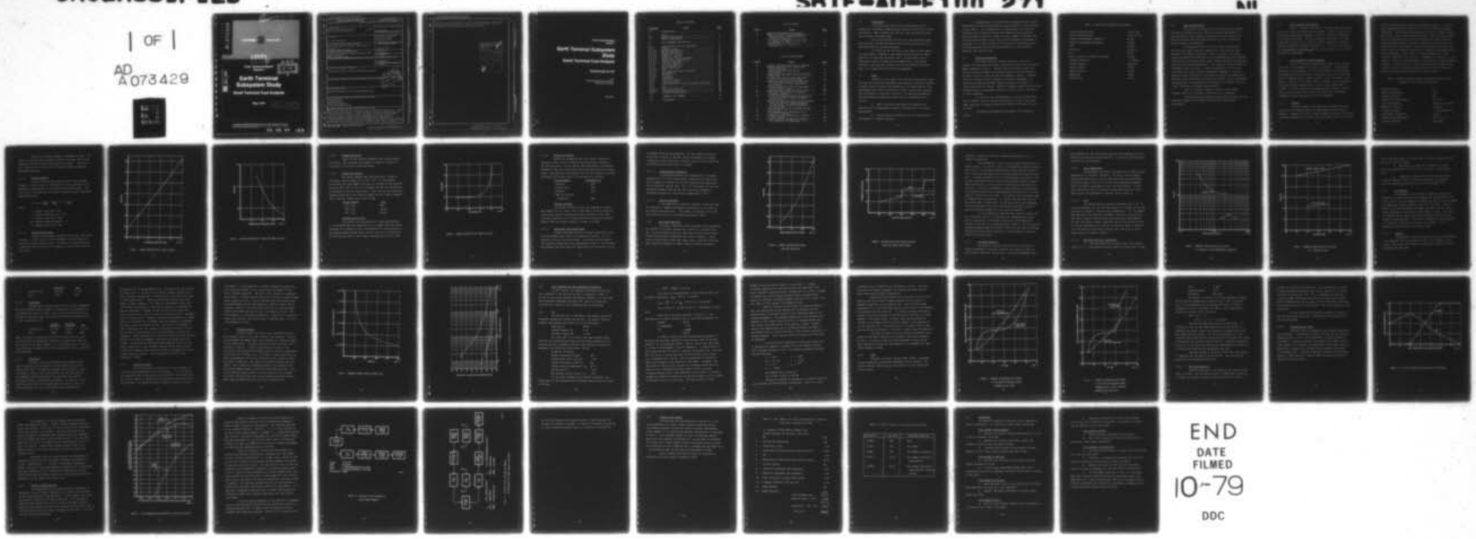
AD-A073 429 COMPUTER SCIENCES CORP FALLS CHURCH VA F/G 17/2.1
EARTH TERMINAL SUBSYSTEM STUDY. VOLUME 1 - SMALL TERMINAL COST --ETC(U)
MAY 79 R WINEBARGER DCA100-76-C-0089

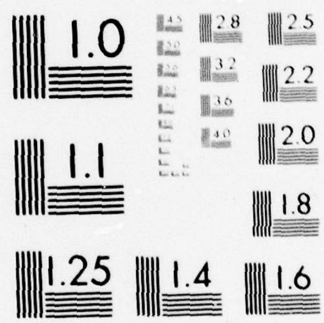
UNCLASSIFIED SBIE-AD-E100 271 NL

| OF |

AD
A073429



END
DATE
FILMED
10-79
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-E100 271

LEVEL III

Final Technical Report
Volume 1

Earth Terminal Subsystem Study

Small Terminal Cost Analysis

May 1979

HARRIS CORPORATION Government Systems Group
Communications Systems P.O. Box 37, Melbourne FL 32901 (305) 727-4000

UNCLASSIFIED, R420, 26 July 1979

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Earth Terminal Subsystem Study. Small Terminal Cost Analysis A073356		5. TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mr. Ross Winebarger		8. CONTRACT OR GRANT NUMBER(s) DCA 100-76-C-0089 Subcontract S-165
9. PERFORMING ORGANIZATION NAME AND ADDRESS Harris Corporation, Government Systems Group P.O. Box 37 Melbourne, Florida 32901		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Task No. 0211
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Communications Engineering Center, R420 1860 Wiehle Avenue Reston, Virginia 22090		12. REPORT DATE May 1979 13. NUMBER OF PAGES 49
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Review relevance five years from submission date.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Earth Terminals
Earth Stations
Satellite Terminals
Satellite Communications

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report addresses the cost sensitivities of the major components of a small economical earth terminal. A baseline X-band terminal is proposed which has a G/T of 20 dB and an EIRP of 72 dBW. Parametric curves are developed which show the changes in hardware cost corresponding to moderate changes in component characteristics around the baseline values. Parametric cost curves are developed for changes in the antenna diameter, RMS surface accuracy, antenna efficiency, antenna wind performance, transmitter power, type of low-noise (over)

405 717

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) cont

amplifier, oscillator stability, and phase noise performance. Cost data is then developed and presented for changes in the terminal G/T, EIRP, and availability around the baseline terminal performance.

Final Technical Report
Volume 1

Earth Terminal Subsystem Study

Small Terminal Cost Analysis

Subcontract S-165

For
Computer Sciences Corporation
Falls Church, Virginia

May 1979

10677

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1.0 Introduction

This report describes the work performed by Harris Corporation, Government Communications Systems Division (Harris GCSD) on Subtask 1, Small Terminal Cost Analysis under Subcontract S-165, Earth Terminal Subsystem Study.

This study provides the basic for cost evaluating small earth terminal designs and allows cost sensitivity analysis to be performed based on selected parameters.

The source of the cost data is the result of the cumulative experience of experts in each design area coupled with vendor quotes on off-the-shelf purchased items. In each major area of technology a panel of experts were assembled and, to the extent practical, cost data was arrived at by the same process that would apply if a response to an RFP was being generated.

1.1 Scope

Included in this report are cost versus performance trade-offs and the various key components that comprise a satellite terminal. A nominal overall terminal performance that is representative of the performance that might be required of a small terminal was selected. This performance is outlined in Section 1.2 - Baseline Assumptions. The key questions addressed in preparing this information are as follows:

- What is the most cost-effective selection and specification of components to achieve a desired level of terminal performance?
- Do any major cost benefits accrue if the baseline performance is slightly altered?

The methodology for determining the communications systems requirements and deriving subsequent system parameters is not addressed in this report. It is assumed that a system analysis has been performed and that system performance requirements based on capacity, satellite power allocations, number of users, number of terminals and link margin requirements led to the baseline assumptions presented in Paragraph 1.2. A cost estimate for this baseline system design will be established and then the design parameters will be modified to determine cost sensitivities.

1.2 Baseline Assumptions

The nominal baseline terminal should be a low cost terminal that provides performance consistent with the list of requirements presented in Table 1. Ground rules for costing are that the terminal should be capable of operation without on-site personnel in an existing facility that provides environmental controls. Wherever possible it should utilize standard off-the-shelf equipment. It should not be made excessively rugged and need not be capable of rapid installation or removal. Based on customer guidance the recurring hardware costs in procurement quantities of 100 is used as the basis for cost estimates.

For availability considerations it has been assumed that 20% of terminal failures require the services of an off-site repair team, resulting in a mean-time-to-repair (MTTR) of 48 hours for such failures.

The baseline performance requirements are presented in Table 1.

Table 1. Baseline Performance Requirements

Transmit Operating Band	7.9-8.4 GHz
Receive Operating Band	7.25-7.75 GHz
Transmit Instantaneous Bandwidth	40 MHz
Receive Instantaneous Bandwidth	40 MHz
EIRP	72 DBW
HPA Rating	500 Watts
G/T	20 dB
Uplink Spurious (including intermods)	-40 dB
Frequency Stability	1×10^{8}/Day
Antenna Tracking	Steptrack
Transmit AM/PM	10^{o}/dB
Modem Interface	70 MHz
Modem Type	UMSTED
Availability	0.994

1.3 Report Organization

This report is divided into four sections; the introduction which concludes with this section on report organization, a section entitled "Cost Tradeoffs and Analysis" which presents the data and analysis that have been carried out on this study and a section containing conclusions.

The second section is in turn divided into two parts. THe first part deals with cost tradeoffs for individual key components of the satellite terminal. Sets of curves of cost versus various parameters and specifications are developed for each component. These curves are based on recent vendor quotes, designer estimates and historical data and extrapolations. The second part uses the material presented in the first part in order to determine a set of curves indicating cost versus terminal performance parameters. The goals here are first to determine if the baseline terminal performance has been most cost effectively provided by the nominal choice of components. The second goal is to determine the sensitivity of terminal costs to slight variations in terminal specifications.

The third section presents a terminal cost summary. Terminal costs as a function of availability are presented.

The fourth section presents conclusions and summarizes the desirable changes to the nominal terminal specification and performance.

2.0 Cost Tradeoffs and Analysis

The cost tradeoffs and analysis that have been carried out during this study are divided into two areas. Section 2.1 deals with cost versus performance tradeoffs for each of several key components of a satellite terminal. The data presented in Section 2.1 is then processed in Section 2.2 in order to provide information on overall terminal performance parameters versus cost. In all the cost analysis, only per terminal, recurring costs for an acquisition of a lot of 100 terminals is considered.

2.1 Cost Tradeoffs on Key Components

Each of the seven paragraphs that comprise this section deals with a key component of a satellite terminal. The components considered are the antenna, HPA, LNA, RF components (those between the antenna and the HPA and LNA), converters, local oscillators and primary frequency source. Modem tradeoffs are not addressed in this report as the use of the UMSTED modem is assumed. For the purpose of providing complete terminal costs, a cost for the UMSTED modem is assumed. For each component, the presented data attemps to characterize the cost sensitivity of both the significant performance parameters and the characteristics of the component.

2.1.1 Antenna

There are numerous cost/performance tradeoffs that can be carried out regarding satellite communication ground terminal antennas. Somewhat arbitrarily, these tradeoffs have been partitioned into those impacting gain, those impacting antenna motion or pointing and those impacting other antenna performance parameters. This paragraph addresses the cost sensitivity for each of these performance parameters. Those impacting antenna gain consist of antenna diameter, rms surface accuracy and antenna efficiency. Those impacting antenna motion or pointing consist of the configuration of axes, extent of required motion, method of tracking, required tracking accuracy and operational wind requirements. Other miscellaneous performance parameters consist of antenna aperture noise temperature and generation of passive intermods. Since several of these parameters are interrelated, a meaningful cost analysis is dependent on examining the cost impact of varying a single parameter while holding all other parameters constant. To facilitate this, the following nominal parameters presented in Table 2 have been selected consistent with the precept of examining cost-effective antennas for a small terminal.

Table 2. Nominal Terminal Antenna Parameters/Characteristics Selected for Cost Sensitivity Analysis

Antenna Diameter	12'
RMS Surface Accuracy	.030"
Antenna Efficiency	60%
Window for Tracking Motion	10^{o} x 10^{o}
Axis Configuration	Traverse - Elevation
Method of Tracking	Steptrack
Tracking Accuracy	<.75 dB signal loss
Operational in Winds of:	45 mph
Antenna Noise Temperature	45^{o} K at 7.5^{o}
Passive Intermods	Acceptable

The cost for nominal antenna is estimated at \$30K. This total cost results from estimates of \$6K for the feed, \$3K for the reflector, \$6K for the servo and \$15K for the mount. These costs were finalized in a "final pricing" meeting attended by Antenna Department personnel.

2.1.1.1 Antenna Diameter

Figure 1 plots antenna subsystem cost versus antenna diameter. In this plot, all characteristics and parameters of the antenna are held constant to the nominal values shown above. The cost curve is derived from the following expression which represents approximate costs.

$$C = (F + S)\left(\frac{D}{D_o}\right) + M\left(\frac{D}{D_o}\right)^{1.2} + R\left(\frac{D}{D_o}\right)^{2}$$

where:

F = Nominal feed cost = \$6K

R = Nominal reflector cost = \$3K

M - Nominal mount cost = \$15K

Do = Nominal antenna diameter = 12'

S = Nominal servo cost = \$6K

2.1.1.2 RMS Surface Accuracy

Figure 2 plots antenna subsystem costs versus RMS surface accuracy. In this plot, all other parameters and characteristics are held to their nominal values. The change in total antenna subsystem cost results strictly from changes in the reflector fabrication costs.

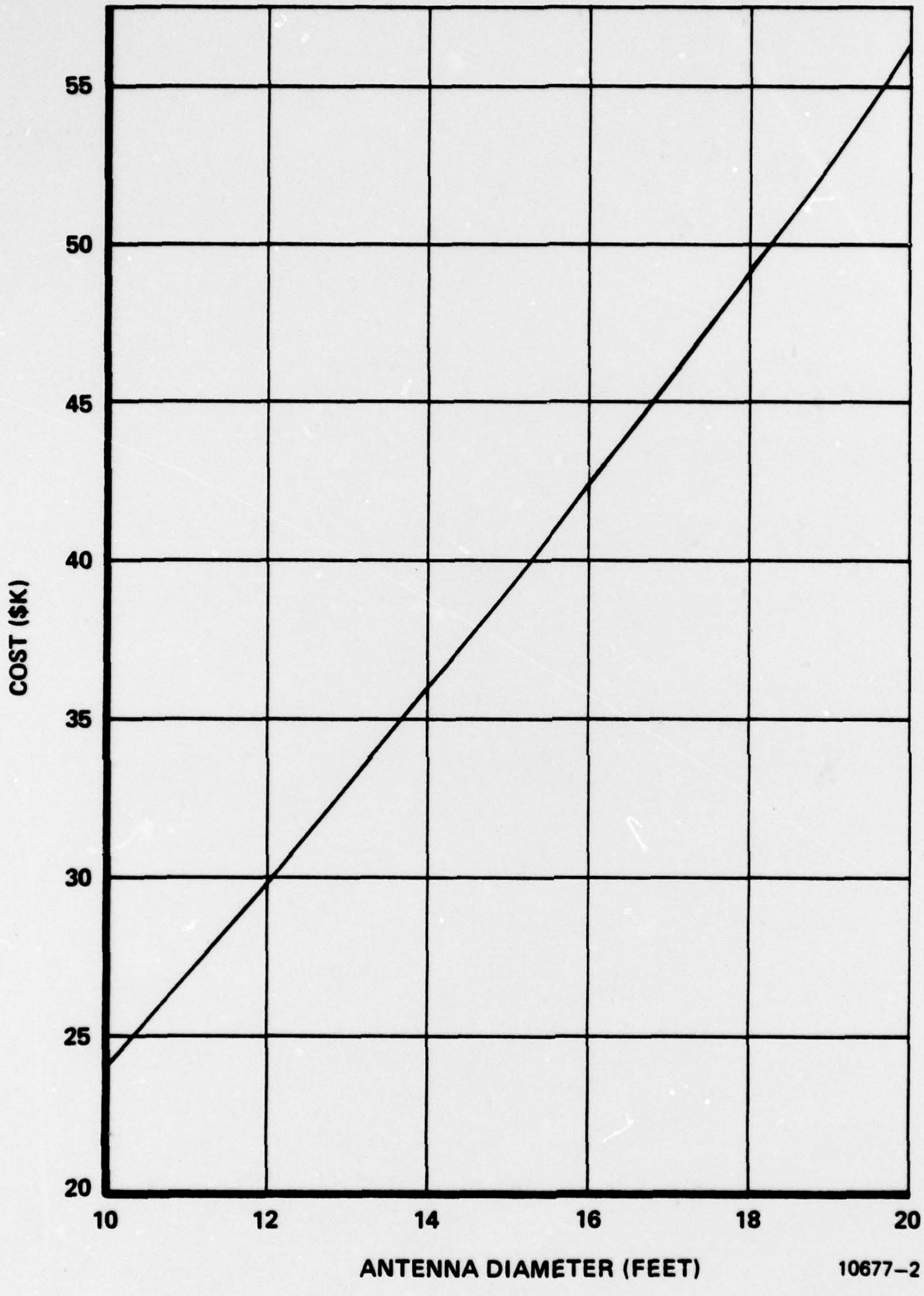


FIGURE 1 - ANTENNA SUBSYSTEM COSTS VERSUS DIAMETER

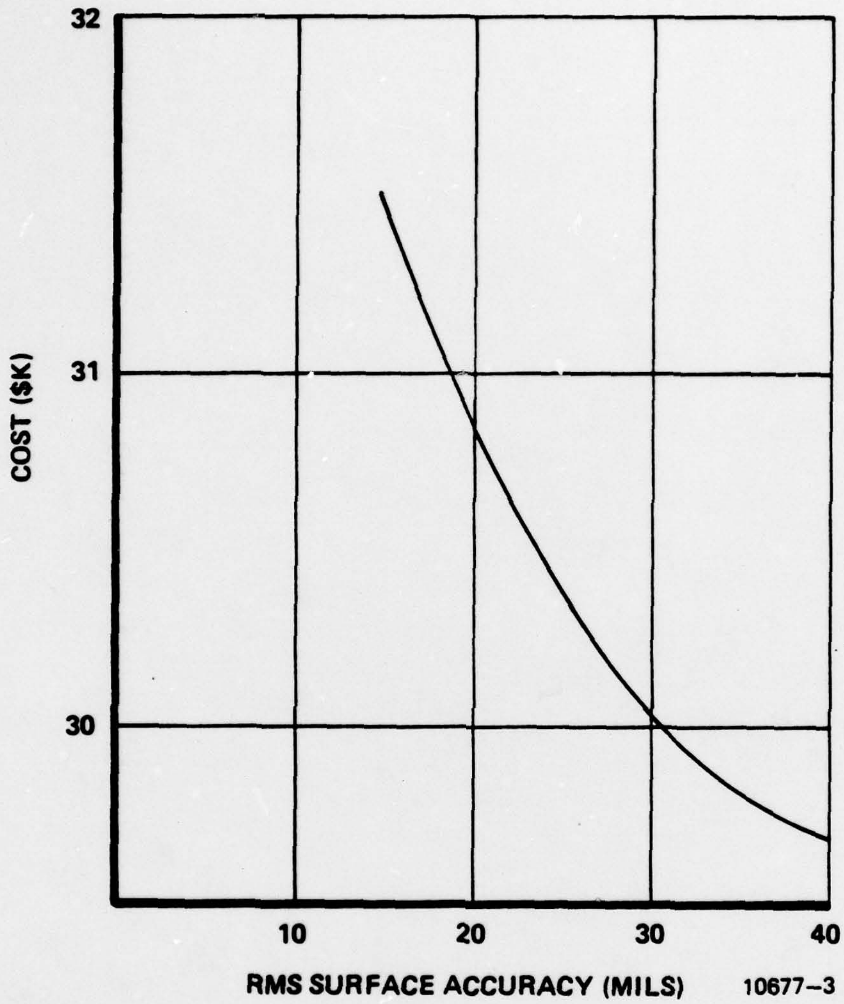


FIGURE 2 - ANTENNA SUBSYSTEM COSTS VERSUS RMS SURFACE ACCURACY

2.1.1.3 Antenna Efficiency

Figure 3 plots antenna subsystem costs versus antenna efficiency. The subsystem cost change is primarily a result of variations in the cost of feed fabrication.

2.1.1.4 Window for Tracking

The nominal antenna described above has a window of continuous tracking capability of $10^\circ \times 10^\circ$. For the nominal operational wind requirement of 45 mph, an increase in the required window to $20^\circ \times 20^\circ$ or $30^\circ \times 30^\circ$ increases the cost of the mount by an estimated 5% and 10% respectively. Thus, the cost for the entire antenna system versus the tracking window size (all other parameters held to nominal values) would be as follows:

Tracking Window	Cost
$10^\circ \times 10^\circ$	$30K
$20^\circ \times 20^\circ$	$31.5K
$30^\circ \times 30^\circ$	$33.0K

Configuration of Axis

The nominal axis configuration is traverse-elevation. It is estimated that the selection of an x-y mount would not impact subsystem cost (because of the limited motion) but the selection of an azimuth-elevation mount would increase the cost of the mount by 10% and thus the cost of the antenna subsystem would rise to $33K.

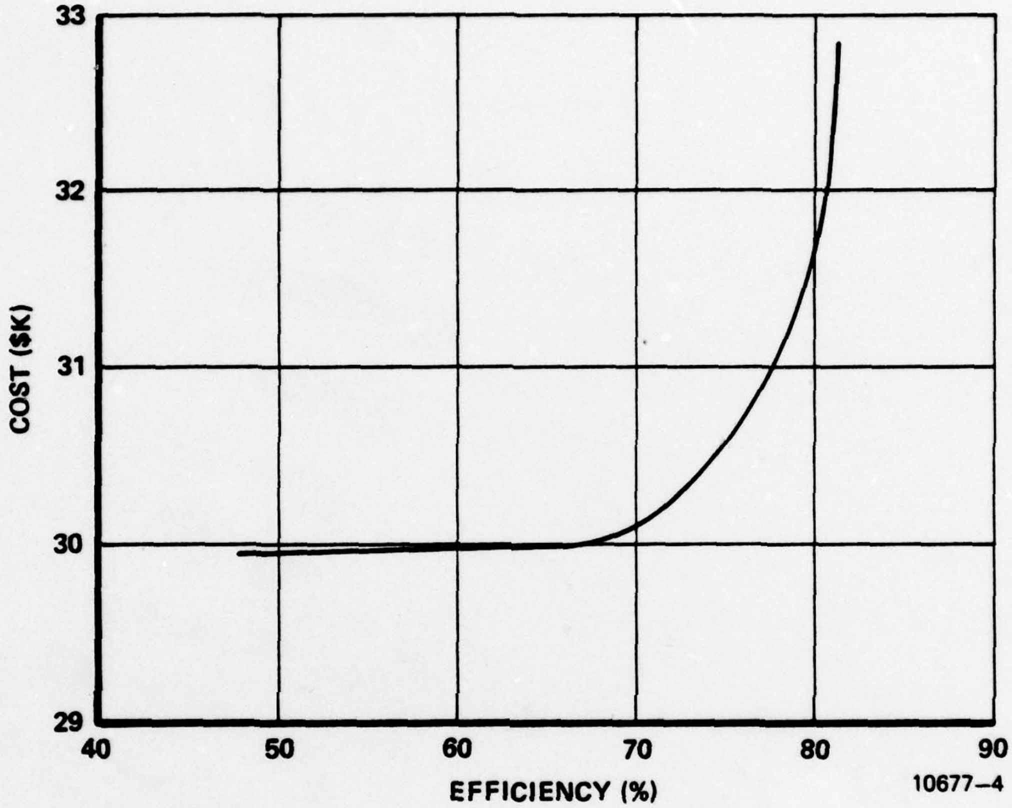


FIGURE 3 - ANTENNA SUBSYSTEM COSTS VERSUS EFFICIENCY

2.1.1.5 Method of Tracking

Making the assumption that some form of tracking is required, limits the cost effect of tracking method selection to the feed and servo. Had no tracking been considered, a substantial decrease in the cost of the mount would have been possible as shown below. The subsystem cost estimates for the three types of tracking considered and for the case of no tracking are as follows:

Tracking Method	Subsystem Cost
Steptrack	$30K
Program Track	$42K
Monopulse	$60K
None (no tracking capability)	$15K

Tracking Accuracy

The nominal tracking accuracy was assumed to provide a 96% probability of a signal loss of less than 0.75 dB at signal to noise ratios capable of maintaining the required bit error rate. Tracking system cost will increase rapidly for tracking accuracies greater than this nominal accuracy in winds of 45 mph.

2.1.1.6 Operational Wind Requirement

Antenna subsystem costs are extremely sensitive to the wind environment under which the antenna must perform. This is especially true for very high winds. An analysis was not carried out regarding radome costs but unquestionably there is a point where wind becomes the overriding cost determinent and, therefore, the use of radomes would be cost-effective. For the range of wind gust velocities of 40 mph to 160 mph, Figure 4 estimates cost impact. A steptrack system providing a tracking accuracy of 0.75 dB at the indicated wind gust velocities is assumed.

2.1.1.7 Antenna Noise Temperature

In considering antenna noise temperature, it becomes apparent that if all the other nominal parameters are fixed there are no degrees of freedom left by which antenna noise temperature can be traded off against cost. At a 7.5^{o} look angle and the given operating frequency band and the other specified parameters, a reasonable estimate for antenna noise temperature is 45^{o} K.

2.1.1.8 Passive Intermods

If the generation of passive intermods in both the feed and reflector is deemed unacceptable, there would be an impact on the antenna subsystem costs. This impact is estimated to be $10K, thus raising the cost of the antenna subsystem to $40K.

2.1.2 High Power Amplifier

Two types of amplifiers were considered viable candidates for the HPA in the small terminal cost analysis, a klystron and a TWT. Curves estimating costs for both entire klystron based transmitters and TWT based transmitters are given in Figure 5. These curves include costs of the tube, power supply, required filtering, power monitoring capability, power control circuitry, necessary

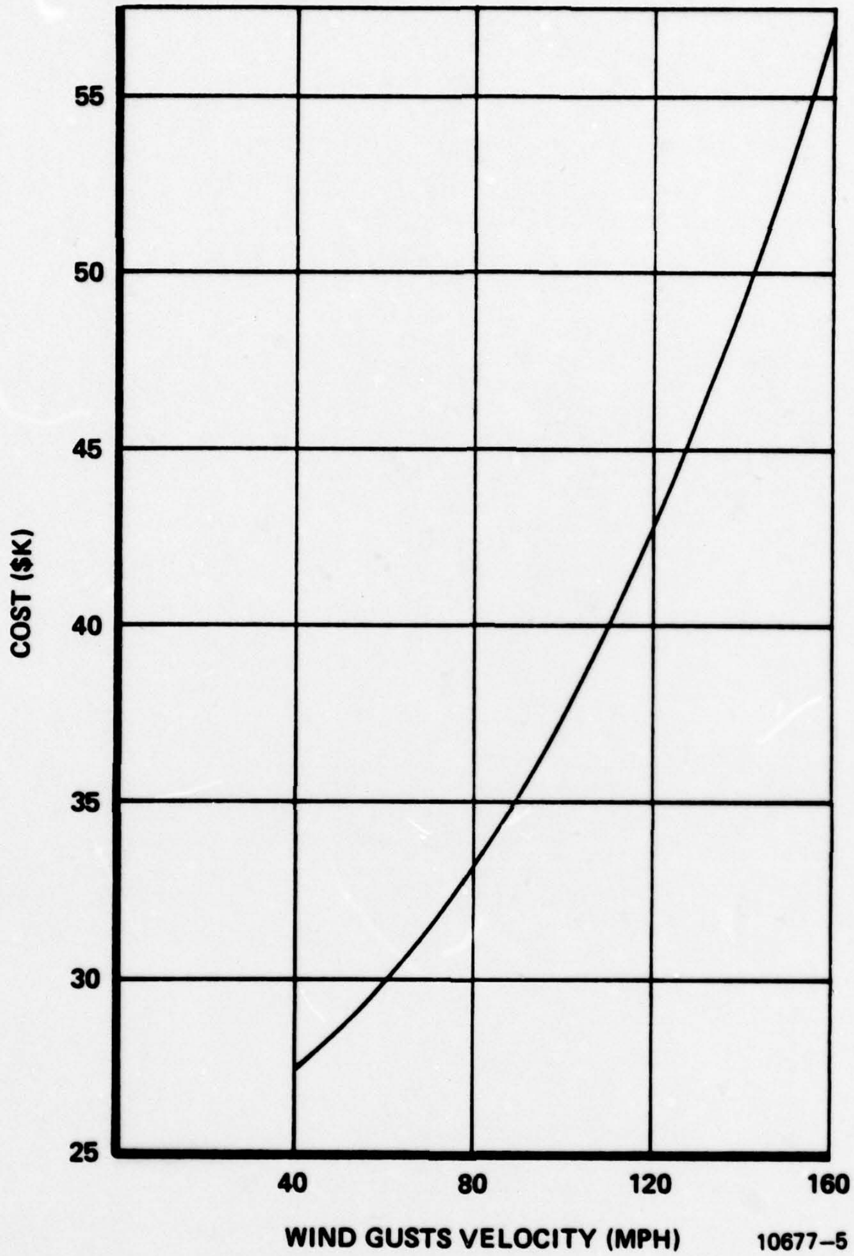


FIGURE 4 - ANTENNA SUBSYSTEM COSTS VERSUS
WIND GUST VELOCITIES

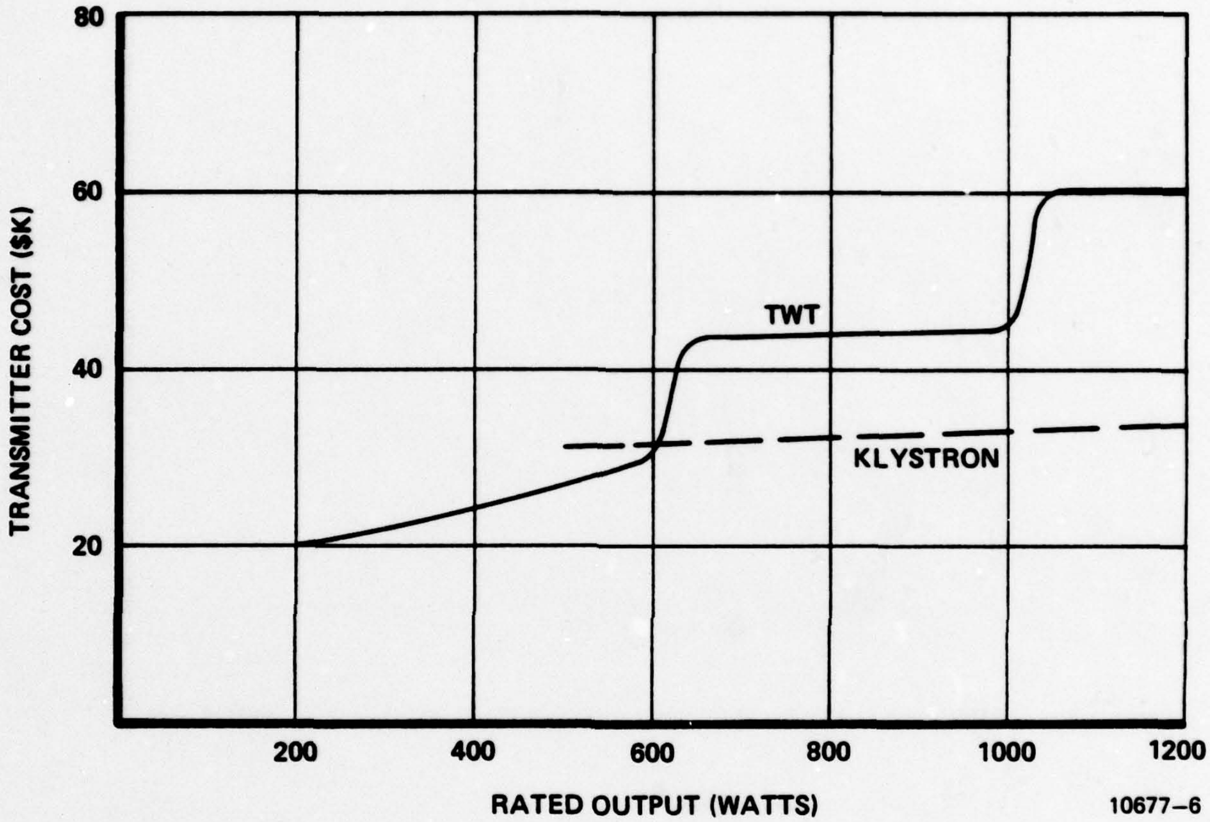


FIGURE 5 - KLYSTRON AND TWT HIGH POWER AMPLIFIER COSTS FOR VARIOUS OUTPUT POWERS

isolators, protective circuitry, cabinet and bracketry (i.e., a complete transmitter).

The breakpoints in the curves have been estimated from a vendor survey. For the TWT, there is a breakpoint at about 600 watts since this is the maximum output available from a helical type TWT. TWT's rated above 600 watts are of the more expensive coupled cavity type. A second breakpoint exists at approximately 1 KW which is the maximum rated tube using air cooling and permanent magnet focusing. Tubes rated above a 1.0 KW are water cooled and use a solenoid for focusing. A third cost breakpoint, necessitated by a significantly more expensive tube exists at approximately 6.0 KW but is out of the range of interest for this study. The klystron over the power range of interest has no breakpoints. As can be seen from the curves at the nominal 500 W output level, the TWT has a small cost advantage. The cost advantage of the TWT is maintained until 600 W at which point the klystron becomes the less costly alternative.

It is worthwhile to note that the curves of Figure 5 do not include the cost of a driver amplifier (approximately $2.5K) which is necessary in the nominal terminal to drive either the klystron or the TWT to a saturated output of 500 W. Had the required terminal bandwidth been only 20 MHz, sufficient gain could have been achieved from the klystron resulting in the avoidance of the additional cost of the driver.

2.1.3 <u>Low Noise Amplifier</u>

Two types of low noise amplifiers were considered as viable candidates for the small terminal cost analysis; they are the parametric amplifier and the FET. The two key parameters that were examined for cost sensitivity were the noise temperature of the amplifier and the gain of the amplifier. In addition some peripheral cost data was also obtained.

2.1.3.1 Noise Temperature

The parametric amplifiers considered had a range of noise temperatures of from 30^{o} K to 250^{o} K. The cost of these paramps ranged from $50K to $11K. The FET amplifiers that were considered had noise figures of 2.6 dB to 4.0 dB (noise temperatures between 238^{o} K and 439^{o} K) and ranged in cost from $3K to $2.2K. In both cases the nominal gain of the amplifier was specified to be 35 dB. These results are presented in graphical form in Figure 6.

2.1.3.2 Gain

The nominal LNA gain that was considered was 35 dB. As could be expected, cost was far less sensitive to changes in required gain than to changes in required noise temperature. It is estimated that the cost of an LNA with a parametric amplifier providing only the initial stage of amplification would varying by approximately $1K over the range of overall amplifier gain of from 25 dB to 50 dB. For the FET amplifier with a nominal 3.5 dB noise figure a range of gain from 30 dB to 40 dB would increase cost from $2.1K to $2.4K. These results are shown in Figure 7.

2.1.3.3 Additional LNA Cost Information

- The requirement for an exceptionally high dynamic range (i.e., a 1 dB compression point output of greater than +15 dBm)

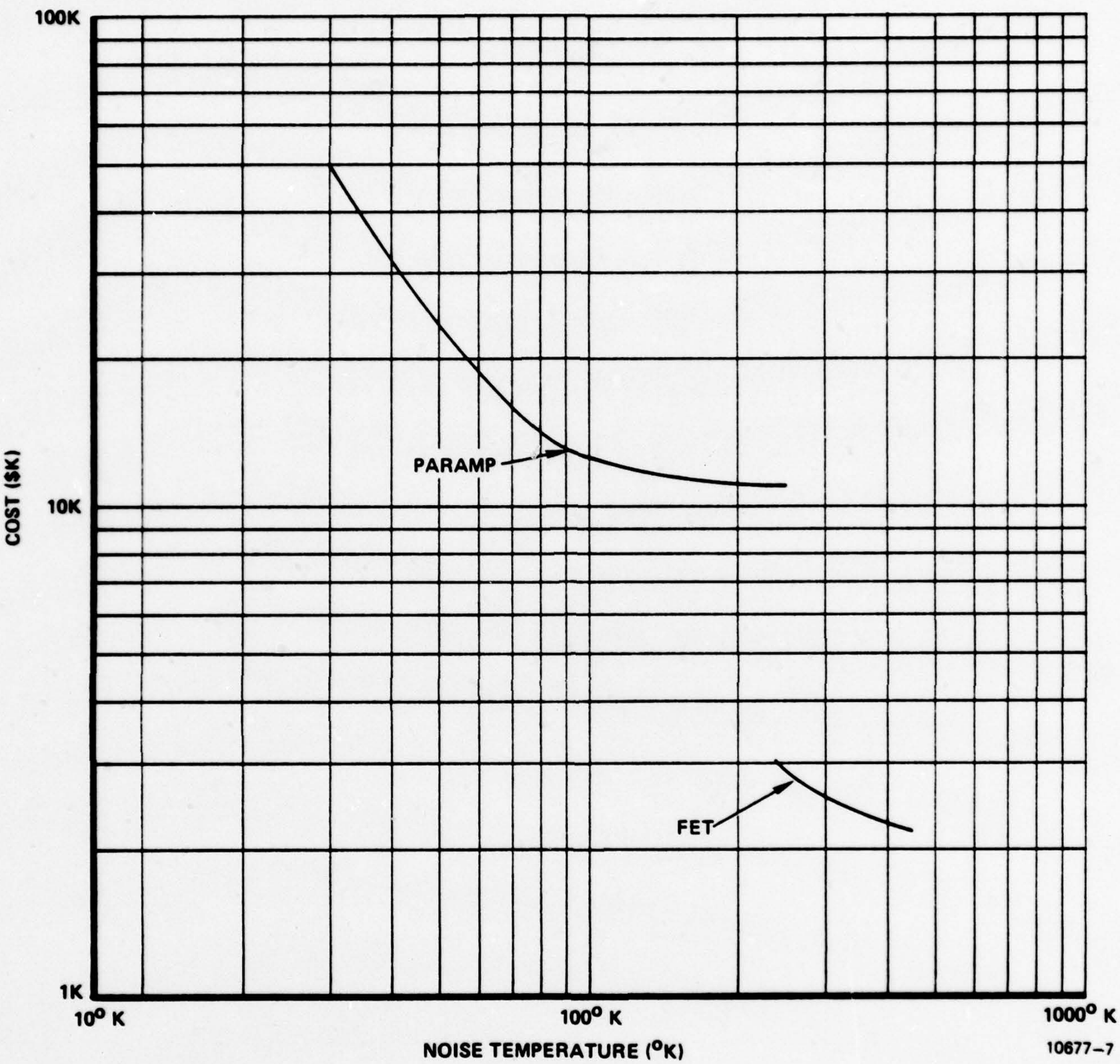


FIGURE 6 - PARAMETRIC AMPLIFIER AND FET LNA COSTS AS A FUNCTION OF NOISE TEMPERATURE PERFORMANCE

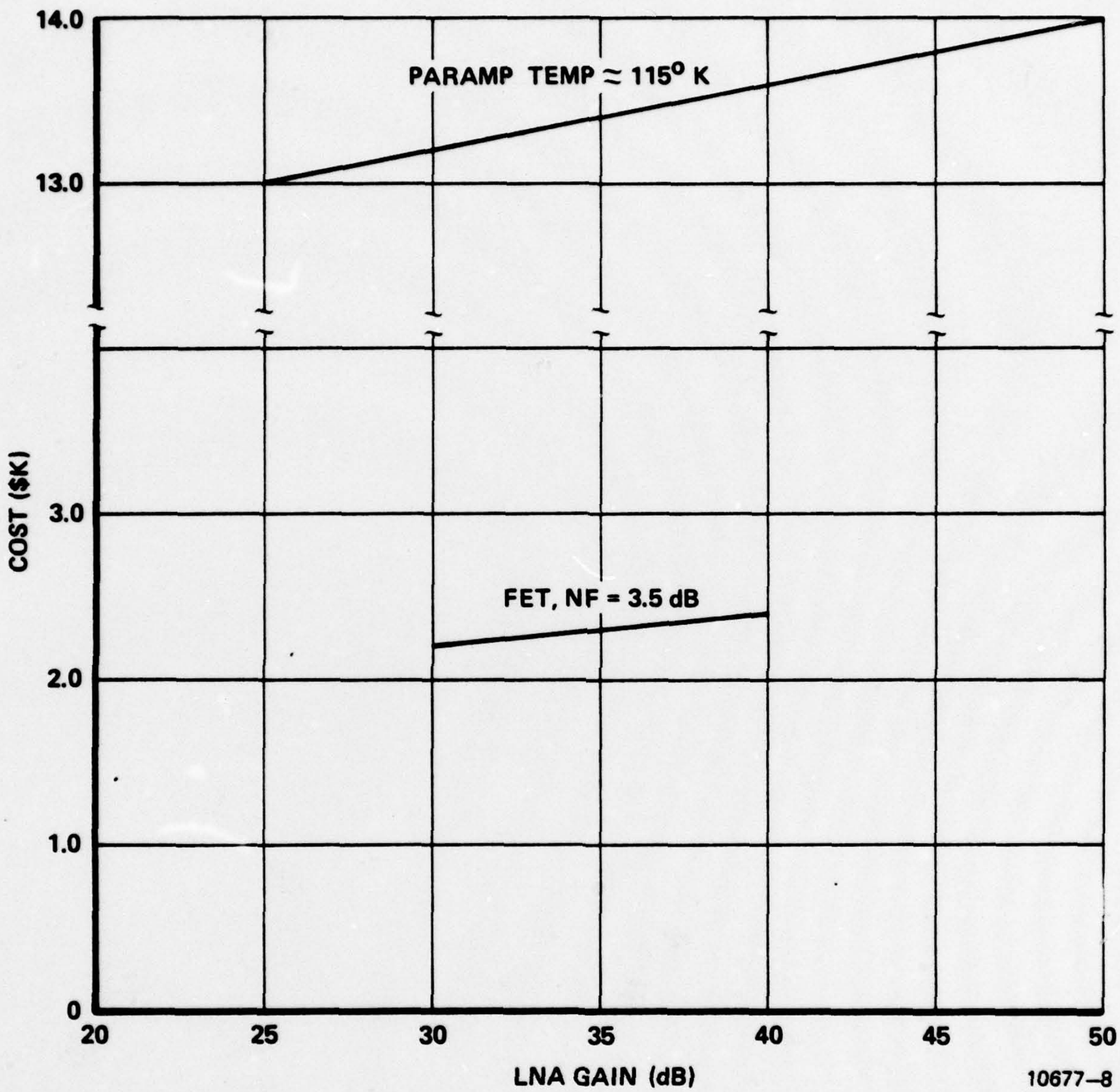


FIGURE 7 - PARAMETRIC AMPLIFIER AND FET LNA COSTS
AS A FUNCTION OF GAIN

for an LNA would result in a significant cost step (perhaps doubling the cost of the FET stages).

- One vendor is producing a cryogenically cooled FET; noise temperature is 80^{0} K to 90^{0} K and cost is approximately $10K.

- Temperature compensation for FET amplifiers adds a cost of $200/unit, but will reduce by about 50%, the change in gain with temperature (estimated to be 0.015 dB/stage/1^{0} C).

2.1.4 RF Components

RF components such as filters, couplers, switches and transmission lines which are placed between the antenna and the LNA in the receive line and between the antenna and the HPA in the transmit line impact key system parameters such as G/T and EIRP. There are several fine grain performance tradeoffs possible, such as linearity versus rejection for both receive and transmit filters. This level of tradeoff however requires more detailed specifications than are currently being addressed. The analysis presented in this paragraph is limited to a cost versus insertion loss tradeoff. This is addressed for both receive and transmit paths.

2.1.4.1 Receiver

The most basic trade involving the front end RF components is to construct them in waveguide or coax. For a nominal filter, coupler, switch and small length of transmission line the following estimates have been made.

	Waveguide	Coax
Insertion Loss	0.50 dB	2.1 dB
Cost	$2150	$550

2.1.4.2 Transmitter

The same basic trade was made for the transmit components with the exception that the length of transmission line between HPA and antenna was taken to be 100'. Also an elliptical guide was considered in addition to the rigid waveguide (WR-137) and coax options for the transmission line.

	Rigid Waveguide	Elliptical Waveguide	Coax
Insertion Loss	2.2 dB	2.5 dB	17.1 dB
Cost	$2500	$2800	$600

NOTE: The ease of installation of the elliptical guide vis-a-vis the WR-137 and the concomitant reduction in installation costs are not included in the above numbers. It is estimated that if installation costs were included the elliptical guide would have a significant cost advantage.

2.1.5 Converters

The basic converter performance specifications that impact converter cost are spectral purity, phase linearity and output power level. In addition secondary characteristics such as the required level of self test and BITE, and the vibration and environmental specifications that the converters must operate through also have a significant cost impact. For example, if the required output level of an upconverter rises above -5 dBm, this necessitates the use of an x-band amplifier and therefore an additional cost of approximately $2.5K. A passive mixer can provide an output level of -10 dBm, but for outputs between -10 dBm and -5 dBm a parametric upconverter is required with a resultant cost impact of approximately $0.5K. Another specification that can have cost impact is phase linearity. For linearity requirements better than $+10^{o}/40$ MHz, equalization is required and the cost of the equalizer must be considered. Probably the most difficult and significant specification to put a dollar value on is spectral purity. Acceptable levels for phase noise, intermods, spurious and harmonics will impact cost, but a complete set of designs would be necessary to determine how cost varied with spectral purity. One basis for estimating is that a projected cost, for converters being built at Harris for NRL which meet an exacting spectral purity requirement, is $22.5K per converter. These converters also include a significant level of BITE, operate in extreme environmental conditions and provide auxiliary outputs. By contrast the converters being supplied on the SC-1 upgrade program have a less stringent spectral purity specification, relaxed environmental specification, no BITE requirements and do not require auxiliary outputs. The projected unit cost for these converters is $10K.

2.1.6 Local Oscillators

The local oscillator function for the up and down converters may be implemented in one of three ways. This is based on the assumption that the conversion are essentially fixed conversions with coarse tunability required only occassionally during the life of the equipment. One method would be to employ a group of discrete oscillators. If the separation in output frequencies between the oscillators was 20 MHz, 25 oscillators would be needed to fully cover a 500 MHz bandwidth. The cost of this approach is estimated to be $12.5K. A second approach would be to utilize a single tunable phase locked oscillator. Such an approach would have poorer phase noise performance but has been used with success on other similar programs at Harris. The oscillator could tune in 5 MHz increments across the 500 MHz band and its cost is estimated at $1.8K. The third approach is a microwave synthesizer. Harris has a synthesizer design that provides 1 kHz tuning across a 500 MHz band. Its cost is estimated to be $10K.

2.1.7 Frequency Source

Various crystal oscillators were considered for use as the frequency source in the small terminal cost analysis. The two key performance parameters that were examined were frequency stability and phase noise. Frequency stability versus oscillator cost is plotted in Figure 8. As can be noted there, the cost of the oscillators varied from $190 to $1000, and the stability performance varied from $\pm 5 \times 10^{-8}$/day to $\pm 1 \times 10^{-10}$/day. Phase noise plots for three representative oscillators along with their respective costs are shown in Figure 9. This data was obtained from more than one vendor. While stability performance versus price appeared to be consistent between vendors, phase noise performance was not. This can be noted on Figure 9 where it can be observed that the $455 oscillator from one vendor had slightly better phase noise performance than the $1000 oscillator had from a second vendor.

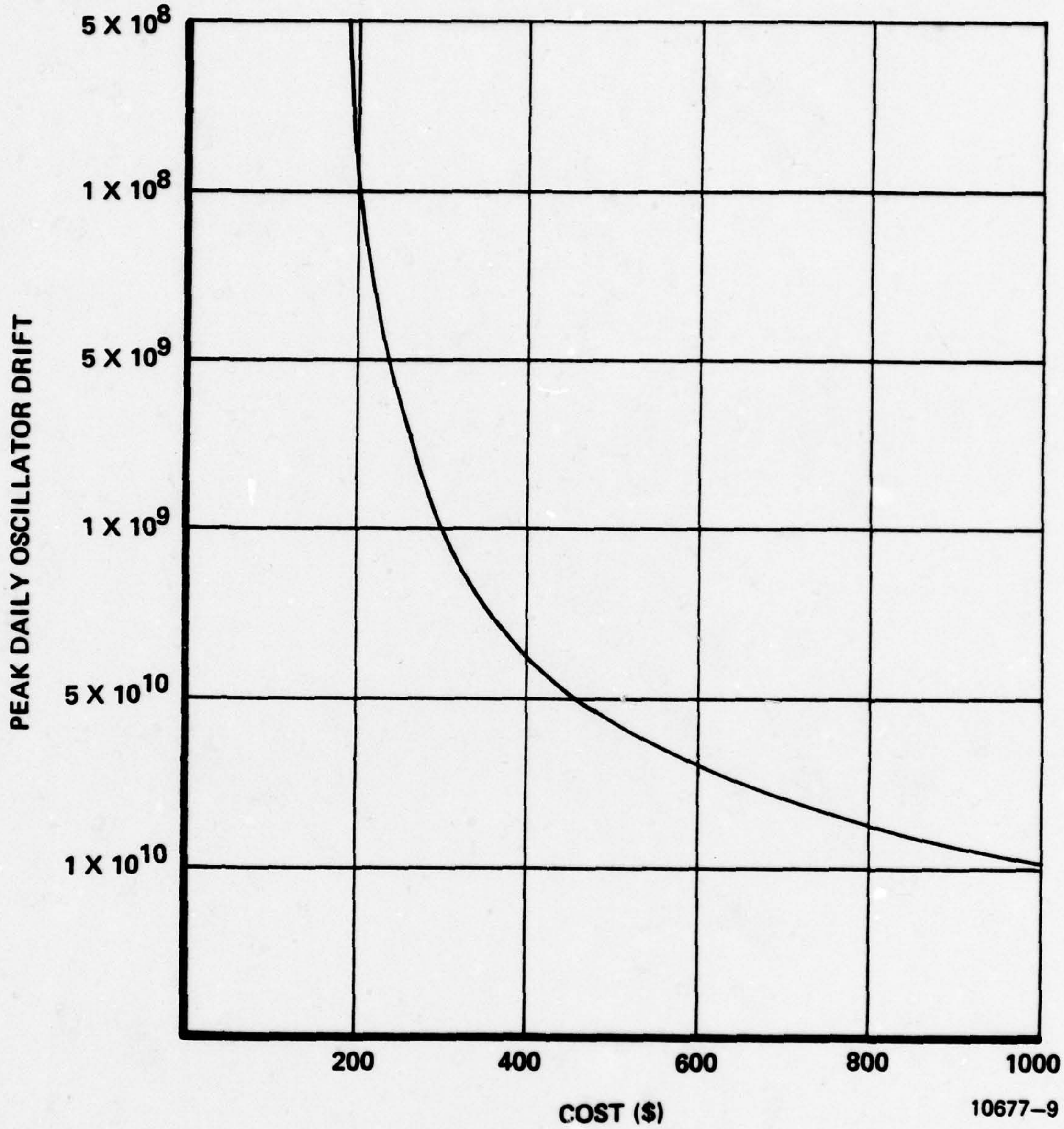


FIGURE 8 - FREQUENCY SOURCE STABILITY VERSUS COSTS

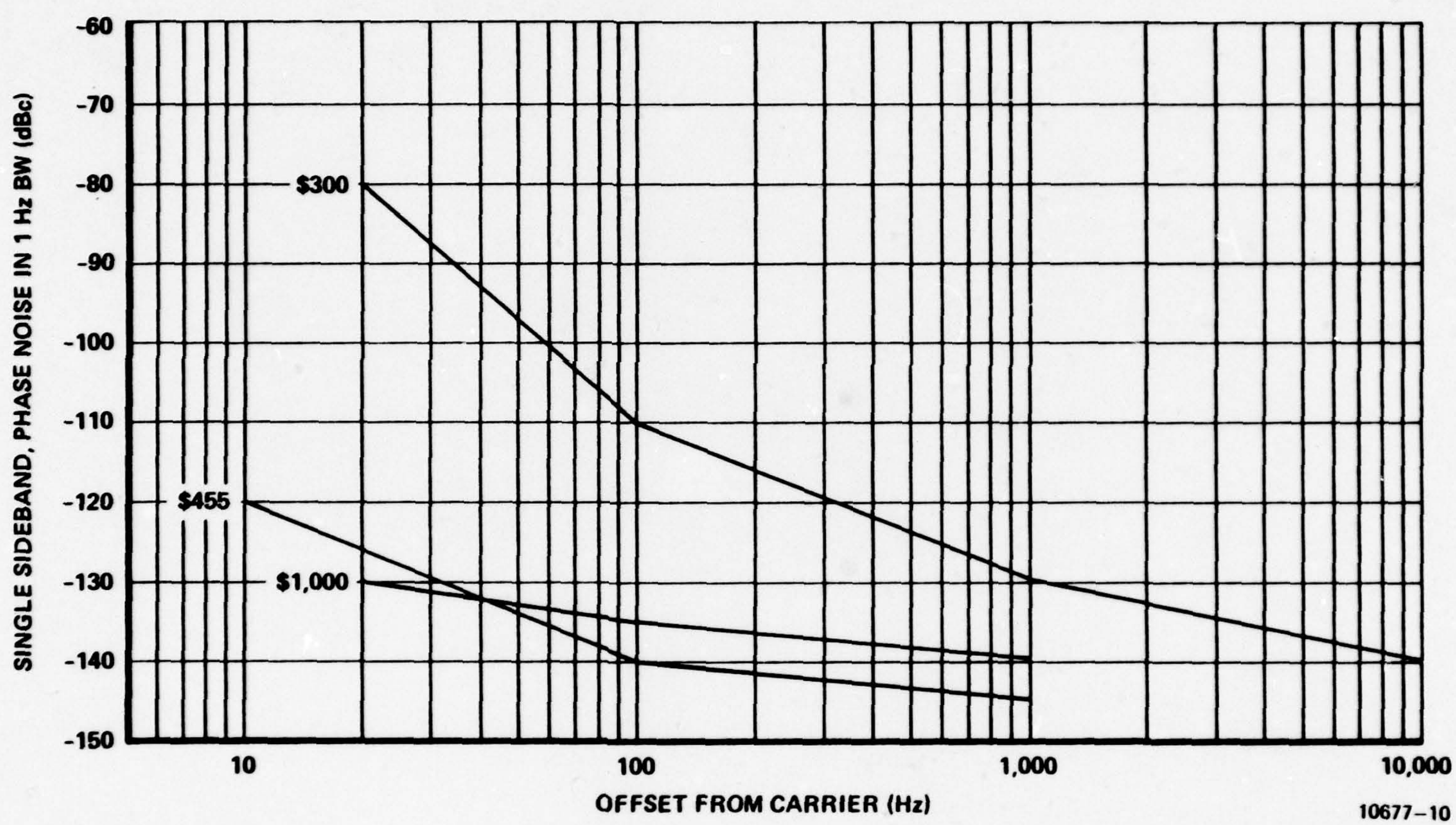


FIGURE 9 - PHASE NOISE PERFORMANCE FOR VARIOUS FREQUENCY SOURCES

2.2 Cost Tradeoffs for Key Performance Parameters

In this section, the component performance versus cost data presented in the previous section is processed in order to arrive at cost versus terminal performance tradeoffs. For the three key performance parameters analyzed (G/T, EIRP and reliability/availability), several of the components must be considered.

2.2.1 G/T

The terminal G/T is impacted by the antenna, LNA and RF components between the antenna and the LNA. The nominal baseline terminal requirements that impact G/T are the following:

Required G/T	20 dB
Antenna Diameter (D)	12 FT
LNA Noise Figure (NF)	3.5 dB

The first task is to confirm that these nominal specifications are consistent and then to use the data presented in the previous section to determine the most cost-effective selection of parameters to achieve the required G/T = 20 dB.

Assume the following:

Antenna aperture efficiency	66%
Antenna feed, ohmic loss (L_F)	.4 dB
Antenna efficiency at OMT (η)	60%
Antenna aperture temperature (T_A)	45° K
Pre LNA loss (L)	.5 dB
RMS antenna surface accuracy (ε)	.030"

For the above assumptions and nominal parameters, the antenna gain at the reference point indicated above can be calculated as follows;

$$G = \eta \left(\frac{\pi n}{\lambda}\right)^2 e^{\left(\frac{4\pi\varepsilon}{\lambda}\right)^2} = 46.43 \text{ dB}$$

The system noise temperature, at the reference point, for an ambient temperature, $T_{AMB} = 325^{o}$ K, is given by

$$T_{SYST} = \frac{T_A}{L_F} + (L-1)\, T_{AMB} + (NF-1)\, T_o L = 26.85 \text{ dB}^{o} \text{ K}$$

Thus system G/T = 19.58 dB which is a reasonable starting point.

Referring to the data presented in Section 2.1, the contributions to overall terminal cost for the three components are:

Antenna	\$30.0K
RF Components	2.15K
FET	2.35K
	\$34.5K

In order to select the most cost-effective approach in achieving the required additional 0.5 dB one must refer to the data presented in the preceding section. There it can be seen that there is no room for improvement in the RF components. To achieve the 0.5 dB increase through the LNA only, requires an LNA NF=3.2 dB. From the LNA cost curve, it can be seen that an FET with this noise figure has a projected cost of \$2.5K. Thus the additional 0.5 dB performance can be bought in this manner for only \$150. If however, the additional 0.5 dB was to be achieved via increased antenna gain the options are an increased efficiency, better surface accuracy, increased antenna size or some combination of the three. If nothing changes but antenna efficiency the 0.5 dB can be made up by an increase of from 60% to 67.6% in efficiency. The cost estimate for this change, as can be noted on Figure 3 is negligible. A change in surface accuracy alone could not achieve the required 0.5 dB, since a perfect surface would only increase gain by .23 dB. A change in antenna size, while holding the other factors constant would require an increase in antenna diameter from 12.0 to 12.7 feet. The cost impact of this change is estimated at $2.0K.

What can obviously be concluded from these estimates is that cost sensitivity of the antenna size far exceeds the cost sensitivities of the other factors in this immediate range of performance parameters. The apparent approach to a cost-effective G/T anywhere in this region, would be first, to increase antenna gain just to the point where an FET could replace a paramp. Second, achieve that antenna gain with an antenna efficiency (at OMT) of approximately 70%, a surface accuracy of .030" and the resulting, in antenna diameter. Third, pay the price for minimum loss front end RF components.

In concluding this paragraph an interesting exercise is to determine the amount of increase in G/T that appears feasible with a minimum increase in cost. The terminal parameters proposed are the following:

η =	70%	ϵ =	.030"
NF =	2.7 dB	L =	.5 dB
D =	12'	T_A =	45^0
L_F =	.25 dB		

The terminal G/T is given by:

$$G/T = 47.09 - 25.59 = 21.50 \text{ dB}$$

The cost of antenna, RF components and LNA are estimated to be $30.15K, $2.15K and $2.9K, respectively. Thus for a total increase in cost of $700 G/T has increased by 1.92 dB. This indicates that the nominal parameters for antenna efficiency and FET noise figure were extremely conservative.

Assuming the 21.50 dB was not sufficient, the two alternatives would be to either increase antenna size or switch to a parametric amplifier as the terminal LNA. Figure 10 plots these alternatives in a form that shows the sum of the costs of the antenna, RF components and LNA versus G/T. The curves have been adjusted to reflect any possible savings in HPA costs due to the use of a larger antenna. From these curves, it appears that the cost-effective solution is to increase the size of the antenna if the required G/T is less than 23.4 dB. If the required G/T is greater than 23.4 dB, the cost-effective solution is to select a cooler front end amplifier.

The plots of Figure 10 do not reflect the possible cost impact of the lower reliability of parametric amplifiers compared to FET's. In Figure 11 the cost data presented in Figure 10 has been adjusted to reflect the requirements for a redundant unit when cooled paramps are used.

2.2.2 EIRP

Effective isotropic radiated power (EIRP) is dependent on the transmitter, post HPA RF components and the antenna. The nominal terminal specifications from Section 1.2 that impact EIRP are as follows:

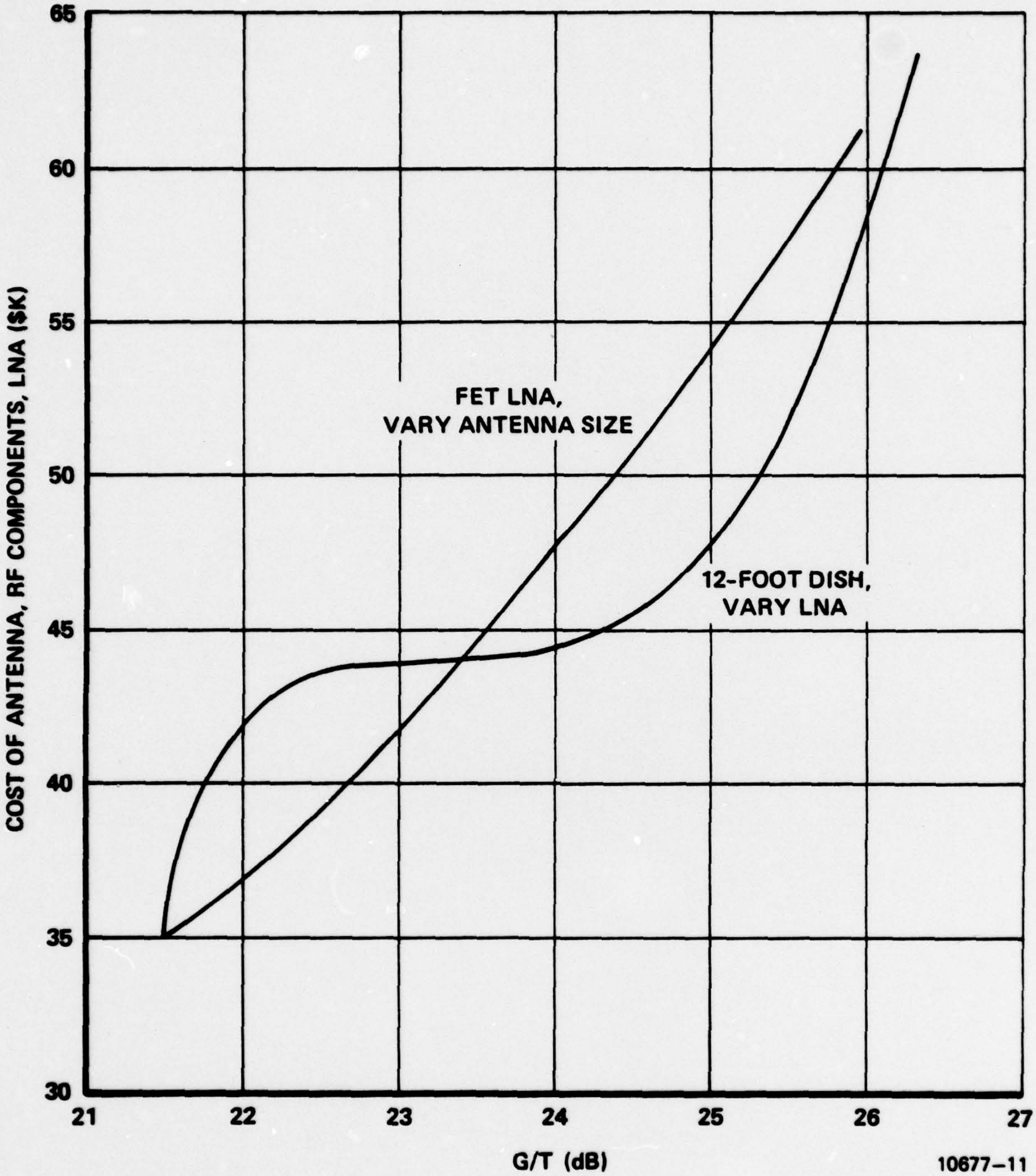


FIGURE 10 - TERMINAL RF SUBSYSTEM COSTS VERSUS G/T FOR FIXED AND VARIABLE ANTENNA DIAMETER AND LNA TYPES

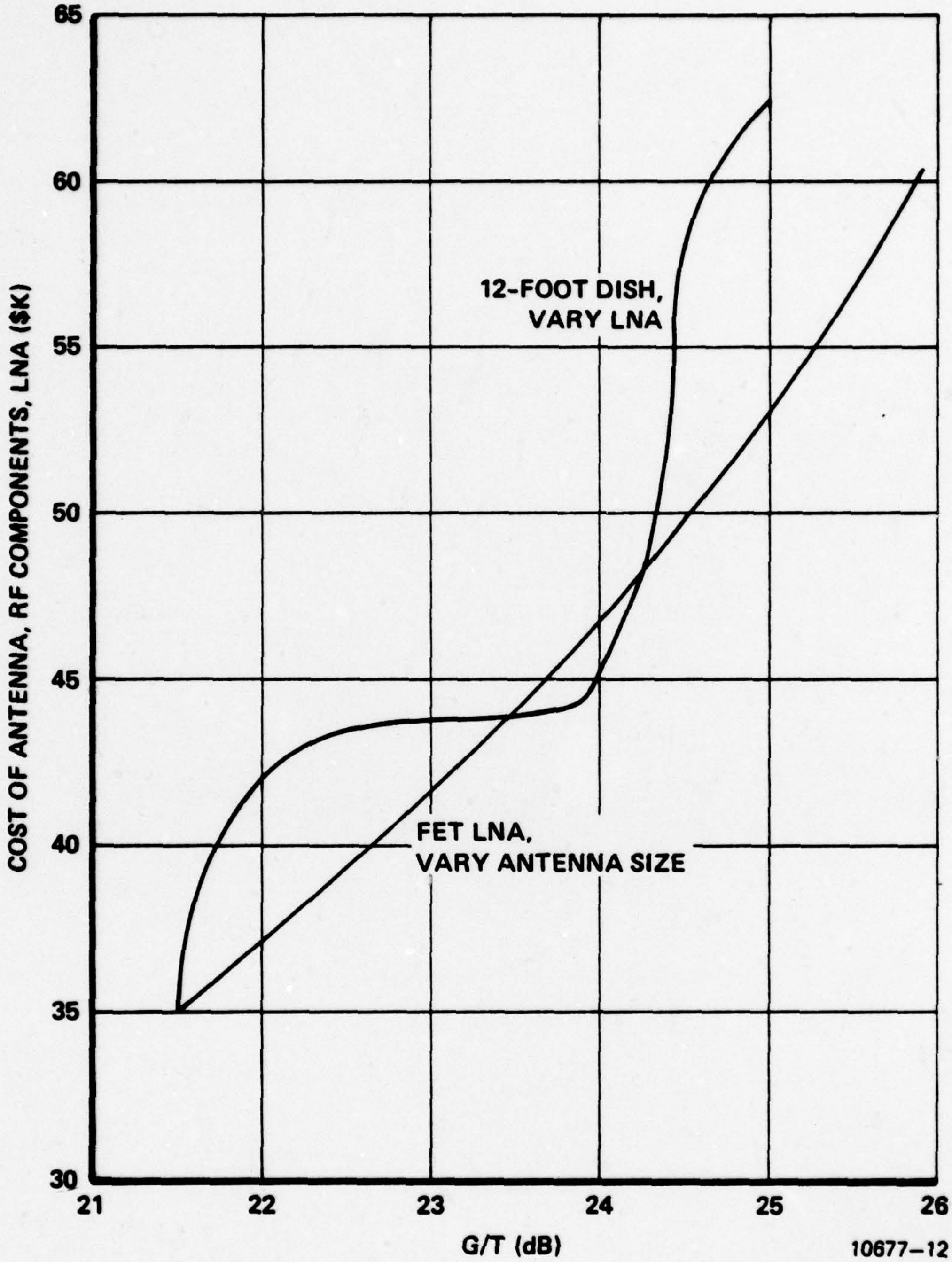


FIGURE 11 - TERMINAL RF SUBSYSTEM COSTS VERSUS G/T FOR FIXED AND VARIABLE ANTENNA DIAMETERS AND LNA TYPES, INCLUDING REDUNDANCY FOR COOLED LNA

EIRP	72 dBW
Antenna Diameter	12 FT
HPA Rating	500 Watts

In Section 2.1.4 the loss of the RF components between the HPA and the antenna was estimated to be 2.5 dB. In Section 2.2.1 it was determined that an antenna efficiency of 66% was achievable with only a minimum cost impact. With these nominal figures the terminal EIRP is given by:

$$EIRP = G_A - L + T$$

$$= 47.54 - 2.5 + 27 = 72.04 \text{ dBW}$$

Thus the 72.0 dBW specification is consistent. If increases in the 72.0 dBW requirement are to be considered it is apparent from Figure 5 that such increases be accomplished in the HPA rather than the antenna. The first approximately 1.7 dB of required EIRP increase can be accomplished with a minimal cost impact by increasing the required rating of the TWT. Required increases in excess of 1.7 dB can be most effectively implemented by switching to a klystron and selecting the appropriate tube size.

Two other factors in addition to EIRP have the potential of impacting the required rating of the HPA. They are AM to PM conversion and intermodulation levels.

2.2.2.1 AM to PM Conversion

AM to PM conversion is attributed to the microwave tube used in the HPA. For the nominal value of 10^{o}/dB taken in Section 1.2 there is no impact resulting from the selection of either a klystron or a TWT as the transmitter. This can be seen in Figure 12 where the AM/PM conversion level versus input drive is plotted for both a klystron and a TWT. It is interesting to note that if a more stringent AM/PM specification was included, the TWT would have an advantage over the klystron in drive levels near saturation but the reverse exists for drive levels 7 dB or more backed off from saturation.

For the nominal specifications presented in Section 1.2 the required rating of the HPA is unaffected by the AM to PM conversion requirement.

2.2.2.2 Intermodulation Levels

Intermod levels are impacted by the antenna, converters, and transmitter. The dominating effect from both the cost and performance points of view is the transmitter. It was estimated in Paragraph 2.1.1 that an intermod free antenna would impact cost by $10K, however, the intermod level mentioned in the antenna design is essentially a receive band intermod problem addressing extremely low intermod levels. Converter generated intermods can be reduced without a significant cost impact through the proper selection of mixers and LO drive levels.

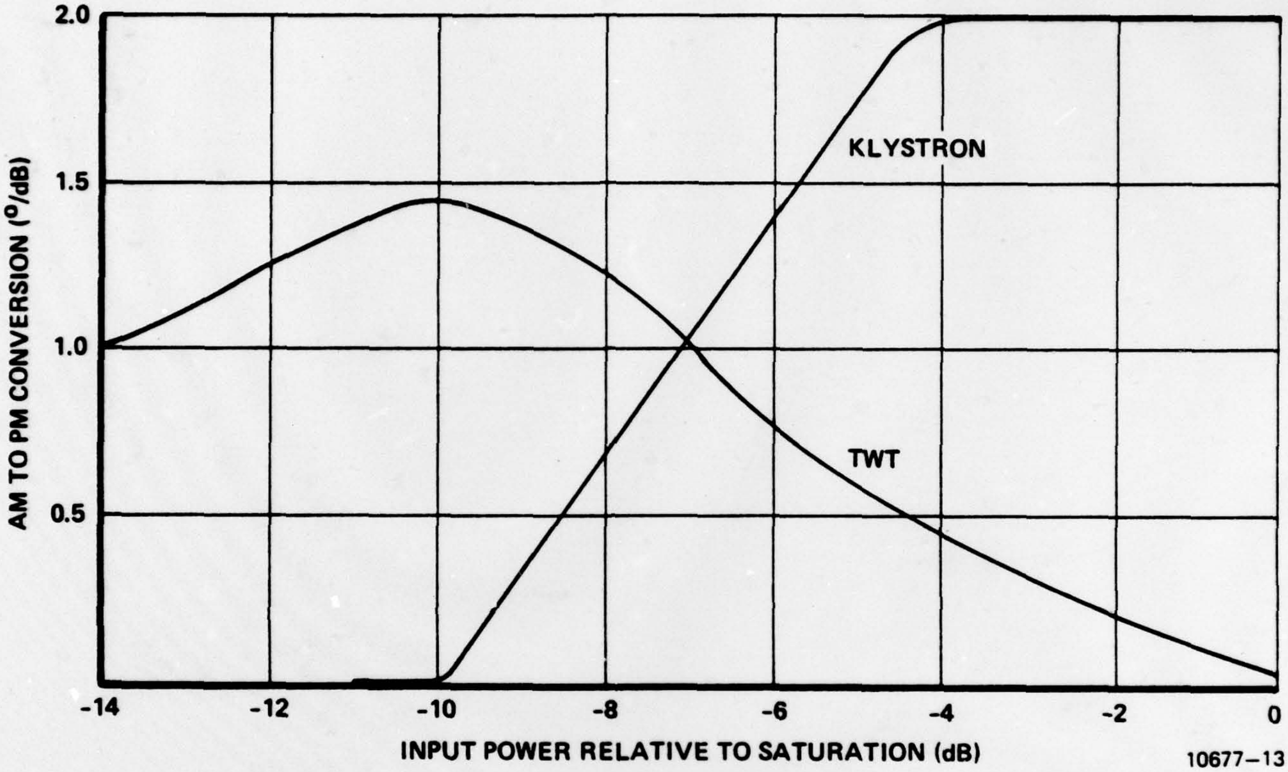


FIGURE 12 - AM TO PM CONVERSION FOR KLYSTRON AND TWT AMPLIFIERS

The transmitter is the key element when considering system intermodulation levels. Figure 13 shows intermod distortion versus tube backoff. This curve is valid for both helix and coupled cavity TWT's as well as kylstrons. It can be seen that for two carrier operation, a saturated tube produces third order intermods only 13 dB below the level of each of the carriers. As drive level backs off, third order intermods drop off approximately 2 dB for every 1 dB backoff. Higher order intermod products drop off at nominal rates of (n-1) dB for every dB of back off (n being the intermod order).

The nominal terminal specifications from Paragraph 1.2 indicate an uplink spurious (including intermods) requirement of -40 dB. Indicated also is a transmit instantaneous bandwidth of 40 MHz. Because of the narrow bandwidth, essentially all transmitter generated intermods will be filterable and therefore the -40 dB specification does not have an impact on a required HPA backoff and therefore does not impact HPA rating or cost.

2.2.3 Reliability/Availability

Two assumptions for the baseline terminal presented in Paragraph 1.2 are of primary importance with respect to the terminal reliability/availability considerations. It was assumed that a minimum terminal reliability of 0.994 is required. This requirement applied to the terminal and did not include prime power failures. Second, it was assumed that 20% of the terminal failures would require the services of an off-site repair team which would result in an MTTR for such failures of 48 hours.

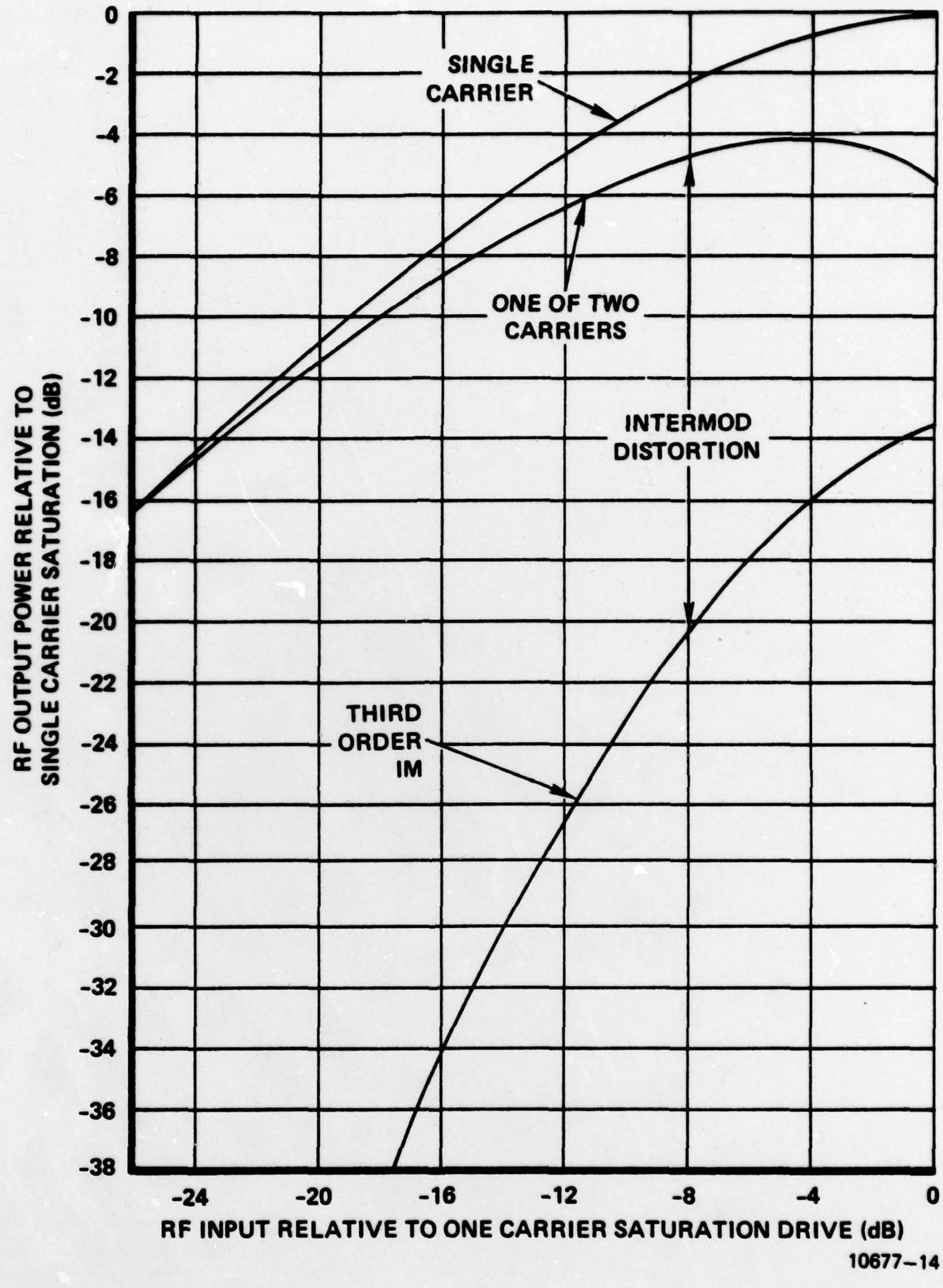


FIGURE 13 - HPA INTERMODULATION DISTORTION AS A FUNCTION OF BACKOFF

Figure 14 presents a reliability block diagram for a single thread terminal using the most cost-effective components chosen to meet the baseline requirements. The estimated mean MTTR for all terminal failures is one hour. The intrinsic availability for this single thread terminal is 0.9989 (i.e., assume 100% sparing, zero logistics time and no requirement for an off-site repair team). When the requirement for the off-site repair team is included the availability drops to 0.9889 which is below the minimum requirement of 0.994 and some redundancy must be provided.

Figure 15 presents a reliability block diagram for a terminal configuration providing dual redundant HPA's and modems. For this terminal configuration it is assumed that a failure in the on-line HPA or modem can be detected and the redundant unit placed in operation within 30 minutes. The mean MTTR for each of these two elements is then essentially reduced to 30 minutes assuming repair action is always initiated promptly on a failed redundant unit (the small probability that both HPA's or both modems will have failures requiring the services of the off-site team within a 48 hours period is ignored). The resulting availability for this configuration is 0.9941 which just meets the minimum availability requirement. If, in addition, a redundant upconverter unit is added, the availability improves to 0.9961 which provides some margin over the minimum requirement.

Using the same assumptions for the addition of redundant units as described above, the availability improves to 0.9974 as a redundant downconverter is added to the configuration having a redundant HPA, modem and converter. When the last relatively high

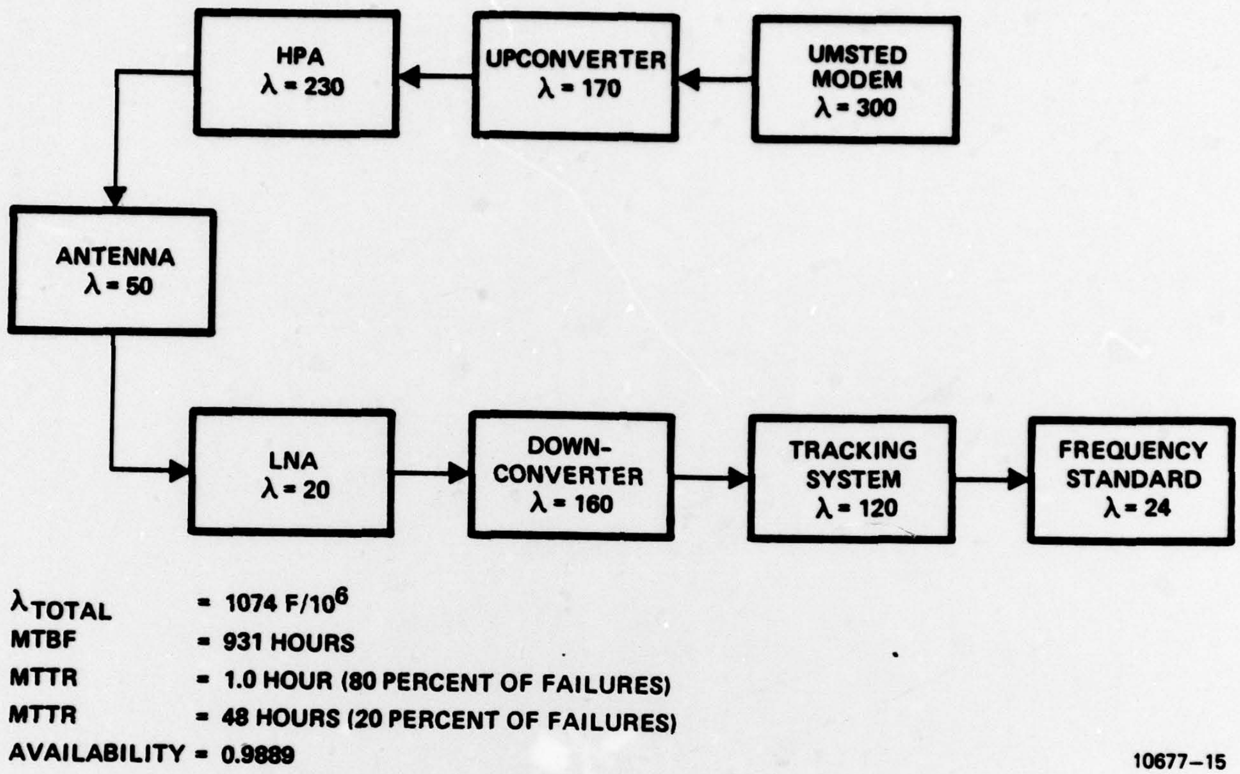
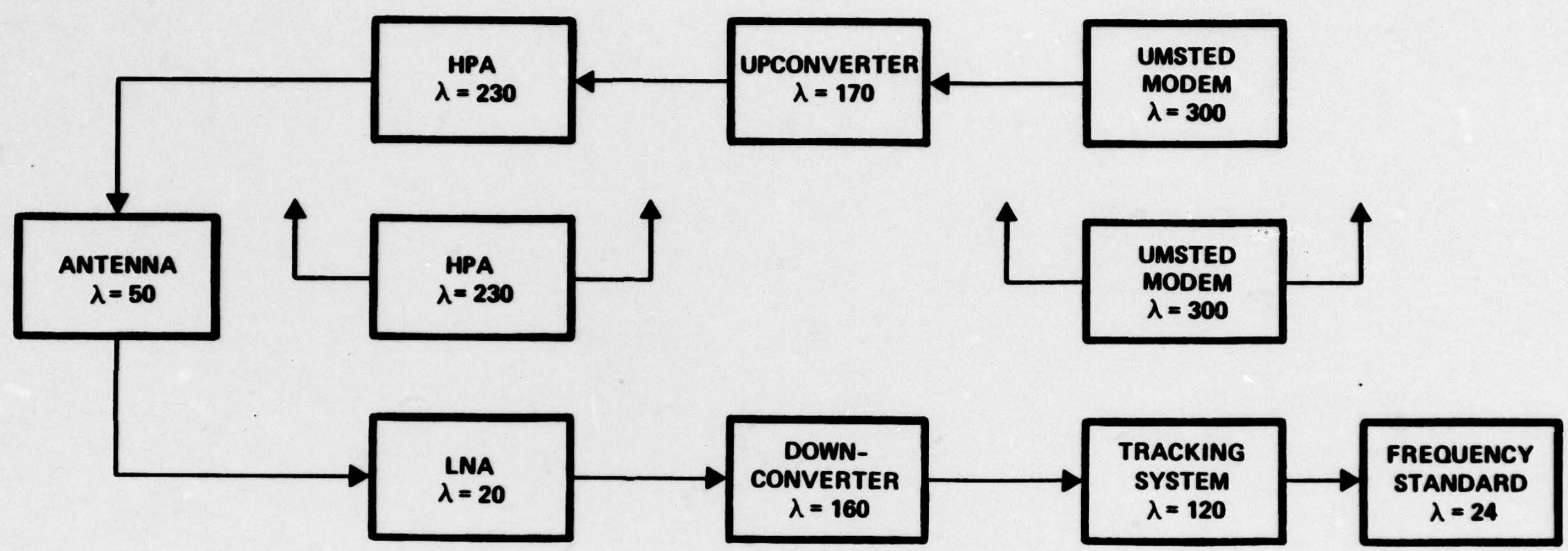


FIGURE 14 - RELIABILITY BLOCK DIAGRAM FOR

SINGLE THREAD TERMINAL



λ_1 = λ HPA + MODEM = 530 F/10^6

$MTBF_1$ = 1886.8 HOURS

$\overline{MTTR}_1$ = 0.5 HOUR (SEE TEXT)

λ_2 = λ ALL OTHER COMPONENTS = 544 F/10^6

$MTBF_2$ = 1838.2 HOURS

$\overline{MTTR}_2$ = 10.4 HOURS

10677–16

FIGURE 15 - RELIABILITY BLOCK DIAGRAM FOR TERMINAL WITH REDUNDANT HIGH POWER AMPLIFIER AND MODEM

failure rate element, the tracking system, is made redundant the availability improves to 0.9985. In Section 3 the above information is used to determine terminal cost as a function of availability.

3.0 Terminal Cost Summary

Utilizing the cost data generated in Section 2, a cost can be generated for a small terminal based on choosing the most cost-effective designs to meet the baseline terminal requirements. A cost summary for a single thread terminal configuration is presented in Table 3. This terminal design will meet all baseline requirements with the exception of availability. It was shown in Paragraph 2.2.3 that such a single thread terminal configuration would provide an availability of only 0.9889 and that a redundant HPA and modem must be provided to meet the availability requirement of 0.994.

Table 4 presents the terminal costs as a function of availability for the terminal parameters chosen.

Table 3. Cost Summary for Single Thread Baseline Terminal
(Cost each in Quantity of 100)

1.	12' diameter limited motion antenna .030" surface accuracy, 45 mph winds, efficiency 60%	$ 30K
2.	500 watt TWT Transmitter	30K
3.	Transmitter Driver	2.5K
4.	Upconverter (W/BITE excellent spectral purity)	22.5K
5.	LNA	3.0K
6.	Downconverter (W/BITE excellent spectral purity)	22.5K
7.	Tracking System	10K
8.	Transmit RF components (WG components)	2.1K
9.	Receive RF components (WG components)	2.8K
10.	Local Oscillators (2 each 5 MHz tuning)	3.6K
11.	Frequency Reference (10^{-8} per day)	0.5K
12.	Modem (UMSTED)	55K
13.	Modem Interface	9K
	Total Equipment Cost	$193.5K
	Material Burden - 12.4%	24.0K
		$217.5K
	Integration Cost - 14%	30.5K
	TOTAL COST	$248.0K

Table 4. Terminal Cost as a Function of Availability

Availability	Cost ($K)	Redundancy Required
0.9889	248	None
0.9941	357	HPA, Modem
0.9961	386	HPA, Modem, Upconverter
0.9974	414.5	HPA, Modem, Upconverter Downconverter
0.9985	427.5	HPA, Modem, Upconverter Downconverter, Tracking System

4.0 Conclusions

The material presented in Sections 2 and 3 resulted in several conclusions. This section delineates those conclusions.

With respect to the antenna:

- The per unit nominal antenna subsystem cost in a lot of 100 is estimated to be $30K.
- Removing the tracking requirement reduces the estimate to $15K for this particular antenna.
- Increasing the diameter of the antenna increases antenna cost at a rate slightly greater than one for one.

With respect to the LNA:

- FET LNA's are available in this band with noise figures approaching 2.6 dB.
- A noise figure requirement better than 2.6 dB necessitates the use of a parametric amplifier and at least a tripling of LNA costs.

With respect to the HPA:

- Below 600 watts a TWT is less costly than a kylstron. Above 600 watts the klystron is less expensive.
- Complete TWT based transmitter at nominal output power costs $30K.

With respect to G/T:

- The G/T of the nominal terminal can be increased to 21.5 dB with only a small cost impact.

- Considering reliability, in most cases improved G/T can most cost effectively be achieved via increases in antenna size as opposed to cooler front ends.

With respect to EIRP:

- Nominal terminal parameters are consistent.
- Small EIRP increases can most cost effectively be provided by higher power transmitters.

With respect to availability

- The required availability of 0.994 cannot be provided by a single thread design.
- Providing a redundant HPA and modem will allow the required availability to be met, but without any margin.
- Meeting the 0.994 availability with some margin requires the use of redundancy for the HPA, modem and upconverter.
- In procurement quantities of 100, it is estimated that small terminals meeting the baseline requirements would cost $248K each for a single thread design, $357K for a redundant configuration just meeting the availability requirement and $386K each for a design providing some availability margin.