coder at twice the television line frequency. This permits an audio bandwidth of 14 kHz to be transmitted. The two samples produced during each line period are converted to pulse code modulation (PCM) signals; the two groups of pulses are then combined, stored and inserted into the television waveform during the next line synchronizing interval.

The system uses a 10-digit binary code. Twenty sound pulses, together with a marker pulse which identifies the start of the sound pulse group, i.e., 21 pulses in all, are accommodated within each line synchronizing period.

In order to provide room for the sound pulses throughout the field blanking interval it is necessary to extend alternate equalizing pulses from 2.35 microseconds to 4.5 microseconds, but no other changes to the video signal are necessary before the sound pulses and video signal are combined.

At the decoder, the sound pulses are extracted and reconverted to normal audio signals and the video waveform is restored to standard form.

The sound pulses are of the 2T form, that is, a raised cosine having a half-amplitude duration of 182 nanoseconds. The complete group of pulses occupies 3.8 microseconds, the spacing between the pulses is 173 nanoseconds at half-amplitude.

The digit train is gated into the television waveform during the 3.8 microseconds interval, and any noise or other irregularities present in the incoming television waveform during this period are, therefore, removed. The leading edge of the synchronizing pulse is left untouched because it is the main timing reference of the video waveform. A compandor is used which gives an improvement of 13 dB in the signal-to-noise ratio of the PCM system and thus renders the 10-digit system slightly better in this respect than one which uses 12 digits but no compandor.

The analogue-to-digital converter samples the audio frequency signal presented to it at twice-line rate, and delivers an output in PCM form to the combiner unit. This unit accepts the vision signal, clamps it during the back porch, and inserts the sound pulses.

The reverse procedure is carried out at the receiving terminal. The combined sound-in-sync signal is fed to the separator unit from which a clamped and restored vision signal is produced. Separated sound pulses are decoded in the digital-to-analogue converter which delivers an audio-frequency signal. The complete coding and decoding terminal equipments each occupy a height of 5¼ inches within a normal 19 inch bay.

Performance

The PCM sound channel is specified by PYE to have the following characteristics:

Amplitude/Frequency Response	±0.7 dB (40Hz to 13.5 KHz)
2nd Harmonic Separation	1 KHz 0dBm > 50 dB + 10 dB > 58 dB
	100Hz 0dB > 50 dB
Signal-to-noise Ratio	64 dB peak signal to peak weighted noise

5.3.2 S.E.L.

The SEL technique involves using a part of the line-blanking interval after shortening the synchronizing pulse. The sound signals are sampled and companded to a given number of bits in a non-return-to-zero code. At the receiving end the pulses are stored, decoded and read out with the original sampling frequency. After passing through a low-pass filter, the signals are available in the original form.

The principal system characteristics are (see Fig. 5-2 and 5-3):

1. source encoding 14 bits linear(each sound signal requires two samples per line)
2. digital companding from 14 bits to 10 bits by means of the 13-segment companding law with CCITT pre-emphasis;
3. transmission of 10-bit words with NRZ pulses
4. binary transmission code;
5. pulse repetition frequency equal to double color sub-carrier frequency (auxiliary frequency used in the system only);
6. transmission time of 4.7 μs on extended back porch of the video signal;
7. pulse amplitudes with 0 and 100 IRE Units;

An integrated sound transmission according to the outlined method offers the following advantages without impairment of the picture and sound quality:

1. applicability to all television standards;

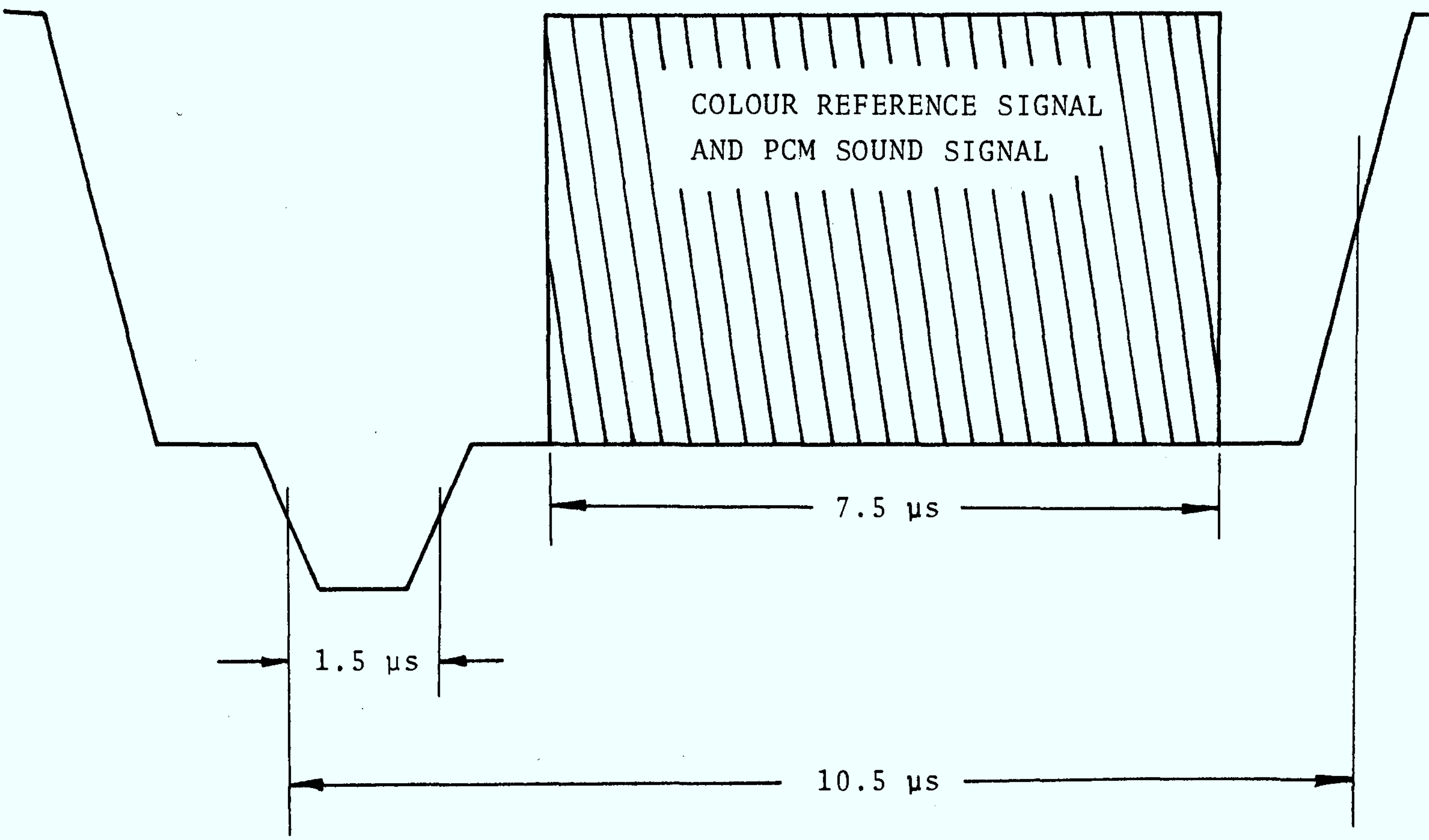

FIGURE 5-2

LINE BLANKING INTERVAL (625/60 PAL)

MODIFIED FOR INTEGRATED SOUND TRANSMISSION.

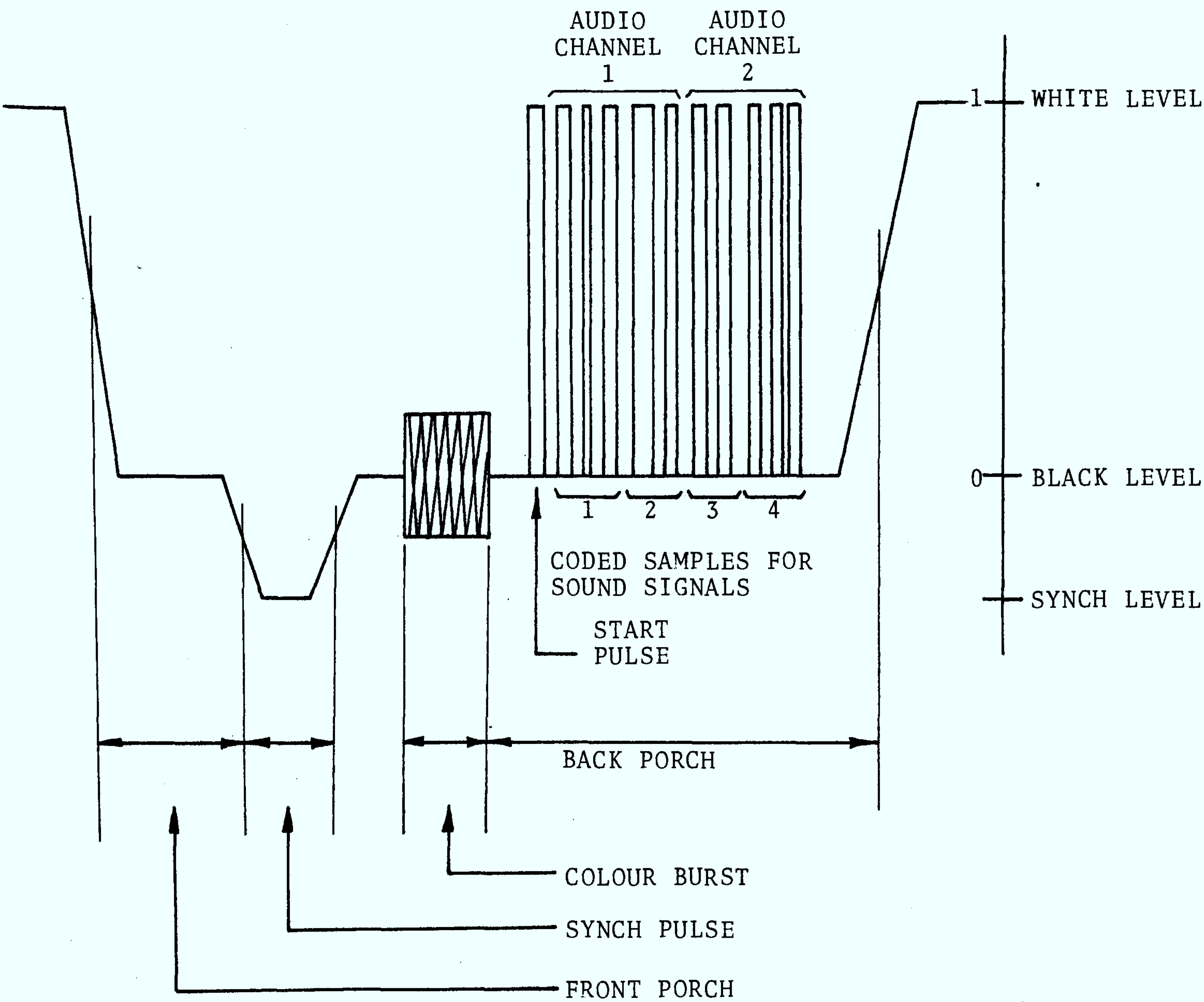

FIGURE 5-3

INTEGRATION OF THE BINARY PCM NRZ PULSES.

2. saving of bandwidth in the case of satellite transmissions, radio-relay links and cable television networks;

3. possibility of transmitting two high-quality sound channels (or several of lesser quality);

4. one transmission link for picture and sound; and

5. considerable reduction of transmitter power, particularly in the case of satellite systems.

5.3.3 N.H.K. (Nippon Hoso Kyokai)

The N.H.K. system (4) which was proposed in 1971 was similar in some respects to the prototype equipment provided by S.E.L. AG. The N.H.K. system was capable of providing two 15 kHz, or three 10 kHz, or other divisions of the basic 30 kHz. To accomodate the sound pulses, the duration of the line synchronizing pulse was abbreviated and the colour burst encoded along with the sound pulses. There were 32 sound pulses and were inserted into the modified back-porch in a ternary PCM Return-to-Zero format with pulse heights between 0 and 100 IRE units.

During the tests of this system on the ATS-1 in mid-1971, impulse noise was noted together with over-deviation. Some hue impairment was also noted on reconstitution of the colour information after the decoding process. The present status of this system is not known.

5.3.4 DATE (Digital Audio for Television)

The capability of the DATE system is four 15 kHz or twenty-four 4 kHz channels or a combination thereof.

The principal system characteristics of DATE are as follows:

1. Each audio input channel is sampled at a rate of 34.42×10^3 times per second (525/60 NTSC colour subcarrier rate divided by 104).

2. Source encoding 14 bits linear

3. Digital companding from 14 bits to 12 bits

4. Pre- and de-emphasis used in the audio channels

5. Robbed-digit framing used to keep track of the audio channels in the bit stream.

6. Bit stream modulated onto a 5.5 MHz subcarrier using 4-phase PSK.

7. Demodulator uses coherent decoding.

Figure 5.4 illustrates the basic configuration of the encoding and decoding process.

Strictly speaking, the DATE system, which utilizes a 5.5 MHz subcarrier above video, should be classified under section 5.2 but in view of the digital techniques employed has been included under section 5.3 instead.

In summary, the advantages of digital techniques for the transmission of program audio with video are:

a. the provision of high quality audio channels or several channels of reduced quality,

b. a single video link can accomodate the composite video plus digital audio channels at a savings in transmitter power (for satellite systems) and maximum utilization of spectrum bandwidth, and

c. excellent audio quality is achievable

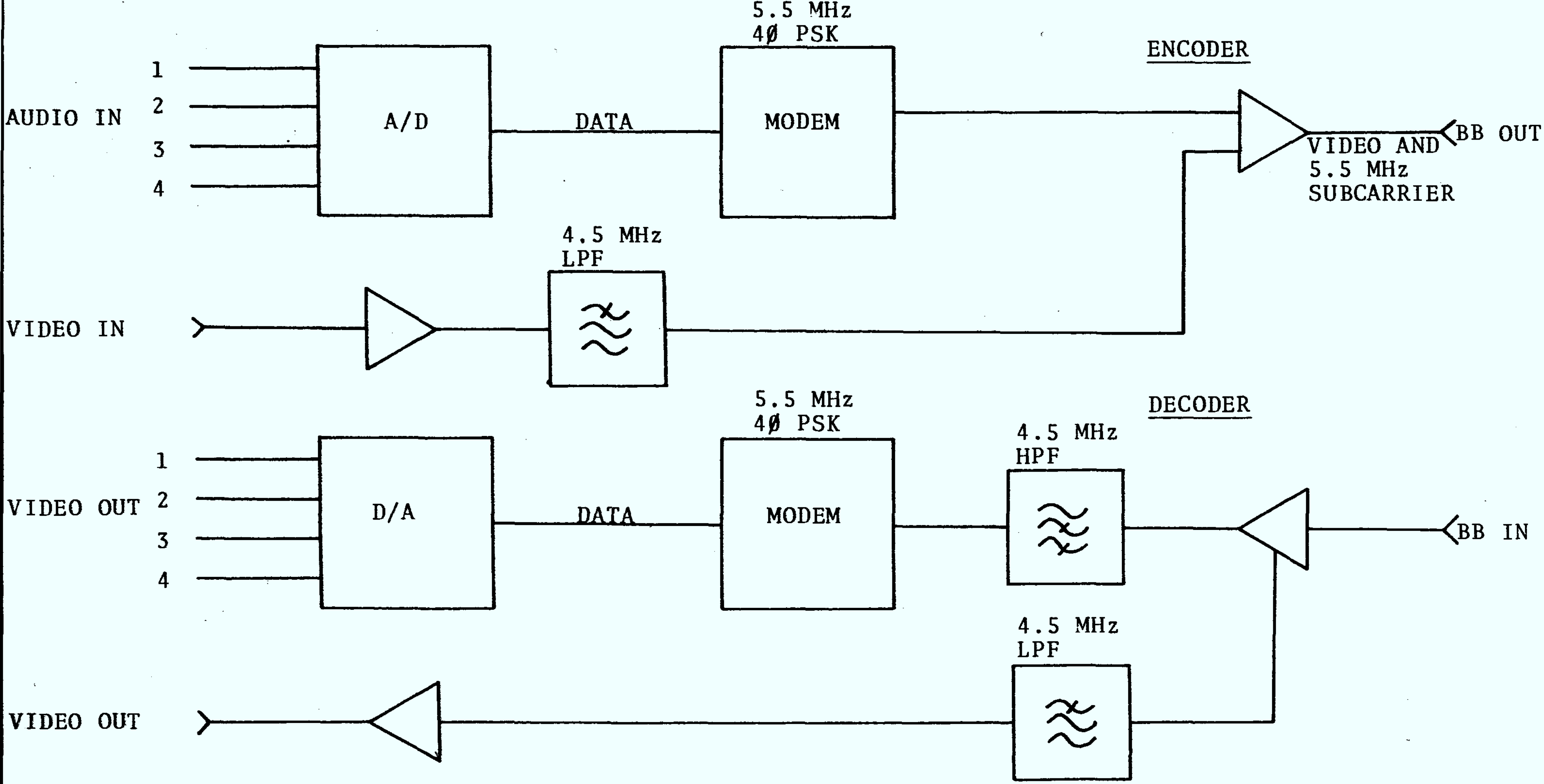

FIGURE 5-4

DATE SYSTEM ENCODER AND DECODER CONFIGURATION

The disadvantages are:

a. presently, high terminal costs for the encoding and decoding process, and

b. with the exception of the DATE system, processing of the video line format is necessary to accomodate the digital audio channel(s).

5.4 Use of Separate RF Carrier

TV Audio (or radio program) signals may be transmitted on separate RF carriers. The most well-known user of this configuration is INTELSAT, where for full transponder television transmissions, the television-associated audio program channel(s) are provided by utilizing a 24 channel/2.5 MHz FM/FDM/FDMA RF carrier located 19.75 MHz below the video carrier frequency in the lower part of the video transponder. For cue/control purposes, a second 24 channel RF carrier located 2.5 MHz above the sound carrier may or may not be used.

There are presently three types of audio program channels used on the INTELSAT satellites:

a. Type I Audio consists of a single 4 kHz VF channel (channel 1 of basic group A 12-60 kHz erect),

b. Type II Audio consists of two 4 kHz VF channels (channels 4 and 5 of basic Group A), and

c. Type III Audio utilizes channels 4, 5 and 6 (24-36 kHz) of basic Group A. This was formerly designated as Type A Audio in INTELSAT document ICSC-45-13E W/1/70, section 3.3.10.

As mentioned previously, for two carrier per transponder video transmissions, the sound carriers are allocated to the SPADE/ SCPC transponder or the sound programs are carried via spare in-band 4 kHz VF channels in existing telephony carrier base-bands.

The advantages of this configuration are:

a. the audio carrier(s) and the video carrier(s) may be accessed independently of each other,

b. the audio and video carriers can originate from two diverse locations, if necessary, and

c. little or no direct baseband interference between the audio and video signals occurs.

The disadvantages are:

a. a separate transmitter for the audio carrier has to be provided,

b. normally a separate downconverter chain and certainly a separate demodulator are necessary to receive the audio carrier; furthermore, the use of an SCPC audio carrier imposes greater stability requirements on the downconverter, an especially important consideration at 12 GHz,

c. valuable RF power and spectrum are used up by the audio carrier(s),

d. when included in the TV transponder, the presence of audio carrier(s) results in the generation of intermodulation product interference within the channel and to the adjacent channels, and

e. when located at the edge of an RF channel band, a narrow band audio carrier is subject to a slow cyclic variation in down-link power due to multipath through the adjacent transponder (this effect is peculiar to the Hughes HS 333 or Anik type satellite).

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6. TECHNOLOGY TRENDS FOR 4 GHz AND 12 GHz TV RECEIVE-ONLY GROUND STATIONS

A typical TV receive-only ground station consists of an antenna, some form of low noise amplifier (LNA) and a TV receiver (comprised of a downconverter and a demodulator) to receive the video and accompanying audio signals from the satellite. A functional block diagram is given in Fig. 6-1.

6.1 Antennas

There were no significant differences identified in antenna technology at 4 GHz and 12 GHz except the obvious gain versus frequency and required tolerance versus wavelength relations.

a. Current Technology

An example of current 4 GHz technology in antennas is the standard product line from Andrew Antennas Co. Ltd.:

- 26 ft. parabolic antenna designed to withstand wind speeds up to 125 m.p.h.

- a 15 ft. air transportable or standard antenna and a 12 ft. lightweight air transportable antenna.

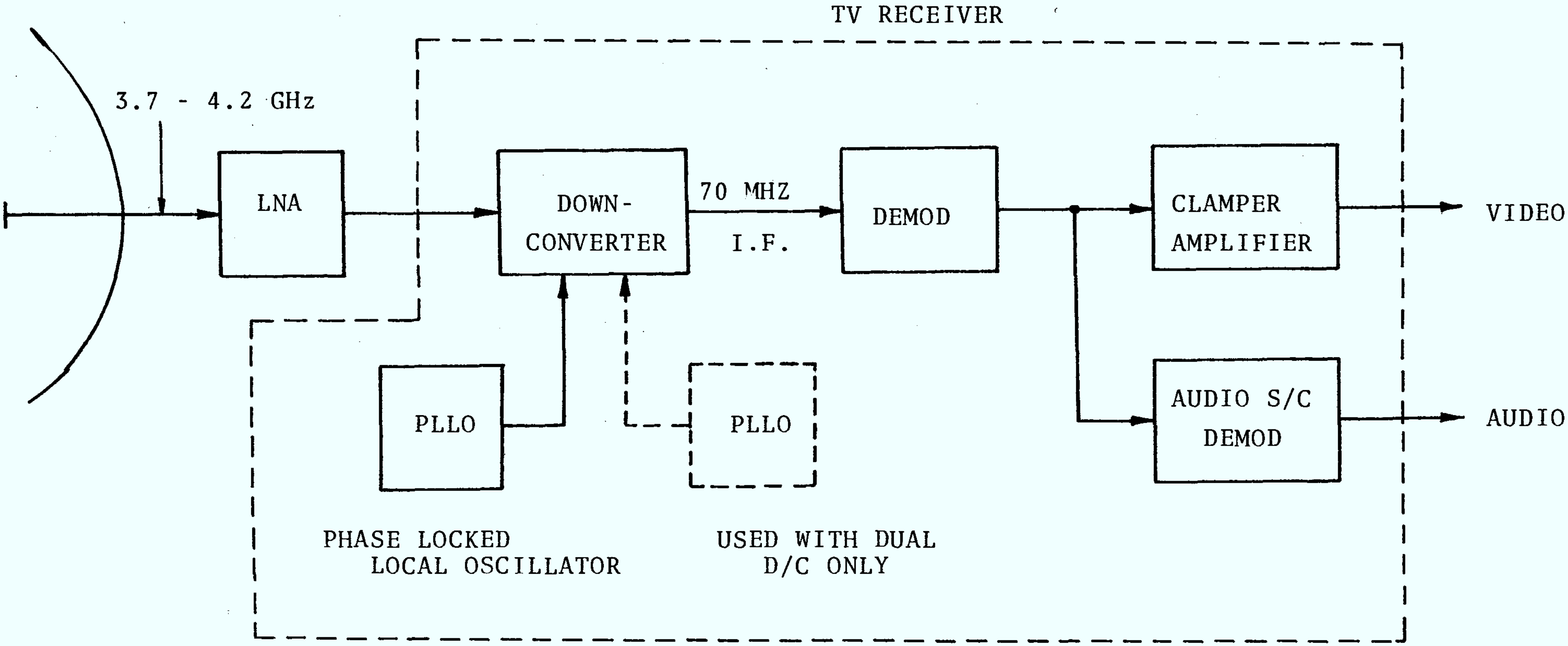


FIGURE 6-1

BLOCK DIAGRAM OF A TYPICAL 4GHz RECEIVE-ONLY TV GROUND STATION

The properties of these antennas are listed in Table 6-1.

b. New Developments

Since most stations are limited on the down-link, improvement in antenna performance will be centered on maximization of efficiency at receive frequencies and lowering of sidelobe levels on transmit frequencies (to minimize unwanted adjacent satellite illumination).

New materials to reduce cost and weight, such as the metallized fiberglass material used in the Prodelin antennas, are being experimented with. Another new development is the conical horn antenna, manufactured by Antennas For Communications Incorporated (AFC Inc.), which has extremely low sidelobe levels that results in the reduction of antenna noise temperature to approximately $3^{o}K$ even at elevation angles as low as 5 degrees. This reduction in antenna noise temperature contribution is only useful, however, if a parametric amplifier with 40^{o} - $50^{o}K$ noise temperature is being used in the amplifying chain. When an LNA with noise temperature of the order of 200 - $300^{o}K$ is being used, antenna noise temperature contribution does not degrade system noise temperature significantly. The principal advantage of a horn antenna for remote terminal applications is the reduction

MANUFACTURER	SIZE	FEED TYPE	GAIN		EFFICIENCY		BEAMWIDTH	
			4 GHz	6 GHz	4 GHz	6 GHz	4 GHz	6 GHz
ANDREW ANTENNA	12 ft transportable	Cassegrain	40.73	43.05	51.6%	36%	$1.4^{o}/1^{o}$	
"	15 ft transportable	Cassegrain	42.7	N/A	55 %	N/A	1.1^{o}	
"	15 ft. standard	Gooseneck	43.5	N/A	60%	N/A	1.1^{o}	
"	26 ft standard	Gregorian	48.4	52.3	60%	65%	0.62/0.40	
PRODELIN INC	10 ft transportable 5 sections fibreglass	Centre feed	39	43	50%	55%	---	
ANTENNAS FOR COMMUNICA-TIONS INC.	9.5 ft effective aperture	Conical horn & Reflector	39.8	43.5	65%	55%	---	

TABLE 6-1

4 GHz ANTENNA CHARACTERISTICS

in interference to and from adjacent satellites and terrestrial microwave systems.

6.2 Low Noise Amplifiers

a. Transistor Amplifiers

Some of the leading U.S. manufacturers of 3.7 to 4.2 GHz state-of-the-art low noise transistor amplifiers (bi-polar and GaAs FET) are Amplica, Avantek, Watkins-Johnson and Hewlett-Packard. Some typical specifications are listed in Table 6-2. The heart of the low noise transistor amplifier is a GaAs FET device which is presently available in three different geometries, viz., 1.2μm, 1.0μm and 0.5μm gate widths. The corresponding noise figures, which depend largely on gate width, at 4 GHz are 2.9 dB, 2.2 dB and 1.5 dB respectively.

GaAs FET devices are supplied by Nippon Electric Company (NEC), Hewlett-Packard and Hitachi. The major European firms and institutions in FET work are in Britain, France and Germany. Siemens AG in Munich and the University of Aachen in West Germany are quite active, along with Thomson CSF and LEP (Laboratory d'Electronique et de Physique Appliquee) in France and SERL (Service Research

MANUFACTURER	TYPE	COOLED OR UNCOOLED	NOISE TEMP	NF (MAX)	BANDWIDTH	GAIN
AMPLICA	GaAS FET	Peltier to -18°C	150°K	1.8 dB	150 MHz inside 3.7-4.2	48 dB
		Uncooled	215°K	2.4 dB	150 MHz inside 3.7-4.2	"
		Peltier to -18°C	190°K	2.2 dB	500 MHz	"
		Uncooled	200°K	2.3 dB	"	"
		"	226°K	2.5	"	"
		"	262°K	2.8	"	"
		"	316°K	3.2	"	"
AVANTEK	Transistor	Uncooled	527°K	4.5 dB	500 MHz	40 dB
	F/B *	"	290°K	3.0	"	42
	F/B	"	359°K	3.5	"	45
	F/B	"	290°K	3.0	"	56
WATKINS-JOHNSON	Transistor Amp	Uncooled	400°K	3.8	500 MHz	25
		"	530°K	4.5	"	25
AIL	Transistor Amp	Uncooled	530°K	4.5	500 MHz	31

* GaAs FET input stages followed by silicon bipolar transistor stages

TABLE 6-2

4 GHz TRANSISTOR LNA's

Laboratories) in England. NEC is, however, generally considered the leading supplier of 0.5μm gate GaAs FET's at present.

All two port amplifying devices exhibit a strong noise dependence on source impedance. FET's are particularly difficult to optimize over broad bandwidths because of the high Q at the input to the device. Compared with bipolar transistors, FET's require closer matching to optimum source impedance for a given noise figure degradation. Therefore, better noise figures are achieved only over narrower bandwidths as can be seen from Table 6-2. Present development work is associated with optimizing the device over wider bandwidths.

b. Parametric Amplifiers

Some leading U.S. manufacturers of 4 GHz parametric amplifiers are AIL (Div. of Cutler-Hammer), LNR and COMTECH. Typical examples of parametric amplifiers (paramps) are presented in Table 6-3.

MANUFACTURER	COOLED OR UNCOOLED	NOISE TEMPERATURE	NOISE FIGURE	BANDWIDTH	GAIN
AIL	Peltier to -18°C	48°K	0.66 dB	500 MHz	50 dB
	Uncooled	60°K	0.8 dB	"	50 dB
	"	75°K	1 dB	"	50 dB
	"	85°K	1.1 dB	"	50 dB
	"	125°K	1.55 dB	"	50 dB
COMTECH	Cooled	55°K max	0.75 dB	500 MHz	55 dB
LNR	Peltier cool	45°K typ	0.63 dB	500 MHz	50 dB
	Cooled	50°K	0.69	"	50 dB
	Cooled	65°K	0.88 dB	"	50 dB
	Uncooled	75°K	1 dB	"	50 dB
	"	85°K	1.1 dB	"	50 dB
	"	95°K	1.23 dB	"	50 dB
	"	120°K	1.5 dB	"	50 dB
NORTHERN TELECOM	Uncooled	100°K	1.28 dB	500 MHz	50 dB
	"	125°K	1.55 dB	"	50 dB
	"	100°K	1.28 dB	250 MHz	50 dB
	"	125°K	1.55 dB	"	50 dB
	"	150°K	1.8 dB	"	50 dB

TABLE 6-3

4 GHz PARAMETRIC AMPLIFIERS

The parametric amplifier usually consists of a thermo-electrically cooled varactor first stage, (e.g. down to about -18^{o}C) and an ambient parametric second stage, which both provide low noise temperature and gains of approximately 12 dB per stage. These two stages are then followed by a bipolar amplifier which increases the overall gain to a desired 50 dB or so. With this configuration noise temperatures of 45^{o}K are attainable. When noise temperatures of 90^{o}K or more are sufficient, only one temperature stabilized (usually heated) parametric stage is used.

The performance of a parametric amplifier is subject to the bandwidth relationship. If its bandwidth is increased, the Q factor of its idler tuned circuit is reduced. This reduces the gain and increases the noise temperature. On the other hand if the bandwidth is reduced, gain can be increased and noise temperature drops. This is why in general it is easier to produce parametric amplifiers with a low noise temperature working with a narrower bandwidth; the cost, therefore, is also lower.

Paramps are still fairly expensive (see section 8) although prices are coming down due to competition from transistor amplifiers.

Figure 6-2 plots the noise temperature vs frequency of various types of low noise amplifiers. This figure is extracted from the January 1975 issue of the Microwave Journal, and is based on 1974 state of the art data.

The results presented are useful when broadly comparing the performance of these devices at 4 GHz and 12 GHz. In all cases, noise temperature increases with increasing frequency, an obvious disadvantage of going to the 12 GHz band. For uncooled para-amps an increase in noise temperature of 30^o - 100^oK can be anticipated. For transistor amplifiers there is a marked rate of increase about 8 GHz, limiting their application at 12 GHz. The least frequency sensitive devices are mixers and tunnel diode amplifiers. The low noise image recovery mixer will almost certainly constitute the front end of the 12 GHz satellite receiver, and may be practicable for the regional system (i.e. EIRP's) considered here. In the near and mid-terms, uncooled para-amps appear to be the most likely contenders at 12 GHz, with transistors having a slight edge at 4 GHz.

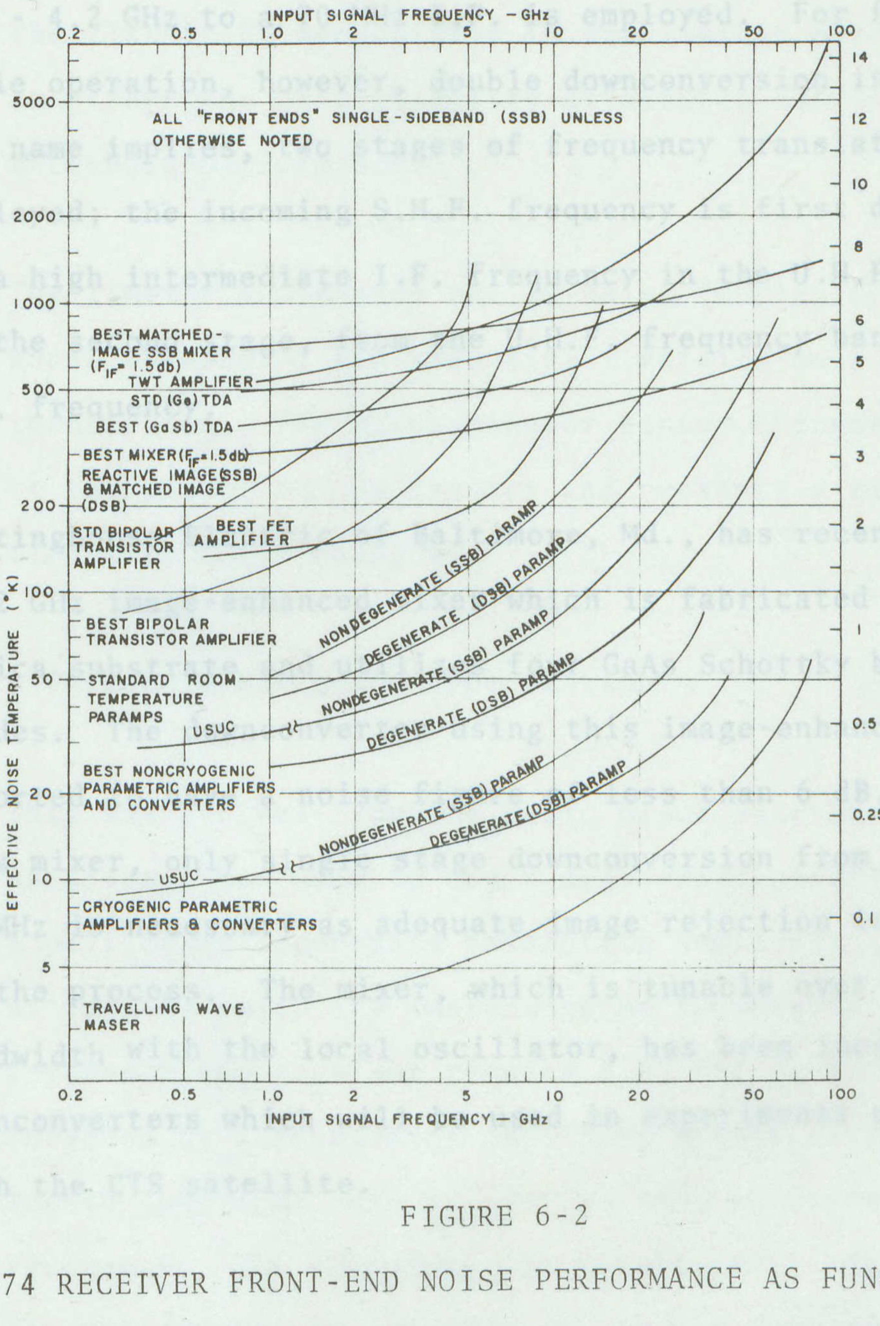


FIGURE 6-2

1974 RECEIVER FRONT-END NOISE PERFORMANCE AS FUNCTION OF INPUT-SIGNAL FREQUENCY - STATE OF THE ART

6.3 Downconverters

For non-frequency-agile operation, as used in the experimental TV receive station at Teslin, single stage downconversion from 3.7 - 4.2 GHz to a 70 MHz I.F. is employed. For frequency-agile operation, however, double downconversion is used. As the name implies, two stages of frequency translation are employed; the incoming S.H.F. frequency is first downconverted to a high intermediate I.F. frequency in the U.H.F. band and in the second stage, from the U.H.F. frequency band to a 70 MHz I.F. frequency.

Westinghouse Electric of Baltimore, Md., has recently developed a 12 GHz image-enhanced mixer which is fabricated on one fused silica substrate and utilizes four GaAs Schottky barrier diodes. The downconverter using this image-enhanced mixer is reported to have a noise figure of less than 6 dB. With this mixer, only single stage downconversion from 12 GHz to 70 MHz is necessary as adequate image rejection is obtained in the process. The mixer, which is tunable over a 1 GHz bandwidth with the local oscillator, has been incorporated in downconverters which will be used in experiments associated with the CTS satellite.

6.4 TV Demodulators

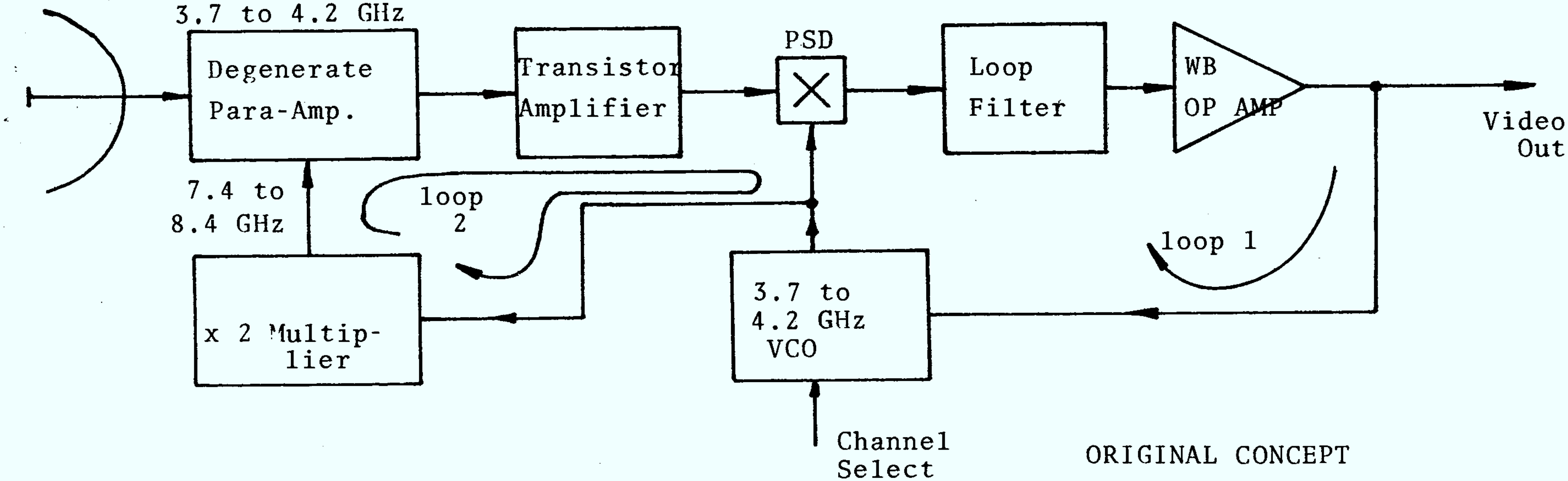
a. Limiter - Discriminator

The classic FM demodulator is the limiter discriminator. It offers the best linearity attainable but the poorest threshold performance.

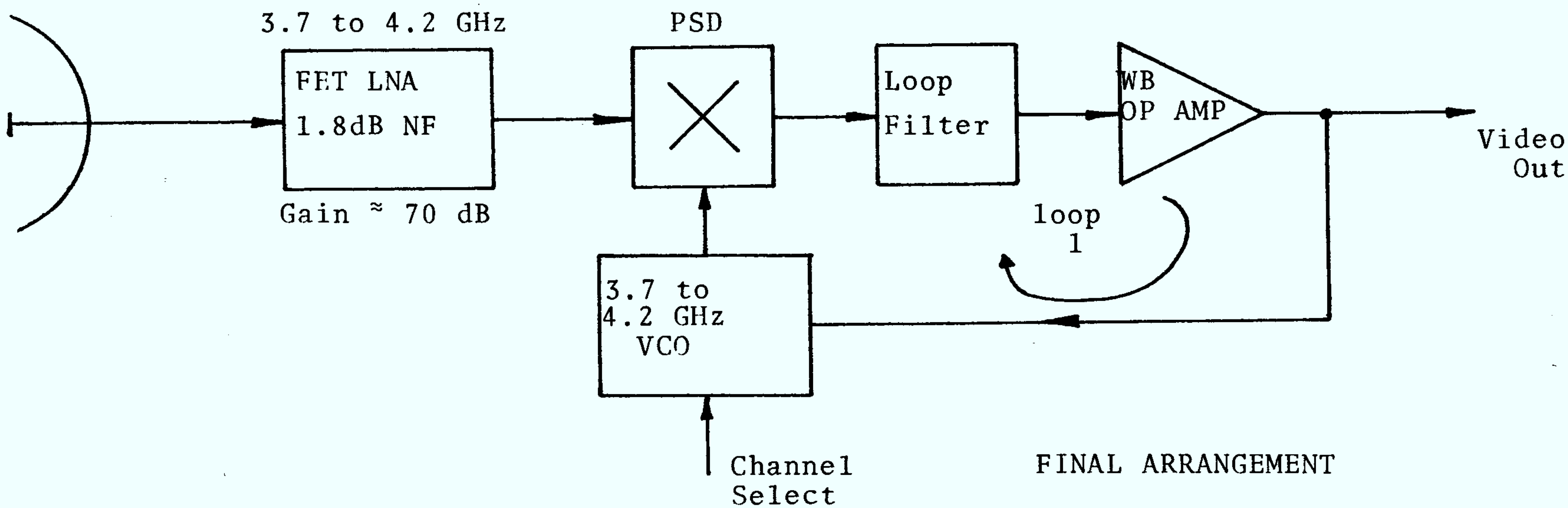
The limiter suppresses the AM noise (during operation above threshold) and essentially retains only zero crossing information. The discriminator senses changes in frequency at the output of the limiter and presents a signal proportional to these changes.

b. A Threshold Extension Type Station

This has evolved from the basic block diagram in Fig. 6-3. An attempt was made to use a degenerate parametric amplifier (a degenerate parametric amplifier is pumped at exactly twice its instantaneous fundamental signal frequency and does not require a 65 Ghz or so pump) followed by a transistor amplifier with a direct phase-locked loop (PLL) demodulator working at microwave frequency. The output of the VCO besides being fed to the pulse detector was also fed to the doubler in order to be used as a synchronous pump in the degenerate para-



ORIGINAL CONCEPT



FINAL ARRANGEMENT

FIGURE 6-3

AN "RF - TO - BB" VIDEO RECEIVER

amplifier. Problems, however, were encountered in synchronizing the paramp. The delay around "loop 2" was simply prohibitively long due to the many amplifier stages in the transistor amplifier needed to produce enough level for the phase detector diodes. In the final arrangment a FET LNA with a 1.8 dB NF was used. It is claimed that the threshold C/N is 8 dB, 2 dB extension over the usual 10 dB and that the receiver could work with a 10 ft. dish in Canada (or 35 dBW EIRP). The cost of this direct RF to baseband receiver might only be about $5K to $6K.

c. The General Phase-Locked Loop Demodulator (Fig. 6-4)

For the general PLL demodulator, the frequency of the incoming carrier coincides with that of a highly linear V.C.O. and demodulation direct to baseband takes place when the two signals are mixed in phase quadrature. The phase of the V.C.O. output is compared with that of the incoming carrier in a phase detector (typically, a double balanced mixer) and the phase error signal is passed through a loop filter and then used to lock the V.C.O. to the incoming signal. The output of the baseband amplifier, after equalisation to compensate for the closed-loop amplitude/frequency response, is a replica of the modulation signal.

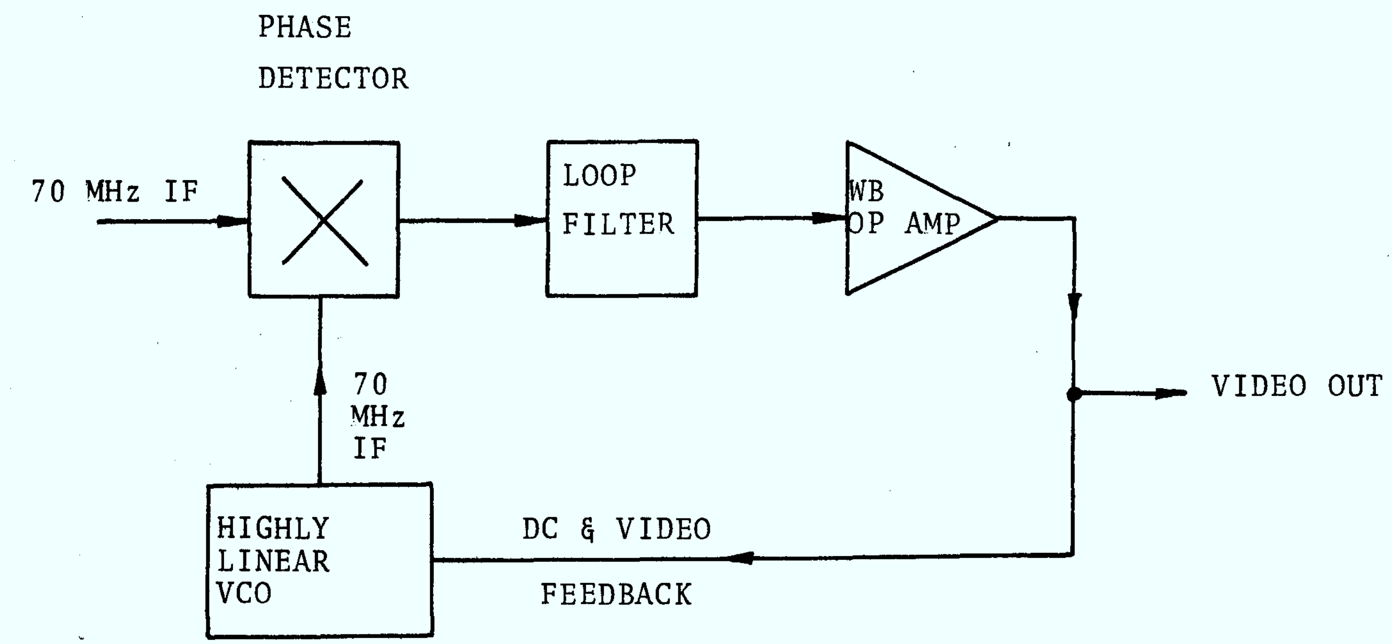


FIGURE 6-4

GENERAL PLL DEMOD AT I.F.

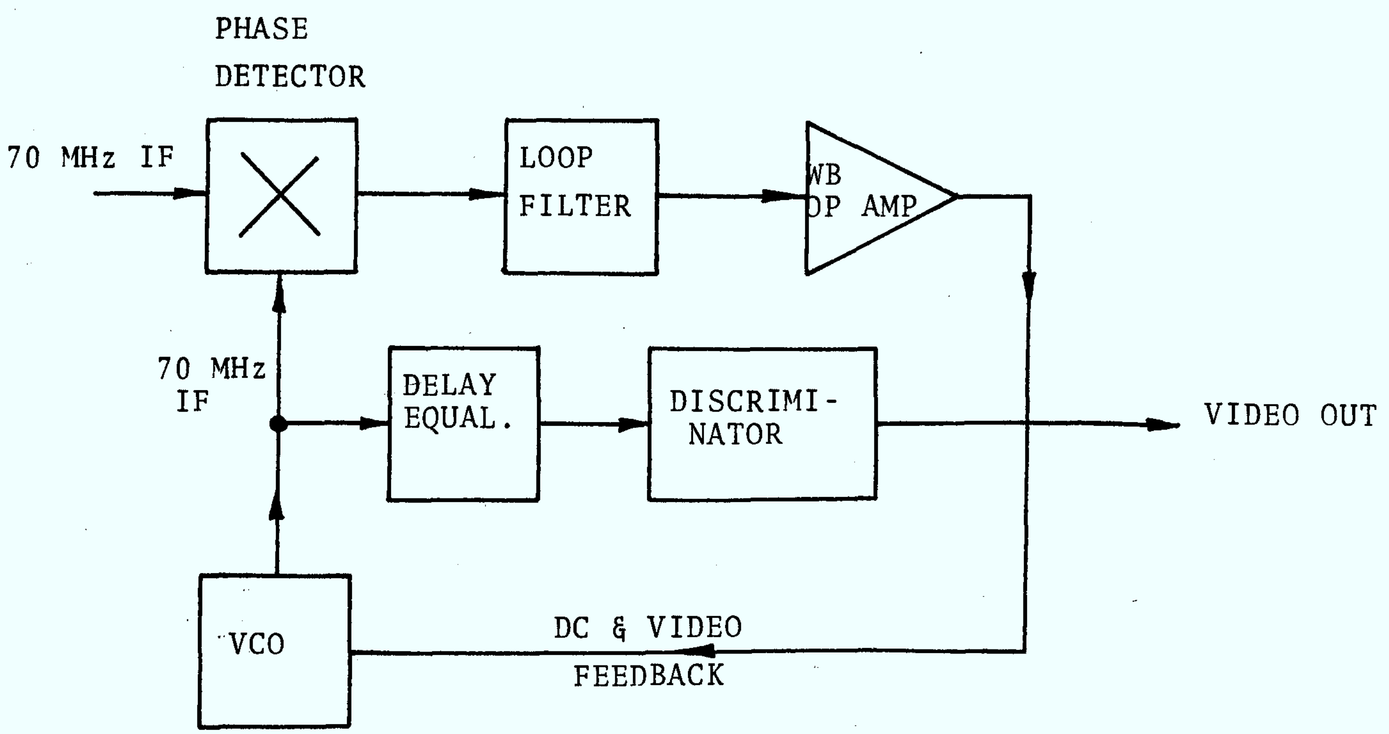


FIGURE 6-5

GENERAL PLL TRACKING FILTER TYPE

DEMOD AT I.F.

Threshold reduction is achieved because the effective bandwidth of the system, as determined by the loop gain and the loop filter, can be considerably less than the Carson bandwidth. Providing the instantaneous phase of the VCO closely tracks the incoming wave the system will remain in lock. But when noise causes the phase error to exceed $\pi/2$ the system becomes unstable and an abrupt change of 2π will occur in the phase of the V.C.O.

d. General PLL Tracking Filter (Fig. 6-5)

The VCO in this case does not have to be of the high linearity type and the loop filter bandwidth may be somewhat less than 3 dB of the baseband bandwidth.

This should increase threshold extension even more than 2 dB. An appreciable portion of the distortion due to the VCO non-linearity is removed by the feedback gain in the locked loop, and accumulated group delay due to the reduced loop bandwidth can be equalized prior to entering the discriminator (equivalent to the discriminator mentioned in 6.4a). In general more complex schemes exist, but so far non have found widespread use.

e. A new family of low-delay FM detectors was discussed by Dr. Jacob Klapper and Edward J.A. Kratt at the National Telecommunications Conference. The demodulator used a wideband quasi-coherent FM discriminator and it is claimed that while possessing interference and adjacent channel cancellation properties, it does not suffer from the threshold effect because it does not use a limiter. A demodulator of this type was made and used at telephone line frequencies but no signal-to noise performance analysis of experimental test results exist at present. Its present status is not known.

7. RADIO PROGRAM DISTRIBUTION

Section 5 has discussed various audio transmission techniques, their advantages and disadvantages. This section focusses attention on the application of the single channel per RF carrier (SCPC) technique for radio program distribution. This is the only reasonable solution if an independently switched system providing live programming from a number of origination points is required, and is the approach taken in CBC's accelerated coverage plan*.

7.1 Signal-To-Noise Equation

The FM equation for an un-multiplexed (i.e. SCPC) program channel is:

$$\frac{TT}{N} = \frac{3}{2} \frac{\Delta f_p^{\ 2}}{f_m^{\ 3}} \frac{C}{N_o} W \qquad (7\text{-}1)$$

where:

Δf_p = peak test tone deviation, kHz-pk

f_m = effective noise bandwidth of the program channel, in kHz

C/N_o = pre-detection carrier-to-noise density ratio, in dB-Hz

W = pre-emphasis and noise weighting advantage, in dB

---

* Channel 2 of the TV audio subcarrier has also been used to carry Northern Broadcast service radio program, but this scheme has limited flexibility, as discussed.

For a nominal 70 Hz to 5 kHz radio program channel bandwidth requirement, assume a corresponding noise bandwidth

f_m = 5.2 kHz

and a CCITT pre-emphasis (Rec. J-21) plus CBC program weighting advantage

$W \simeq 1.5$ dB,

then the variables, for system design purposes, are the peak deviation and the carrier-to-noise density ratio. Expressing the equation in logarithmic terms:

$$\frac{TT}{N}\ (\text{dB}) = 20 \log (\Delta f_p) + \left[\frac{C}{N_o}\right] \text{dB} - 107.75 \qquad (7\text{-}2)$$

For a given carrier backoff, earth station G/T and relevant satellite parameters (G/T, ϕ_{sat}, and EIRP), the C/N_o here can be computed using equations 3-13, 3-14, and 3-15 given in section 3.

7.2 System Performance

We do not attempt to summarize S/N performance of a radio program link for all the proposed satellite models, as in the case of TV. Rather, to demonstrate the relationship between S/N performance, allowable bandwidth, carrier EIRP and earth station G/T, results are presented only for the existing radio program system.

7.2.1 Bandwidth-G/T Relationship

The bandwidth-G/T relationship discussed previously in the case of TV (section 3.1) is defined by the minimum C/N constraint and the down-path thermal noise allocation. Assuming a 12 dB objective, and allowing 1 dB degradation from other sources *, the down-link thermal C/N (unfaded)

$$\left(\frac{C}{N}\right)_d = \text{EIRP} - \text{OBO} - \text{FSL}_d + G/T - 10 \log k - 10 \log (B) \qquad (7\text{-}3)$$

must exceed 13 dB

With

$$\text{EIRP} = 35 \text{ dBW}$$

$$\text{FSL}_d = 196.7 \text{ dB}$$

$$10 \log (k) = -228.6$$

$$\left(\frac{C}{N}\right)_d = 13 \text{ dB},$$

$$10 \log (B) = G/T + 53.9 - \text{OBO} \qquad (7\text{-}4)$$

---

* For saturated operation of a large TV carrier and a "small" radio program carrier, about 5 dB of small signal suppression can be expected. The contribution of up-link noise will therefore be 5 dB less than for the video link, and is small over the range of G/T's considered. However, a considerable amount of video spill-over and crosstalk under peak deviation conditions can be expected, as well as slow variations in output level due to multipath through the adjacent transponder.

This relationship has been plotted in Fig. 7-1 for

OBO = 18 dB, 20 dB, and 22 dB

7.2.2 Bandwidth - Deviation Relationship

The bandwidth - deviation relationship is constrained by the allowable distortion. A major factor in this relation is the allowable peak factor for radio program service. Generally, program loading is such that the S/N is defined at a test tone level used as a quasi-peak level, 8 dB above average level. Momentary peaks are expected, depending on program material and whether compressors are used, up to 18 dB above average level. Therefore a 10 dB peak factor is employed*, i.e.,

$$B = 2\ (3.17\ \Delta f_p + 5)\ \text{kHz} \tag{7-5}$$

This results in

$$\Delta f_p = \frac{B - 10\ \text{kHz}}{6.34}\ \text{kHz - pk} \tag{7-5a}$$

---

* Companders have in fact been employed in the existing Telesat system, giving a subjective S/N advantage of 10-15 dB depending on the program material and listener. A measurable S/N advantage through over-deviation could also be obtained against annoyance due to momentary distortion peaks

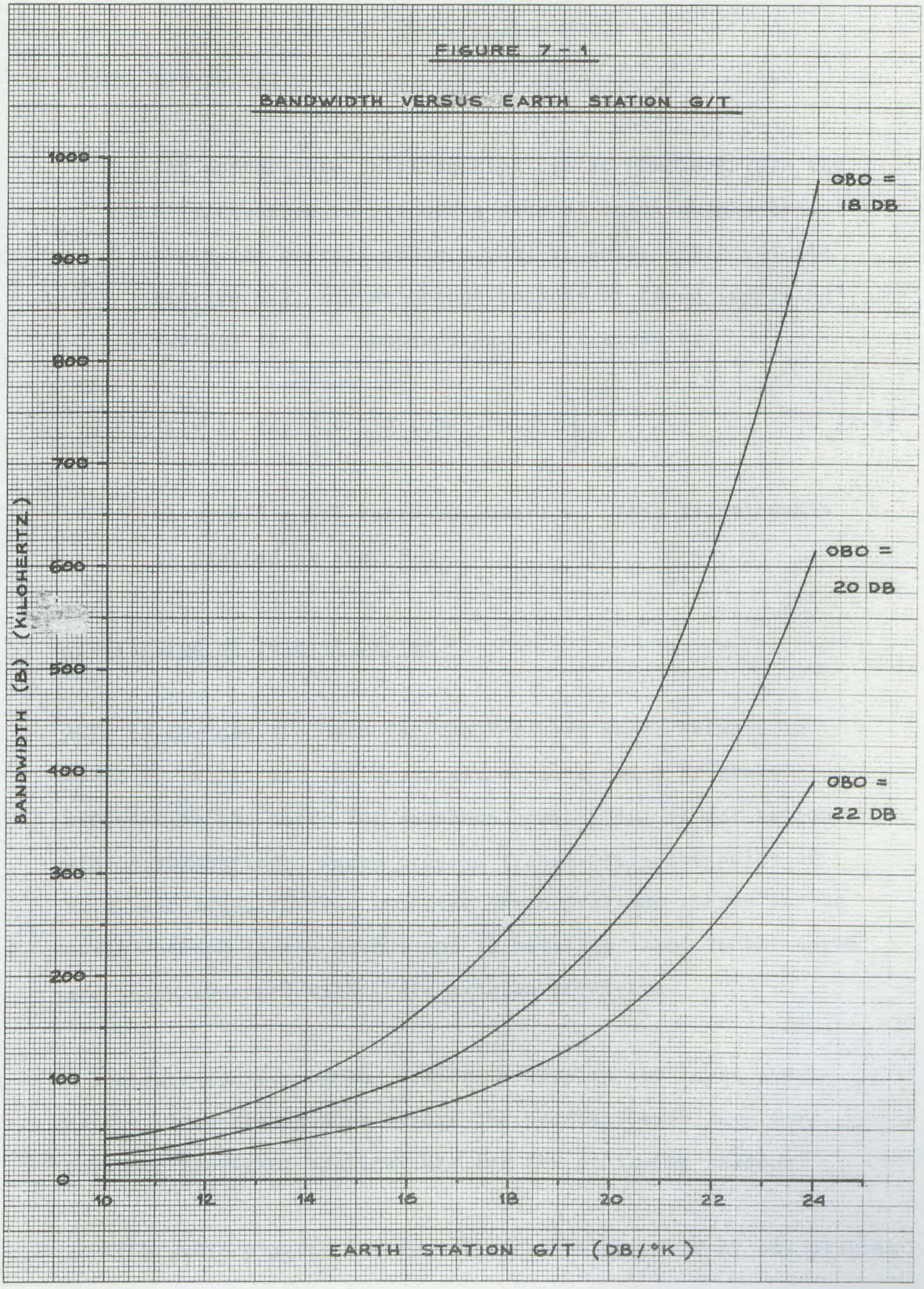


FIGURE 7-1
BANDWIDTH VERSUS EARTH STATION G/T
BANDWIDTH (B) (KILOHERTZ)
1000
900
800
700
600
500
400
300
200
100
0
10
12
14
16
18
20
22
24
EARTH STATION G/T (DB/°K)
OBO = 18 DB
OBO = 20 DB
OBO = 22 DB

7.2.3 S/N vs G/T

The appropriate relationships can be combined into the TT/N equation to produce a general relationship between the overall audio signal-to-noise ratio and the receive G/T; for an output backoff of 20 dB (existing system) the non-compandored S/N is given by:

$$\frac{TT}{N} = 10 \log \left[.9\ GTR\ (GTR - 3.8)^2 \right] \qquad (7\text{-}6)$$

where GTR = G/T ratio in numerics. This relationship is plotted in Fig. 7-2.

7.3 Description of Telesat System

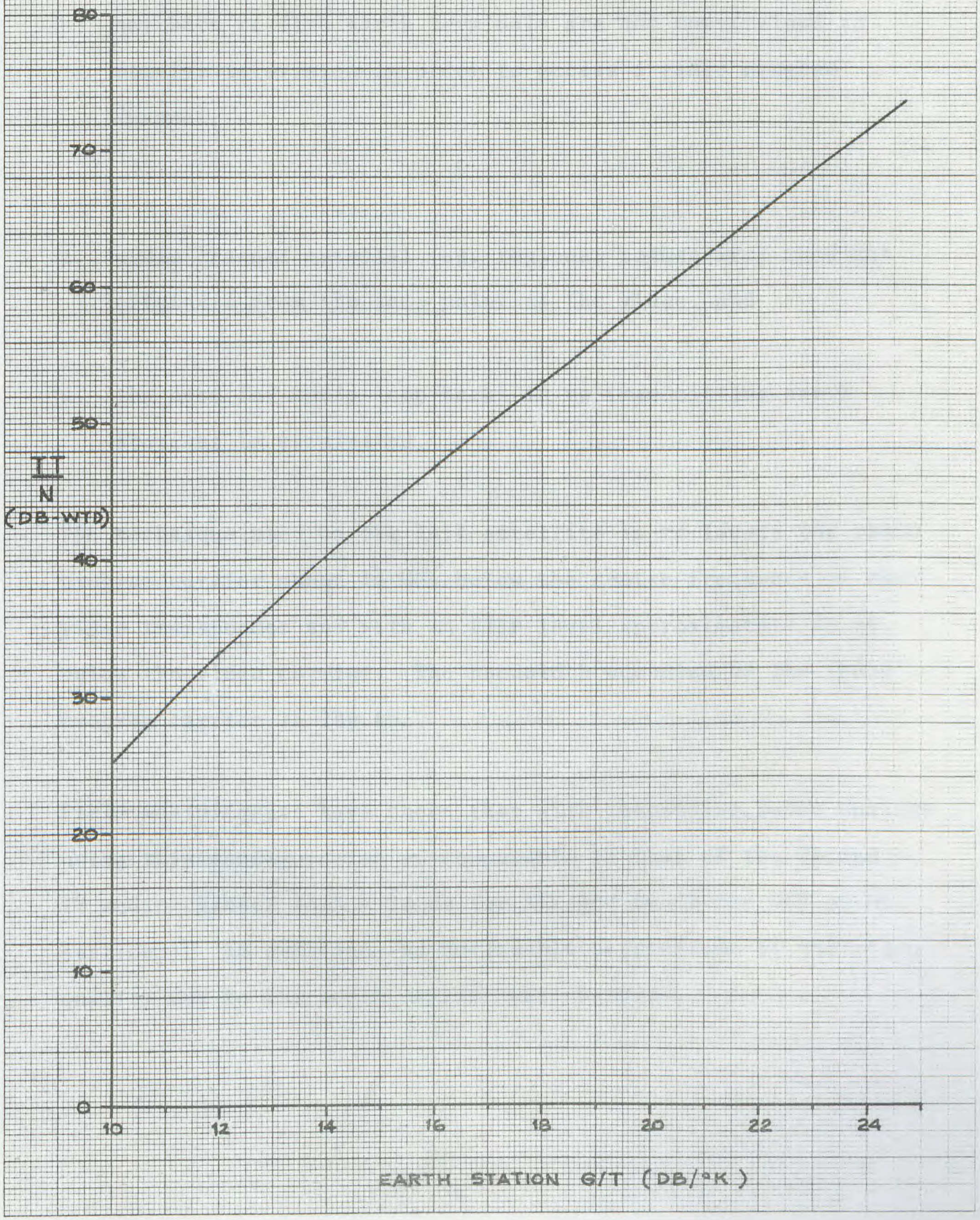
SCPC techniques are used for the Northern Radio Network in order to facilitate the broadcast of live radio programs produced in the north for northern communities or for nation-wide distribution. Radio program transmitters are being or have been added to five existing earth stations (three in the north and two in the south) and 16 existing sites in the north are being equipped with radio program receivers.

A separate radio program carrier located in the lower part of the video transponder offers the needed flexibility for northern broadcast applications for the following reasons:

a. the radio program carrier slot can be accessed by any program

FIGURE 7-2

UNFADED TEST TONE-TO-NOISE RATIO VERSUS EARTH STATION G/T (OBO = 20 DB)



origination centre,

b. northern receive earth terminals are not constrained to receive television in order to access a radio program channel,

c. audio channel material (eg. regional commentary) need not originate from the same point as the video, and

d. the need for audio loop-backs in re-transmitting earth stations is eliminated.

The technique used on the Anik satellite is to locate the radio program carrier about 16 MHz below the centre-frequency of the video transponder and with an EIRP level approximately 20 dB below the video carrier. The bandwidth occupied by the radio program carrier is 200 kHz.

Field measurements have shown that with companding, audio quality using this configuration is comparable to that of the second TV audio channel (S/N = 53 dB for RTV and 56 dB for NTV or HR stations). In addition, no noticeable degradation of the video quality due to the audio carrier was observed.

8. TV RECEIVE EARTH STATION SUBSYSTEM COSTS

8.1 Cost Data Gathering and Results

In order to obtain the necessary cost information on the major subsystems of a receive ground station, namely the antenna, the low-noise amplifier front-end, and the T.V. receiver (downconverter plus demodulator), a mail campaign was instituted whereby prepared equipment specification and cost data sheets for the three subsystems were sent to equipment manufacturers both in Canada and in the United States.

In order to generate reasonable "typical" cost vs quantity information required to estimate earth station cost, it was necessary to establish a basis by which similar equipment from a number of manufacturers could be compared.

Accompanying the specification sheets was an explanation for the request for such cost information and that the study was being conducted under the auspices of the Canadian Government's Department of Communications. Confidentiality of source information was clearly pointed out.

With the inopportune intervention of the prolonged strike of the Canadian postal workers, letters destined for Canadian manufacturers were not forwarded until the strike was terminated in the second week of December. Nevertheless, letters destined for manufacturers in the U.S.A. were mailed within the U.S.A. in the early part of November with the hope that upon resumption of mail delivery in Canada, feedback from the U.S. manufacturers would be established within a short time thereafter.

However, this was not found to be the case. After a protracted period of no response, with allowance for clearance of backlogged mail, a second batch of letters was mailed during the latter part of December to manufacturers emphasizing the urgent need for cost information in view of the advanced state of the study. In addition, a number of the leading manufacturers in their particular fields were contacted by telephone with no appreciable success. A list of the manufacturers contacted is presented in Appendix B (Table B-1) and the result of the mail campaign can be summarized as follows:

	4/6 GHz & 12/14 GHz	Digital
No. of manufacturers contacted	34	3
Cost data received from	12	0
Brochure only received from	6	1
No response from	16	2

Possible reasons for the general lack of response from manufacturers are that:

1) a manufacturer may not forsee any immediate benefit to his company, and therefore, no incentive to expend time, effort and money to compile cost data.

2) a manufacturer's policy may be to with-hold cost information unless in direct response to a quotation.

3) a manufacturer may feel that cost data could, whether purposefully or inadvertently, be released to his competitors with detrimental effects to his company (confidentiality of source information was clearly emphasized in the two letters).

From the sparse amount of cost data on 12/14 GHz subsystems received, it would seem that this market is extremely limited at present. This situation was subsequently confirmed in telecons with a few U.S. and Canadian marketing agents. The CTS project has apparently had little appreciable effect on the 12/14 GHz market for the reason that it is an experimental project just getting underway.

Possible large future markets for 12/14 GHz hardware are the U.S. Post Office for electronic mail delivery and the S.B.S. (formerly C.M.L.) 12/14 GHz satellite for exclusive data communications links. Intelsat will be conducting feasibility studies of the 12/14 GHz band using the INTELSAT V's, the first of which is due to be launched in the 1979 - 80 time-frame. The European Orbital Test Satellite (OTS) due to be launched in mid-1977 is also an experimental satellite using frequencies between 11 and 14 GHz.

Because of the present uncertainty surrounding the use of the 12/14 GHz band, manufacturers are being extremely cautious and, as far as is known, no large funding by U.S. manufacturers of research and development of 12/14 GHz hardware has yet been undertaken.

This is in direct contrast to the tried and true 4/6 GHz band for which:

--a large international market for both satellite ground station and radio relay equipment has existed for many years

--there has been great effort spent in the design and development of hardware, backed up by the results of years of in-service operation

--keen competition among North American suppliers has accelerated ongoing development aimed at reducing costs.

Where possible, cost data received from manufacturers has been supplemented by in-house cost information.

8.2 Reduction of Cost Data

In order to provide a common data base from which capital costs for subsystems can be derived, it is necessary to process the information such that equipment is compared on an equal performance basis. This has not always been possible as equipment specifications have in several cases not been provided with the cost data. The subsystems costed are assumed to conform to the following general specifications:

(a) all antennas are equipped with receive-only feeds;

(b) all antennas are focal-fed;

(c) all antennas have a wind survival capacity of 100 m.p.h. or greater (unless indicated otherwise);

(d) all low-noise amplifiers have a 500 MHz bandwidth and gain greater than or equal to 40 dB;

(e) all T.V. receivers (downconverter plus demodulator) are non-frequency-agile, can provide a 1v p-p video signal and one audio program channel at the baseband interface point.

Cost data obtained from U.S. manufacturers has been changed to Canadian prices by adding 3% for exchange rate and 17.5% for customs duty. Note that the following have not been included:

(a) broker's fee - a typical rate of 1 to 3% of the total value of the shipment is presently the going rate and is applied on a sliding basis, that is, the greater the cost of the shipment, the lesser the percentage charged. A large prime contractor, however, would probably use in-house brokers with the service costs being recovered under general administrative fees.

(b) transportation costs - see section 9

(c) Provincial Sales Tax - see section 9

(d) Federal Sales Tax - see section 9

The results of the cost data gathering have been summarized in graphical and tabular forms in the ensuing pages.

DIAMETER		RECEIVE GAIN *	FOCAL/	UNIT COST IN CANADIAN DOLLARS				COMMENTS
FEET	METER	dBi	CASSEGRAIN	QTY 1	QTY 10	QTY 100	QTY 1000	
6	1.83	35.0	Focal	2,860				Receive-only
8	2.44	37.6	"	3,570				" "
10	3.05	39.5	"	4,250				" "
12	3.66	41.1	"	6,380				" "
15	4.57	43.0	"	12,030				" "
12	3.66	41.1	Focal	4,860	4,760	----	----	
15	4.57	43.0	Focal	8,170	8,010	----	----	
6.5	1.98	35.7			4,840	3,870	2,900	
11.5	3.51	40.7			12,100	8,290	5,690	
18	5.49	44.6			21,780	16,940	11,500	
26	7.92	47.8			33,890	26,630	18,150	
10	3.05	39.5	Focal			4,130		
15	4.57	43.0	Focal			8,260		
11	3.35	40.3				8,180		
16	4.88	43.6				13,550		
15	4.57	43.0				14,440		
15	4.57	43.0	Focal			6,900		150 Lot

* 55% efficiency assumed

TABLE 8-1

4 GHz ANTENNA COSTS

...../2

DIAMETER		RECEIVE GAIN *	FOCAL/	UNIT COST IN CANADIAN DOLLARS				COMMENTS
FEET	METER	dBi	CASSEGRAIN	QTY 1	QTY 10	QTY 100	QTY 1000	
6	1.83	35.2	Focal	----	2,340	1,840	1,780	Survival
12	3.66	41.6	Cassegrain	8,070	7,910	7,270	7,110	80 M.P.H.
15	4.57	43.7	"	10,590	10,380	9,530	9,320	(Receive Only)
18	5.49	45.7	"	----	28,080	15,060	13,730	
26	7.92	48.5	"	31,450	30,820	28,300	27,670	
6	1.83	35.2	Focal	----	2,540	2,000	1,940	Survival
12	3.66	41.6	Cassegrain	8,970	8,790	8,070	7,890	100 M.P.H.
15	4.57	43.7	"	11,770	11,540	10,590	10,360	(Receive Only)
18	5.49	45.7	"	----	30,520	16,350	14,930	
26	7.92	48.5	"	34,940	34,240	31,450	30,750	

* 55% efficiency assumed

TABLE 8-1 (cont'd)

4 GHz ANTENNA COSTS

PARAMP/ TRANSISTOR	NOISE TEMP	NOISE FIG.	BAND WIDTH	GAIN	UNIT COST IN CANADIAN DOLLARS				COMMENTS
	°K	dB	MHz	dB	QTY 1	QTY 10	QTY 100	QTY 1000	
PARAMP	48		500	50	22,390				Cooled
"	60		500	50	21,420				
"	75		500	50	18,760				
"	85		500	50	17,910				
"	125		500	50	13,920				
TRANSISTOR	226	2.5	500	50	4,840				
TRANSISTOR									
"	200	2.3	500	48	4,540	4,050	3,330	2,540	
"	226	2.5	500	48	4,050	3,630	2,900	2,180	
"	262	2.8	500	48	3,330	2,970	2,240	1,750	
"	316	3.2	500	48	3,090	2,780	2,060	1,570	
"	375	3.6	500	48	2,720	2,420	1,820	1,450	
"	492	4.3	500	48	2,240	2,000	1,510	1,270	
"	695	5.3	500	48	2,000	1,820	1,390	1,150	
"	1000	6.5	500	40	1,630	1,450	970	790	
TRANSISTOR	527	4.5	500	40	1,720	1,560	1,380	1,210	
"	289	3.0	500	42	2,330	2,100	1,860	1,630	
"	200	2.3	500	43	3,450	3,100	2,760	2,410	Peltier-cooled
"	359	3.5	500	45	3,030	2,720	2,420	2,120	
"	527	4.5	500	47	1,790	1,610	1,430	1,250	
"	200	2.3	500	57	4,600	4,140	3,680	3,220	Peltier-cooled
"	289	3.0	500	56	3,990	3,590	3,200	2,800	
PARAMP	100		500	50	13,700	13,700	11,000	9,700	
"	125		500	50	11,200	11,200	9,000	7,800	
"	100		250	50	8,400	8,400	6,800	5,500	
"	125		250	50	7,900	7,900	6,300	5,200	
"	150		250	50	6,800	6,800	4,700	3,300	

TABLE 8-2

4 GHz LNA COSTS

...../2

PARAMP/ TRANSISTOR	NOISE TEMP	NOISE FIG.	BAND WIDTH	GAIN	UNIT COST IN CANADIAN DOLLARS				COMMENTS
	°K	dB	MHz	dB	QTY 1	QTY 10	QTY 100	QTY 1000	
TRANSISTOR	200	2.3	500	50	3,630	3,630	2,180		
"	250	2.7	500				1,820	1,300	
"	290	3.0	500				1,550	1,110	
PARAMP	85		500				18,660		
"	150		500				13,990		
TRANSISTOR	330	3.3	500				5,460		
PARAMP	90		500				14,950		
"	110		500				12,410		
"	135		500				11,190		
"	160		500				9,980		
PARAMP	90		500				11,320		
"	110		500				10,230	8,130	
"	130		500				8,290	6,600	
PARAMP	55		500				32,680		
TRANSISTOR	290	3.0	500				3,440		
PARAMP	88		500	50			11,320	8,770	
"	130		500	50			9,560		
"	175		500	50			8,830		
TRANSISTOR	300	3.1	500				2,920		

TABLE 8-2(cont'd)

4 GHz LNA COSTS

RF BANDWIDTH	NOISE FIGURE	UNIT COST IN CANADIAN DOLLARS				COMMENTS
MHz	dB	Qty 1	Qty 10	Qty 100	Qty 1000	
500	12	8,470	8,470	7,560	(on request)	
500	N/A		22,270			
500	N/A	14,500	12,500	11,250		
500	N/A		14,520			2 dB T. E.†
500	< 6.0		4,440*	3,410		* 50 LOT
500	7		11,100	9,500	4,900	
			10,050	8,800	4,600	Fix-Tuned

† Threshold Extension

TABLE 8-3

4 GHz TV RECEIVER COSTS

DIAMETER		RECEIVE GAIN *	FOCAL/ CASSEGRAIN	UNIT COST IN CANADIAN DOLLARS				COMMENTS
FEET	METER	dBi		QTY 1	QTY 10	QTY 100	QTY 1000	
6	1.83	44.6	Focal	2,370				Rx Only
8	2.44	47.2	"	3,090				" "
10	3.05	49.1	"	3,760				" "
12	3.66	50.7	"	5,910				" "
15	4.57	52.6	"	11,540				" "
3	0.91	38.6		3,900	3,000	2,550		
5	1.52	43.0		6,500	5,000	4,250		
10	3.05	49.1		11,700	9,000	7,650		
15	4.57	52.6		16,250	12,500	10,630		
3	0.91	38.6	Focal		9,570	1,870	1,100	Survival 80 M.P.H. (Receive-only)
6	1.83	45.6	"		2,340	1,840	1,780	
12	3.66	50.4	"		4,890	3,850	3,740	
15	4.57	52.2	"		7,530	5,940	5,770	
18	5.49	54.7	Cassegrain		28,080	15,060	13,730	
3	0.91	38.6	Focal		10,400	2,030	1,200	Survival 100 M.P.H. (Receive-only)
6	1.83	45.6	"		2,540	2,000	1,940	
12	3.66	50.4	"		5,310	4,190	4,060	
15	4.57	52.2	"		8,180	6,460	6,270	
18	5.49	54.7	Cassegrain		30,520	16,350	14,930	

* 55% efficiency assumed.

TABLE 8-4

12 GHz ANTENNA COSTS

NOISE FIGURE	NOISE TEMP.	BAND-WIDTH	GAIN	UNIT COST IN CANADIAN DOLLARS				COMMENTS
dB	^{o}K	MHz	dB	Qty 1	Qty 10	Qty 100	Qty 1000	
2.5	230	500	15			9,000		Estimated price only
2.3	200	500	15	19,500	15,000	12,750		
5.5	740	500	10	6,500	5,000	4,250		

TABLE 8 - 5

12 GHz LNA COSTS

RF BANDWIDTH	NOISE FIGURE	UNIT COST IN CANADIAN DOLLARS				COMMENTS
MHz.	dB	Qty 1	Qty 10	Qty 100	Qty 1000	
500	8.0	8,470	7,870	6,660	3,630	
500	6.5	9,680	9,080	7,870	4,840	
500	5.5		3,150*	2,780		* 50 LOT
500	N/A	23,400	18,000	15,300		

TABLE 8-6

12 GHz TV RECEIVER COSTS

MISCELLANEOUS COSTS

1. 4 GHz Radio Program Receivers

Quantity 1-5	\$21.5K	Approximate costs
Quantity 10	\$10K - 15K	
Expandor (Qty 1)	\$2K	

2. Shelter: 5'-8" X 5'-8" X 6'-3" (inside dimensions)

10 - 20 units	\$ 2,050 each
20 - 50 units	\$ 1,998 each
50 - 100 units	\$ 1,898 each

Units are provided knocked down, skid packaged, F.O.B. plant, F.S.T. and P.S.T. extra.

3. Estimated documentation costs (Quantity 100 earth stations)

$$\text{Cost per earth station} \sim \frac{\$\ 10K}{100} + \$200$$

$$= \$300$$

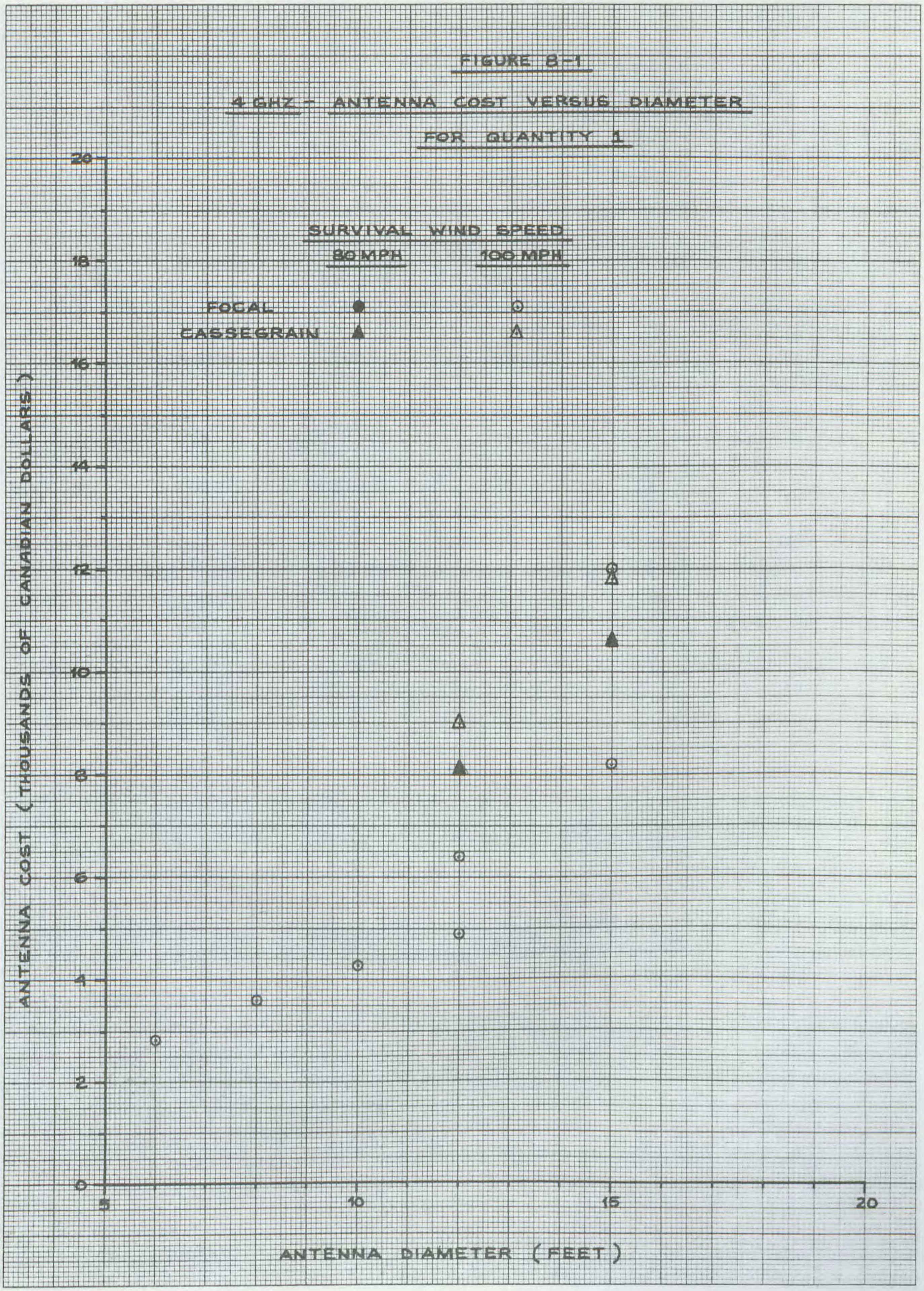


FIGURE 8-1
4 GHZ - ANTENNA COST VERSUS DIAMETER
FOR QUANTITY 1
SURVIVAL WIND SPEED
80 MPH
100 MPH
FOCAL
CASSEGRAIN
ANTENNA COST (THOUSANDS OF CANADIAN DOLLARS)
ANTENNA DIAMETER (FEET)
0
2
4
6
8
10
12
14
16
18
20
5
10
15
20

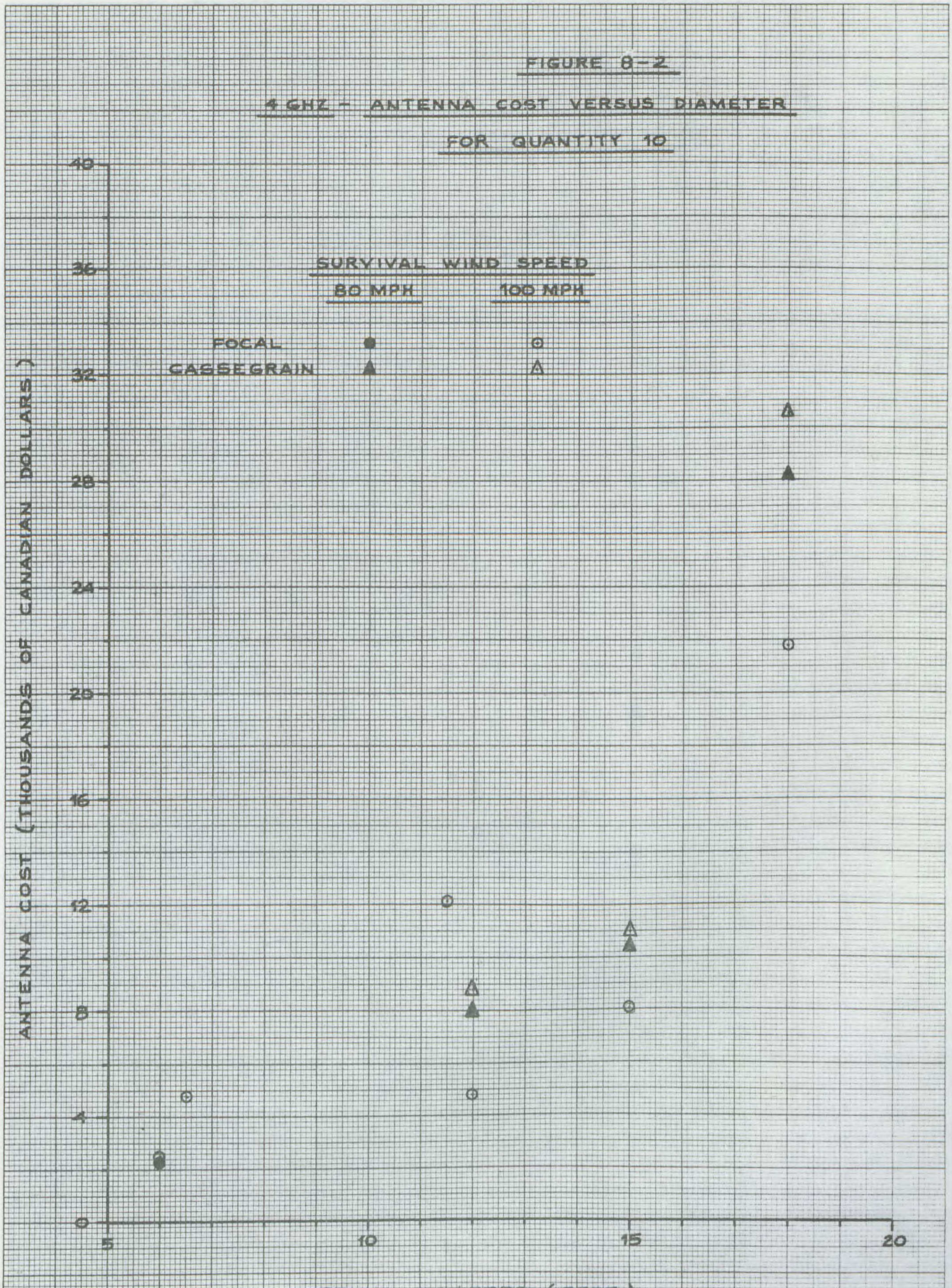


FIGURE 8-2
4 GHZ - ANTENNA COST VERSUS DIAMETER
FOR QUANTITY 10
SURVIVAL WIND SPEED
80 MPH
100 MPH
FOCAL
CASSEGRAIN
ANTENNA COST (THOUSANDS OF CANADIAN DOLLARS)
0
4
8
12
16
20
24
28
32
36
40
5
10
15
20
ANTENNA DIAMETER (FEET)

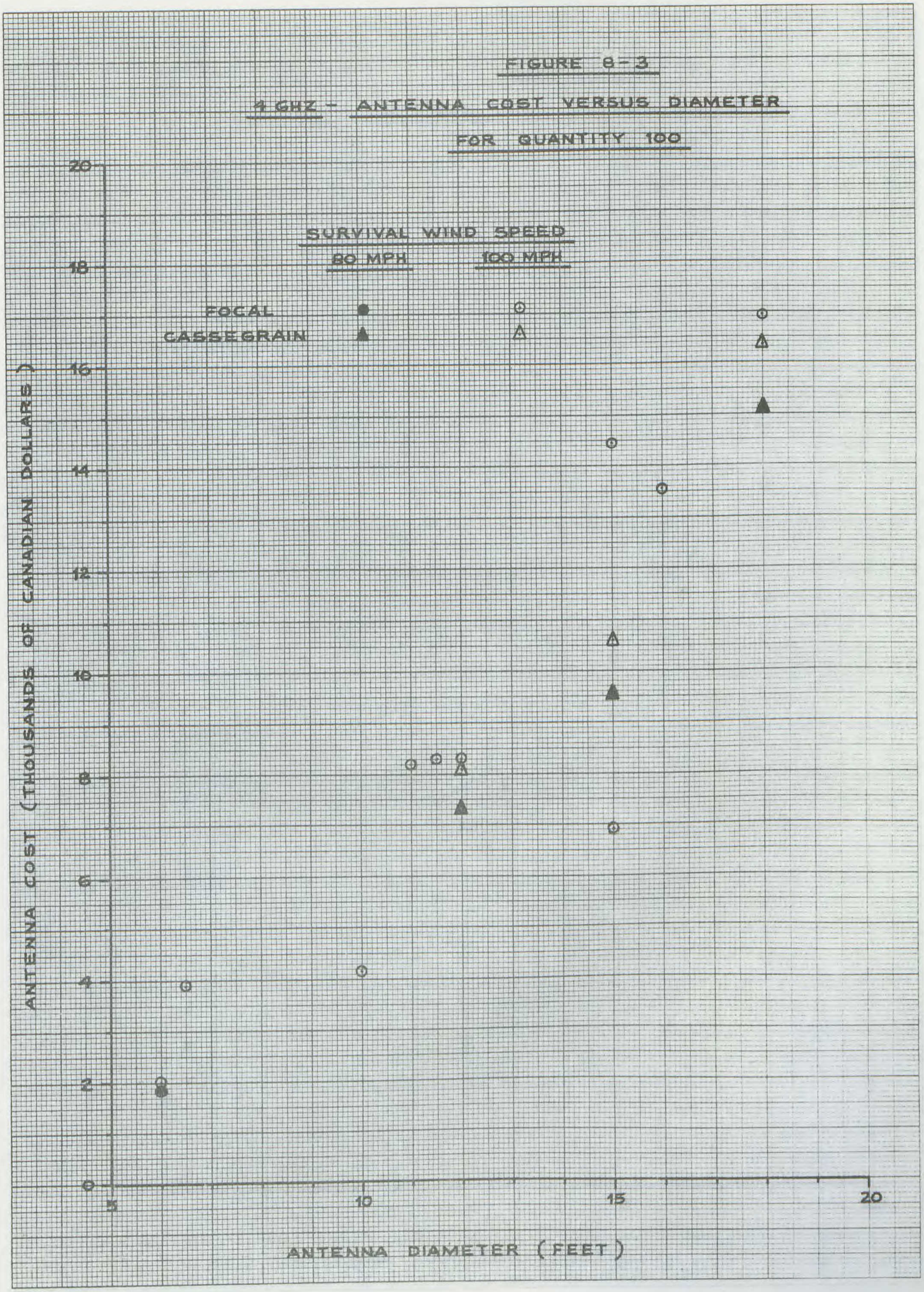


FIGURE 8-3
4 GHZ - ANTENNA COST VERSUS DIAMETER
FOR QUANTITY 100
SURVIVAL WIND SPEED
80 MPH
100 MPH
FOCAL
CASSEGRAIN
ANTENNA COST (THOUSANDS OF CANADIAN DOLLARS)
ANTENNA DIAMETER (FEET)
0
2
4
6
8
10
12
14
16
18
20
5
10
15
20

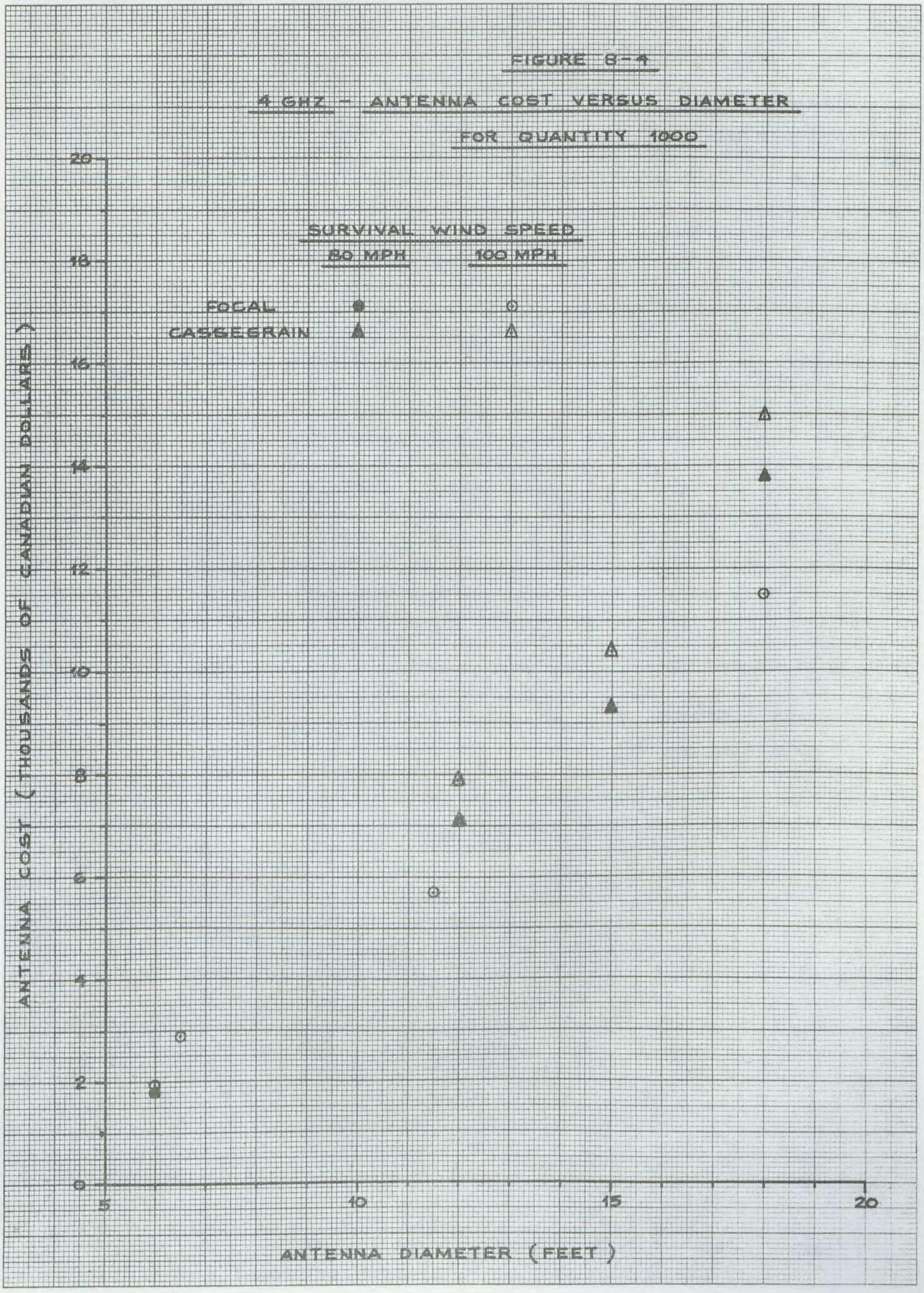


FIGURE 8-4
4 GHZ - ANTENNA COST VERSUS DIAMETER
FOR QUANTITY 1000
SURVIVAL WIND SPEED
80 MPH
100 MPH
FOCAL
CASSEGRAIN
ANTENNA COST (THOUSANDS OF CANADIAN DOLLARS)
0
2
4
6
8
10
12
14
16
18
20
5
10
15
20
ANTENNA DIAMETER (FEET)

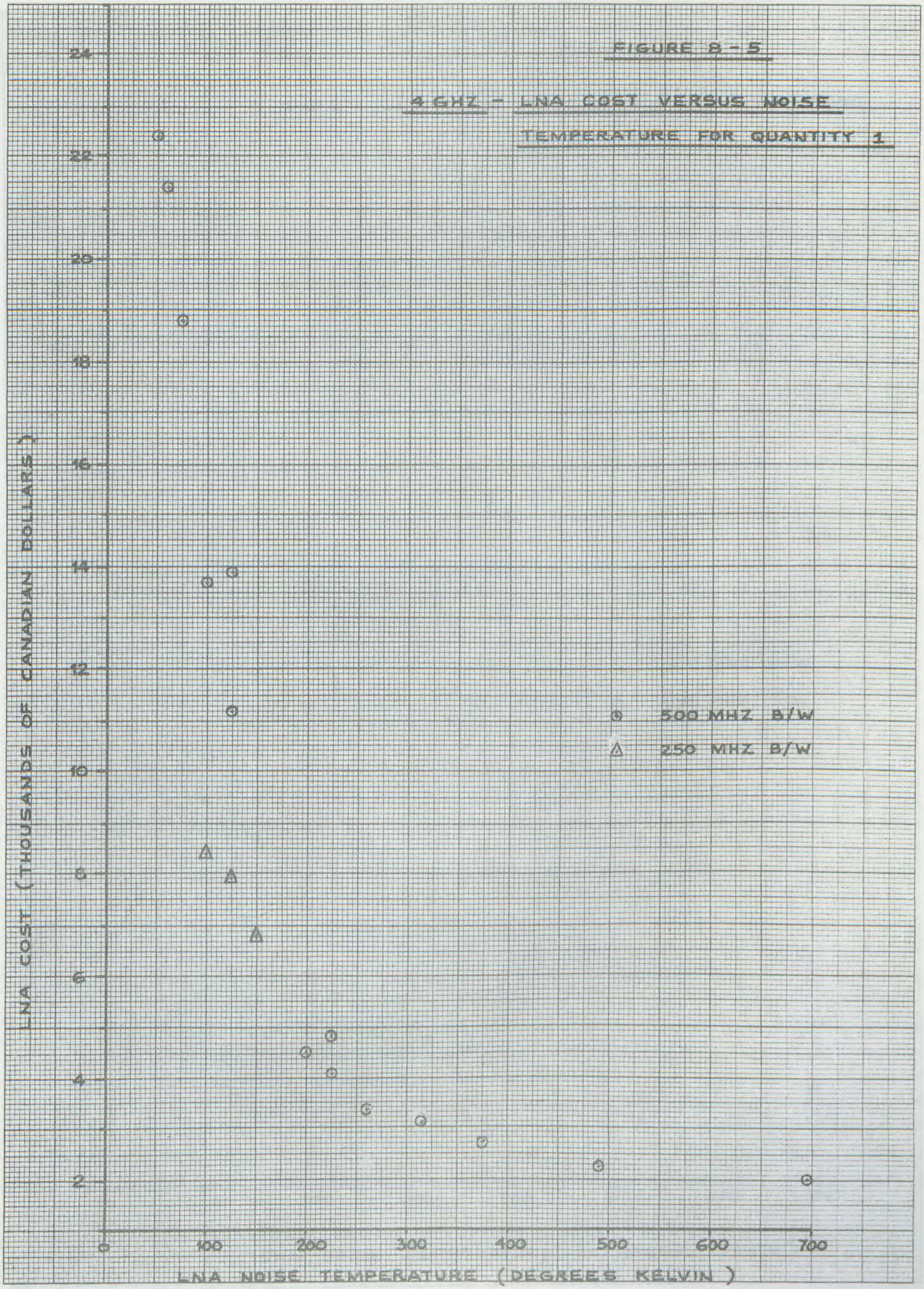


FIGURE 8 - 5
4 GHZ - LNA COST VERSUS NOISE
TEMPERATURE FOR QUANTITY 1
LNA COST (THOUSANDS OF CANADIAN DOLLARS)
LNA NOISE TEMPERATURE (DEGREES KELVIN)
500 MHZ B/W
250 MHZ B/W
24
22
20
18
16
14
12
10
8
6
4
2
0
100
200
300
400
500
600
700

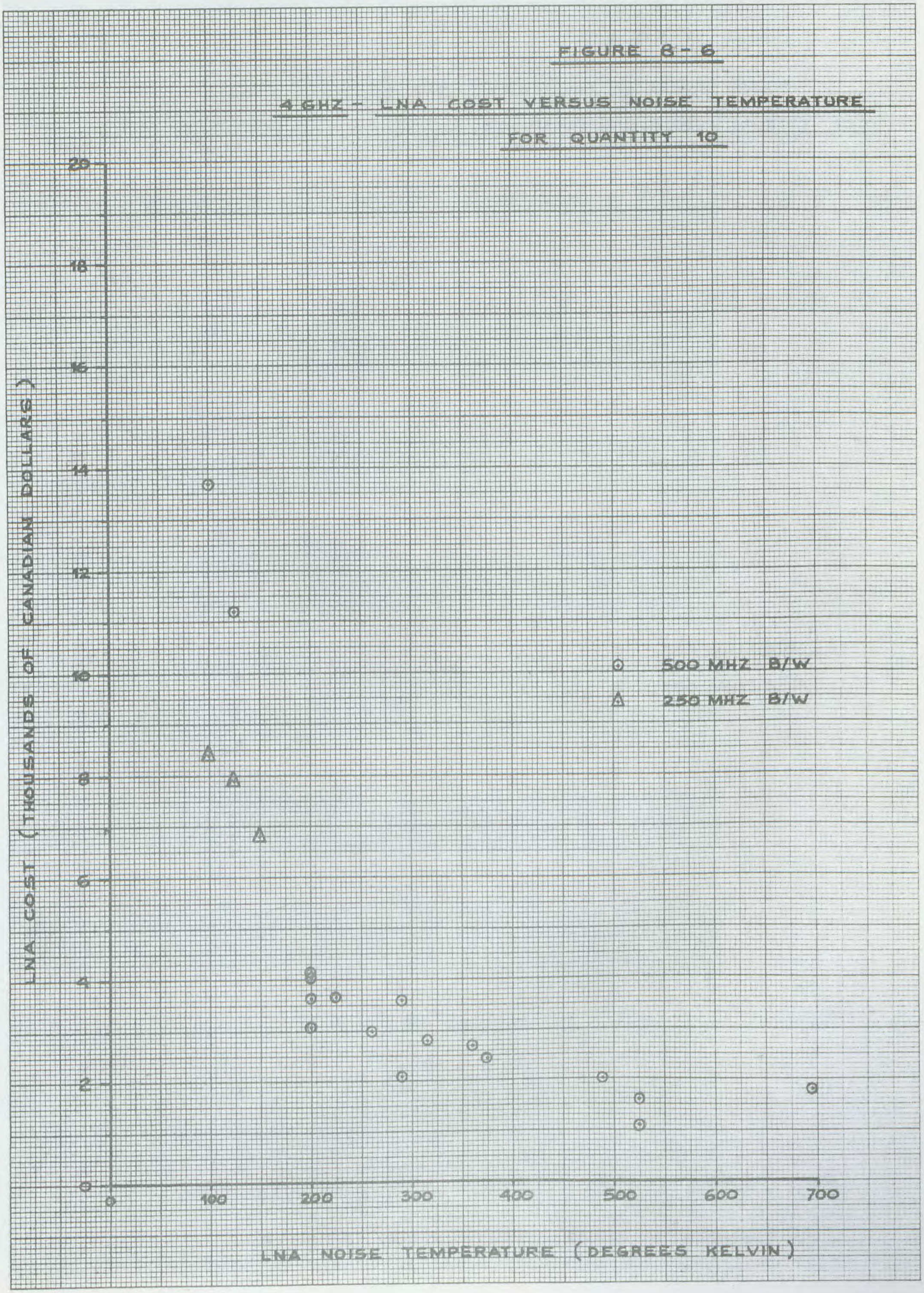


FIGURE 8-6
4 GHZ - LNA COST VERSUS NOISE TEMPERATURE
FOR QUANTITY 10
LNA COST (THOUSANDS OF CANADIAN DOLLARS)
LNA NOISE TEMPERATURE (DEGREES KELVIN)
500 MHZ B/W
250 MHZ B/W
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600
700

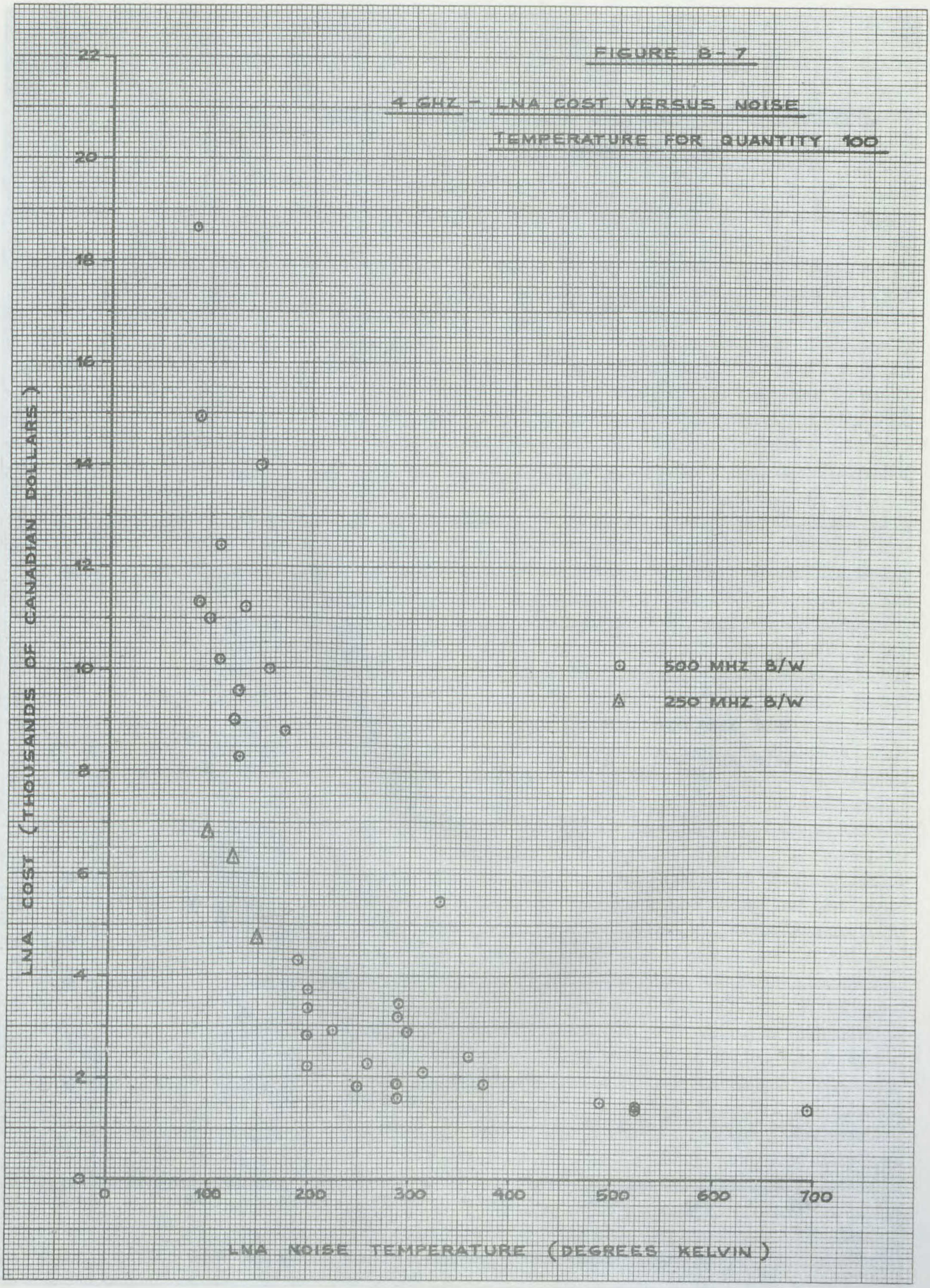


FIGURE 8-7
4 GHZ - LNA COST VERSUS NOISE
TEMPERATURE FOR QUANTITY 100
LNA COST (THOUSANDS OF CANADIAN DOLLARS)
LNA NOISE TEMPERATURE (DEGREES KELVIN)
0
2
4
6
8
10
12
14
16
18
20
22
0
100
200
300
400
500
600
700
500 MHZ B/W
250 MHZ B/W

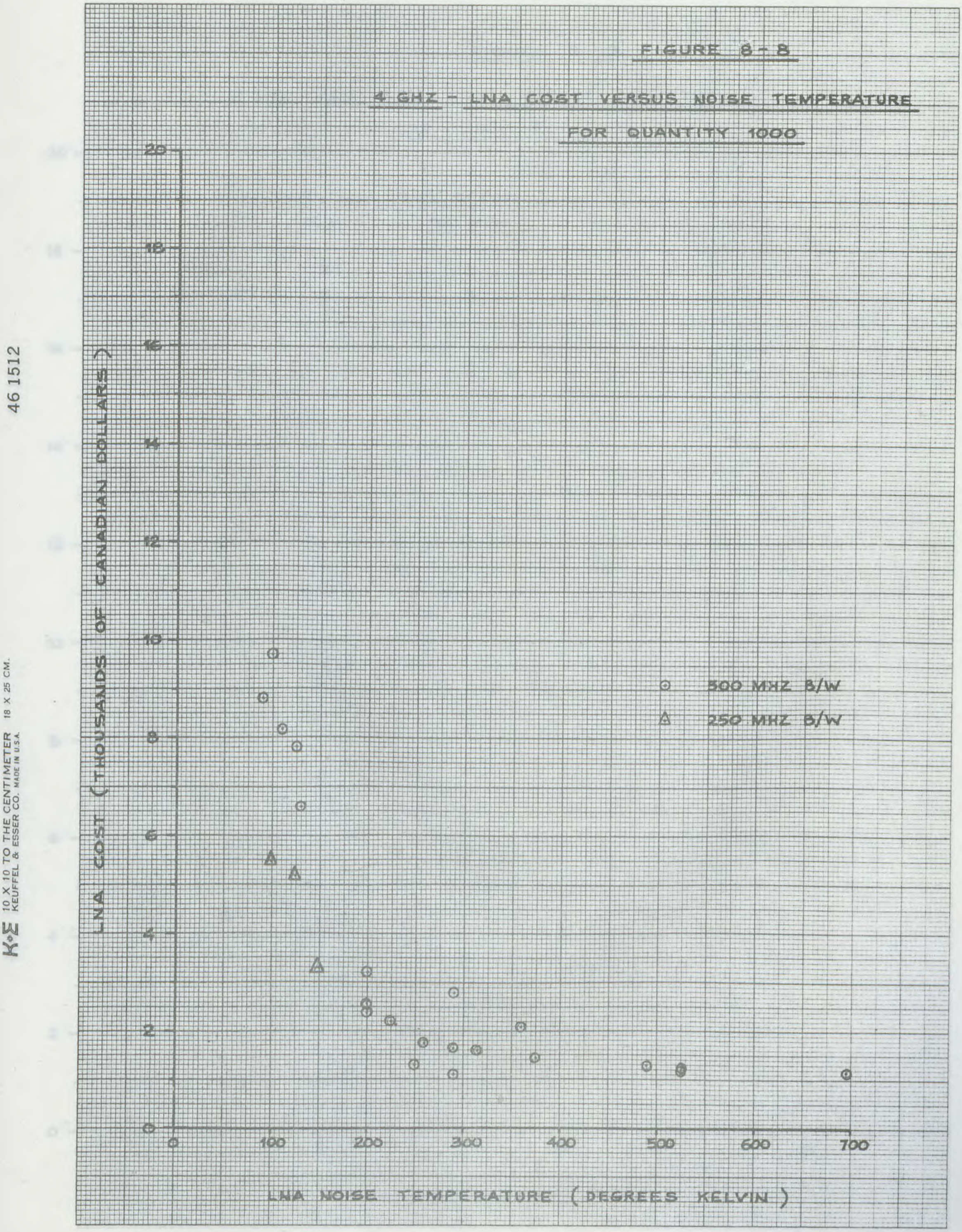


FIGURE 8-8
4 GHZ - LNA COST VERSUS NOISE TEMPERATURE
FOR QUANTITY 1000
LNA COST (THOUSANDS OF CANADIAN DOLLARS)
LNA NOISE TEMPERATURE (DEGREES KELVIN)
500 MHZ B/W
250 MHZ B/W
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600
700
46 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

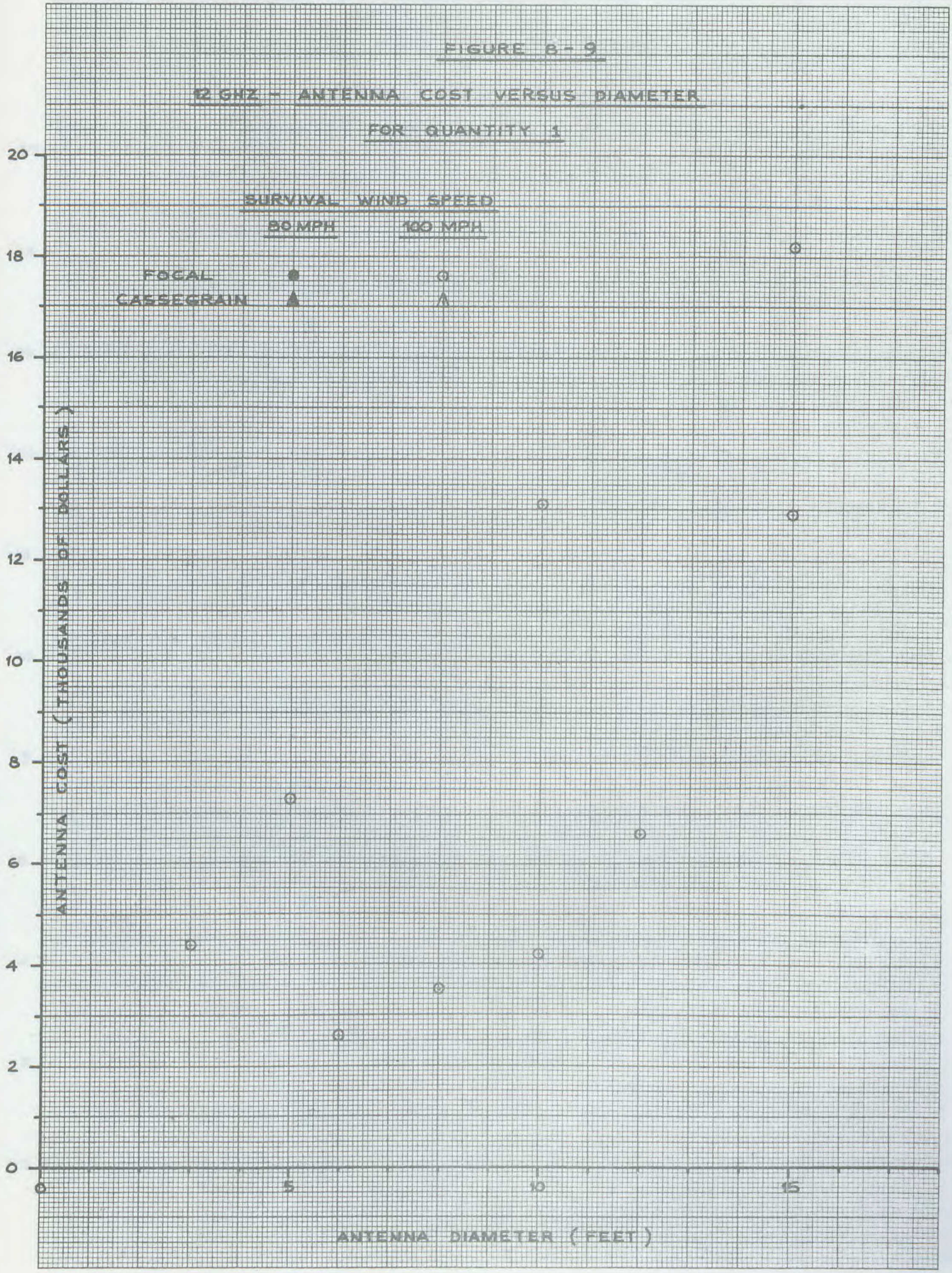


FIGURE 8-9
12 GHZ - ANTENNA COST VERSUS DIAMETER
FOR QUANTITY 1
SURVIVAL WIND SPEED
80 MPH
100 MPH
FOCAL
CASSEGRAIN
ANTENNA COST (THOUSANDS OF DOLLARS)
ANTENNA DIAMETER (FEET)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15

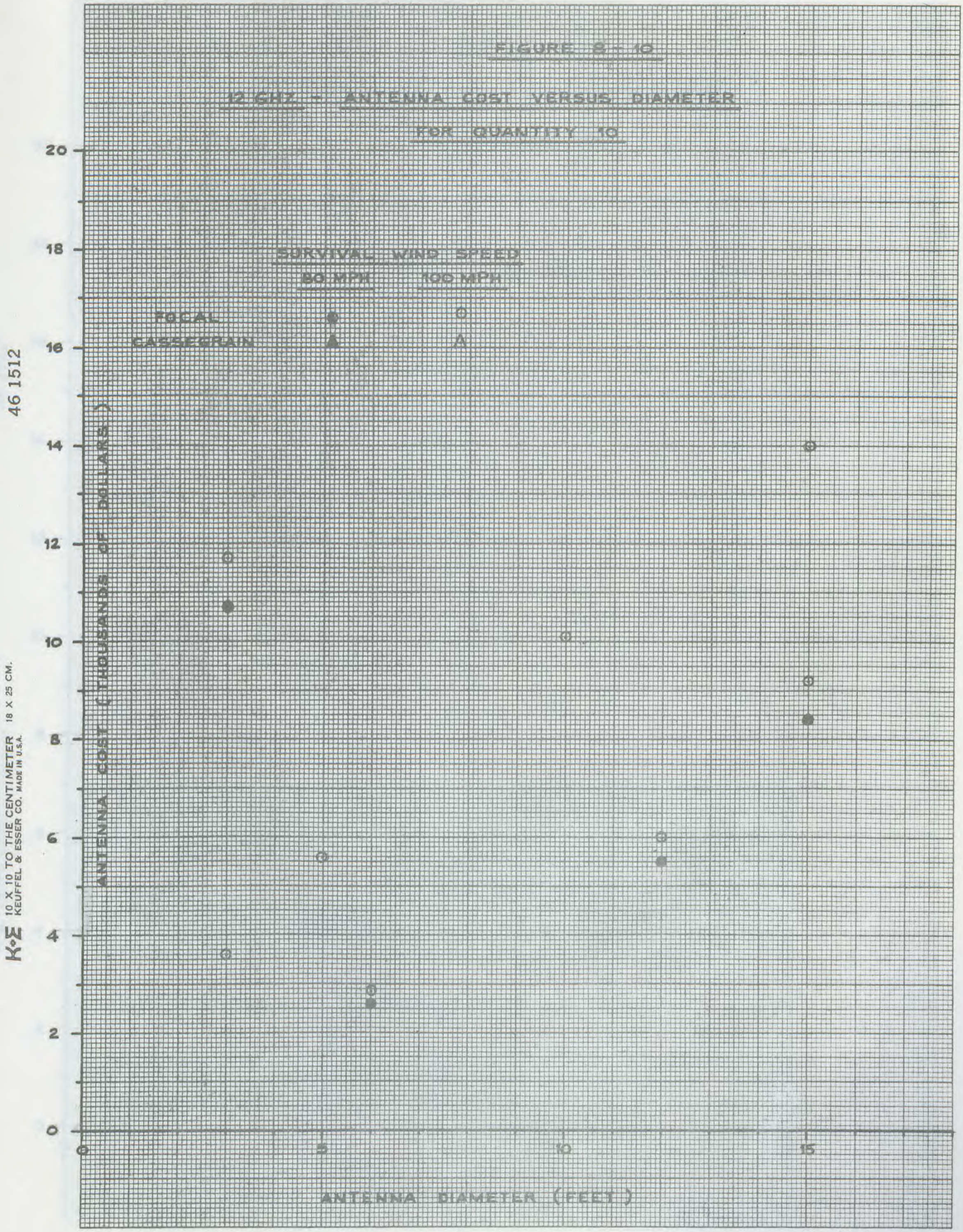


FIGURE 8-10
12 GHZ - ANTENNA COST VERSUS DIAMETER
FOR QUANTITY 10
SURVIVAL WIND SPEED
80 MPH
100 MPH
FOCAL
CASSEGRAIN
ANTENNA COST (THOUSANDS OF DOLLARS)
ANTENNA DIAMETER (FEET)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
46 1512
K&E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

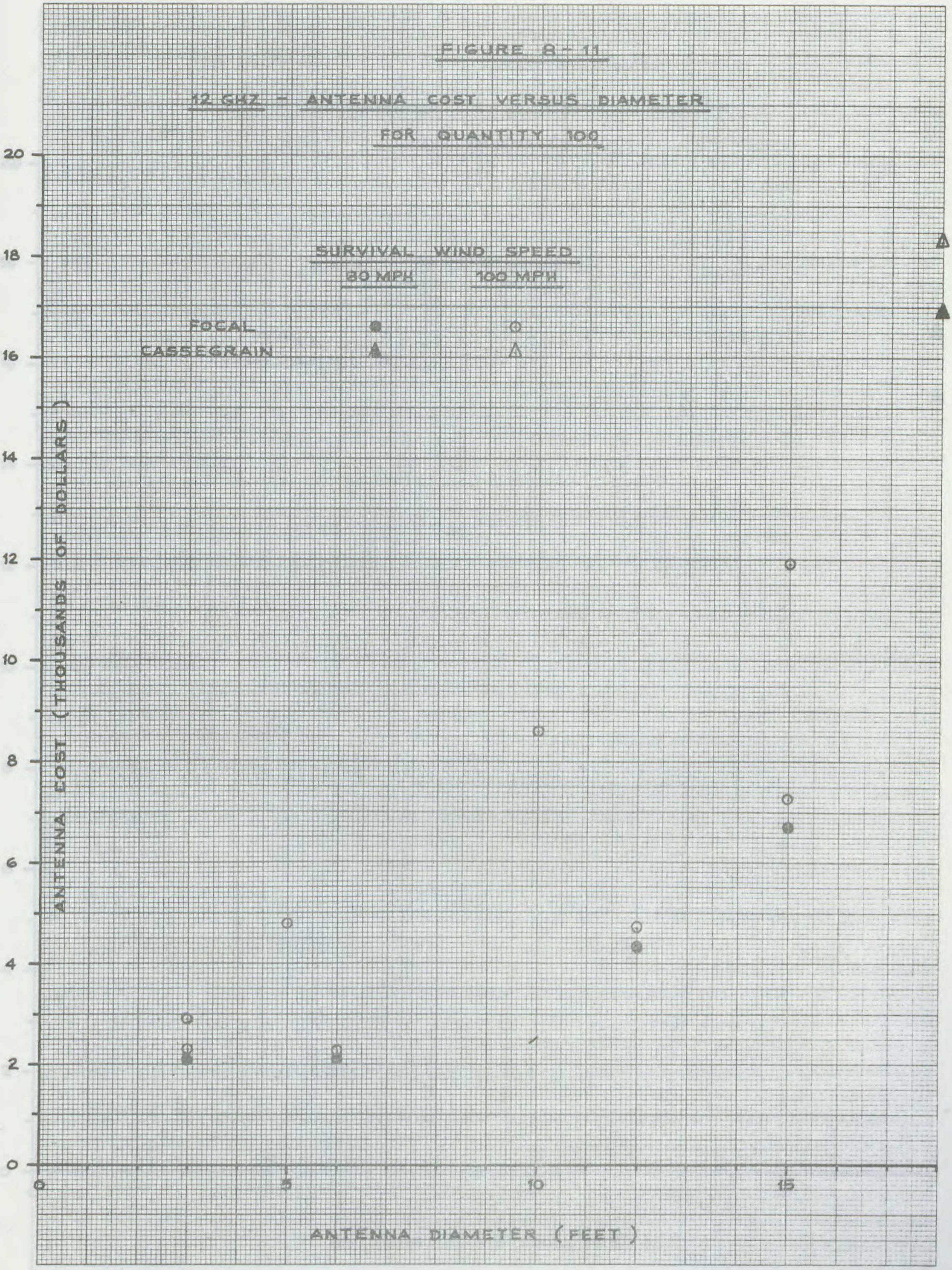


FIGURE 8-11
12 GHZ - ANTENNA COST VERSUS DIAMETER
FOR QUANTITY 100
SURVIVAL WIND SPEED
80 MPH
100 MPH
FOCAL
CASSEGRAIN
ANTENNA COST (THOUSANDS OF DOLLARS)
ANTENNA DIAMETER (FEET)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15

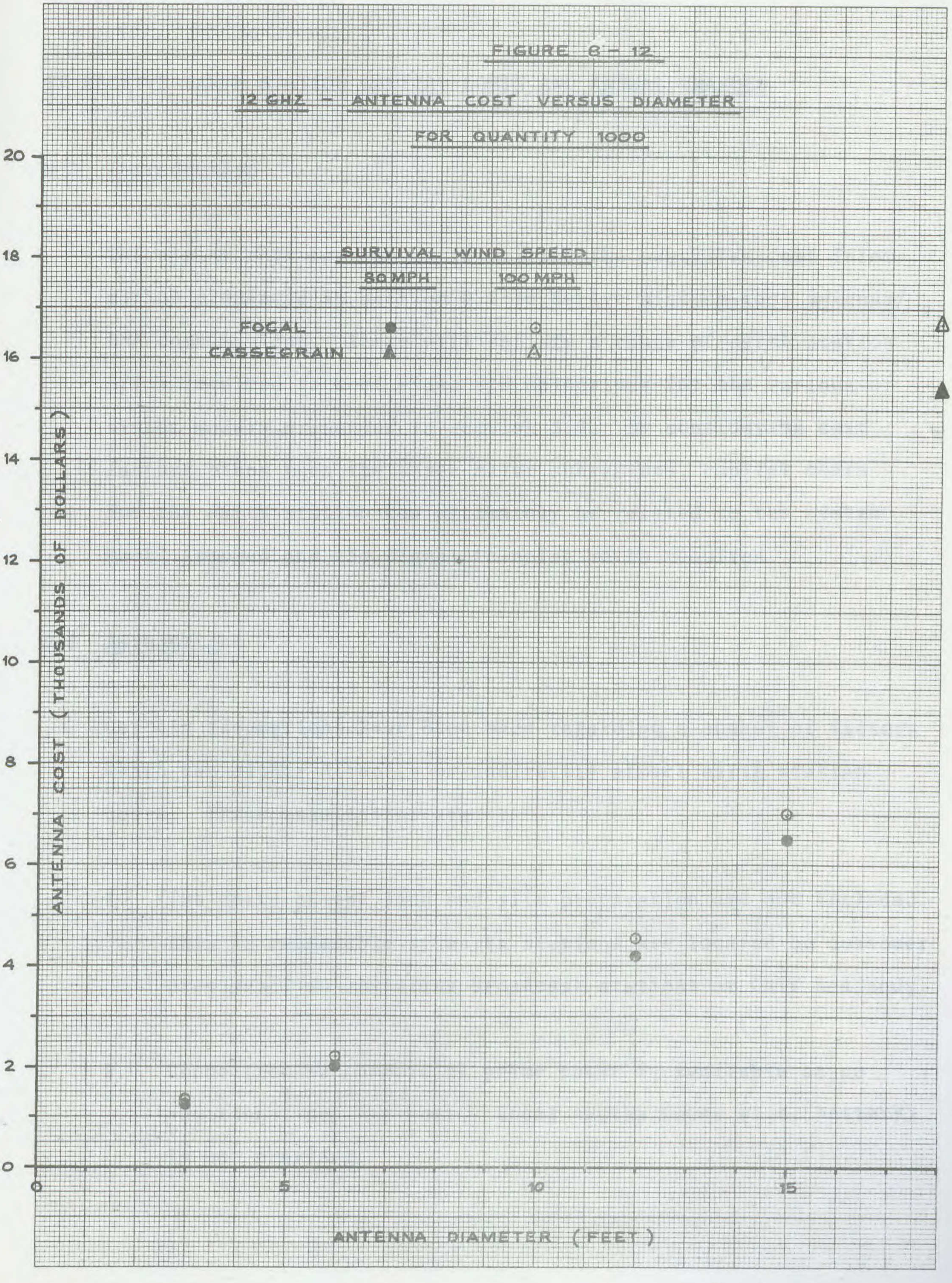


FIGURE 8 - 12
12 GHZ - ANTENNA COST VERSUS DIAMETER
FOR QUANTITY 1000
SURVIVAL WIND SPEED
80 MPH
100 MPH
FOCAL
CASSEGRAIN
ANTENNA COST (THOUSANDS OF DOLLARS)
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
ANTENNA DIAMETER (FEET)

9. TV RECEIVE EARTH STATION CAPITAL COSTS AND ANNUAL CHARGES

9.1 Introduction

The aim of this section is to utilize the subsystem cost information presented in section 8.2 to derive minimum-cost antenna/LNA combinations. These will satisfy a range of earth station G/T's required to meet video S/N objectives for the various system models presented in section 3.3. By considering cost factors other than the three major subsystems, capital costs for the earth station can ultimately be related to the system model assumed and the signal-to-noise ratio required.

9.2 Assumptions

Certain assumptions have been made regarding a number of factors which can either directly or indirectly affect earth station costs. These assumptions are:

1. The costs of the land and site preparation are not included. This is reasonable if earth stations are located on customer premises,e.g., existing broadcast stations or CATV headends.

2. Connection to commercial prime power is available at no additional capital cost. Local backup power (i.e. battery) is not provided.

3. The increased installation costs incurred in permafrost regions to ensure that antenna and equipment shelter foundations are properly insulated have not been considered.

4. Earth station sites are accessible by existing maintained roads (ie. road transportation is employed without any extra cost for road construction or maintenance).

5. Local construction capability is available.

6. Local public accomodation is available.

7. Telephone service is available to the community. This facility is important in the reporting of earth station faults to some sort of regional maintenance depot, which, for example, may be co-located with the regional TV origination centre.

8. The cost of microwave backhaul has not been included here. Since backhaul is unnecessary at 12 GHz while it might be required at 4 GHz (see section 10), this assumption essentially favours the 4 GHz band in any cost comparison with the 12 GHz band.

It is important to note that where these assumptions are not satisfied, some increase in earth station annual charge will result. In fact, for the existing television receive (RTV and NTV) earth stations, extra costs have been incurred due to the "remoteness" of the location and/or the necessity for land purchase and backhaul.

9.3 Subsystem Capital Costs

The two variables which affect station performance and ultimately the capital cost of an earth station are the antenna and the low noise amplifier (LNA). The TV receiver consisting of a non-frequency-agile downconverter and a normal TV demodulator * is a fixed cost item that does not affect the video signal-to-noise ratio as long as equipment performance meets network TV performance specifications. It is assumed that a TV receiver will provide a standard 1 V p-p video signal and one audio program channels at the baseband interface point.

* Threshold extension has also been considered in the models costed.

Other cost factors which affect station capital cost are fixed and do not affect video signal-to-noise performance except under adverse circumstances.

To minimize an earth station's capital costs, it is therefore necessary only to minimize the cost of the antenna plus LNA. In order to illustrate the variation of cost with varying values of G/T and hence video signal-to-noise ratio, an average cost for the antenna and the LNA has to be derived from the cost graphs presented in section 8.2. An average cost curve which is determined to be the best fit for the scatter points on the graphs can then be drawn from visual inspection.

Once the average cost curves for the antenna and the LNA have been determined, various combinations of antenna diameter and LNA noise temperature can be derived that will satisfy a particular G/T requirement (see Fig. 9-1 and 9-2). By costing out each combination using values derived from the average cost curves, a minimum cost combination can be chosen. Repeating this procedure for a range of G/T's, as determined previously for each system model in section 3.3, a number of discrete data points can be plotted which when connected by some best-fit curve will yield a minimum antenna plus LNA cost versus earth station G/T curve.

Video S/N can then be related to cost by simply re-plotting the G/T versus S/N curves presented in section 3.3 on the cost

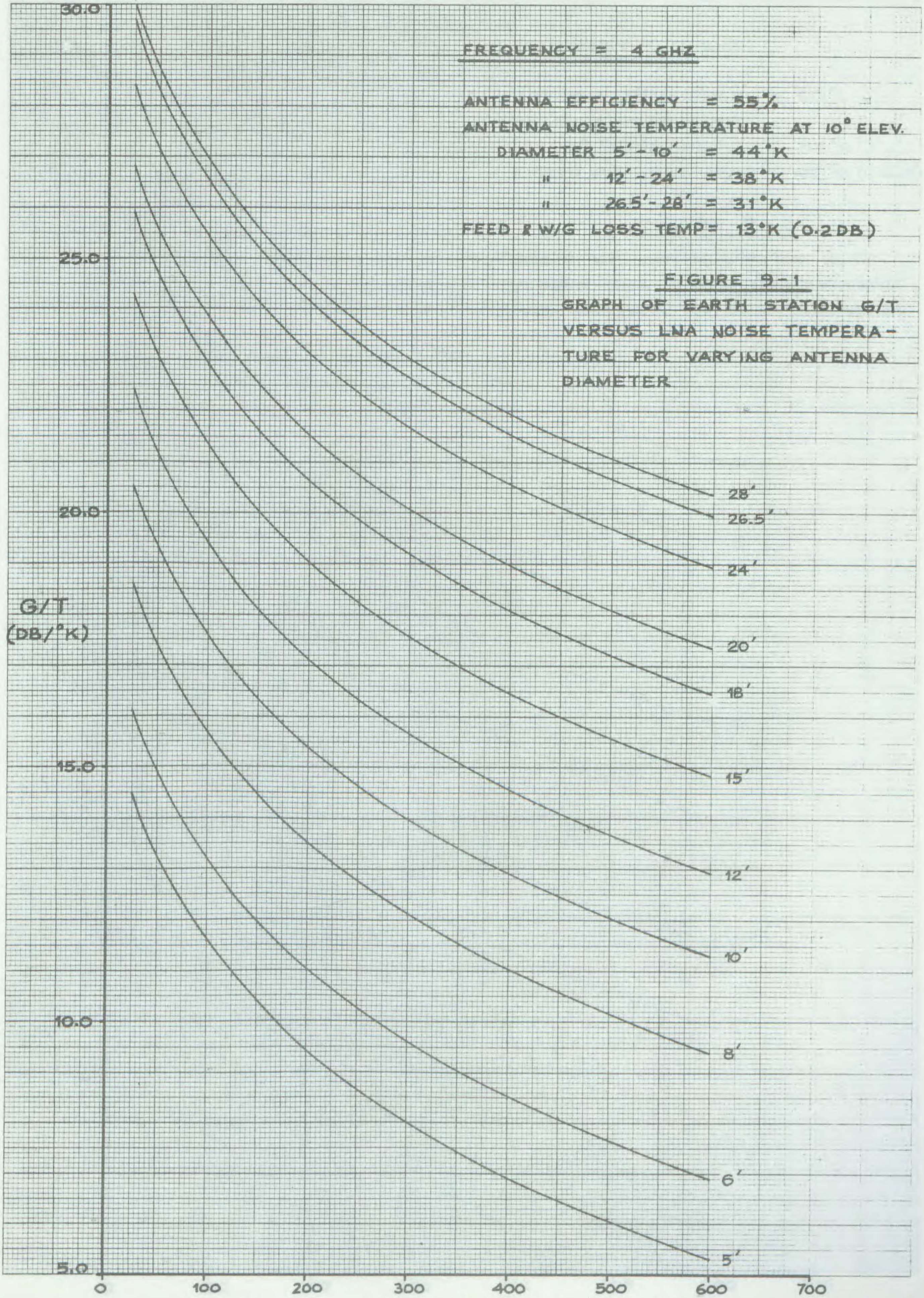


FIGURE 9-1

GRAPH OF EARTH STATION G/T VERSUS LNA NOISE TEMPERATURE FOR VARYING ANTENNA DIAMETER

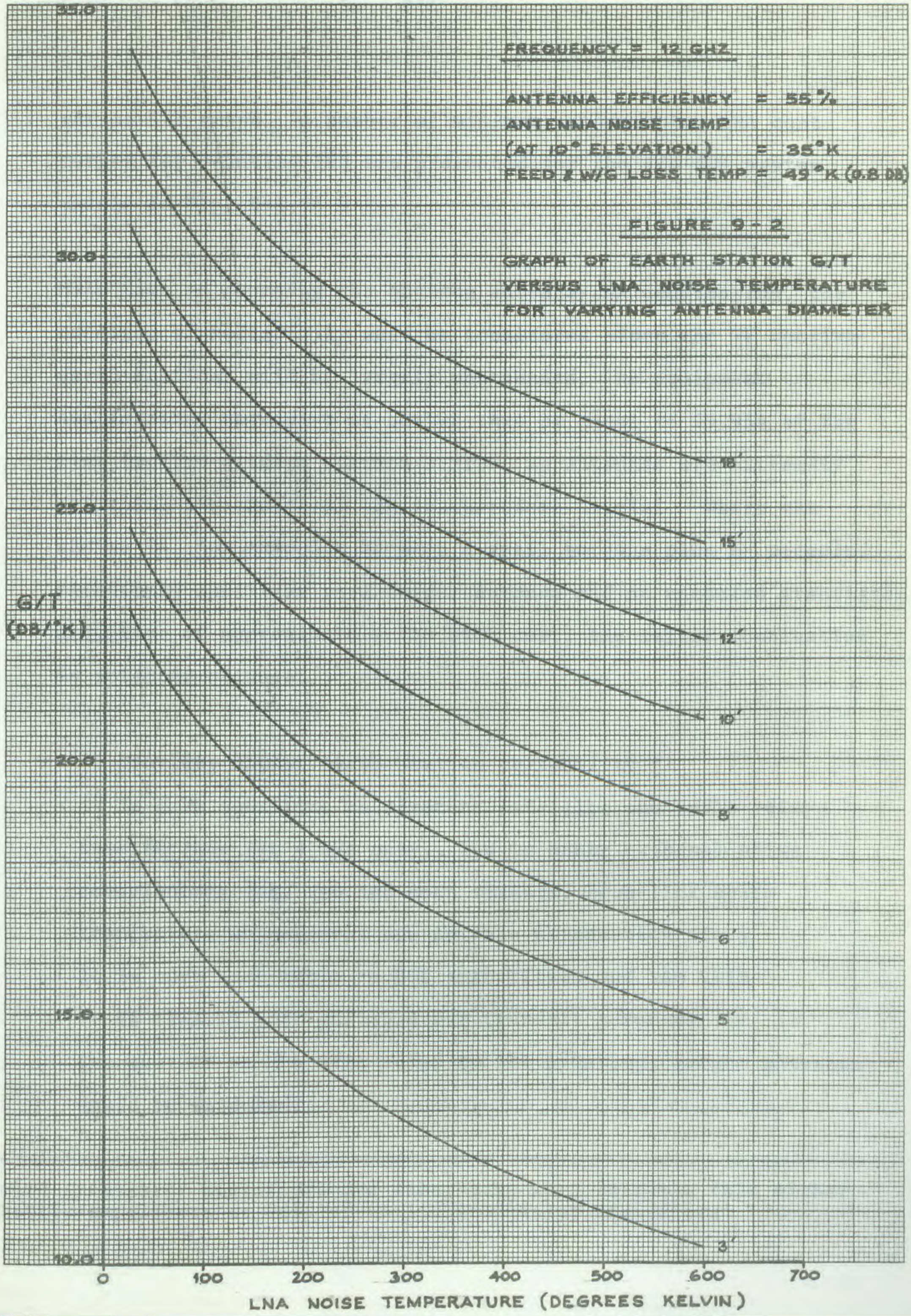


FIGURE 9-2
GRAPH OF EARTH STATION G/T VERSUS LNA NOISE TEMPERATURE FOR VARYING ANTENNA DIAMETER

versus G/T graph. A number of minimum antenna plus LNA cost curves for quantity 100 are presented for the 4/6 GHz system models in Fig. 9-3 to 9-5.

Note that in choosing the optimum antenna/LNA combination, the question of reliability must be considered since the TV receive earth stations will be largely unattended. An equipment availability objective of better than or equal to 99.95% of the time implies a large station MTBF; as antennas are extremely reliable, the choice of LNA is therefore crucial. Where the choice is, for example, between a small antenna plus an uncooled parametric amplifier vs a larger antenna and an uncooled transistor amplifier at approximately the same cost, the latter combination is selected because:

- it provides higher earth station reliability *
- it is less sensitive to adjacent satellite and radio relay interference (at 4 GHz only), and to other external noise contributors (eg. sun and moon transit, down-link noise temperature enhancement due to rain attenuation etc.)
- it is more acceptable to DOC authorities and the CCIR
- it is clearly more suitable for transmit purposes (i.e. if the cost of an HPA were added to the equation, larger antennas would be favoured)

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* Uncooled transistor amplifiers are inherently more reliable than either parametric amplifiers or Peltier-cooled transistor amplifiers.

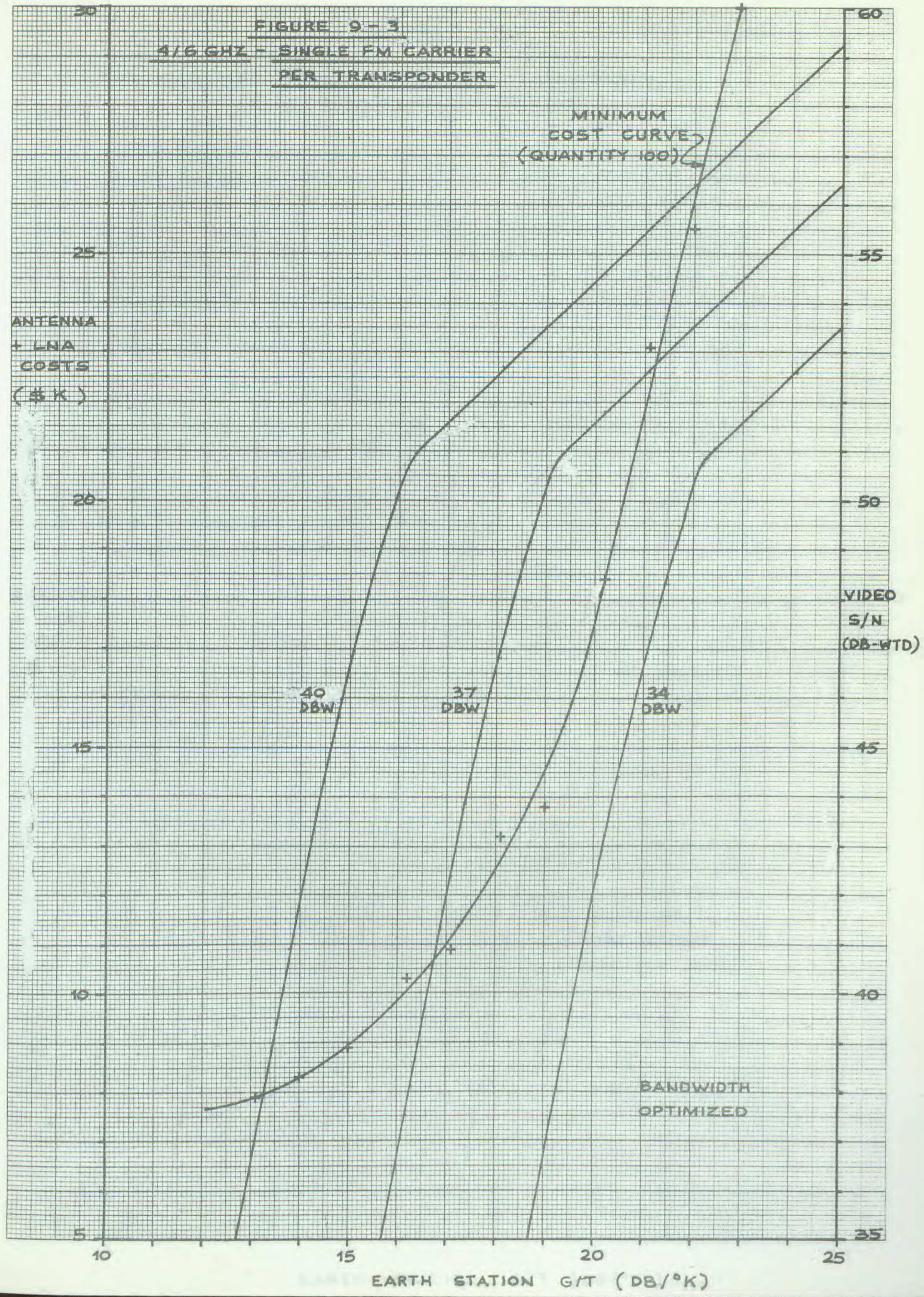
FIGURE 9 - 3
4/6 GHZ - SINGLE FM CARRIER
PER TRANSPONDER
MINIMUM
COST CURVE
(QUANTITY 100)
ANTENNA
+ LNA
COSTS
($ K)
VIDEO
S/N
(DB-WTD)
40
DBW
37
DBW
34
DBW
BANDWIDTH
OPTIMIZED
5
10
15
20
25
30
35
40
45
50
55
60
EARTH STATION G/T (DB/°K)

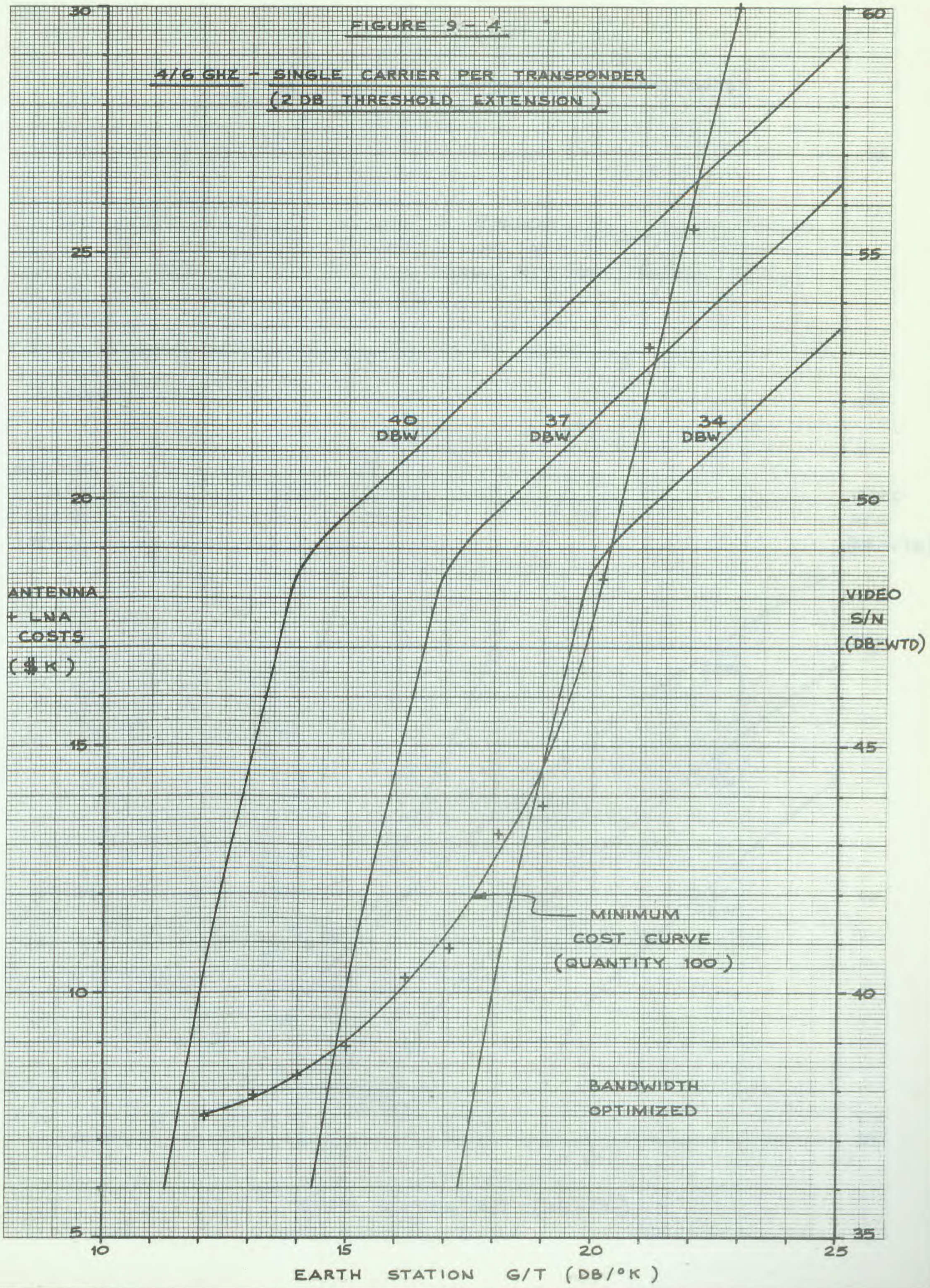
FIGURE 9-4
4/6 GHZ - SINGLE CARRIER PER TRANSPONDER
(2 DB THRESHOLD EXTENSION)
40 DBW
37 DBW
34 DBW
ANTENNA + LNA COSTS ($K)
VIDEO S/N (DB-WTD)
MINIMUM COST CURVE (QUANTITY 100)
BANDWIDTH OPTIMIZED
EARTH STATION G/T (DB/°K)
5
10
15
20
25
30
35
40
45
50
55
60

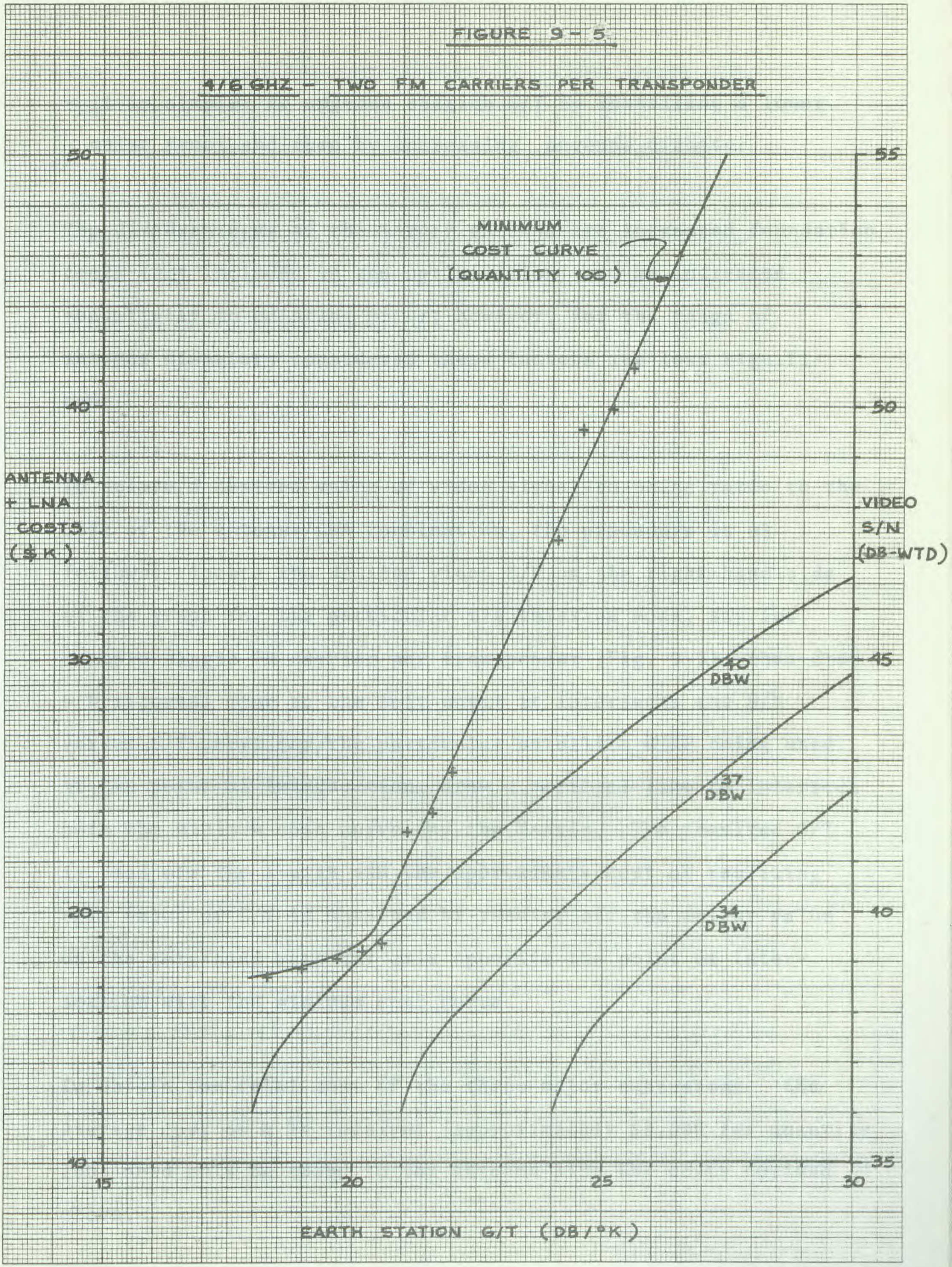
FIGURE 9-5
4/6 GHZ - TWO FM CARRIERS PER TRANSPONDER
MINIMUM COST CURVE (QUANTITY 100)
ANTENNA + LNA COSTS ($K)
VIDEO S/N (DB-WTD)
40 DBW
37 DBW
34 DBW
EARTH STATION G/T (DB/°K)
50
40
30
20
10
55
50
45
40
35
15
20
25
30

- it is simpler to upgrade station G/T by installing a lower noise front end than by increasing antenna diameter

The disadvantages of the larger antenna are increased foundation costs (not included in the optimization) and an increased sensitivity to pointing error; however, for the range of antenna diameters considered these factors are less significant.

To relate a desired value of video signal-to-noise ratio to the cost of the antenna/LNA combination, the procedure is as follows: locate the desired video S/N on the right-hand-side of the graph for the particular transmission mode, say for example single FM carrier per transponder (Fig. 9-3), then draw a horizontal line to the left until it intersects the S/N versus G/T curve for the particular satellite EIRP being used. At the point of intersection, draw a vertical line to intersect both the minimum cost curve and the X-axis. The required G/T is read off the X-axis and the approximate cost of realizing this value of G/T is obtained by reading off the dollar value on the left-hand vertical axis opposite the point of intersection with the minimum cost curve.

To obtain the total cost of the three major subsystems the average cost of a TV receiver (approximately $9,000 for quantity 100) need only be added to the antenna plus LNA costs derived above.

Cost curves have not been plotted for other quantities for the simple reason that the cost data available for quantities 1, 10 and 1000 does not allow any meaningful average costs to be derived. Although cost discount versus quantity varied amongst manufacturers, the following discounts for the three subsystems were determined as being the average from discussions with various manufacturers:

		PERCENTAGE DISCOUNT		
FROM	TO	ANTENNA	LNA	TV RECEIVER
QTY 1	QTY 10	2	10	0
QTY 10	QTY 100	10	23	14
QTY 100	QTY 1000	5	18	50

TABLE 9-1

PERCENTAGE DISCOUNT IN COST FOR VARYING QUANTITIES OF EARTH STATION SUBSYSTEMS

Due to the lack of any real data base for 12/14 GHz subsystems, any attempts at costing the 12/14 GHz system models cannot be supported with any degree of confidence. However, in order to present some sort of results for the 12/14 GHz system models, hypothetical costs for 12 GHz subsystems will be generated from the existing 4 GHz cost data by applying arbitrary multiplying factors for the different subsystems under the assumption that:

a. a large market existed for 12/14 GHz hardware and

b. the same degree of research and development funding, as applied to the 4/6 GHz frequency band, was applied to the 12/14 GHz frequency band.

It is highly unlikely that these assumptions will be fulfilled by the 1978 time frame of this study as nearly all prospective users of the 12/14 GHz satellite band are doing so on an experimental basis, the only known exception being Satellite Business Systems (S.B.S.) who are currently seeking the F.C.C.'s approval for the launch of their first commercial 12/14 GHz satellite in the 1979 time frame.

It is believed that the higher costs of 12 GHz subsystems will, in general, stem from the need to provide the following:

1. Higher manufacturing tolerances, e.g., antenna reflector surfaces, low-loss circulators, waveguides, etc.

2. Higher performance R.F. components e.g. varactors, pump sources, local oscillators, GaAs FET's, etc.

3. Adequate test equipment and test-jigs.

The multiplying factors which have been used are:

1. 12 GHz antennas - multiplying factor of 1.0

2. 12 GHz LNA's* - multiplying factor of 1.5

3. 12 GHz TV and Radio Program Receivers - multiplying factor of 1.2

These factors were applied to the 'average' costs used to cost out the 4 GHz system models and the hypothetical 12 GHz costs were subsequently used to derive 'minimum cost' curves for two of the 12 GHz system models (see Figs. 9-6 and 9-7) and for deriving 12 GHz earth station capital costs in section 9.4 (Tables 9-5 and 9-6).

---

* Presently available 12 GHz low noise front-ends are limited to parametric amplifiers for noise temperatures less than 250°K with state-of-the-art GaAs FET amplifiers and image-enhanced mixers next available in the region of 4.0 to 5.0 dB NF (the development of a <4.0 dB NF GaAs FET amplifier is currently being pursued).

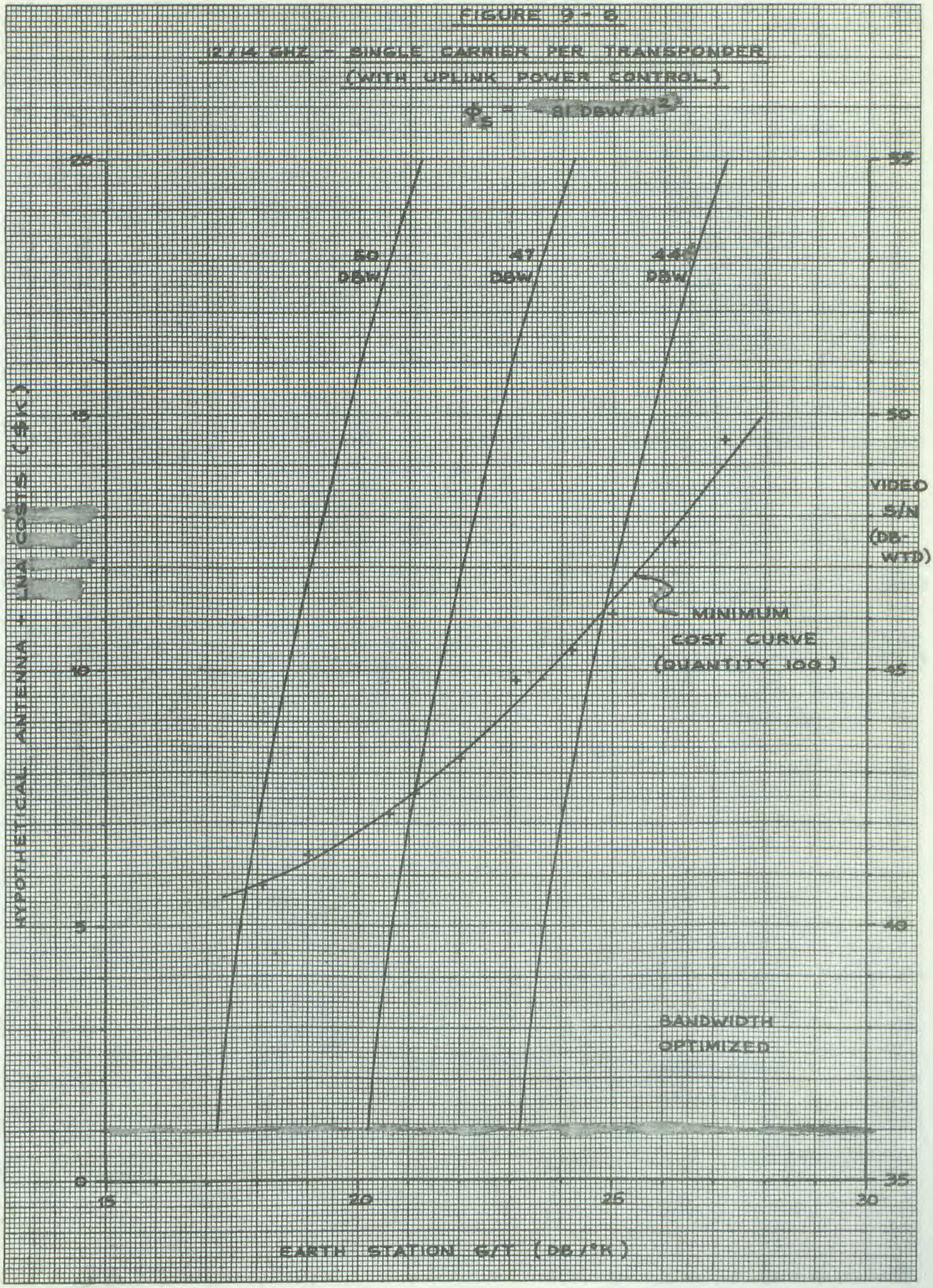

FIGURE 9-6
12/14 GHZ - SINGLE CARRIER PER TRANSPONDER
(WITH UPLINK POWER CONTROL)
Φ_S = -81 DBW/M²
50 DBW
47 DBW
44 DBW
MINIMUM COST CURVE (QUANTITY 100)
BANDWIDTH OPTIMIZED
HYPOTHETICAL ANTENNA + LNA COSTS ($K)
VIDEO S/N (DB-WTD)
EARTH STATION G/T (DB/°K)
0
5
10
15
20
35
40
45
50
55
15
20
25
30

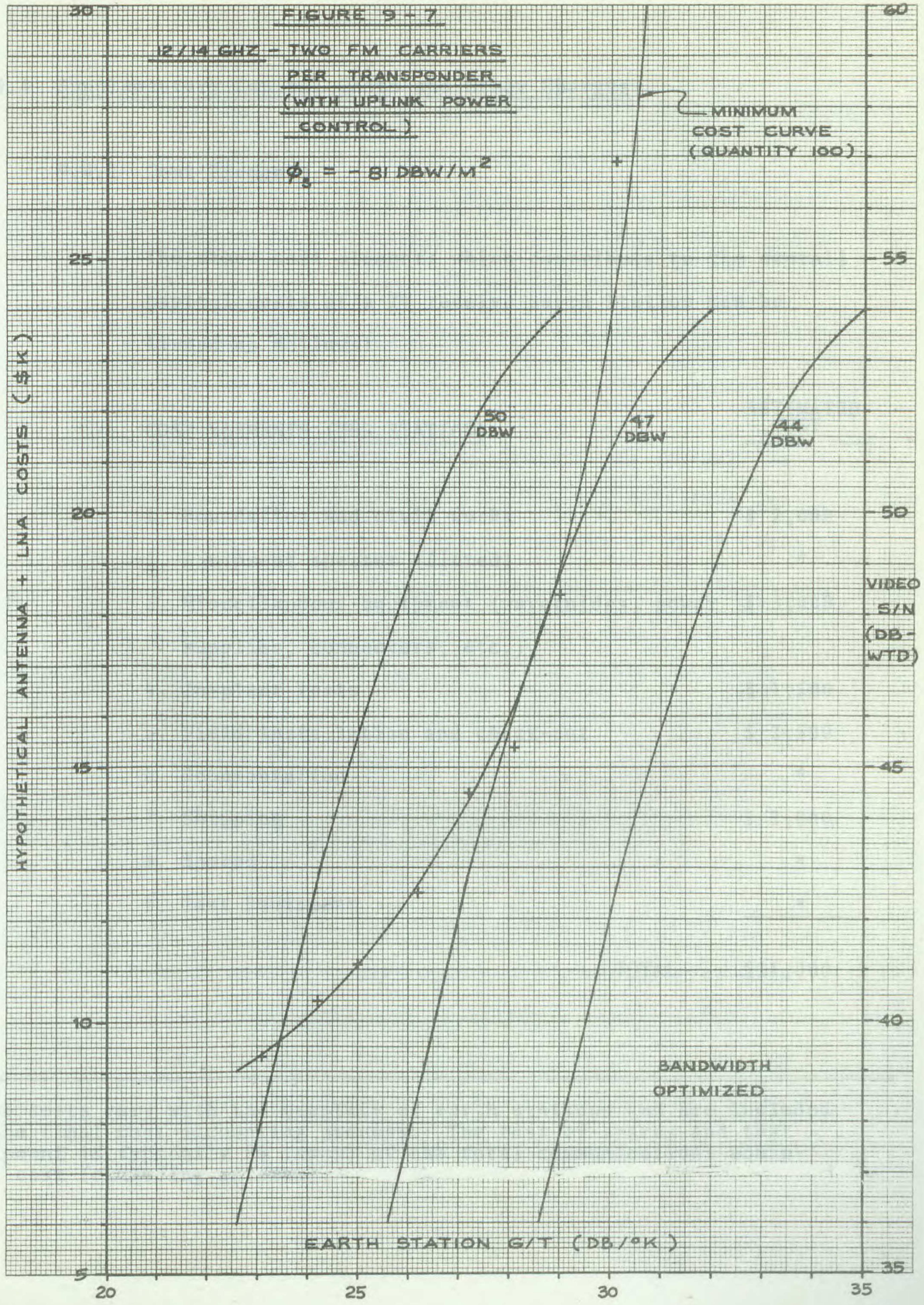
FIGURE 9 - 7
12/14 GHZ - TWO FM CARRIERS PER TRANSPONDER (WITH UPLINK POWER CONTROL)
ϕ_s = - 81 DBW/M^2
MINIMUM COST CURVE (QUANTITY 100)
50 DBW
47 DBW
44 DBW
BANDWIDTH OPTIMIZED
HYPOTHETICAL ANTENNA + LNA COSTS ($K)
VIDEO S/N (DB-WTD)
EARTH STATION G/T (DB/°K)
30
25
20
15
10
5
60
55
50
45
40
35
20
25
30
35

9.4 Supplementary Capital Costs and Other Charges

9.4.1 Cost Elements

The other cost elements which contribute to the overall capital costs of a TV receive earth station can be listed as follows:

COST ELEMENTS (PER STATION)	ESTIMATED COST
1. Foundation and civil works	$ 2,000
2. Equipment shelter (fitted)	*
3. Miscellaneous equipment (waveguides, power supplies, connectors, etc.)	$ 3,000
4. In-plant tests	$ 1,500
5. Field Installation and check-out	$ 2,500
6. Documentation	*
7. Shipping	$ 2,000
8. Spares	*
9. Test Equipment	*
TOTAL	$11,000

* These costs vary with the quantity of earth stations and are included in the final cost accounting process. The cost of spares and test equipment is typically 6% (each) of the total communications equipment cost (excluding antenna).

Note that the cost of an earth station could be reduced by locating the communications equipment inside a customer's existing building (e.g. existing broadcast stations or CATV headends). In addition, prime power charges would be reduced somewhat as the need for providing separate environmental controls would be eliminated.

The cost of general administrative and engineering charges for the overall planning and logistics for implementing such a regional network of earth stations is usually a percentage of the unit earth station subtotal capital costs (i.e., Federal and Provincial Sales Tax are excluded) and, therefore, varies with the quantity of earth stations. A value of 10% is used here for calculation purposes.

9.4.2 Operational and Maintenance Costs

In view of the proven high reliability of TV receive earth stations, maintenance can reasonably be on a corrective basis, with possibly a yearly inspection visit to verify that earth stations are performing to systems specifications. In this manner, operating costs can be kept to a minimum without greatly compromising performance, even when uncooled parametric amplifiers are used* (The MTBF's of uncooled parametric amplifiers are typically greater than 20,000 hours; for transistorized LNA's, MTBF's of 50,000 - 60,000 hours are quoted).

A possible maintenance configuration might be that a regional maintenance depot would be collocated with the regional TV distribution centre and its associated earth station. All test equipment and spares to serve a number of TV receive earth stations on a regional basis would be located at this depot.

Apart from the yearly routine visit plus any emergency visits to the earth stations by a technician, it might be expedient to employ some local help on a part time basis who would be responsible for the general welfare of the station, for example, clearing accumulated snow from the antenna and checking that the heater and air-conditioner work (depending on the time of the year). This person could also be responsible for reporting faults to the maintenance depot for appropriate action.

Maintenance costs per earth station can be approximated

---

* The service availability of Telesat's non-redundant remote TV receive (RTV) earth stations which employ uncooled parametric amplifiers has been about 99.9%.

as follows:

	ESTIMATED COST PER ANNUM
1. Yearly routine visit (1 day)	$ 750
2. Local Maintenance	$1000
TOTAL	$1750

The cost of a yearly routine visit could vary depending on where the regional maintenance depot is located.

Prime power rates vary between 3 and 15 cents per kilowatt-hour across Canada with the lower electricity rates being encountered in the larger population centres and are fairly constant throughout a Province. Higher rates usually prevail in remote, low population areas that are typical in the Yukon and the North-West Territories.

A prime power rate of 10 cents per kilowatt-hour is assumed for calculation purposes. Power consumption will vary to some extent and will depend on individual earth station location and the local climatic conditions throughout the year. The prime power charges presented below are, therefore, based on estimated consumption per earth station:

ITEM	APPROX. LOAD RATING	DURATION OF CONTINUOUS USE	RATE PER KW-HR	COST PER ANNUM
	WATTS	DAYS	CENTS	DOLLARS
1. Communications Equip.				
a. With Paramp (uncooled)	200	365	10	175
b. With Transistor LNA	100	365	10	88
2. Lighting	100	60	10	14
3. Air-Conditioner	1,500*	30	10	108
4. Heater	500	180	10	216
5. Incidentals	300	60	10	43

TOTAL: a. Paramp (uncooled) $556

b. Transistor LNA $469

The total estimated operational and maintenance cost per annum for each earth station (independent of quantity) is:

a. With paramp (uncooled) $ 2,300 (approx)

b. With transistor LNA $ 2,200 (approx)

* The 5000 Btu/hr (1.5 kw) A/C unit is one of the smallest units available commercially and its capacity is greatly in excess of requirements to cool a small shelter.

9.5 Capital Cost and Annual Charges Versus Video Signal-To-Noise Ratio

Capital cost and annual charges are presented here for a number of video S/N's using the 4/6 GHz system models and are shown in Tables 9-2 to 9-4. Costs are shown for quantity 100 earth stations only; for other quantities, costs can be derived using the quantity discount figures listed in Table 9-1. In addition, hypothetical capital costs and annual charges for two of the 12/14 GHz system models are shown in Tables 9-5 and 9-6.

It must be stressed that the cost of the subsystems used are average costs only, derived in an arbitrary manner from the cost data gathered in this study, and may not be indicative of the true market value of specific components presently available. The exercise is useful, however, in enabling one to obtain 'ball-park' capital costs for TV receive earth stations and to see how the cost varies with required video S/N*, satellite EIRP, and number of carriers per transponder. To obtain more accurate estimates of earth station capital costs for any given model, one can focus attention on deriving a more detailed earth station specification and generating the costs of the specific subsystems.

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* In all cases, video signal-to-noise ratio could be improved on a dB for dB basis with the use of over-deviation at no additional capital cost.

TABLE 9-2

4/6 GHz - SINGLE FM CARRIER PER TRANSPONDER

		QUANTITY 100								
Satellite EIRP (dBW)		34			37			40		
Available Satellite Bandwidth (MHz)		36			36			36		
Video Signal-To-Noise Ratio (dB-wtd)		40	44	48	40	44	48	40	44	48
Required Earth Station G/T (dB/^oK)		19.6	20.4	21.4	16.6	17.4	18.4	13.6	14.4	15.4
Antenna	Diameter (Ft.)	18	18	18	12	15	15	10	10	10
	Capital Cost ($K)	15.5	15.5	15.5	7.7	10.6	10.6	6.0	6.0	6.0
LNA	Noise Temperature (^oK)	226	200	160 *	226	300	226	330	262	200
	Noise Figure (dB)	2.5	2.3	1.9	2.5	3.1	2.5	3.3	2.8	2.3
	Capital Cost ($K)	2.9	3.2	8.0	2.9	2.3	2.9	2.1	2.6	3.2
TV Receiver Capital Cost ($K)		9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Radio Program Receiver Capital Cost ($K)		12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Subsystems Capital Cost ($K)		39.5	39.8	44.6	31.7	34.0	34.6	29.2	29.7	30.3
Equipment Shelter (Fitted) ($K)		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Documentation ($K)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Supplementary Capital Costs ($K)		11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Test Equipment and Spares ($K)		2.9	2.9	3.5	2.9	2.8	2.9	2.8	2.8	2.9
Sub-Total ($K)		57.7	58.0	63.4	49.9	52.1	52.8	47.3	47.8	48.5
Administrative & Engineering Charges (+10%) ($K)		5.8	5.8	6.3	5.0	5.2	5.3	4.7	4.8	4.8
Applicable F.S.T.(+12%)($K)		6.9	7.0	7.6	6.0	6.2	6.3	5.7	5.7	5.8
Applicable P.S.T.(+7%) ($K)		4.5	4.6	5.0	3.9	4.1	4.1	3.7	3.8	3.8
Unit E/S Capital Cost ($K)		75.0	75.3	82.3	64.8	67.6	68.5	61.4	62.1	63.0
E/S Annual Op. Charges ($K)		2.2	2.2	2.3	2.2	2.2	2.2	2.2	2.2	2.2

* The use of a half-band(250 MHz) paramp might be considered here with its corresponding lower cost (see section 8-2).

TABLE 9-3

4/6 GHz - SINGLE FM CARRIER PER TRANSPONDER

(2 dB THRESHOLD EXTENSION)

		QUANTITY 100								
Satellite EIRP (dBW)		34			37			40		
Available Satellite Bandwidth (MHz)		36			36			36		
Video Signal-To-Noise Ratio (dB-wtd)		40	44	48	40	44	48	40	44	48
Required Earth Station G/T (dB/°K)		18.0	18.9	19.8	15.0	15.9	16.8	12.0	12.9	13.8
Antenna	Diameter (Ft.)	15	15	18	10	12	12	10	10	10
	Capital Cost ($K)	10.6	10.6	15.5	6.0	7.7	7.7	6.0	6.0	6.0
LNA	Noise Temperature (°K)	262	200	250	226	262	200	492	375	316
	Noise Figure (dB)	2.8	2.3	2.7	2.5	2.8	2.3	4.3	3.6	3.2
	Capital Cost ($K)	2.6	3.2	2.6	2.9	2.6	3.2	1.5	1.9	2.2
TV Receiver Capital Cost ($K)		9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Radio Program Receiver Capital Cost ($K)		12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Subsystems Capital Cost ($K)		34.3	34.9	39.2	30.0	31.4	32.0	28.6	29.0	29.3
Equipment Shelter (Fitted) ($K)		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Documentation ($K)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Supplementary Capital Costs ($K)		11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Test Equipment and Spares ($K)		2.8	2.9	2.8	2.9	2.8	2.9	2.7	2.8	2.8
Sub-Total ($K)		52.4	53.1	57.3	48.2	49.5	50.2	46.6	47.1	47.4
Administrative & Engineering Charges (+10%) ($K)		5.2	5.3	5.7	4.8	5.0	5.0	4.7	4.7	4.7
Applicable F.S.T.(+12%)($K)		6.3	6.4	6.9	5.8	6.0	6.0	5.6	5.6	5.7
Applicable P.S.T.(+7%) ($K)		4.1	4.2	4.5	3.8	3.9	3.9	3.6	3.7	3.7
Unit E/S Capital Cost ($K)		68.1	69.0	74.5	62.6	64.3	65.2	60.5	61.1	61.5
E/S Annual Op. Charges ($K)		2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2

TABLE 9-4

4/6 GHz - TWO FM CARRIERS PER TRANSPONDER

		QUANTITY 100								
Satellite EIRP (dBW)		34			37			40		
Available Satellite Bandwidth (MHz)		17			17			17		
Video Signal-To-Noise Ratio (dB-wtd)		40	42	44	40	42	44	40	42	44
Required Earth Station G/T (dB/°K)		27.2	29.5	32.0	24.2	26.5	29.0	21.2	23.5	26.0
Antenna	Diameter (Ft.)	26.5	26.5	----	26.5	26.5	26.5	18	26.5	26.5
	Capital Cost ($K)	31.5	31.5	----	31.5	31.5	31.5	15.5	31.5	31.5
LNA	Noise Temperature (°K)	75	25†	----	200	100	35†	160*	226	100
	Noise Figure (dB)	1.0	0.4	----	2.3	1.3	0.5	1.9	2.5	1.3
	Capital Cost ($K)	17.0	>50	----	3.2	14.5	>50	8.0	2.9	14.5
TV Receiver ** Capital Cost ($K)		9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Radio Program Receiver Capital Cost ($K)		12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Subsystems Capital Cost ($K)		69.6	----	----	55.8	67.1	----	44.6	55.5	67.1
Equipment Shelter (Fitted) ($K)		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Documentation ($K)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Supplementary Capital Costs ($K)		11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Test Equipment and Spares ($K)		4.6	----	----	2.9	4.3	----	3.5	2.9	4.3
Sub-Total ($K)		89.5	----	----	74.0	86.7	----	63.4	73.7	86.7
Administrative & Engineering Charges (+10%) ($K)		9.0	----	----	7.4	8.7	----	6.3	7.4	8.7
Applicable F.S.T.(+12%)($K)		10.7	----	----	8.9	10.4	----	7.6	8.8	10.4
Applicable P.S.T.(+7%) ($K)		7.0	----	----	5.8	6.8	----	5.0	5.8	6.8
Unit C/S Capital Cost ($K)		116.2	----	----	96.1	112.5	----	82.3	95.7	112.5
E/S Annual Op. Charges ($K)		2.3	----	----	2.2	2.3	----	2.3	2.2	2.3

* See footnote to Table 9-2

†Cryogenically-cooled Paramp

** Earth Stations are fitted to receive only <u>one</u> of the two RF video carriers.

TABLE 9-5

12/14 GHz - SINGLE FM CARRIER PER TRANSPONDER

(WITH UPLINK POWER CONTROL)

$\phi_s = -81\ dBW/m^2$

	QUANTITY 100								
Satellite EIRP (dBW)	44			47			50		
Available Satellite Bandwidth (MHz)	72			72			72		
Video Signal-To-Noise Ratio (dB-wtd)	40	44	48	40	44	48	40	44	48
Required Earth Station G/T (dB/^oK)	23.7	24.4	25.3	20.7	21.4	22.3	17.7	18.4	19.3
Antenna — Diameter (Ft.)	10	10	12	8	8	10	6	6	8
Antenna — Capital Cost ($K)	6.0	6.0	7.7	4.4	4.4	6.0	3.0	3.0	4.4
LNA — Noise Temperature (^oK)	262	200	262	359	300	375	375	330	527
LNA — Noise Figure (dB)	2.8	2.3	2.8	3.5	3.1	3.6	3.6	3.3	4.5
LNA — Capital Cost ($K)	3.9	4.8	3.9	3.0	3.4	2.8	2.8	3.2	2.1
TV Receiver Capital Cost ($K)	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9
Radio Program Receiver Capital Cost ($K)	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4
Subsystems Capital Cost ($K)	35.2	36.1	36.9	32.7	33.1	34.1	31.1	31.5	31.8
Equipment Shelter (Fitted) ($K)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Documentation ($K)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Supplementary Capital Costs ($K)	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Test Equipment and Spares ($K)	3.5	3.6	3.5	3.4	3.4	3.4	3.4	3.4	3.3
Sub-Total ($K)	54.0	55.0	55.7	51.4	51.8	52.8	49.8	50.2	50.4
Administrative $ Engineering Charges (+10%) ($K)	5.4	5.5	5.6	5.1	5.2	5.3	5.0	5.0	5.0
Applicable F.S.T.(+12%)($K)	6.5	6.6	6.7	6.2	6.2	6.3	6.0	6.0	6.0
Applicable P.S.T.(+7%) ($K)	4.2	4.3	4.4	4.0	4.1	4.1	3.9	3.9	4.0
Unit E/S Capital Cost ($K)	70.1	71.4	72.3	66.7	67.3	68.5	64.6	65.2	65.4
E/S Annual Op. Charges ($K)	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2

N.B. All subsystem capital costs are hypothetical only and some LNA noise temperatures shown may not be realizable at present.

TABLE 9-6

12/14 GHZ - TWO FM CARRIERS PER TRANSPONDER

(WITH UPLINK POWER CONTROL)

$\emptyset_s = -81\ dBW/m^2$		QUANTITY 100								
Satellite EIRP (dBW)		44			47			50		
Available Satellite Bandwidth (MHz)		34			34			34		
Video Signal-To-Noise Ratio (dB-wtd)		40	44	48	40	44	48	40	44	48
Required Earth Station G/T (dB/°K)		29.5	30.5	31.8	26.5	27.5	28.8	23.5	24.5	25.8
Antenna	Diameter (Ft.)	18	18	18	15	15	18	10	12	12
	Capital Cost ($K)	15.5	15.5	15.5	10.6	10.6	15.5	6.0	7.7	7.7
LNA	Noise Temperature (°K)	200	150	100	316	226	262	262	330	226
	Noise Figure (dB)	2.3	1.8	1.3	3.2	2.5	2.8	2.8	3.3	2.5
	Capital Cost ($K)	4.8	12.6	21.8	3.3	4.4	3.9	3.9	3.2	4.4
TV Receiver * Capital Cost ($K)		10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9
Radio Program Receiver Capital Cost ($K)		14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4
Subsystems Capital Cost ($K)		45.6	53.4	62.6	39.2	40.3	44.7	35.2	36.2	37.4
Equipment Shelter (Fitted) ($K)		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Documentation ($K)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Supplementary Capital Costs ($K)		11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Test Equipment and Spares ($K)		3.6	4.6	5.6	3.4	3.6	3.5	3.5	3.4	3.6
Sub-Total ($K)		64.5	73.2	83.6	57.9	59.2	63.5	54.0	54.9	56.3
Administrative $ Engineering Charges (+10%) ($K)		6.4	7.3	8.4	5.8	5.9	6.4	5.4	5.5	5.6
Applicable F.S.T.(+12%)($K)		7.7	8.8	10.0	7.0	7.1	7.6	6.5	6.6	6.8
Applicable P.S.T.(+7%) ($K)		5.1	5.7	6.6	4.5	4.6	5.0	4.2	4.3	4.4
Unit E/S Capital Cost ($K)		83.8	95.1	108.5	75.2	76.8	82.4	70.1	71.3	73.1
E/S Annual Op. Charges ($K)		2.2	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.2

N.B. All subsystem capital costs are hypothetical only and some LNA noise temperatures shown may not be realizable at present.

* Earth Stations are fitted to receive only one of the two RF video Carriers.

The approximate cost of retrofitting an additional TV receiver to an earth station might be as follows:

ITEM	ESTIMATED COST
1. One-only TV receiver	$10,500
2. Installation and check out	$ 1,000
3. Miscellaneous fittings	$ 500
SUB TOTAL	$12,000
Applicable F.S.T. (12%)	$ 1,440
Applicable P.S.T. (7%)	$ 940
TOTAL ~	$14,400

The additional prime power charge per annum is approximately $44 (~ 50 watts X 365 days @ 10 cents per kW-Hr).

The approximate cost of retrofitting an additional radio program receiver might be as follows:

ITEM	ESTIMATED COST
1. One-only radio program receiver	$15,000*
2. Installation and check out	$ 1,000
3. Miscellaneous fittings	$ 500
SUB TOTAL	$16,500
Applicable F.S.T. (12%)	$ 1,980
Applicable P.S.T. (7%)	$ 1,294
TOTAL ~	$19,800

The additional prime power charge per annum is approximately $44 (~ 50 watts X 365 days @ 10 cents per kW-Hr).

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* Price of an expandor included.

REFERENCES

1. Miller, A.D.D., "Operational Experience with Small Unattended Television Receive Earth Stations", AIAA 5th Communications Satellite Systems Conference, Los Angeles, April 1974, AIAA Paper No. 74-454.

10. SITE SELECTION AND BACKHAUL

10.1 Introduction

It is generally assumed that sharing of frequency bands between terrestrial stations of the Fixed Service and earth stations of the Fixed Satellite Service requires relatively large separations between these stations to avoid unreasonable interference. The highly developed terrestrial network in many areas, especially common near traffic centres, presently results in remote locations for the earth stations. Consequently, the cost of providing interconnection from the earth stations to the traffic centres becomes significant; in the case of the Canadian domestic system, backhaul from the Heavy Route (HR) and Network Television (NTV) stations has been achieved through the use of costly 1 up to 4 hop microwave systems.

This section considers the constraints on siting a 4 GHz TV receive earth station and the implications of relaxing the normal interference criteria. Broadly speaking, shielding and co-ordination techniques are available which can reduce the geographic separation required between microwave repeaters and earth stations. However, it should be emphasized that in specific cases such techniques vs the use of backhaul should be examined both in the context of cost-effectiveness and risk. This section is tutorial in nature, discussing in general terms the tradeoffs and alternatives available.

10.2 Regulatory Requirements in Establishing an Earth Station

A. D.O.C. Licencing Procedure

Any earth station to be used for transmission and/or reception must be licenced to operate by the Department of Communications. The frequency spectrum is increasingly regarded as a valuable and limited resource, and the intent of the licencing procedure is to conserve this resource and ensure that it is used to greatest benefit. For this reason the licencing procedure requires that economic justification be given for establishing an earth station or microwave system, and that technical competence in spectrum conservation be demonstrated.

Specifically, the licencing procedure as stated in the Provisional Radio Standards Procedure 113 requires that the following documents be submitted to the D.O.C. in support of an earth station licence application:

1. A Letter of Intent and an Economic/Commercial Brief 12 months prior to the anticipated date of licencing. The Letter of Intent should give the general characteristics of the earth station and the Economic/Commercial Brief should provide economic justification for its establishment.

2. A Systems Engineering Brief and two forms, Application for Licence to Install and Operate a Radio Station in Canada and Particulars of Proposed Site and Antenna Structures, 3 months prior to the anticipated date of licence. The Engineering Brief consists of detailed specifications of the transmit and receive equipment, antenna system, and system parameters.

In addition, the earth station must be co-ordinated with those agencies operating terrestrial microwave systems in the 4 and 6 GHz frequency bands within the earth station co-ordination area. Table 10-1 lists the Canadian agencies operating in the 4 and/or 6 GHz bands. For Canadian agencies co-ordination is undertaken directly between the agencies involved and the relevant correspondence submitted to D.O.C. For international co-ordination, required when the co-ordination area falls outside Canadian territory, D.O.C. undertakes to co-ordinate the earth station, a process which may require up to 3 months. D.O.C. will also co-ordinate the earth station with government departments (e.g. DND, MOT, DOC, etc.)

The frequency co-ordination brief is comprised of the material given in Table 10-2. This is required for domestic as well as international co-ordination and should be included as part of the Engineering Brief.

TABLE 10-1

LIST OF AGENCIES OPERATING IN THE 4 AND/OR 6 GHz BAND IN 1975

Bell Canada	Quebec, Ontario, N.W.T.	4,6
Newfoundland Telephone Co.	Newfoundland	6
CNCP Telecommunications	Canada	4,6
Maritime Telegraph & Telephone	Nova Scotia, P.E.I.*	4,6
Eastern Telephone & Telegraph	Nova Scotia, New Brunswick	4
New Brunswick Telephone	New Brunswick	4,6
Quebec Telephone	Quebec	4,6
La Tuque Telephone	Quebec	6
Dorchester Telephone	Quebec	6
Hydro-Quebec	Quebec	6
Quebec North Shore and Labrador Railway	Quebec, Labrador	6
Northern Quebec Telephone Co.	Quebec	4
Ontario Northland Comm.	Ontario	6
Manitoba Telephone System	Manitoba	4,6
Saskatchewan Telecomm.	Saskatchewan	4,6
Alberta Government Telephone	Alberta	4,6
British Columbia Telephone	British Columbia	4,6
British Columbia Railway	British Columbia	6
Telesat Canada	Canada	4,6
Teleglobe (COTC)	Nova Scotia, British Columbia	4,6

*MTT undertakes co-ordination of the Island Telephone Company microwave systems in P.E.I. (6 GHz only)

TABLE 10-2

CONTENTS OF THE FREQUENCY CO-ORDINATION BRIEF

1. Site details - co-ordinates, ground elevation, location on topographic map, angle formed by horizon from the centre of the antenna for all azimuths, Radio Climatic Zone, Rain Climatic Zone.

2. Frequency Plan

3. Emission Characteristics - transmitter power, EIRP, power radiated in any 4 kHz bandwidth, transmit frequencies.

4. Receive Characteristics - receive frequencies, figure of merit (G/T), system noise temperature.

5. Antenna Characteristics - type, size, height of centre above ground level, transmit and receive gain, gain along the horizon for all azimuths.

B. D.O.C. Licencing Policy

Frequency spectrum is allocated to users on a first come, first served basis. Thus anyone proposing to establish a microwave system or earth station must show that no interference problems will arise to existing licenced systems as a result of the proposal.

Furthermore, once an agency has been issued a licence to operate a microwave system, having shown economic justification, technical acceptability, and freedom from interference problems with existing systems, the carrier has the right to develope that system, according to traffic requirements, to the full number of channels allocated to the frequency band the microwave system operates in. Thus in the 4 and 6 GHz bands, earth stations must be co-ordinated over the full 500 MHz band shared between satellite and terrestrial systems.

Co-ordination calculations must be based on existing equipment being used by the microwave system even though it may be obsolete and have poor RFI characteristics in comparison with current technology. However, if an existing microwave system is to be expanded, D.O.C. may require that obsolete equipment be replaced with that meeting present standards. This is particularly true in the 6 GHz band where a number of microwave systems still use non-standard frequency plans.

Some restriction may be placed on earth station parameters because of adjacent satellite interference considerations. The preferred orbital arc for domestic service to the U.S. and Canada is in heavy demand, so that although Canada enjoys a 5^o spacing between its satellites, the U.S. is considering a spacing of only 3^o or 4^o. This may restrict the minimum antenna diameter which can be used so that the sidelobe level at 3^o to 5^o is acceptably low. This point is most relevant to earth stations with transmit capability, where the significant parameter is the EIRP radiated at 3^o to 5^o off the main beam which has tentatively been restricted to no more than 18 dBW/4kHz.

Considering the 12 and 14 GHz bands, it appears that these bands will be allocated exclusively to satellite service in Canada. However, in the U.S. part of the bands may be allocated to terrestrial use in which case earth stations operating in these bands in Canada close to the border will have to be co-ordinated with terrestrial systems in the U.S.

The earth station co-ordination calculations and procedures must in general conform to the CCIR Recommendations which are listed below.

C. Pertinent CCIR Recommendations and Reports

The following CCIR Recommendations and Reports, adopted by the XIII Plenary Assembly, Geneva, 1974, concern the frequency co-ordination of earth stations with terrestrial systems.

Recommendation 354-2 (Vol. IV) in conjunction with Rec. 421-3 (Col. XII) and Rec. 451-2 (Vol. XII) give the permissible noise level in the hypothetical satellite reference circuit, as defined in Rec. 352-2 (Vol. IV), for systems carrying T.V.; Rec. 483 (Vol. IV) gives the interference power not to be exceeded from other satellite systems.

Rec. 446-1 (Vol. IV) requires that energy dispersal be used to minimize the power in any 4 kHz bandwidth. Report 384-2 (Vol. IV) discusses various energy dispersal techniques.

The earth station antenna radiation envelope pattern at 4 and 6 GHz should be no worse than that given in Rec. 465-1 (Vol. IV) and Report 391-2 (Vol. IV).

This pattern should also be used for interference studies in the absence of more accurate data. For antennas with $D/\lambda > 100$ (i.e. antenna diameter greater than about 25 ft. at 4 GHz), the gain is given by:

$$G = \begin{cases} 32 - 25 \log \theta & 1^{\circ} \le \theta \le 48^{\circ} \\ \sout{-48}\ -10 & \theta > 48^{\circ} \end{cases}$$

where G = antenna gain in dB relative to an isotropic radiator

and θ = off-axis angle in degrees

D = antenna diameter

λ = wavelength

For $D/\lambda < 100$, use of the following antenna pattern is suggested:

$$G = 52 - 10 \log (D/\lambda) - 25 \log \theta.$$

Rec. 358-2 (Vol. IX) specifies that the maximum power flux density in any 4 kHz band received at the surface of the earth must be:

$$F = \begin{cases} -152 & \theta \le 5^{\circ} \\ -152 + (\theta - 5)/2 & 5^{\circ} < \theta \le 25^{\circ} \\ -142 & 25^{\circ} < \theta \le 90^{\circ} \end{cases}$$

where F = power flux density dBW/m^2

θ = angle of arrival above the horizon in degrees

The maximum EIRP from a radio relay station is specified in Rec. 406-3 (Vol. IX) as being 55 dBW. This value should be used in frequency co-ordination calculations.

Following Rec. 359-3 (Vol. IX) a co-ordination area should be prepared for the purpose of frequency co-ordinating the earth station with terrestrial microwave systems, and determining which radio relay stations are potential interference problems. The calculation of this co-ordination area is described in Report 382-2 (Vol. IX). Report 448-1 (Vol. IX) gives methods of identifying more precisely whether particular radio relay stations falling within the co-ordination area can create interference problems.

10.3 Interference Considerations

A. Interference Criteria

To find the maximum allowable interference power, the quality of the service to be provided must first be specified. For T.V. the median or 20% of the time value of S/N may vary from 56 dB (for network or international service especially where microwave backhaul is required between the earth stations and the studio or broadcast transmitter) to 46 dB (for cable T.V. with the earth station co-located with the cable distribution network centre). For short periods of time (i.e. 0.01%) this is relaxed to allow for variations in level of the interfering signals due to propagation characteristics.

Using the improvement factor for the modulation scheme and the contributions obtained from weighting and pre-emphasis, the C/N is found for the specified S/N. A link calculation for the satellite system is required to find the received carrier power and the total allowable noise contribution. A noise budget is derived from this last figure, allowing for up-link and down-link thermal noise, equipment non-linearities, adjacent satellite interference, and interference from terrestrial microwave systems. An interference reduction factor may be applied to the last contribution depending upon the modulation characteristics of the satellite signal (wide band FM for example), and those of the terrestrial signals (low index FM for 1200 channel telephony, FM for T.V., pure carrier for hot standby protection, or PSK for digital systems).

B. Methods of Reducing the Interference Problem

Frequency co-ordination on the basis outlined previously can be very restrictive in that an earth station will usually have to be located in a valley some distance away from the community it is serving to obtain adequate shielding from interference. This entails terrestrial backhaul and possibly expensive site development.

However, by relaxing some of the criteria, a station can often be located quite close to the centre it is serving. For example, in the Telesat Canada system, the Network T.V. earth station serving Montreal (which was co-ordinated for transmission and reception of network quality signals on a 500 MHz basis) is about 70 miles west of the city, although on several occasions Telesat transportable stations were erected in the downtown area to receive T.V.

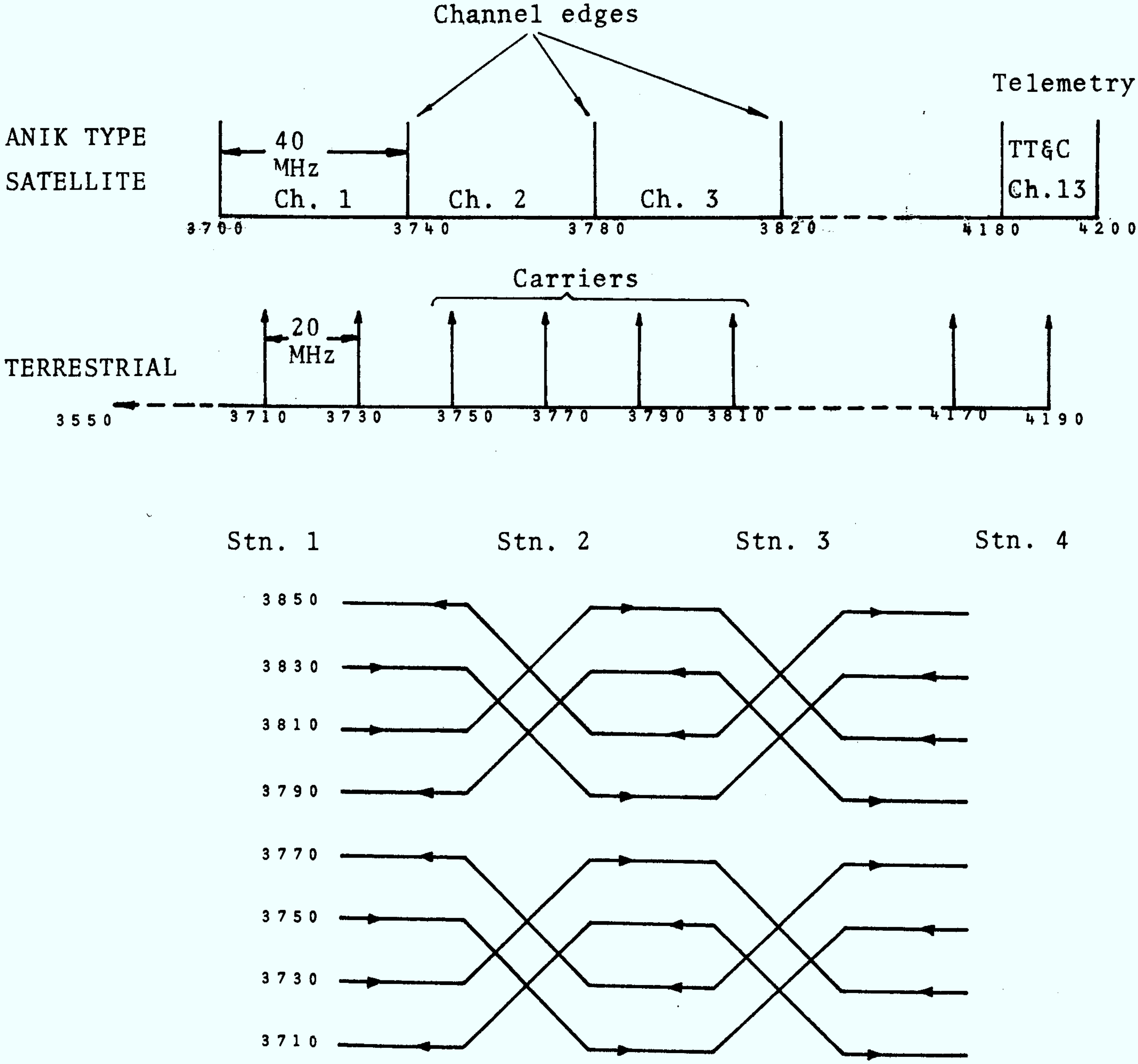
Co-ordination on an individual frequency rather than 500 MHz basis would considerably alleviate the problem of siting an earth station. An agreement would be required with the agencies operating terrestrial systems to forego development at the frequency being received by the earth station.

This proposal has a number of drawbacks however. In the 4 GHz band, the frequency plan followed by radio relay systems is such that they transmit in alternate 20 MHz slots (See Figure 10-1). In a heavily loaded system, such as those in the Montreal - Ottawa - Toronto area it might be difficult to find a satellite channel free from interference. In addition for a satellite system distributing T.V., one must find the same free channel available in all locations.

To meet interference margins, the earth station is usually sited in a valley to obtain shielding from radio relay stations using the natural terrain.* One might also consider artificial shielding of two forms.

The first is to place the antenna in a pit and put a mound of earth around it. This might be quite feasible from a cost viewpoint if the earth station antenna is fairly small (15 ft. say) and it could provide 20 to 25 dB shielding. The second is to use nearby buildings for shielding. This is somewhat risky because the buildings may not be permanent and new construction may block the view to the satellite. The amount of shielding obtained could not be predicted beforehand and would have to be measured. This would increase the cost of the

* This conflicts with the requirements for local re-broadcasting where the objective is to obtain maximum coverage over a given area. Depending on circumstances, one could probably build the TV broadcast transmitter on top of the nearest hill with interconnection cabling between the broadcast tower and the earth station.



<u>Note</u>: A particular microwave station has half of every satellite channel allocated to its transmit frequency plan.

FIGURE 10-1

FREQUENCY PLAN OF 4 GHz* TERRESTRIAL SYSTEMS

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* (At 6 GHz the standard channel spacing is 29.65 MHz and 2 frequency plans are used - staggered with respect to each other).

installation due to both the requirement for special RFI (radio frequency interference) measuring equipment and the associated engineering effort. However, measurement can lead to smaller interference margins (interference calculations and assumed antenna patterns are conservative), and in many cases allow terminals to be located near a city studio, transmitter, or cable head end.

Special antennas with low first order sidelobes (e.g. horn antennas) are attractive from an adjacent satellite interference standpoint, but not very helpful in reducing terrestrial microwave interference. In the north where elevation angles are low such interference is not normally a problem. In the south where elevation angles exceed 10^{o} it is the higher order sidelobes that are critical.

Limitation of the orbital arc that the earth station must cover may reduce blocking constraints from buildings, etc., in downtown areas, but does not buy much from an RFI standpoint at higher elevation angles, i.e. in most of southern Canada. At low elevation angles restricting the orbital arc may reduce co-ordination problems for both transmit and receive.

Three schemes have been identified as cost-effective alternatives to moving an installed earth station if interference becomes a problem during operation.

(1) Artificial site shielding:
(previously discussed)

(2) Interference cancellation:
Interference at a particular earth station is significant at only a single direction of arrival and usually at a discrete carrier frequency. Microwave equipment to provide cancellation of an interfering signal is theoretically possible, and has been implemented at the Goonhilly (U.K.) station to reduce the effects of a bothersome radio relay interferer.

(3) Reduced microwave power:
The terrestrial carrier might be induced to reduce carrier power on the interfering link if the satellite carrier provided a proportionally more sensitive (lower noise figure) receiver or higher directivity antennas.

These fall-back positions might be used to justify a reduction in the margins normally assumed in interference calculations.

10.4 Statistics of Radio Relay Interference

The long term (i.e. one hour) median interfering signal level has a log-normal probability density function. The variance depends upon the path length (NBS Tech. Note 101 uses a fudge term called "effective distance" as giving best agreement with observation), being high for short paths especially where diffraction is the controlling loss mechanism, but decreasing as path length increases and troposcatter becomes dominant.

The variance obtained by joining the 20% and 0.01% criteria does not have much meaning since it applies to no particular path (or perhaps to some sort of average of all paths), and the 20% is controlling for short diffraction paths while the .01% is controlling for long troposcatter paths.

For very small percentages of time the log-normal distribution based on variation of hourly medians may in fact break down*. Furthermore, the distribution for small percentages of time is very much a function of climate. For continental climates unusual propagation modes occur infrequently but in maritime climates

* The short term or instantaneous power is Rayleigh distributed.

propagation via ducting is much more frequent. So here there are two different propagation mechanisms, one controlling for large percentages of the time (diffraction or troposcatter) and one controlling for short percentages of the time (ducting).

In general, the statistical behaviour of microwave interference into a T.V. receive earth station is highly location dependent, and it is difficult to generalize on the effect of relaxing the normal .01% criterion to say .05%.

10.5 Baseband Interference

Interference calculations treat the interfering carrier(s) as white noise without regard to their effect on baseband performance. For the 4GHz satellite and radio relay frequency plans depicted in Fig. 10-1 this approach is unduly pessimistic in the case of a single T.V. carrier per transponder, but optimistic in the two carrier case. The explanation for this lies in the fact that for interfering FM carriers the resulting baseband S/N depends on both the carrier-to-interference ratio and the separation between carrier frequencies. In the case of FDM/FM interference into a video carrier, subjective tests (CCIR Report 449, Rev. 72) indicate that as the frequency separation increases the C/I producing barely perceptible interference drops.

Subjective (perceptibility threshold) and objective (video S/N) advantages of at least 10 dB result from the staggering of the low deviation FM radio relay carriers ±10 MHz about a single T.V. carrier centred in a satellite RF channel. With two carriers per transponder there will essentially be no staggering improvement, ~~i.e.~~., assuming operation above FM threshold, the single TV carrier per transponder line can tolerate ~~a C/I~~ at least 10 dB ~~below~~ more interference relative to the carrier level than that allowable in the two carriers per transponder case.

10.6 Site Selection Procedure

The following information and material is required for site selection:

1. Topographic maps issued by the Department of Energy, Mines, and Resources of the area involved. This includes detailed maps of the immediate area (1:50000 or 1:25000 scale if they exist) and 1:250,000 maps of the region likely to be encompassed by the co-ordination zone.

2. A listing of the 4 and 6 GHz radio relay stations of agencies operating in the co-ordination area along with the parameters relevant to interference calculations (co-ordinates, ground elevation, and for each adjacent link, the name, azimuth, transmit frequencies and power, receive frequencies, antenna type and height above ground level).

3. Main and cross polarization envelopes of the radiation pattern of all the radio relay station antennas.

4. Access to computer facilities because of the large number of calculations involved.

Provided some latitude exists in the choice of site for the earth station, the first step in site selection consists in making a map study to find a location which will be shielded by the natural terrain without incurring excessive costs due to site development, power availability, and backhaul requirements.

Once a site has been chosen and its co-ordinates determined, the antenna gain along the horizon is calculated. First the horizon angle made by the antenna is determined using data from the topographic maps (for preliminary calculations it will usually suffice to assume the horizon angle is zero especially if the minimum elevation angle to the satellite is greater than 10^{o}). Then the discrimination angle of the earth station antenna along the horizon through 360^{o} in azimuth is calculated. If the earth station is to be co-ordinated for a known fixed satellite position, this calculation is straight forward. However, if it is to be co-ordinated for an orbital arc, the discrimination angle must be obtained by an approximate graphical method outlined in Report 382-2, CCIR, Geneva 1974 or iteratively using a computer program. Once the discrimination angle is obtained, the corresponding antenna gain along the horizon is calculated.

From the list of radio relay stations, those falling outside the co-ordination zone can immediately be eliminated. For preliminary calculations, the co-ordination zone might be approximated by a "worst case" circle of 300 to 500 km and all stations beyond this distance dropped from further consideration.

The next step in the culling process is to make a conservative estimate of the path loss between the earth station and each radio relay station (based on the curves in CCIR Report 382-2) and to calculate the gain of the radio relay station antennas in the direction of the earth station. An estimate of the interference power received by the earth station can be obtained using the formula:

$$P_r(p) = P_t + G_t - D_t - L(p) + G_r$$

where: $P_r(p)$ is the interference power exceeded for less than p percent of the time, received at the earth station from a particular radio relay station;

P_t is the radio relay station transmitter power;

G_t is the radio relay station antenna gain (note that for a permanent earth station, $P_t + G_t$ should be taken as 55 dBW);

D_t is the radio relay station antenna discrimination in the direction of the earth station;

L(p) is the path loss between the two stations which will be exceeded for p percent of the time;

and G_r is the earth station antenna gain along the horizon in the direction of the radio relay station.

This assumes that great circle propagation over the horizon is controlling (CCIR Report 382-2, Vol. IX, p. 299). Great circle propagation via the main beam of the earth station may be controlling when the elevation angle is less than 12^o. However, this will occur infrequently for stations in southern Canada (where potential interference problems are most likely) operating into a satellite between 80^o and 120^o W longitude. Further, the conservative nature of this culling process should ensure that no radio relay station for which the second mode is controlling will be unjustifiably eliminated. The latter remark also applies to radio relay stations for which scattering from hydrometeors is controlling.

Radio relay stations producing estimated interference levels below the criteria set for the earth station can now be eliminated from further consideration.

If the earth station is to be co-ordinated on a channel basis rather than a 500 MHz band basis, any radio relay stations not transmitting in the channels being received by the earth station can also be eliminated at this point. This is rather desirable since the next step can be a time consuming one requiring considerable effort. By the same token, the remaining radio relay stations should be examined to see whether with a reasonable amount of shielding, either natural or artificial or both, the potential interference problem they represent can be overcome. If not it is pointless to continue.

For the remaining stations, a detailed calculation of the path loss is usually required, based upon the topography between the two points (i.e. the path profile) and using methods such as those described in NBS Technical Note 101 to calculate the diffraction and troposcatter. loss.

Hopefully at this point all radio relay stations have been eliminated as potential interference problems. In doubtful cases, it may be desirable to undertake an on site measurement program, particularly in view of the following:

(1) path loss calculations tend to be conservative in order to account for the variability among individual paths and the inaccuracy of topographic information;

(2) the antenna patterns used are the worst case radiation envelopes;

(3) and in urban areas artificial shielding in the form of buildings may provide additional path loss which is difficult to evaluate analytically.

REFERENCES

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11. AREAS OF FURTHER STUDY

This section identifies those areas in which follow-on work could extend the utility of this study. Broadly speaking, these fall into the following three categories:

- network objectives
- economic factors
- technical considerations

11.1 Network Objectives

In order to make appropriate design choices and arrive at reasonable estimates for costs, it is necessary to define in some detail the objectives of the regional network. This report has attempted to set forth appropriate system calculations and cost data; however, to draw final conclusions regarding the most effective implementation of a regional system, one must first consider:

1. Who will be served?
   - average number of users per receive location
   - number of TV channels per receive location
   - geographic definition of "region" (i.e. areas of coverage)*

* This might have over-riding importance at 12/14 GHz where spot beams which do not cover the far north are anticipated.

- number of years of anticipated service

2. Network Operation
   - number of origination points (i.e. transmit accesses)
   - program distribution techniques employed (frequency agility requirements, switching and multiplex arrangements, transportable facilities)
   - use of and interface with existing and planned terrestrial transmission (microwaves, cable) and broadcast (VHF, UHF) facilities
   - network growth and development
   - use of earth station facilities for other than TV program reception (e.g. voice communications, teleconferencing, etc.)

3. Performance Requirements
   - desired video S/N and availability
   - other TV performance requirements
   - back-up facilities

4. Institutional Issues
   - who delivers the signals (public or private network, or both)?
   - who pays for the system and who collects revenue from it (Government subsidized CBC, private networks, cable companies, "Pay" TV, etc.)?
   - who rents space segment and owns/rents earth segment?

- earth station and broadcast licences (subject to federal and possibly provincial government regulation)
- interconnection arrangements and interface standards
- sharing 12 GHz spectrum with direct broadcasting satellite
- sharing 4 GHz spectrum with radio relay facilities

11.2 Economic Factors

This study has neglected several key economic issues which in part determine the feasibility of regional TV distribution via satellite. Among these are:

- user acceptance vs video quality and associated cost
- user acceptance vs number of TV channels and program material
- demand for service on a region by region basis, identification of "optimum" regions, origination centres, and receive locations
- cost comparison of alternative proposed satellite systems, including realistic estimates of space segment charges
- cost/performance comparison with terrestrial alternatives, clear identification of where and when satellite solution is most cost effective
- estimated cost per user of implementing system.

If these issues are examined objectively and carefully using accurate cost data, a reasonable basis for decision will have been established.

11.3 Technical Factors

The specification of the TV distribution system and consideration of associated systems engineering problems have received a broad-brush treatment at best. In order to arrive at a minimum-cost design meeting the needs of the system, further analysis and perhaps engineering development are required. The following briefly lists those areas requiring further in-depth analysis:

- effects of over-deviation on subjective and objective TV performance
- effects of transponder (filter and TWT distortions) on transmission performance
- design of two TV carrier per transponder systems (ref. section 2.2)
- network limitations with spot beams
- optimum utilization of wider bandwidth transponders (e.g. multi-carrier TV, mixed traffic modes such as TV plus SCPC)
- adjacent channel and adjacent satellite interference to and from regional TV system
- interference with radio relay systems, feasibility of eliminating backhaul
- availability vs fade margin at 12/14 GHz, use of special techniques such as transmit and/or receive earth station diversity, topological diversity, and up-link power control
- subjective performance of NETEC and other digital TV systems
- design of 12 GHz earth terminals to receive TV

- the optimization of 12/14 GHz satellite parameters (e.g., EIRP, saturation flux density, transponder bandwidth) to facilitate the efficient transmission of television
- operation and maintenance of TV receive earth stations

While this report has taken a more detailed look at the performance and cost of existing TV receive earth stations subsystems, a more concentrated focus on specific products and future development (especially at 12/14 GHz) would be a useful addition to the study.

APPENDIX A

THIS SECTION CONTAINS TABULAR SUMMARIES OF THE KEY SYSTEM CALCULATION PARAMETERS FOR THE VARIOUS SYSTEM MODELS AT 4/6 GHz AND 12/14 GHz AND IS THE DATA SOURCE FOR THE G/T VERSUS VIDEO S/N GRAPHS CONTAINED IN SECTION 3.3.

TABLE A-1 4/6 GHz - *SINGLE FM VIDEO CARRIER PER TRANSPONDER*

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=34	EIRP=37	EIRP=40
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	17.8	3.4	84.8	104.6	84.8	18.9	15.9	12.9
38	19.1	4.1	85.1	104.6	85.2	19.3	16.3	13.3
40	20.7	5.0	85.4	104.6	85.5	19.6	16.6	13.6
42	22.6	6.0	85.8	104.6	85.9	20.0	17.0	14.0
44	24.9	7.2	86.3	104.6	86.3	20.4	17.4	14.4
46	27.6	8.6	86.7	104.6	86.8	20.9	17.9	14.9
48	30.8	10.2	87.2	104.6	87.3	21.4	18.4	15.4
50	34.7	12.2	87.7	104.6	87.8	21.9	18.9	15.9
52	36.0	12.9	89.2	104.6	89.3	23.4	20.4	17.4
54	36.0	12.9	91.2	104.6	91.4	25.5	22.5	19.5

TABLE A-2 4/6 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

(2dB Threshold Extension)

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=34	EIRP=37	EIRP=40
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	19.1	4.1	83.1	104.6	83.2	17.3	14.3	11.3
38	20.7	5.0	83.4	104.6	83.5	17.6	14.6	11.6
40	22.6	6.0	83.8	104.6	83.9	18.0	15.0	12.0
42	24.9	7.2	84.3	104.6	84.3	18.4	15.4	12.4
44	27.6	8.6	84.7	104.6	84.8	18.9	15.9	12.9
46	30.8	10.2	85.2	104.6	85.2	19.3	16.3	13.3
48	34.7	12.2	85.7	104.6	85.7	19.8	16.8	13.8
50	36.0	12.9	87.2	104.6	87.3	21.4	18.4	15.4
52	36.0	12.9	89.2	104.6	89.3	23.4	20.4	17.4
54	36.0	12.9	91.2	104.6	91.4	25.5	22.5	19.5

TABLE A-3 4/6 GHz - TWO FM VIDEO CARRIERS PER TRANSPONDER

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=34	EIRP=37	EIRP=40
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	16.2	3.6	84.4	97.6	84.6	24.0	21.0	18.0
38	17.0	4.0	85.4	97.6	85.7	25.1	22.1	19.1
40	17.0	4.0	87.4	97.6	87.8	27.2	24.2	21.2
42	17.0	4.0	89.4	97.6	90.1	29.5	26.5	23.5
44	17.0	4.0	91.4	97.6	92.6	32.0	29.0	26.0
46	17.0	4.0	93.4	97.6	95.5	34.9	31.9	28.9
48	17.0	4.0	95.4	97.6	99.4	38.8	35.8	32.8
50	17.0	4.0	97.4	97.6	110.9	50.3	47.3	44.3
52	17.0	4.0	99.4	97.6	*			
54	17.0	4.0	101.4	97.6	*			

* Uplink C/N_o limited

TABLE A-4 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

With Uplink Power Control

Single Carrier Saturation Flux Density = -87 dBW/m^2

						REQUIRED G/T $dB/^oK$		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	16.3	2.4	89.4	97.1	90.2	23.8	20.8	17.8
38	17.1	3.0	89.6	97.1	90.5	24.1	21.1	18.1
40	18.2	3.6	89.9	97.1	90.8	24.4	21.4	18.4
42	19.6	4.4	90.2	97.1	91.2	24.8	21.8	18.8
44	21.3	5.3	90.6	97.1	91.7	25.3	22.3	19.3
46	23.4	6.4	91.0	97.1	92.2	25.8	22.8	19.8
48	25.8	7.7	91.4	97.1	92.7	26.3	23.3	20.3
50	28.7	9.2	91.9	97.1	93.4	27.0	24.0	21.0
52	32.1	10.9	92.3	97.1	94.1	27.7	24.7	21.7
54	36.2	12.9	92.9	97.1	94.9	28.5	25.5	22.5

TABLE A-5 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

With Uplink Power Control

Single Carrier Saturation Flux Density = -84 dBW/m^2

S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T $dB/^oK$ EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	16.3	2.4	89.4	100.1	89.8	23.4	20.4	17.4
38	17.1	3.0	89.6	100.1	90.0	23.6	20.6	17.6
40	18.2	3.6	89.9	100.1	90.4	24.0	21.0	18.0
42	19.6	4.4	90.2	100.1	90.7	24.3	21.3	18.3
44	21.3	5.3	90.6	100.1	91.1	24.7	21.7	18.7
46	23.4	6.4	91.0	100.1	91.5	25.1	22.1	19.1
48	25.8	7.7	91.4	100.1	92.0	25.6	22.6	19.6
50	28.7	9.2	91.9	100.1	92.6	26.2	23.2	20.2
52	32.1	10.9	92.3	100.1	93.1	26.7	23.7	20.7
54	36.2	12.9	92.9	100.1	93.8	27.4	24.4	21.4

TABLE A-6 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER:

With Uplink Power Control

Single Carrier Saturation Flux Density = -81 dBW/m^2

S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T $dB/^oK$ EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	16.3	2.4	89.4	103.1	89.6	23.2	20.2	17.2
38	17.1	3.0	89.6	103.1	89.8	23.4	20.4	17.4
40	18.2	3.6	89.9	103.1	90.1	23.7	20.7	17.7
42	19.6	4.4	90.2	103.1	90.4	24.0	21.0	18.0
44	21.3	5.3	90.6	103.1	90.8	24.4	21.4	18.4
46	23.4	6.4	91 0	103.1	91.2	24.8	21.8	18.8
48	25.8	7.7	91.4	103.1	91.7	25.3	22.3	19.3
50	28.7	9.2	91.9	103.1	92.2	25.8	22.8	19.8
52	32.1	10.9	92.3	103.1	92.7	26.3	23.3	20.3
54	36.2	12.9	92.9	103.1	93.3	26.9	23.9	20.9

TABLE A-7 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER:

Without Uplink Power Control

Single Carrier Saturation Flux Density = -87 dBW/m^2

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	15.6	2.0	93.2	97.1	95.5	29.1	26.1	23.1
38	16.3	2.4	93.4	97.1	95.8	29.4	26.4	23.4
40	17.1	3.0	93.6	97.1	96.2	29.8	26.8	23.8
42	18.2	3.6	93.9	97.1	96.7	30.3	27.3	24.3
44	19.6	4.4	94.2	97.1	97.4	31.0	28.0	25.0
46	21.3	5.3	94.6	97.1	98.1	31.7	28.7	25.7
48	23.4	6.4	95.0	97.1	99.1	32.7	29.7	26.7
50	25.8	7.7	95.4	97.1	100.3	33.9	30.9	27.9
52	28.7	9.2	95.9	97.1	101.9	35.5	32.5	29.5
54	32.1	10.9	96.3	97.1	104.3	37.9	34.9	31.9

TABLE A-8 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

Without Uplink Power Control

Single Carrier Saturation Flux Density = -84 dBW/m^2

						REQUIRED G/T $dB/^{o}K$		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	15.6	2.0	93.2	100.1	94.2	27.8	24.8	21.8
38	16.3	2.4	93.4	100.1	94.4	28.0	25.0	22.0
40	17.1	3.0	93.6	100.1	94.7	28.3	25.3	22.3
42	18.2	3.6	93.9	100.1	95.1	28.7	25.7	22.7
44	19.6	4.4	94.2	100.1	95.5	29.1	26.1	23.1
46	21.3	5.3	94.6	100.1	96.0	29.6	26.6	23.6
48	23.4	6.4	95.0	100.1	96.5	30.1	27.1	24.1
50	25.8	7.7	95.4	100.1	97.2	30.8	27.8	24.8
52	28.7	9.2	95.9	100.1	97.9	31.5	28.5	25.5
54	32.1	10.9	96.3	100.1	98.7	32.3	29.3	26.3

TABLE A-9 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

Without Uplink Power Control

Single Carrier Saturation Flux-Density = -81 dBW/m^2

S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T dB/°K		
						EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	15.6	2.0	93.2	103.1	93.7	27.3	24.3	21.3
38	16.3	2.4	93.4	103.1	93.9	27.5	24.5	21.5
40	17.1	3.0	93.6	103.1	94.1	27.7	24.7	21.7
42	18.2	3.6	93.9	103.1	94.5	28.1	25.1	22.1
44	19.6	4.4	94.2	103.1	94.8	28.4	25.4	22.4
46	21.3	5.3	94.6	103.1	95.2	28.8	25.8	22.8
48	23.4	6.4	95.0	103.1	95.7	29.3	26.3	23.3
50	25.8	7.7	95.4	103.1	96.2	29.8	26.8	23.8
52	28.7	9.2	95.9	103.1	96.8	30.4	27.4	24.4
54	32.1	10.9	96.3	103.1	97.4	31.0	28.0	25.0

TABLE A-10 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

(2 dB Threshold Extension): With Uplink Power Control

Single Carrier Saturation Flux Density = $-87 dBW/m^2$

S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T dB/°K		
						EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	17.1	3.0	87.6	97.1	88.1	21.7	18.7	15.7
38	18.2	3.6	87.9	97.1	88.5	22.1	19.1	16.1
40	19.6	4.4	88.2	97.1	88.8	22.4	19.4	16.4
42	21.3	5.3	88.6	97.1	89.2	22.8	19.8	16.8
44	23.4	6.4	89.0	97.1	89.7	23.3	20.3	17.3
46	25.8	7.7	89.4	97.1	90.2	23.8	20.8	17.8
48	28.7	9.2	89.9	97.1	90.8	24.4	21.4	18.4
50	32.1	10.9	90.3	97.1	91.4	25.0	22.0	19.0
52	36.1	12.9	90.9	97.1	92.0	25.6	22.6	19.6
54	40.8	15.3	91.4	97.1	92.8	26.4	23.4	20.4

TABLE A-11 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

(2dB Threshold Extension): With Uplink Power Control

Single Carrier Saturation Flux Densiry = -84 dBW/m^2

S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T dB/°K		
						EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	17.1	3.0	87.6	100.1	87.9	21.5	18.5	15.5
38	18.2	3.6	87.9	100.1	88.2	21.8	18.8	15.8
40	19.6	4.4	88.2	100.1	88.5	22.1	19.1	16.1
42	21.3	5.3	88.6	100.1	88.9	22.5	19.5	16.5
44	23.4	6.4	89.0	100.1	89.3	22.9	19.9	16.9
46	25.8	7.7	89.4	100.1	89.8	23.4	20.4	17.4
48	28.7	9.2	89.9	100.1	90.3	23.9	20.9	17.9
50	32.1	10.9	90.3	100.1	90.8	24.4	21.4	18.4
52	36.1	12.9	90.9	100.1	91.4	25.0	22.0	19.0
54	40.8	15.3	91.4	100.1	92.0	25.6	22.6	19.6

TABLE A-12 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

(2dB Threshold Extension): With Uplink Power Control

Single Carrier Saturation Flux Density = -81 dBW/m^2

						REQUIRED G/T dB/^oK		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	17.1	3.0	87.6	103.1	87.7	21.3	18.3	15.3
38	18.2	3.6	87.9	103.1	88.0	21.6	18.6	15.6
40	19.6	4.4	88.2	103.1	88.4	22.0	19.0	16.0
42	21.3	5.3	88.6	103.1	88.7	22.3	19.3	16.3
44	23.4	6.4	89.0	103.1	89.1	22.7	19.7	16.7
46	25.8	7.7	89.4	103.1	89.6	23.2	20.2	17.2
48	28.7	9.7	89.9	103.1	90.1	23.7	20.7	17.7
50	32.1	10.9	90.3	103.1	90.6	24.2	21.2	18.2
52	36.1	12.9	90.9	103.1	91.1	24.7	21.7	18.7
54	40.8	15.3	91.4	103.1	91.7	25.3	22.3	19.3

TABLE A-13 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

(2dB Threshold Extension): Without Uplink Power Control

Single Carrier Saturation Flux Density = -87 dBW/m^2

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	16.3	2.4	91.4	97.1	92.7	26.3	23.3	20.3
38	17.1	3.0	91.6	97.1	93.0	26.6	23.6	20.6
40	18.2	3.6	91.9	97.1	93.5	27.1	24.1	21.1
42	19.6	4.4	92.2	97.1	93.9	27.5	24.5	21.5
44	21.3	5.3	92.6	97.1	94.5	28.1	25.1	22.1
46	23.4	6.4	93.0	97.1	95.1	28.7	25.7	22.7
48	25.8	7.7	93.4	97.1	95.8	29.4	26.4	23.4
50	28.7	9.2	93.9	97.1	96.7	30.3	27.3	24.3
52	32.1	10.9	94.3	97.1	97.6	31.2	28.2	25.2
54	36.2	12.9	94.9	97.1	98.8	32.4	29.4	26.4

TABLE A-14 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

(2dB Threshold Extension): Without Uplink Power Control

Single Carrier Saturation Flux Density = -84 dBW/m^2

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	16.3	2.4	91.4	100.1	92.0	25.6	22.6	19.6
38	17.1	3.0	91.6	100.1	92.3	25.9	22.9	19.9
40	18.2	3.6	91.9	100.1	92.6	26.2	23.2	20.2
42	19.6	4.4	92.2	100.1	93.0	26.6	23.6	20.6
44	21.3	5.3	92.6	100.1	93.4	27.0	24.0	21.0
46	23.4	6.4	93.0	100.1	93.9	27.5	24.5	21.5
48	25.8	7.7	93.4	100.1	94.4	28.0	25.0	22.0
50	28.7	9.2	93.9	100.1	95.0	28.6	25.6	22.6
52	32.1	10.9	94.3	100.1	95.7	29.3	26.3	23.3
54	36.2	12.9	94.9	100.1	96.4	30.0	27.0	24.0

TABLE A-15 12/14 GHz - SINGLE FM VIDEO CARRIER PER TRANSPONDER

(2dB Threshold Extension): Without Uplink Power Control

Single Carrier Saturation Flux Density = -81 dBW/m^2

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	16.3	2.4	91.4	103.1	91.7	25.3	22.3	19.3
38	17.1	3.0	91.6	103.1	91.9	25.5	22.5	19.5
40	18.2	3.6	91.9	103.1	92.3	25.9	22.9	19.9
42	19.6	4.4	92.2	103.1	92.6	26.2	23.2	20.2
44	21.3	5.3	92.6	103.1	93.0	26.6	23.6	20.6
46	23.4	6.4	93.0	103.1	93.4	27.0	24.0	21.0
48	25.8	7.7	93.4	103.1	93.9	27.5	24.5	21.5
50	28.7	9.2	93.9	103.1	94.4	28.0	25.0	22.0
52	32.1	10.9	94.3	103.1	95.0	28.6	25.6	22.6
54	36.2	12.9	94.9	103.1	95.6	29.2	26.2	23.2

TABLE A-16 12/14 GHz - TWO FM VIDEO CARRIERS PER TRANSPONDER:

With Uplink Power Control

Single Carrier Saturation Flux Density = -87 dBW/m^2

						REQUIRED G/T $dB/^oK$		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	14.4	2.6	88.8	90.1	94.8	33.7	30.7	27.7
38	15.4	3.1	89.7	90.1	96.3	35.2	32.2	29.2
40	16.7	3.8	89.5	90.1	98.2	37.1	34.1	31.1
42	18.2	4.6	89.9	90.1	103.4	42.3	39.3	36.3
44	20.0	5.5	90.3	90.1	*			
46	22.1	6.6	90.7	90.1	*			
48	24.6	7.8	91.2	90.1	*			
50	27.6	9.4	91.7	90.1	*			
52	31.0	11.1	92.2	90.1	*			
54	34.0	12.6	93.1	90.1	*			

* Uplink C/N_o limited

TABLE A-17 12/14 GHz - TWO FM VIDEO CARRIERS PER TRANSPONDER

With Uplink Power Control

Single Carrier Saturation Flux Density = -84 dBW/m^2

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	14.4	2.6	88.8	93.1	90.8	29.7	26.7	23.7
38	15.4	3.1	89.2	93.1	91.4	30.3	27.3	24.3
40	16.7	3.8	89.5	93.1	92.0	30.9	27.9	24.9
42	18.2	4.6	89.9	93.1	92.7	31.6	28.6	25.6
44	20.0	5.5	90.3	93.1	93.5	32.4	29.4	26.4
46	22.1	6.6	90.7	93.1	94.5	33.4	30.4	27.4
48	24.6	7.8	91.2	93.1	95.7	34.6	31.6	28.6
50	27.6	9.4	91.7	93.1	97.2	36.1	33.1	30.1
52	31.0	11.1	92.2	93.1	99.5	38.4	35.4	32.4
54	34.0	12.6	93.1	93.1	*			

* Uplink C/N_o limited

TABLE A-18 12/14 GHz - TWO FM VIDEO CARRIER PER TRANSPONDER

With Uplink Power Control

Single Carrier Saturation Flux Density = -81 dBW/m^2

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	14.4	2.6	88.8	96.1	89.7	28.6	25.6	22.6
38	15.4	3.1	89.2	96.1	90.2	29.1	26.1	23.1
40	16.7	3.8	89.5	96.1	90.5	29.4	26.4	23.4
42	18.2	4.6	89.9	96.1	91.1	30.0	27.0	24.0
44	20.0	5.5	90.3	96.1	91.6	30.5	27.5	24.5
46	22.1	6.6	90.7	96.1	92.2	31.1	28.1	25.1
48	24.6	7.8	91.2	96.1	92.9	31.8	28.8	25.8
50	27.6	9.4	91.7	96.1	93.6	32.5	29.5	26.5
52	31.0	11.1	92.2	96.1	94.5	33.4	30.4	27.4
54	34.0	12.6	93.1	96.1	96.1	35.0	32.0	29.0

TABLE A-19 12/14 GHz - TWO FM VIDEO CARRIERS PER TRANSPONDER:

Without Uplink Power Control

Single Carrier Saturation Flux Density = -87 dBW/m^2

						REQUIRED G/T dB/°K		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	13.5	2.1	92.6	90.1	*			
38	14.4	2.6	92.8	90.1	*			
40	15.4	3.1	93.2	90.1	*			
42	16.7	3.8	93.5	90.1	*			
44	18.2	4.6	93.9	90.1	*			
46	20.0	5.5	94.3	90.1	*			
48	22.1	6.6	94.7	90.1	*			
50	24.7	7.9	95.2	90.1	*			
52	27.6	9.4	95.7	90.1	*			
54	31.0	11.1	96.2	90.1	*			

* Uplink C/N_o limited

TABLE A-20 12/14 GHz - TWO FM VIDEO CARRIERS PER TRANSPONDER

Without Uplink Power Control

Single Carrier Saturation Flux Density = -84 dBW/m^2

						REQUIRED G/T dB^oK		
S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	EIRP=44	EIRP=47	EIRP=50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	13.5	2.1	92.6	93.1	101.9	40.8	37.8	3.48
38	14.4	2.6	92.8	93.1	104.9	43.8	40.8	37.8
40	15.4	3.1	93.2	93.1	*			
42	16.7	3.8	93.5	93.1	*			
44	18.2	4.6	93.9	93.1	*			
46	20.0	5.5	94.3	93.1	*			
48	22.1	6.6	94.7	93.1	*			
50	24.7	7.9	95.2	93.1	*			
52	27.6	9.4	95.7	93.1	*			
54	31.0	11.1	96.2	93.1	*			

* Uplink C/N_o limited

TABLE A-21 12/14 GHz - TWO FM VIDEO CARRIERS PER TRANSPONDER:

Without Uplink Power Control

Single Carrier Saturation Flux Density = -81 dBW/m^2

S/N	B_{CR}	ΔF_V	$(C/N_o)_t$	$(C/N_o)_u$	$(C/N_o)_d$	REQUIRED G/T dB/°K		
						EIRP=44	EIRP=47	EIRP-50
dB-wtd	MHz	MHz-pk	dB-Hz	dB-Hz	dB-Hz	dBW	dBW	dBW
36	13.5	2.1	92.6	96.1	95.1	34.0	31.0	28.0
38	14.4	2.6	92.8	96.1	95.6	34.5	31.5	28.5
40	15.4	3.1	93.2	96.1	96.3	35.2	32.2	29.2
42	16.7	3.8	93.5	96.1	96.9	35.8	32.8	29.8
44	18.2	4.6	93.9	96.1	97.8	36.7	33.7	30.7
46	20.0	5.5	94.3	96.1	98.9	37.8	34.8	21.8
48	22.1	6.6	94.7	96.1	100.4	39.3	36.3	33.3
50	24.7	7.9	95.2	96.1	102.4	41.3	38.3	35.3
52	27.6	9.4	95.7	96.1	106.0	44.9	41.9	38.9
54	31.0	11.1	96.2	96.1	*			

* Uplink C/N_o limited

APPENDIX B

THIS SECTION CONTAINS A LIST OF THE EARTH STATION SUBSYSTEM MANUFACTURERS CONTACTED DURING THE MAIL CAMPAIGN.

TABLE B-1

LIST OF EARTH STATION SUBSYSTEM MANUFACTURERS CONTACTED.

COMPANY	ANTENNA	LNA	RECEIVER	RESPONSE STATUS	
				NEGATIVE	POSITIVE
Andrew Antenna	X				X
Ancom, Inc	X			X	
Collins Radio	X		X	X	
E-Systems Inc	X			X	
Commco Inc	X				X
Northern Elec.		X	X		X
Avantek		X			X
Amplica Inc		X			X
Watkins Johnson		X		X	
Comtech Labs		X	X	X	
AIL Div Cutler Hammer		X	X	X	
LNR Comm. Inc		X			X
RCA Ltd	X		X	X	
Prodelin Inc	X				X
Radio Mech. Struct.	X			X	
Hughes Aircraft	X	X	X	X	
Rantec Div	X			X	
Delta Benco Cascade			X	X	
Raytheon Canada			X	X	
Radiation Sys. Inc.	X				X
SED Sys. Ltd.			X		X
Microdyne			X		X
Scientific Atlanta	X		X		X
Scientific Atlanta (Canada)	X		X	X	
Varian Assoc		X			X
ITT Comm.Div (Canada)	X	X	X		X
Aeroneutronic Ford	X	X	X	X	
AII Systems	X	X	X		X
Westinghouse Elec			X		X
General Electric	X	X	X		X
GTE Sylvania	X		X	X	
Com Dev		X		X	
California Microwave			X		X

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TABLE B-1 (Cont'd)

COMPANY	ANTENNA	LNA	RECEIVER	RESPONSE STATUS	
				NEGATIVE	POSITIVE
Ferranti Ltd		X		X	
<u>DIGITAL TV EQUIPMENT</u>					
Sumitomi Shoji (NETEC)					X
Comsat Labs (DITEC)				X	
Nissho Iwai America (Fujitsu)				X	

--A STUDY OF THE COST/PERFORMANCE TRADEOFFS FOR REGIONAL TELEVISION DISTRIBUTION VIA SATELLITE : FINAL REPORT.