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SUBJECT ANTENNA DIAMETER TRADE-OFF STUDY

Attached is a copy of the Antenna Diameter Trade-off Study done for the Navigation Study Team.

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This predicts $60M ($89)
for 100 m No design, no computer,
no optics.

ANTENNA DIAMETER TRADE-OFF STUDY

1.0 Introduction

This report documents a study undertaken to establish preliminary trade-offs between antenna reflector diameters and receiver front-end options. The intent of the study was to provide a guide to the system designer rather than a cookbook. Detail costs will have to be based on detail specifications.

The approach used in the study was to establish a per unit cost for the antenna and front-end options. The M & O costs were then added to develop the life-cycle costs, which were compared to the figure of merit. The figure of merit is a standard measure of performance for an antenna system and is formed by the gain divided by the noise temperature (given as G/T).

2.0 Antenna Structures

The general requirements for the antenna are based on standard DSN performance and quality criteria. It is assumed that the unit will be an AZ-EL mount used to track at sidereal rates, with a maximum slew rate of 1°/sec. and with a reasonable efficiency (55%) at X-band. Reflector shaping, which can result in X-band efficiencies of 75%, was not considered because of the variable cost impact. Also, the station will be designed for unattended operations in an environment similar to Goldstone. The expected range of reflection diameter is 9 meters (30 feet) to 27 meters (90 feet).

During the study, an item of concern was raised regarding the stability of the phase center of the antenna. This concern is based on the intended use of the antenna as a radiometric instrument. Recent tests at DSS-14 and DSS-13, however, show that this is not a major problem, particularly for smaller antennas. The measurements of DSS-14 show a motion of the axis intersection of 2.5mm for nominal temperature ranges and 8mm for an extreme temperature. The measurements of DSS-13 show a variation of 2 to 3mm from temperature, wind and bearing runout. Therefore, based on these data and for these diameters, it was assumed phase center stability would not be a problem, and no cost delta was added.

The initial cost of the antenna for the proposed range of reflection diameters is based on an empirical curve which is a function of the reflector diameter. This curve is shown in Figure 1 and is a combination of work done in previous studies.

Parametric studies done by Ford Aerospace for the LAAS Project for the range of reflector diameters of 30 to 100 meters resulted in a curve, the form of which can be expressed as follows:

$$C = KD^{2.55}$$

where the constant, K, and the exponent, 2.55, have been evaluated from a curve of known antenna costs and diameters. The exponent value of 2.55 represents the current balance between labor and material used in fabricating and constructing an antenna.

For diameters of 27 meters and below, recent data from antenna fabricators have been used to fill out the curve. Harris Corporation recently completed three 18-meter-diameter antennas and is in production on 12-meter antennas. E-Systems and Scientific Atlantic also supplied data.

The resulting curve of initial cost versus antenna diameter is shown in Figure 1. It should be noted that this curve reflects only the variable cost portion of the total cost of an antenna subsystem. This includes the structure, the mechanical assemblies and the servo drives, and power amplifiers, all erected and tested in the field. It does not include the pointing computer, the system level testing, or the design and other R. F. optics.

The estimates for maintenance of the antenna are based on rationale developed in previous studies done for the LAAS Project. Man-hour per year estimates were developed for 9-meter and 26-meter antennas. A straight-line variation versus antenna diameter was assumed. A figure of $30K per man-year was used to develop a yearly maintenance cost. This yearly cost was then multiplied by 10 for the ten-year cost, which is plotted as a function of diameter in Figure 1. It should be noted that this curve represents only the variable part of the maintenance costs; there is a smaller fixed cost which is independent of diameter. All of the estimated costs are shown in FY '79 dollars without escalation or contingency.

3.0 R. F. Optics

One of the preliminary requirements is that the system will be used simultaneously at S- and X-Band. Three microwave optics designs were considered to achieve this: focal point S-X feed, cassegrainian S-X (using the newly developed JPL coaxial S-X feed), and a hybrid design containing an X-band cassegrainian feed and an S-band focal point feed. This hybrid system utilizes a dichroic subreflector which passes S-band frequencies and reflects X-band.

In general, the system requirements will dictate the R. F. configurations. The cassegrain configuration is more expensive to build but provides lower noise performance. Additionally, the traveling wave maser can, in practice, only be used in a cassegrainian system. The physical size of the unit virtually precludes its placement at the focal point of the paraboloid. The transistor amplifiers are much smaller in size and can be used at either focal point.

Because of the physical size of the feed horn, a problem arises with the use of the JPL coaxial S-X feed on small antennas. The horn is so large that it causes additional aperture blockage. A curve of this blockage is shown in Figure 2.

The typical DSN antenna has been built with a subreflector diameter which is 10% of the diameter of the primary reflector. This combination was selected to minimize blockage losses and to reduce sidelobes. Figure 2 shows that, due to the horn and a 10% subreflector, the central blockage increases sharply for primary reflector diameters below 30 meters. If the subreflector size is increased 20%, the break point of the curve is approximately 12 meters. A 9-meter antenna would have an additional 0.5db loss due to the blockage of a 20% subreflector and the JPL coaxial S-X feed.

Figure 3 shows the secondary effects of increasing the relative size of the subreflector. The increase in sidelobe level shown in this figure is the effect of central blockage only, and 4 to 6db should be added to account for the effect of the quadripod. Therefore, a 20% subreflector, supported by a quadripod, could result in sidelobe levels which are only -12db. These relatively high sidelobes would cause serious noise degradation if the antenna is required to point near the sun. Figure 3 also shows a 0.5 loss due to beam directivity for a 20% subreflector.

4.0 Low Noise Amplifiers

A variety of options for the receiver front-end are available to the systems designer. The options include traveling wave maser (TWM), parametric amplifiers (PARAMPS), and transistor amplifiers (GASFETS). Table 1 shows the expected values of temperature and cost for the various options.

The traveling wave maser option, compatible with this dual-frequency application, is composed of two parametric upconverters with a K-band TWM. The assembly would provide the wide band-width required for this application. As noted above, the TWM's are typically used only in a cassegrain configuration because of the size and weight of the assembly. The maintenance time required is based on DSN experience and is estimated to be 85mh/yr. 2380/hr 28 mh/yr ≈ 1880.

The PARAMP can be designed for either ambient cooling or cryogenic refrigeration, with noise temperatures and costs changing accordingly. The DSN does not have recent experience with PARAMPS and therefore must rely on vendor information.

There is some concern about using PARAMPS in an unattended station, but there should be no problem as the vendor indicates the C-band units are being used in new comsat stations. The maintenance time required is assumed to be the same as the TWM.

The transistor amplifiers, or GASFETS, are also available with either ambient cooling or cryogenic cooling. The packaging size for these units is much smaller than the TWM, and they are suitable for installation at either the focal point or in a cassegrain cone. The maintenance for these units is approximated at 25 hours per year for ambient units and 50 hours per year for cooled units.

5.0 Results

The results of the study are shown in Figure 4, which is a plot of figure of merit versus cost for the X-band performance of 3 front-end options. The cost ordinate represents the total life-cycle cost of dual frequency capability using front-ends of the same type. Because of the multiple options available to the system designer, the effects of horn and sub-reflector blockage have not been included in this plot. Therefore, the TWM figure of merit curve could be off by 1db at a 30-foot diameter and is probably not usable below that diameter with the S-X horn.

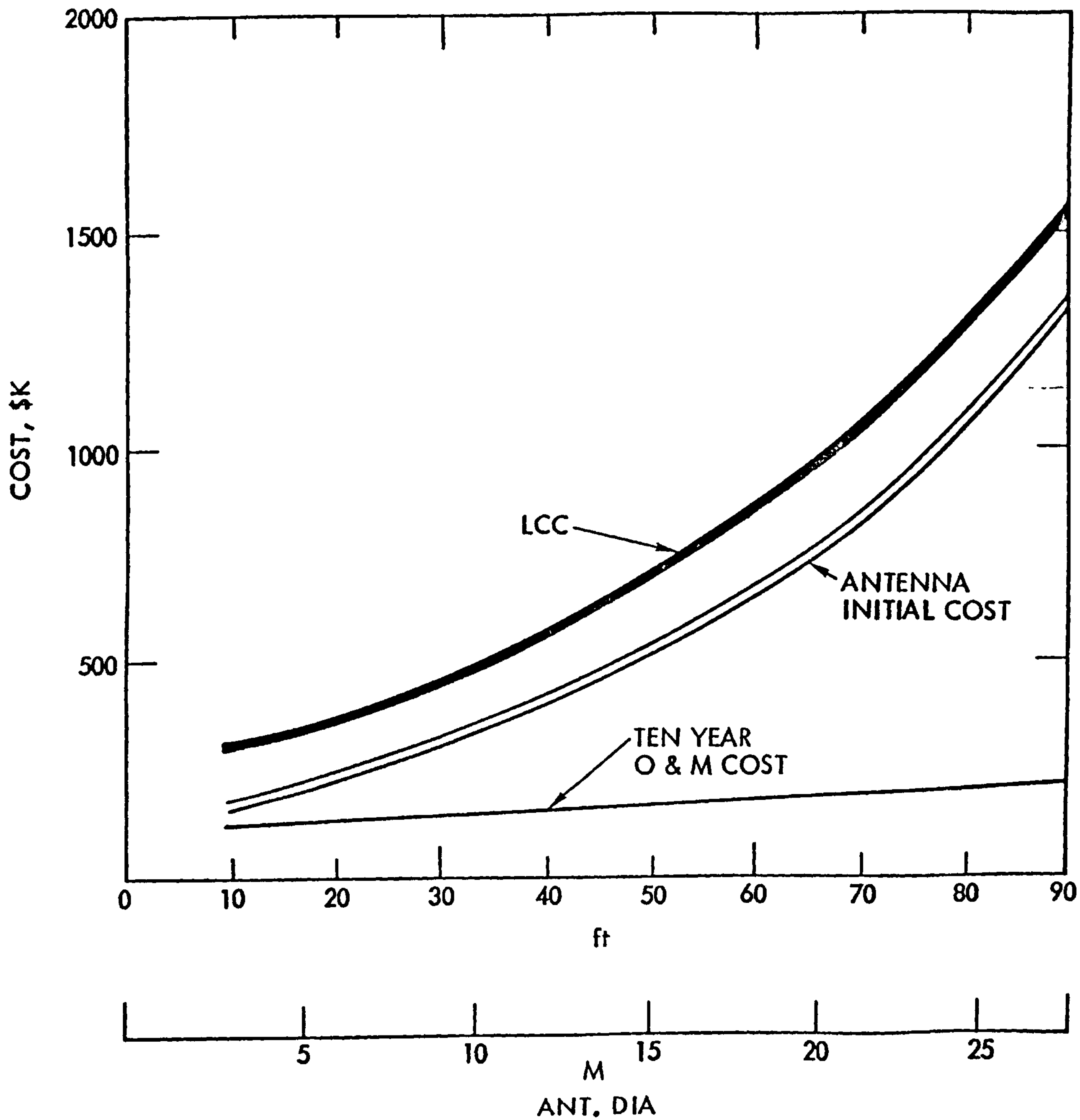
It should be emphasized that these curves are intended to give the system designer a guide. They do not take into account all of the factors which might preclude a particular configuration for a particular application. Also, the effect of offset feeds and shaped reflectors have not been evaluated. However, as a guide, these curves provide the system designer a starting point to determine what combination should be studied for his application.

TABLE 1

LOW - NOISE AMPLIFIER OPTIONS

AMPLIFIER TYPE	NOISE TEMP. KELVIN		SYSTEM TEMP. KELVIN		INITIAL COST (EACH BAND), $	10 YEAR MAINT. COST (EACH BAND), $	LIFE-CYCLE COST (BOTH BANDS), $
	S	X	S	X			
<u>TWM's</u>	5	8	25	30	400K	12K	824K
<u>PARAMPS</u>							
CRYOGENIC	20	40	40	60	100K	12K	224K
AMBIENT	40	100	60	120	45K	12K	115K
<u>GASFET</u>							
CRYOGENIC	45	90	65	110	20K	8K	56K
AMBIENT	125	300	145	320	5K	4K	18K

Figure 1. Antenna Life Cycle Cost



INCLUDES: STRUCTURE
PANELS
DRIVES & SERVO

DOES NOT INCLUDE:
DESIGN
POINTING SYSTEM
SPARES

82ft
1.15 M

$$Cost = K D^{2.55}$$

$$1.15 = K \, 25^{2.55}$$

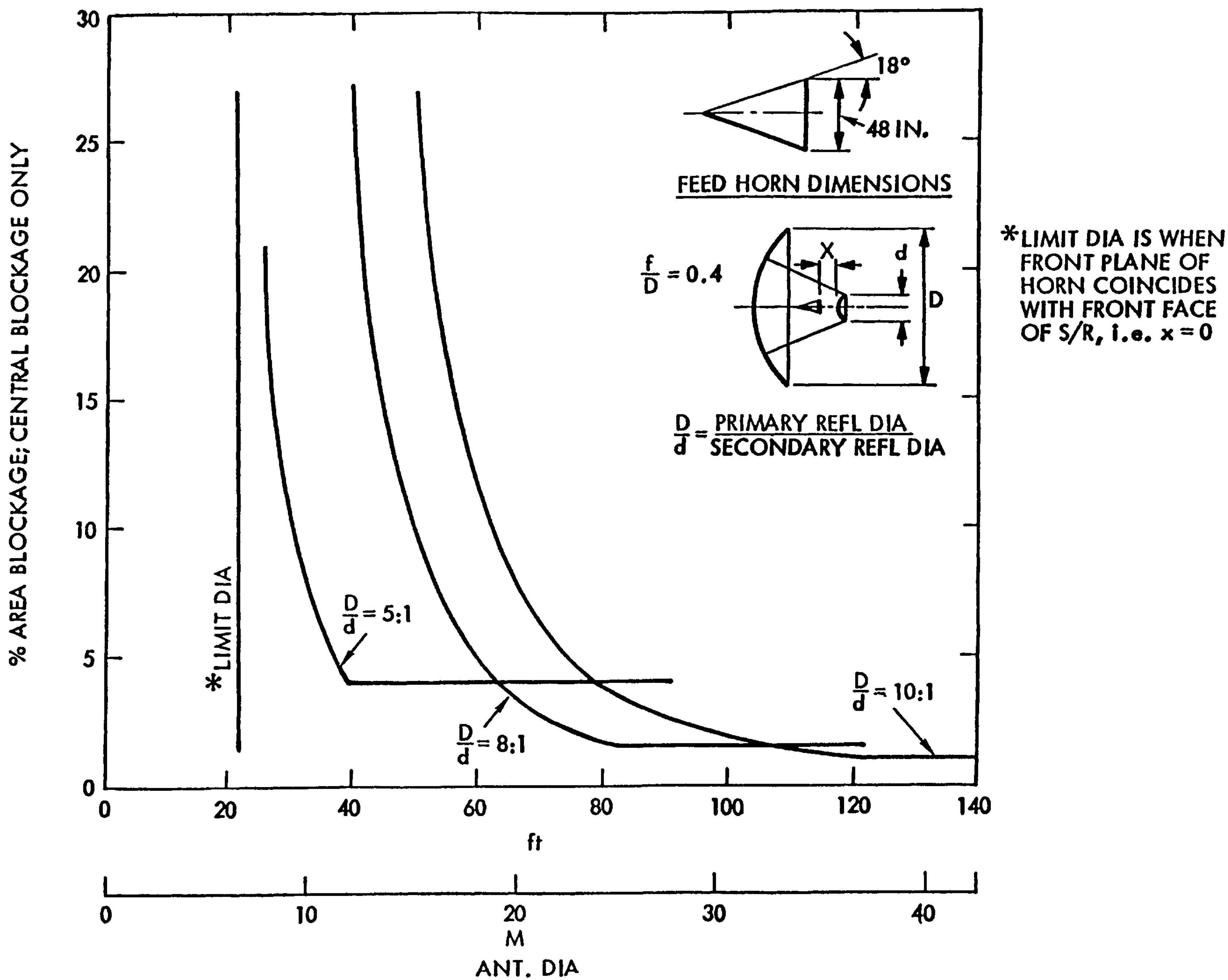
$$K = \frac{1.15}{25^{2.55}} = 3.13..$$

100M → $39M ($79)

→ 60M ($89)

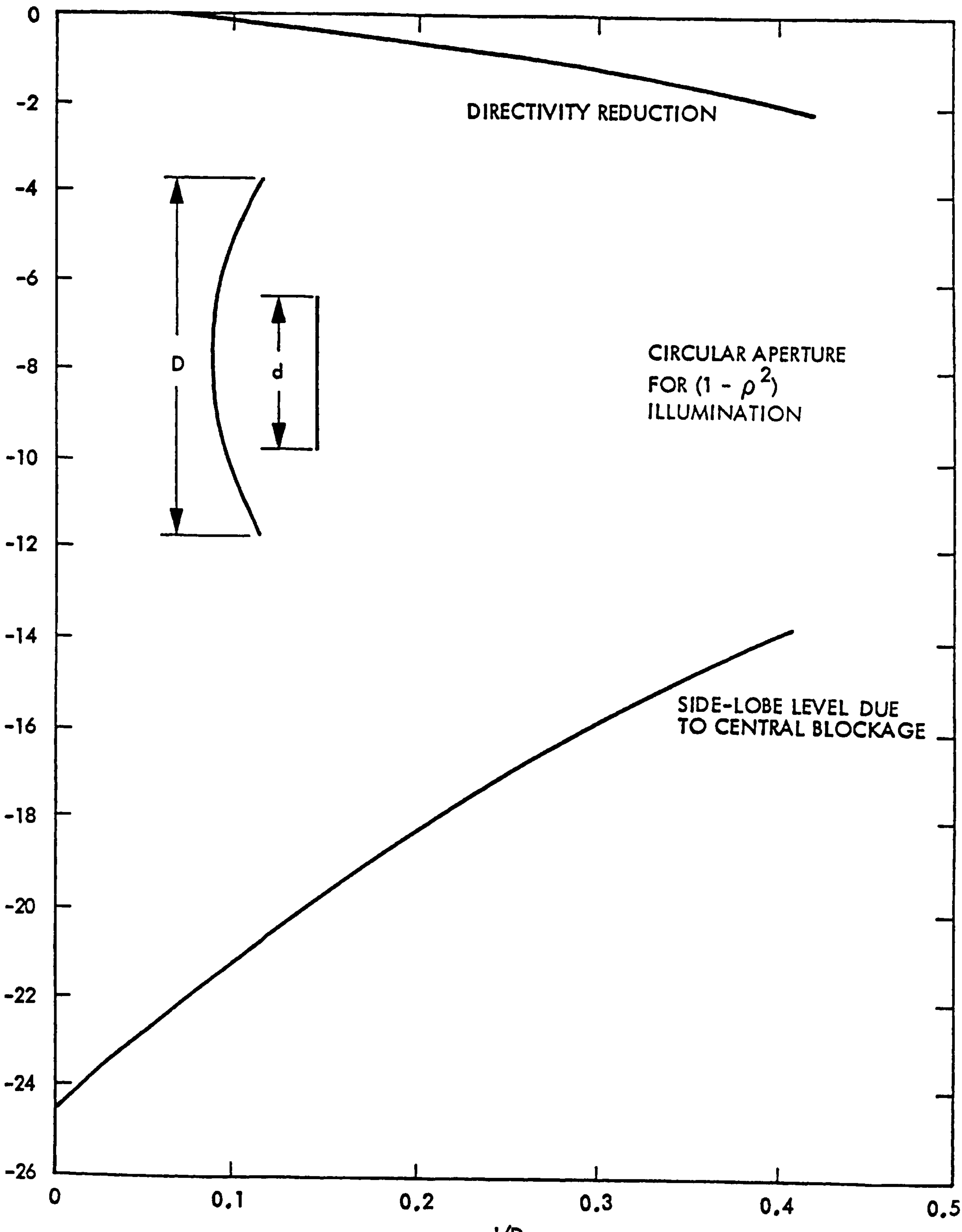
Assumes 4% inflation
1979 → 198[illegible]

Figure 2



% AREA BLOCKAGE; CENTRAL BLOCKAGE ONLY
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
ft
0
10
20
30
40
M
ANT. DIA
*LIMIT DIA
D/d = 5:1
D/d = 8:1
D/d = 10:1
18°
48 IN.
FEED HORN DIMENSIONS
f/D = 0.4
X
d
D
D/d = PRIMARY REFL DIA / SECONDARY REFL DIA
*LIMIT DIA IS WHEN FRONT PLANE OF HORN COINCIDES WITH FRONT FACE OF S/R, i.e. x = 0

Figure 3


0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
0
0.1
0.2
0.3
0.4
0.5
d/D
DIRECTIVITY REDUCTION
D
d
CIRCULAR APERTURE
FOR (1 - ρ2)
ILLUMINATION
SIDE-LOBE LEVEL DUE
TO CENTRAL BLOCKAGE

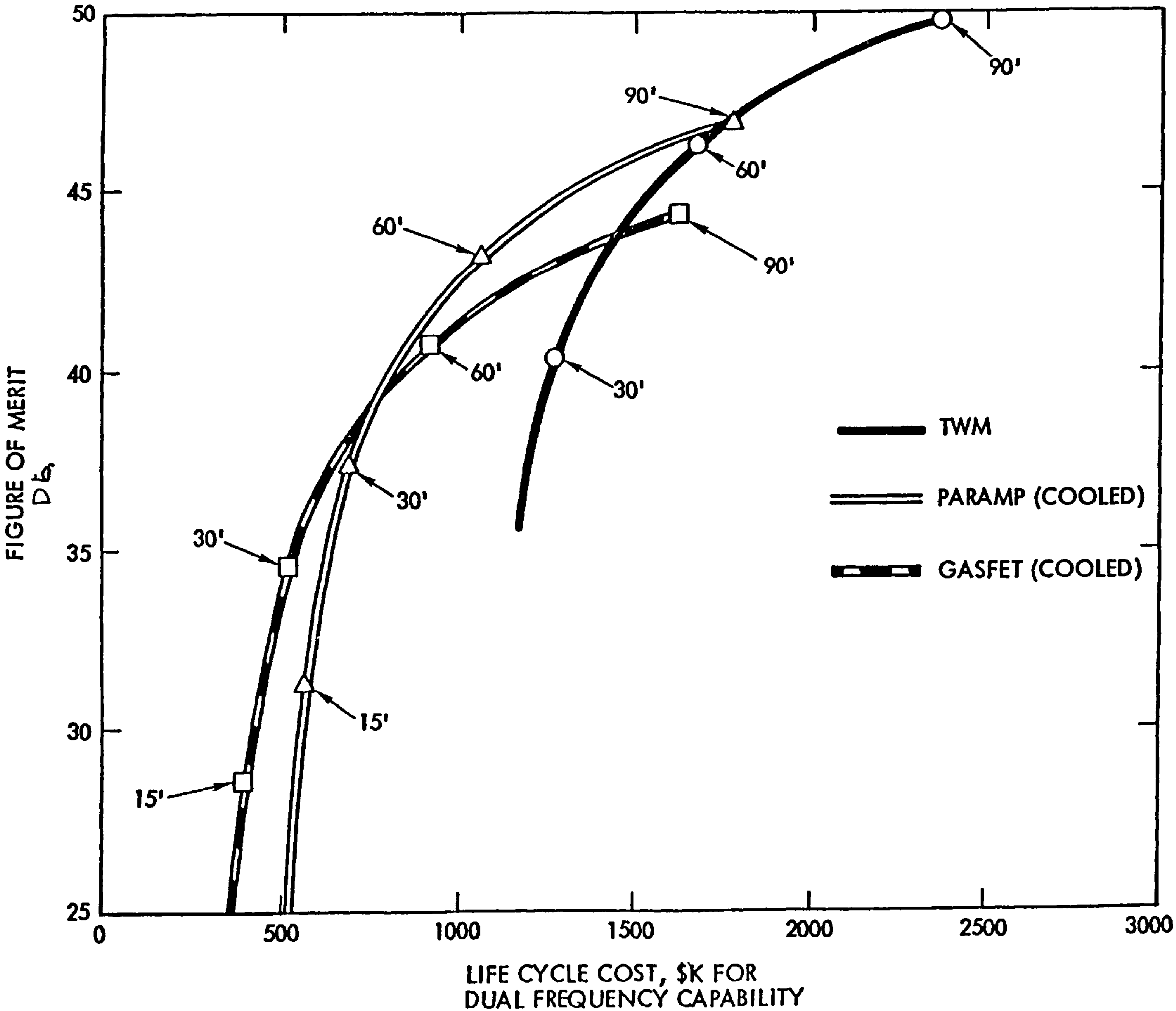
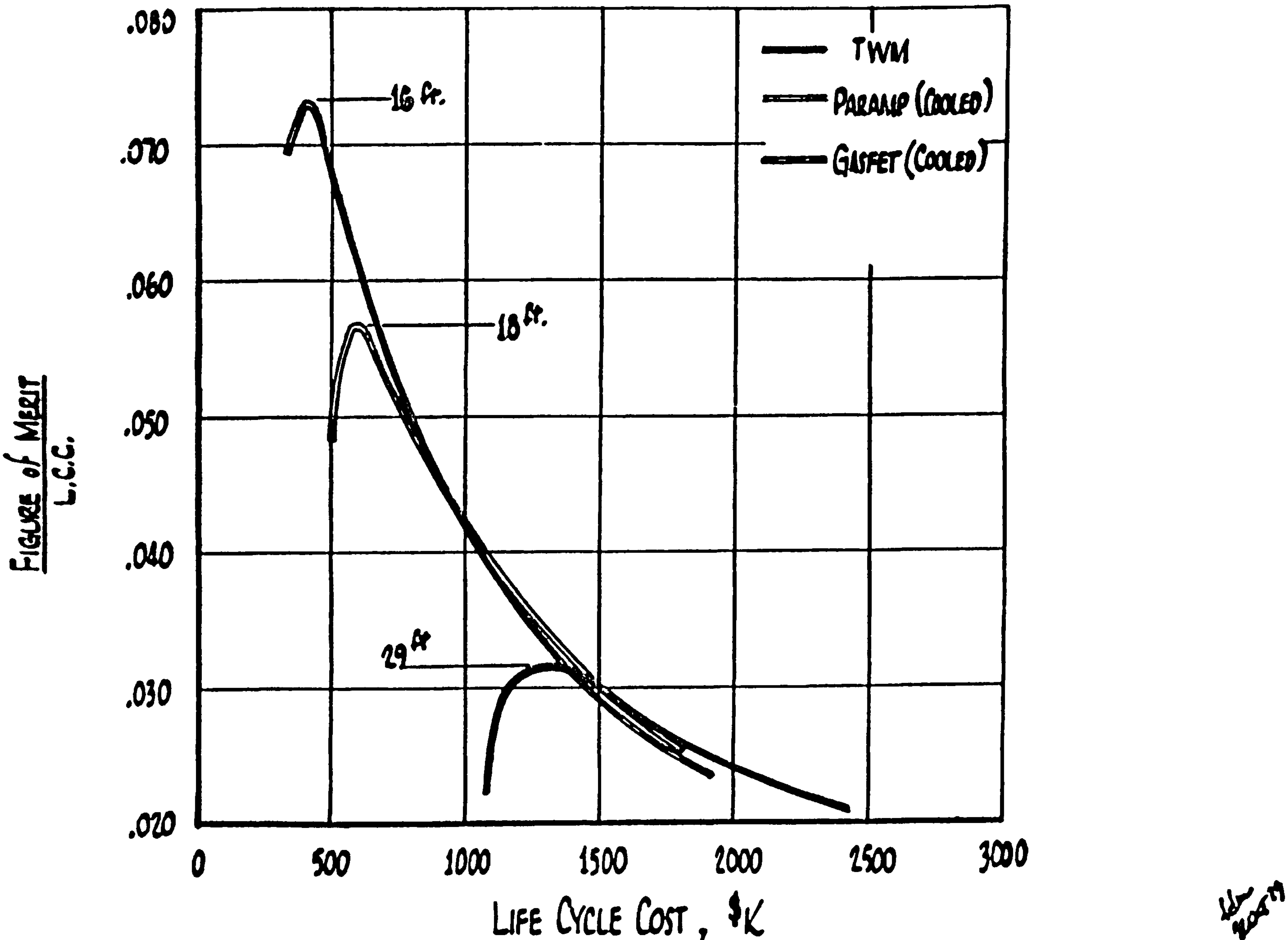

50
45
40
35
30
25
FIGURE OF MERIT
Db,
0
500
1000
1500
2000
2500
3000
LIFE CYCLE COST, $K FOR
DUAL FREQUENCY CAPABILITY
90'
90'
60'
60'
90'
60'
60'
30'
30'
30'
15'
15'
TWM
PARAMP (COOLED)
GASFET (COOLED)

FIG. 5


TWM
PARAMP (COOLED)
GASFET (COOLED)
16 FT.
18 FT.
29 FT
.080
.070
.060
.050
.040
.030
.020
0
500
1000
1500
2000
2500
3000
FIGURE OF MERIT / L.C.C.
LIFE CYCLE COST, $K