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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-625

Error Analysis for Mariner Venus/Mercury 1973 Conducted at the JPL Mesa West Antenna Range

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PREFACE

The work described in this report was performed by the Telecommunications Division of the Jet Propulsion Laboratory.

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FIGURES

ABSTRACT

Theoretical analysis and experimental data are combined to yield the errors to be used with antenna gain, antenna patterns, and R.F. cable insertion loss measurements for the Mariner Venus Mercury 1973 Flight Project. These errors apply to measurements conducted at the JPL Mesa, West Antenna Range, on the high gain antenna, low gain antenna, and R.F. coaxial cables.

SECTION I

INTRODUCTION

1.1 SCOPE

This memorandum contains the error analysis and resulting errors on gain and patterns of antennas and insertion loss of cables for the Mariner Venus/Mercury 1973 Program and the rationale for the parameters included. The errors pertain to measurements conducted at the West Antenna Range on the Mesa of JPL.

All errors are treated as symmetrical - equal plus and minus. Some of these actually tend to have unequal plus and minus values; however, in each case the entire range of uncertainty is used and then halved to make the error symmetrical. By this method the effect on the final error for gain, pattern, or insertion loss by each contributing error has equal probability of being conservative or optimistic.

1.2 PURPOSE

The gain and insertion loss errors, resulting from a worst case linear addition of the measurement parameters, will be used for the various link analyses for the MVM'73 Mission.

1.3 APPLICABLE DOCUMENT

The measurements conducted on MVM'73 antennas and cables were in accordance with TP 508906, "S/X-Band Antenna Subsystem Mariner Venus/Mercury 1973 Flight Equipment Performance Acceptance Test Procedure For."

1.4 SUMMARY OF ERRORS

A summary of the antenna gain and cable insertion loss errors, derived in this memo, is shown in the following table.

COMPONENT	FREQUENCY (MHz)	ERROR (dB)
High Gain Antenna (HGA)	2297.9	± 0.214
High Gain Antenna (HGA)	8415	± 0.322
Low Gain Antenna (LGA)	2115.6	± 0.334
Low Gain Antenna (LGA)	2297.6	± 0.360
Cable Assembly - LGA	2115.6/2297.9	± 0.081
Cable Assembly - HGA	2297.9	± 0.093
Cable Assembly - HGA to XTX	8415	± 0.276

The antenna pattern errors are not adaptable to a concise chart as the above so they are displayed in Section 3.2.

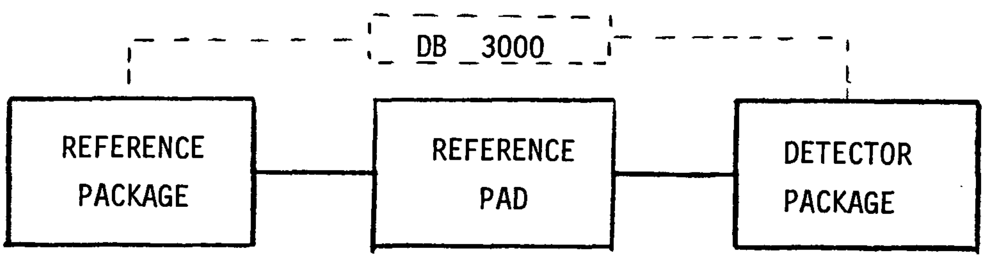
SECTION II

DERIVATION OF ERRORS

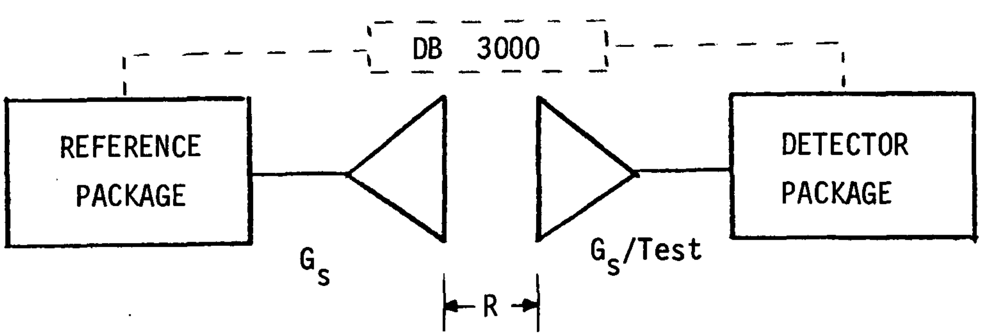
2.1 ERROR ANALYSIS

2.1.1 Antenna Gain Error

The analysis of the antenna gain error is based on the measurement method described in TP 508906. The absolute antenna gain is calculated from measurements conducted using the three antenna method. In this method three sets of measurements are conducted of insertion loss between the terminal of one antenna and the terminal of another antenna for accurately known phase center separations for the three different combinations of the three antennas. Each set of measurements consists of a reference measurement of a known attenuation pad and a test measurement between the terminals of two antennas.



REFERENCE MEASUREMENT



TEST MEASUREMENT

The method results in three equations with three unknown antenna gains whose solutions will yield the gain of each antenna. For MVM'73 two gain standard antennas and a test antenna were used to yield the gain of the test antenna as follows:

$$(1)\quad G_{s1} + G_{s2} = SL_G - Pad_r - (DB\ 3000_G - DB\ 3000_{REFG})$$

$$(2)\quad G_{s1} + Test = SL_T - Pad_r - (DB\ 3000_{T1} - DB\ 3000_{REFT1})$$

$$(3)\quad G_{s2} + Test = SL_T - Pad_r - (DB\ 3000_{T2} - DB\ 3000_{REFT2})$$

Solving

$$(4)\quad Test = 1/2 \Big[2\ SL_T - SL_G - Pad_r + (DB\ 3000_G - DB\ 3000_{REFG}) - (DB\ 3000_{T1} - DB\ 3000_{REFT1}) - (DB\ 30000_{T2} - DB\ 3000_{REFT2}) \Big]$$

Where

G_{sn} = Gain in dB of gain standard n

Test = Gain in dB of test antenna

SL = Space loss in dB ($SL = 20 \log_{10} F + 20 \log_{10} R - 37.872$)

F = Frequency in MHz

R = Range in feet

Pad_r = Reference pad attenuation in dB

SL_T = Space loss for test antenna to gain standard

SL_G = Space loss for gain standard antenna to gain standard antenna (GSA)

$DB\ 3000_n$ = DB 3000 reading for GSA1 to GSA2 (n = G) (See test measurement sketch)
GSA1 to Test (n = T1)
GSA2 to Test (n = T2)

$DB\ 30000_{REFn}$ = DB 3000 reference reading (n = G, T1, T2) (See reference measurement sketch)

By examining Equation 4 the contribution of each separate error on the total gain error can be found.

The errors are not as adaptable to "random" and "constant" designations resulting in 3/2 or 1/2 multiplier factors as in the Mariner 1969 and 1971 Programs due to the frequencies, pads, and distances employed in the present measurements.

2.1.1.1 Reference Pad Contribution. The same reference pad was used for each of the three measurements to calculate the gain of a test antenna. The pad error would remain the same for each of the measurements; therefore, in Equation 4 if

$$Pad_r = \text{Pad Measured Value} + \text{Pad Error}$$

substituting

$$Test = 1/2\ [\text{Pad Measured Value} + \text{Pad Error}] + \text{Other Parameters}$$

the resulting reference pad contribution to the test antenna gain error is one-half the pad error.

2.1.1.2 Antenna Phase Center Location Contribution. The actual phase center location of an antenna could be different than that used to calculate the space loss for each measurement. The location error for each antenna would not change from measurement to measurement; however, the error in dB will be dependent on the distance (R) for each measurement. The three equations (1, 2, 3) can be rewritten to focus on this error:

(5) $G_{s1} + G_{s2} = SL_G + \emptyset C_{s1} + \emptyset C_{s2} + \text{Other Parameters}$

(6) $G_{s1} + Test = SL_T + \emptyset C_{T1} + \emptyset C_T + \text{Other Parameters}$

(7) G_{s2} + Test = $SL_T + \not{0}C_{T2} + \not{0}C_T$ + Other Parameters

where

$\not{0}C_T$ = distance in dB (at test antenna to SGA distance) actual phase center of test antenna is from assumed phase center.

$\not{0}C_{sn}$ = distance in dB (at SGA to SGA distance) actual phase center of SGAn is from assumed phase center.

$\not{0}C_{Tn}$ = distance in dB (at SGAn to test distance) actual phase center of SGAn is from assumed phase center.

In solving for the gain of the test antenna, the following results:

(8) Test = $1/2\,[2SL_T - SL_G + 2\not{0}C_T + \not{0}C_{T1} + \not{0}C_{T2} - \not{0}C_{s1} - \not{0}C_{s2}]$ + Other Parameters

The mathematical sign contained in each $\not{0}C$ is independent from antenna to antenna; however, the sign of $\not{0}C_{s1}$ and $\not{0}C_{S2}$ is the same as $\not{0}C_{T1}$ and $\not{0}C_{T2}$, respectively; therefore, the error contribution due to the phase center location becomes

$$\text{Phase Center Error Contribution} = |\not{0}C_T| + \frac{|\not{0}C_{s1} - \not{0}C_{T1}|}{2} + \frac{|\not{0}C_{s2} - \not{0}C_{T2}|}{2}$$

One can note that if all measurement distances were the same, the error would be equal to $\not{0}C_T$ as in MM'71.

2.1.1.3 <u>Antenna to Antenna Distance Error Contribution</u>. The distance (R) used to calculate the space loss (SL) in Equations 1, 2, and 3 could be in error due to placement or measurement. In Equation 4 if

$$SL_T = SL_{T\ ACTUAL} + \Delta\ SL_T$$

$$SL_G = SL_{G\ ACTUAL} + \Delta\ SL_G$$

where $\Delta\ SL_n$ = Error of Space Loss n Due to Distance Error

Then

(9) Test = $1/2\,[2\,(SL_{T\ ACTUAL} + \Delta\ SL_T) - (SL_{G\ ACTUAL} + \Delta\ SL_G)]$ + Other Parameters

Since the sign of each error is independent of the others, the contribution to the gain error is then the following:

$$\text{Distance Error Contribution} = |\Delta\ SL_T| + 1/2\ |\ \Delta\ SL_G|$$

2.1.1.4 DB 3000 Error Contribution. The DB 3000 readings in Equation 4 could be in error due to DB 3000 inherent error and DB 3000 repeatability error. By substituting in Equation 4 with an error term for each DB 3000 reading and noting that the sign of each term is independent, the following error contribution would result:

$$\text{DB 3000 Error Contribution} = 1/2\ [\Delta\text{DB } 3000_G + \Delta\text{DB } 3000_{T1} + \Delta\text{DB } 3000_{T2}]$$

where

ΔDB 3000_n = the magnitude of the error in the DB 3000 between reference and test readings (n = G, T1, T2) (See measurement sketches)

If all readings were in the same range on the DB 3000, the error would reduce to 3/2 times the DB 3000 error for each set of readings.

2.1.1.5 Connector Repeatability Contribution. For each DB 3000 reading there is a mating of connectors; therefore, the error due to connector repeatability between reference and test readings in Equation 4 would result in the following:

(10) $\text{Test} = 1/2\ [\ \Delta\text{CNTR}_G + \ \Delta\text{CNTR}_{T1} + \Delta\text{CNTR}_{T2}] + \text{other parameters}$

where

ΔCNTR_n = The magnitude of error due to connector repeatability for all mating between reference and test readings (n = G, T1, T2) in dB. (See measurement sketches)

All connectors in any set of measurements are the same type of connector and a reference or a test reading is made after two connector matings (each end of a reference pad or test setup). Each ΔCNTR in Equation 10 would consist of four connections; therefore, Equation 10 could be changed to the following:

(11) $\text{Test} = 1/2\ [4\text{ MATE} + 4\text{ MATE} + 4\text{ MATE}] + \text{other parameters}$

where

MATE = the error due to the mating of a male and female connector

The error contribution is then the following:

Connector Error Contribution = 6 MATE

2.1.1.6 Section VSWR Contribution. The section VSWR error appears each time there is a mating of connectors (for a DB 3000 reading). If the VSWR of all packages and pads were equal, the error contribution would reduce to a simple term like that for connector error; however, since all VSWR's are not the same, each connection must be carried individually. The error terms would appear in Equation 1, 2, and 3 as follows:

(12) $G_{s1} + G_{s2} = SL_G - Pad_r - [DB\ 3000_G + \Delta VSWR_G - (DB\ 3000_{REFG} + \Delta VSWR_{REFG})]$

(13) $G_{s1} + Test = SL_T - Pad_r - [DB\ 3000_{T1} + \Delta VSWR_{T1} - (DB\ 3000_{REFT1} + \Delta VSWR_{REFT1})]$

(14) $G_{s2} + Test = SL_T - Pad_r - [DB\ 3000_{T2} + \Delta VSWR_{T2} - (DB\ 3000_{REFT2} + \Delta VSWR_{REFT2})]$

where

$\Delta VSWR_n$ = the mismatch error due to each mating for a DB 3000 reading in dB (n compatible with DB 3000 reading subscript)

Each error shown in Equation 12, 13, and 14 involves the mismatch error due to two connections (each end of the reference pad or test setup). The sign of each error term is independent of any of the other error terms; therefore, the solution for the test antenna gain will show all the errors:

$$\text{(15)}\quad \text{Test} = 1/2\ [\ 2\ SL_T - SL_G - Pad_r + (DB\ 3000_G - DB\ 3000_{REFG})$$

$$- (DB\ 2000_{T1} - DB\ 3000_{REFT1}) - (DB\ 3000_{T2} - DB\ 3000_{REFT2})$$

$$+ \Sigma\ \Delta\ VSWR]$$

The error contribution is then one-half the sum of the VSWR mismatch errors.

2.1.1.7 Polarization Contribution. The gain of the test antenna will have a potential error if the standard gain antennas have a polarization that is slightly elliptical rather than right hand circular. The error term appears as an error on each two antenna gain measurements as shown below:

$$\text{(16)}\quad G_{s1} + G_{s2} = X + POL_G$$

$$\text{(17)}\quad G_{s1} + \text{Test} = Y + POL_{T1}$$

$$\text{(18)}\quad G_{s2} + \text{Test} = Z + POL_{T2}$$

yielding

$$\text{(19)}\quad \text{Test} = 1/2\ [\ Y + Z - X + POL_{T1} + POL_{T2} - POL_G\ ]$$

where

POL_n = polarization mismatch error for each two antenna combination (n = G, T1, T2)

Since each antenna alignment is independent in roll head orientation from measurement to measurement, each polarization error term can have a random sign; therefore, the error contribution is the following:

$$\text{Polarization Error Contribution} = 1/2\ \Sigma\ POL$$

2.1.1.8 Bolometer Nonlinearity Contribution. For each measurement there is a different power level incident on the test bolometer. The bolometer nonlinearity will place an error on each reading which will appear in Equation 4 for each DB 3000 reading:

$$(19)\quad \text{Test} = 1/2 \Big[2\,SL_T - SL_G - Pad_r + \Big\{ (DB\ 3000_G + DB\ 3000_{REFG}) + \Delta\ BOLO_G \Big\}$$

$$- \Big\{ (DB\ 3000_{TL} - DB\ 3000_{REFT1}) + \Delta\ BOLO_{T1} \Big\}$$

$$- \Big\{ (DB\ 3000_{T2} - DB\ 3000_{REFT2}) + \Delta\ BOLO_{T2} \Big\}$$

where

$BOLO_n$ = the magnitude of bolometer error due to nonlinearity between a reference reading and a test reading (dB) (n =G, T1, T2)

The three error terms in Equation 19 are independent; therefore, the error contribution is a linear summation:

$$\text{Bolometer Error Contribution} = 1/2\ (\Delta\ BOLO_G + \Delta\ BOLO_{T1} + \Delta\ BOLO_{T2})$$

Since the nonlinearity is the same over the power range used, the above reduces to:

$$\text{Bolometer Error Contribution} = 3/2 \Delta BOLO$$

2.1.1.9 Antenna Pointing Contribution. The possible alignment error in placing the peak of the beam would cause an error term to appear in the combined gain of each pair of antennas for Equation 1, 2, and 3 as shown in the following:

$$(20)\quad G_{s1} + G_{s2} = X + \Delta\ P_G$$

$$(21)\quad G_{s1} + \text{Test} = Y + \Delta\ P_{T1}$$

$$(22)\quad G_{s2} + \text{Test} = Z + \Delta\ P_{T2}$$

Solving for the gain of the test antenna yields

$$(23)\quad \text{Test} = 1/2\ (Y + Z - X + \Delta P_{T1} + \Delta P_{T2} - \Delta P_G)$$

where

ΔP_n = the pointing error between perfect alignment and the actual alignment (dB)

The pointing exercise for each measurement is independent of the other measurements; therefore, the error contribution becomes the following:

$$\text{Pointing Error Contribution} = 1/2 \; \Sigma \; \Delta \; P$$

2.1.1.10 Near Field Measurement Contribution. The gain of each set of antennas is measured at a distance which is not the ideal (i.e., approaching an infinite distance); therefore, the measured gain is lower than the true far field gain. A term can be added to Equations 1, 2, and 3 to show the actual gain, giving the following:

(24) $G_{s1} + G_{s2} = X + \Delta \; G_G$

(25) $G_{s1} + \text{Test} = Y + \Delta \; G_{T1}$

(26) $G_{s2} + \text{Test} = Z + \Delta \; G_{T2}$

Solving for test yields

(27) $\text{Test} = 1/2 \; (Y + Z - X + \Delta G_{T1} + \Delta G_{T2} - \Delta G_G)$

where

$\Delta \; G_n$ = the gain adjustment (dB) for each set of measurements assuming S.L. is calculated from aperture to aperture*

This does not yield an error contribution as with the preceding terms but is an adjustment term. The gain is adjusted by

$$\text{Adjustment to Test} = 1/2 \; (\Delta G_{T1} + \Delta G_{T2} - \Delta G_G)$$

*Taken from A. Ludwig, "Near-Field Coupling," unpublished memo

2.2 ERROR FACTORS

2.2.1 DB 3000 Inherent Error

The focal point of the gain measurement and insertion loss measurement systems used for the MVM'73 program is the DB 3000-2, Precision Insertion Loss Measurement Set (manufactured by Systron-Donner). The DB 3000-2 Instructional Manual gives the following table as the overall accuracy of the instrument:

DB 3000 RANGE (dB)	OVERALL ACCURACY (dB)
0 - 1.0	± 0.007
1.0 - 10	± 0.017
10 - 20	± 0.050

The older DB 3000 manual gives an accuracy of ± 0.100 dB for the 20 - 25 dB range. This value was used in the analysis; however, the range was not used for measurements of MVM'73 components.

2.2.2 DB 3000 Repeatability

The DB 3000 repeatability was investigated through the ranges from 0 to 25 dB at both S-band and X-band. The test setup was adjusted to give a DB 3000 reading in the desired range and then the attenuation knobs on the instrument were randomly turned off value. The null was repeated and the attenuation value recorded. The recorded data are shown in Figures 1 and 2. Since the readings should not be frequency dependent, the worst case measurements for both frequencies were combined for use in the error analysis as follows:

DB 3000 RANGE (dB)	DB 3000 REPEATABILITY (dB)
0 - 1.0	± 0.002
1 - 5	± 0.004
5 - 10	± 0.005
10 - 15	± 0.005
15 - 20	± 0.017
20 - 25	± 0.018

2.2.3 Connector Repeatability

Connector repeatability was measured by mating and demating a pair of connectors several times and recording the DB 3000 reading after each mating. The type N connector repeatability data is shown in Figure 3. The 4CT connector repeatability was tested in two different ways. The 4CT connection was tested by itself by immobilizing the other components, such as the coupler and feed line. After each connection the change in DB 3000 reading should have represented only the effect on the 4CT connector. The connection was also tested when the components were allowed to move simulating the movement to the ends of a test cable. The results are shown in Figures 4 and 5. These tests were made with a set of 4CT-N adapters which have stainless steel mating surfaces. The cables have aluminum mating surfaces which might form a better surface under connector torquing; however, the adapter data was assumed to be representative and was used in the analysis as follows:

	CONNECTOR REPEATABILITY (dB)	
CONNECTOR	S-Band	X-Band
Type N	±.002	±.0025
Type 4CT and Comp.	±.00375	±.0075
Type 4CT	±.0015	±.004

Since any test measurement consists of a pair of connections for a reference and a pair for the test article, the repeatability tolerance is taken as four times the single tolerance for each set of measurements.

2.2.4 VSWR Mismatch

The mismatch at a connector due to VSWR differences between each package can be estimated by assuming the worst case match (the multiple of the two) or the best match (the dividend of the two). The added insertion loss due to this mismatch is shown in Figure 6. The VSWR of each package was tuned on an Alford

Slotted Line at S-band and a HP Slotted Line at X-band. Since the residual of each line was in the 1.06 to 1.07 range, an external tuner on the line was used to yield an effective 1.01 residual for measurements at the desired frequencies. By procedure each test pad or package was tuned to a VSWR of less than 1.01: however, the test articles were utilized without retuning with a maximum VSWR of 1.02 at S-band and 1.04 at X-band. The VSWR of the standard gain antennas were maintained in the 1.04 to 1.08 range. For the analysis the 1.08 figure was used. The error for the section VSWR is calculated by taking the worst case difference between the best match and worst match at a connection and dividing by two (A sample calculation is shown in Section 3.1.1.1.).

2.2.5 Bolometer Nonlinearity

Weinschell Model 1192 P-8 bolometer elements were used early in the program. These elements have a maximum error of ±0.01 dB for incident power levels below -7 dBm per Weinschell spec. Later in the program Narda N603 elements were used due to availability and Narda's commitment to the same tolerance as Weinschell listed. It was found that some Weinschell elements were not built per drawing. This did not appear to affect their accuracy within our measurement ability; however, the elements were easily burned out by excess power levels. The present Weinschell elements are per drawing and present procedure is to use either Weinschell or Narda elements.

2.2.6 Phase Center Location and Separation

The range equation was used to calculate the space loss between the antennas as part of the gain measurement. The distance between antennas used in the calculation was the distance between phase centers. The errors associated with these phase centers are the location within the antenna and the physical measurement of distance.

The time available and priorities allowed only phase center measurement of the low gain antenna. By utilizing a two-channel phase comparison of the signal received by the low gain antenna relative to the phase of the transmitted signal and visual monitoring with the Theodolite, the phase center was measured to be 0.5 inches inside the aperture formed by the cones. The shape of the measured phase comparison curve was relatively constant over locations ± 1/2 inch from the above location so this was carried as the error. The S-band standard gain horns carried phase center locations of 23 inches (2115.6 MHz) and 20.5 inches (2297.9 MHz) inside the respective apertures with an error of ± 2 inches from the Mariner '71 Program. The phase center location of each X-band standard gain antenna (SGA) was taken as 2.1 inches inside the aperture. This is the linear phase center location given by Jack Hardy from measurements for "Gain Calibration of Horn Antenna Using Pattern Integration," JPL TR 32-1572. The error was arbitrarily assumed to be ± 1 inch due to the polarization difference of the SGA and the slight difference between this horn and the one calibrated by Hardy. The phase center location of the MVM'73 high gain antenna was taken as the dish aperture during Type Approval measurements and continued for Flight Approval measurements to allow comparison. This location was considered to be conservative since the Mariner '71 high gain antenna had a location 4 inches into the dish with an error of ± 2 inches. An error of ± 2 inches was assumed for the MVM'73 high gain antenna to keep it consistent with the S-band standard gain antennas.

An error on the measurement of distance between antenna phase centers is taken as ± 1/4 inch from numerous measurements made with the Theodolite and two different steel tapes.

2.2.7 Polarization Mismatch

The antenna gain of the test antenna is measured with standard gain antennas having a slightly elliptical polarizazton. This ellipticity causes a mismatch error which is calculated using equations from R. W. Hartop, "Power Loss Between Arbitrarily Polarized Antennas," JPL TR 32-457. The SGA were adjusted to an ellipticity less than .25 dB on axis; however, for the X-band SGA the effective field had a higher ellipticity at 507 feet due to reflections. The field was assumed to have an effective 1.0 dB ellipticity from tests with a 40-inch linear dish. The ellipticity of the antennas used for calculations are as follows:

TEST ANTENNA	ELLIPTICITY (dB)
HGA, S-Band	0.65
HGA, X-Band	1.20
LGA, S-Band	2.20
SGA, S-Band	0.25
SGA, X-Band (100')	0.25
SGA, X-Band (507')	1.00

The resulting errors are calculated as follows:

TEST	ERROR (dB)
SGA - HGA (S-Band)	± 0.005
SGA - SGA (S-Band)	± 0.002
SGA - LGA (S-Band)	± 0.016
SGA - SGA (X-Band)	± 0.002
SGA - HGA (X-Band)	± 0.034

2.2.8 Range Mechanical Errors

The mechanical parameters of the mount were measured to ascertain the alignment of the various axes and the mechanical positions relative to the dial readings. The mechanical/dial relationships needed for measurements included the roll position of the head (for patterns), azimuth position of mount (patterns), alignment of the mast (for patterns and beam alignment), and perpendicularity of the high gain antenna mount to the head roll axis (for beam alignment). The roll position and the azimuth position versus dial reading and recorder position tracked well. The alignment of the mast caused some concern when it was found that the head rotated 1/2 inch off the center of rotation of the mount when the positioner moved in azimuth. This was found to be mast warpage due to heat. The same measurement yielded 0.05 inch when conducted before sunrise. The perpendicularity of the mounting plate was checked per procedure with a mirror and Theodolite. The antenna alignment measurements showed a repeatability within 0.25 minutes. This repeatability could have represented the perpendicularity of the mounting plate or it could result from the random use of three one-inch spacers between the mounting plate and the handling frame. All other mechanical parameters were checked repeatedly by other means, such as, Theodolite, vernier angle gauge, and steel measuring tape.

2.2.9 Recorder Error

The rectangular recorder used for pattern measurements was a SA Series 1520 calibrated with a SA test set. The pen response is specified by SA to an accuracy of ± 0.15 for logarithmic patterns.

2.2.10 Recording System Drift

The recording system was set up "closed loop" from the generator through the transmitting cable on the tower to a bolometer and in turn to the recorder. The recorder was set on time drive and run for 100 minutes. The drift was negligible compared to transmitter output changes. A change of 0.025 dB could be seen on the paper and agreed with visual observations of the transmitter monitoring HP 415. During pattern measurements the patterns were rerun if the output was noted to shift more than this at S-band and more than 0.05 dB at X-band.

2.2.11 Range Reflections

The effect of range reflections was measured by taking several roll patterns of each antenna at the desired frequency, taking image patterns (180° clock from the initial set) and reverse overlaying the patterns. Figures 7, 8, and 9 show the composite worst case variations from the measurements.

For the high gain patterns, best overall pattern overlays produced a non-zero difference in the region of the peak of the pattern due to the slight degree of pen tolerance.

SECTION III

ANTENNA MEASUREMENT ERRORS

3.1 GAIN ERRORS

3.1.1 Reference Pad Errors

3.1.1.1 S-Band Pad Errors. There were two reference pads used for the S-band antenna measurements - one for 2115.6 MHz and one for 2297.9 MHz. The S-band pad errors are figured using Figure 10. Each reference pad was calibrated using a type N barrel for an initial reference and an intermediate pad. For instance, the 2115.6 MHz pad was measured as follows:

1. The type N barrel gave a null on the HP 415 at 1.495 dB on the DB 3000 with a reference package and detector package setup.

2. The barrel was removed and an intermediate pad inserted in the test setup. The DB 3000 was adjusted to 17.681 dB to yield a null on the HP 415.

3. The intermediate pad gave a null at 2.686 dB on the DB 3000 in another reference and detector package setup.

4. The intermediate pad was removed and the reference pad inserted in the test setup. The DB 3000 was adjusted to 14.505 dB to yield a null on the HP 415.

The barrel is 0.028 dB*, resulting in an intermediate pad value of 16.214 dB (17.681 - 1.495 + 0.028). This yields a reference pad value of 28.033 dB (14.505 - 2.686 + 16.214). The pad errors from Figure 10 are ±0.111 dB and ±0.202 dB, respectively. (The reference pad error is the sum of the intermediate pad error and the pad to pad measurement error.)

The listed errors of the figure are from the measurements previously described. The highest readings on the DB 3000 established the column to be used from Figure 10.

*This value for the barrel was computed from the difference of the VSWR due to an open on the slotted line and the VSWR due to the open after adding the barrel. It is considered to be a conservative value (high) from measurements made with this type of barrel and a male-male adapter.

The section VSWR error contribution for barrel to intermediate pad was slightly higher than that for intermediate pad to reference pad due to the 1.10 VSWR of the barrel. The barrel to package connection has a mismatch which can range from a VSWR of 1.07 to 1.13 at each end. The insertion loss difference for this range of VSWR can be .024 dB* or a possible error of ± .012 dB. The pad to package connection mismatch can range from a VSWR of 1.00 to 1.06 at each end. This difference can yield an insertion loss range of .0076 dB or a possible error of ± .004 dB. The error of a pad measurement from a barrel reference is then ± .016 dB and a pad measurement from a pad reference is ± .008 dB for the VSWR contribution.

The 2297.9 MHz pad was measured to be 27.627 ± .168 dB by using an intermediate pad of 19.019 ± .111 dB. These errors are based on DB 3000 ranges of 5 - 10 dB for the 27 dB pad and 15 - 20 dB for the 19 dB pad.

3.1.1.2 X-Band Pad Error. The reference pad used at X-band was measured at 8415 MHz to have an insertion loss of 30.018 ± .240 dB using Figure 11. The reference pad was measured using a barrel and intermediate pad which had a loss of 16.341 ± .123 dB. The errors shown in Figure 11 resulted from DB 3000 readings in the 15 - 20 range, pad and package VSWR's of 1.04, and barrel VSWR of 1.08.

3.1.2 High Gain Antenna Gain Errors

3.1.2.1 HGA S-Band Gain Error. The S-band gain of the HGA was measured at 2297.9 MHz. From Section II the individual errors can be combined to yield the overall gain error. The HGA gain was measured at a distance of 200 feet, in the 1-5 dB range on the DB 3000, and the VSWR of the HGA was 1.10.

* The loss difference of 0.024 dB can be found from Figure 6 - .017 dB (1.13 VSWR) minus .005 dB (1.07 VSWR) for each end of the pad.

ERROR FACTOR	CONTRIBUTION (dB)	REMARKS	SECTION
DB 3000 Inher. & Repeat	± 0.032	3/2 (.021)	2.1.1.4
Type N Repeat	± 0.012	6 (.002)	2.1.1.5
Section VSWR	± 0.021	.014 + 1/2 (.013)	2.1.1.6
Antenna Point	± 0.015	3/2 (.010)	2.1.1.9
Bolo. Nonlin.	± 0.030	3/2 (.020)	2.1.1.8
Phase Center Location	± 0.012	$\emptyset C_G$	2.1.1.2
Reference Pad	± 0.084	1/2 (.168)	2.1.1.1
Distance Error	± 0.002	± 1/4 "	2.1.1.3
Polarization Mismatch	± 0.006	.005 + 1/2 (.002)	2.1.1.7
HGA S-Band Gain Error =	± 0.214		

3.1.2.2 HGA X-Band Gain Error. The X-band gain of the HGA was measured at 8415 MHz. The individual errors can be combined to yield the overall gain error. The HGA gain was measured at a distance of 507 feet, in the 1 - 5 dB range on the DB 3000, and the VSWR of the HGA was 1.20.

ERROR FACTOR	CONTRIBUTION (dB)	REMARKS	SECTION
DB 3000 Inher & Repeat	± 0.032	.021 + 1/2 (.022)	2.1.1.4
Type N Repeat	± 0.015	6 (.0025)	2.1.1.5
Section VSWR	± 0.050	.037 + 1/2 (.026)	2.1.1.6
Antenna Point	± 0.030	3/2 (0.020)	2.1.1.9
Bolo. Nonlin.	± 0.030	3/2 (.020)	2.1.1.8
Phase Center Location	± 0.009	.003 + 1/2 (.0129)	2.1.1.2
Reference Pad	± 0.120	1/2 (.240)	2.1.1.1
Distance Error	± 0.001	± 1/4"	2.1.1.3
Polarization Mismatch	± 0.035	.03445 + 1/2 (.0019)	2.1.1.7
HGA X-band Gain Error	= ± 0.322		

3.1.3 Low Gain Antenna Gain Errors

The LGA gain was measured at 2115.6 MHz and 2297.9 MHz. The difference in pad error and DB 3000 range resulted in a difference in the error between the two frequencies. The LGA gain was measured at a distance of 27.5 feet, the 5 - 10 dB range on the DB 3000 (10 - 15 dB at 2297.9 MHz), the VSWR of the LGA was 1.4. The following shows the combining of individual errors for the overall gain error.

ERROR FACTOR	CONTRIBUTION (dB) 2115.6/2297.9	REMARKS	SECTION
DB 3000 Inher & Repeat	± 0.033/0.066	0.022 + ½ (.022)/.055 + ½ (.022)	2.1.1.4
Type N Repeat	± 0.012	6 (.002)	2.1.1.5
Section VSWR	± 0.037	.030 + ½ (.013)	2.1.1.6
Antenna Point	± 0.015	3/2 (.010)	2.1.1.9
Bolo. Nonlin.	± 0.030	3/2 (.020)	2.1.1.8
Phase Center Location	± 0.092	.052 + (.052 - .012)	2.1.1.2
Reference Pad	± 0.101/.084	½ (.202) / ½ (.168)	2.1.1.1
Distance Error	± 0.007	± 1/4"	2.1.1.3
Polarization Mismatch	± 0.017	.01605 + 1/2 (0.0019)	2.1.1.7
LGA S-band Gain Error = ± 0.334/0.360			

3.2 PATTERN ERRORS

3.2.1 High Gain Antenna Pattern Errors

3.2.1.1 HGA S-Band Pattern Errors. The HGA pattern errors at 2297.9 MHz are the sum of the pen response error (± 0.15 dB), system drift, or transmitter stability (±0.025 dB), and the error from the pattern difference chart (Figure 7). To obtain absolute gain level, one must use the absolute gain level at the peak with an error of ±0.214 dB as a reference on the pattern in addition to the pattern error.

HGA S-BAND PATTERN ERROR

PATTERN LEVEL BELOW PEAK - dB	ERROR = ± (X DB + Y DB/DB)	
	X	Y
0 - 2	0.275	- 0.050
2 - 14	0.175	0.0
14 - 18	-2.625	0.200
18 - 24	0.375	0.033
24 - 30	-7.625	0.366
30 - 39	3.375	0.0

3.2.1.2 HGA X-Band Pattern Errors. The HGA pattern errors at 8415 MHz are the sum of the pen response error (± 0.15 dB), system drift, or transmitter stability (0.05 dB), and the error from the pattern difference chart (Figure 8). To obtain absolute gain level, one must use the absolute gain level at the peak with an error of ± 0.322 dB as a reference on the pattern in addition to the pattern error.

HGA X-BAND PATTERN ERROR

PATTERN LEVEL BELOW PEAK - dB	ERROR = ± (X DB + Y DB/DB)	
	X	Y
0 - 2	0.300	-.050
2 - 4	0.200	0.0
4 - 6	-0.300	0.125
6 - 8	1.200	-0.125
8 - 12	0.200	0.0
12 - 16	-1.300	0.125
16 - 24	-4.00	0.294
24 - 34	-5.440	0.235
34 - 39	5.400	0.0

3.2.2 Low Gain Antenna Pattern Errors

The low gain antenna pattern errors at S-band are the sum of the pen response error (± 0.15 dB), system drift, or transmitter stability (± 0.025 dB), and the errors from the pattern difference chart (Figure 9). To obtain the absolute gain level at a point, one must use the absolute gain with its error of ±0.343 dB at 2115.6 MHz and ± 0.369 dB at 2297.9 MHz at a cone angle of 90° as a reference in addition to the pattern errors. The LGA has a "doughnut" pattern similar to that of a simple dipole. The pattern has a peak near 90° cone rather than at 0° like previous Mariner low gain antennas; therefore, the pattern errors tend to be minimum near 90° cone.

LGA S-BAND PATTERN ERRORS

CONE ANGLE (Degrees)	ERROR = ± (X DB + Y DB/deg)	
	X	Y
0 - 10	8.675	0.0
10 - 20	9.375	-0.070
20 - 30	13.675	-0.285
30 - 40	17.425	-0.410
40 - 70	1.692	-0.017
70 - 100	0.758	-0.0033
100 - 110	0.425	0.0
110 - 130	0.150	0.0025
130 - 160	-0.825	0.010
160 - 170	-93.625	0.590
170 - 180	6.675	0.0

SECTION IV

CABLE INSERTION LOSS ERRORS

4.1 CABLE ERROR FACTORS

The error determination of insertion loss measurements is much like that of the pad errors; however, the connectors are type 4CT and the movement of the couplers and other associated connectors influenced the measurements more than those with the type N connectors. The 4CT repeatability was measured by mating and demating the type 4CT interface between two 4CT-N adapters. The data shown in Figures 4 and 5 show two sets of readings. For the first set, the coupler and detector sections were allowed to move, which is representative of utilizing these components for the cable measurements. For the other set of data, the coupler and detector were immobilized to check the 4CT repeatability representative of any internal 4CT interface within the cable assembly.

The 4CT repeatability and section VSWR were used with previous errors to make the error charts shown in Figures 12 and 13.

4.2 S-BAND CABLE ERRORS

4.2.1 LGA Cable Assembly Error (S-Band)

The S-band error on the LGA cable assembly loss can be calculated from Figure 12 using the 1 - 5 dB range and the fact that there is one 4CT interface (the assembly consists of two cables) in addition to the connectors attached to the reference and detector packages. The error is ± 0.081 dB (0.078 + 0.003).

4.2.2 HGA Cable Assembly Error (S-Band)

The S-band error on the HGA cable assembly loss can be calculated from Figure 12 and adjusting for five 4CT interfaces in the assembly (six cables in assembly). The error is ± 0.093 dB (0.078 + 0.015).

4.3 X-BAND CABLE ERRORS

4.3.1 HGA Cable Assembly Error (X-Band)

The X-band error on the HGA cable assembly loss (less jumper cable to transmitter) can be calculated using Figure 13 and adjusting for four 4CT interfaces in the assembly (five cables). The error is ± 0.154 dB (0.122 + 0.032).

4.3.2 Individual Cable Error (X-Band)

The X-band error on the loss of individual cables can be calculated using Figure 13 with no extra 4CT interfaces. The error is ± 0.122 dB (0.122 + 0). This error is appropriate for the X-band jumper cable which connects to the X-band transmitter. This cable has a 4CT connector on one end and an OSM 501-1 connector on the other. To measure the insertion loss, two of these cables are connected with an OSM 217 adapter (barrel); the insertion loss is measured from 4CT to 4CT; and one-half the insertion loss attributed to each cable. The loss from one-half of the barrel should cancel toward a conservative answer for any length difference in the two jumpers used. The VSWR of the OSM interfaces from OSM spec are comparable to the 4CT interfaces on a cable so the error chart (Figure 13) should apply.

4.3.3 HGA to Transmitter Cable Assembly Error (X-Band)

The insertion loss for the cable assembly from the HGA to the transmitter is the sum of the jumper cable loss and the loss of the assembly of the other five cables. The error is also the sum of the errors for these two measurements which equals ± 0.276 dB.

FIGURE 1 - DB 3000 REPEATABILITY (S-BAND)

2115.6 MHz

VALUE	Δ
0.174	-----
0.174	-----
0.1755	.0015
0.175	.0005
0.1745	.0005
0.1735	.001
0.175	.0015
0.174	.001
0.1735	.0005
0.1745	.001
WORST Δ	.0015

VALUE	Δ
3.210	----
3.210	----
3.208	.002
3.209	.001
3.210	.001
3.214	.004
3.2125	.0015
3.211	.0015
3.2125	.0015
3.214	.0015
WORST Δ	.004

VALUE	Δ
6.028	----
6.0285	.0005
6.027	.0015
6.029	.002
6.0285	.0005
6.027	.0015
6.0275	.0005
6.0285	.001
6.0275	.001
6.0285	.001
WORST Δ	.002

VALUE	Δ
11.834	---
11.834	---
11.834	---
11.836	.002
11.832	.004
11.836	.004
11.835	.001
11.830	.005
11.8295	.0005
11.825	.0045
WORST Δ	.005

VALUE	Δ
17.747	---
17.752	.005
17.769	.017
17.754	.015
17.747	.007
17.754	.007
17.748	.006
17.760	.012
17.758	.002
17.755	.003
WORST Δ	.017

VALUE	Δ
23.243	---
23.232	.011
23.243	.011
23.247	.004
23.240	.007
23.255	.015
23.253	.002
23.248	.005
23.238	.010
23.240	.002
WORST Δ	.015

FIGURE 1 - DB 3000 REPEATABILITY (S-BAND)

CONTINUED

2297.9 MHz

VALUE	Δ
0.332	---
0.331	.001
0.329	.002
0.3305	.0015
0.329	.0015
0.329	---
0.327	.002
0.325	.002
0.324	.001
0.3235	.0005
WORST Δ	.002

VALUE	Δ
9.665	---
9.665	---
9.6615	.0035
9.657	.0045
9.654	.003
9.650	.004
9.6495	.0005
9.650	.0005
9.655	.005
9.657	.002
WORST Δ	.005

VALUE	Δ
15.276	----
15.272	.004
15.273	.001
15.274	.001
15.271	.003
15.271	---
15.274	.003
15.272	.002
15.270	.002
15.266	.004
WORST Δ	.004

VALUE	Δ
25.060	---
25.068	.008
25.073	.005
25.065	.008
25.068	.003
25.065	.003
25.060	.005
25.055	.005
25.068	.013
25.050	.018
WORST Δ	.018

FIGURE 2

DB 3000 REPEATABILITY (8415 MHz)

VALUE	Δ
.271	---
.269	.002
.269	---
.268	.001
.266	.002
.266	---
.2665	.0005
.268	.0015
.2665	.0015
.265	.0015
WORST Δ	.002

VALUE	Δ
1.981	---
1.9815	.0005
1.981	.0005
1.979	.002
1.979	---
1.981	.002
1.979	.002
1.980	.001
1.9805	.0005
1.9795	.001
WORST Δ	.002

VALUE	Δ
5.070	---
5.0715	.0015
5.069	.0025
5.070	.001
5.071	.001
5.072	.001
5.0715	.0005
5.0715	---
5.0715	---
5.0715	---
WORST Δ	.0025

VALUE	Δ
7.9505	---
7.9485	.002
7.9505	.002
7.9483	.0022
7.948	.0003
7.9495	.0015
7.9485	.001
7.949	.0005
7.9495	.0005
7.949	.0005
WORST Δ	.0022

VALUE	Δ
11.5335	---
11.5325	.001
11.533	.0005
11.5335	.0005
11.5345	.001
11.5335	.001
11.5345	.001
11.5365	.002
11.536	.0005
11.5365	.0005
WORST Δ	.002

VALUE	Δ
15.844	---
15.834	.010
15.835	.001
15.8385	.0035
15.8325	.006
15.831	.0015
15.8285	.0025
15.826	.0025
15.827	.001
15.8245	.0025
WORST Δ	.010

VALUE	Δ
21.754	---
21.765	.011
21.770	.005
21.758	.012
21.765	.007
21.760	.005
21.760	---
21.758	.002
21.753	.005
21.764	.011
WORST Δ	.012

FIGURE 3

TYPE N CONNECTOR REPEATABILITY MEASUREMENTS

	S-BAND		X-BAND		
	VALUE	Δ	VALUE	Δ	
2297.9 MHz	.425	---	2.891	---	8415 MHz
	.429	.004	2.893	.003	
	.428	.001	2.892	.001	
	.429	.001	2.894	.002	
	.428	.001	2.893	.001	
	.4275	.0005	2.892	.001	
	.4255	.002	2.8925	.0005	
	.429	.0035	2.890	.0025	
	.425	.004	2.889	.001	
	.429	.004	2.888	.001	
2115.6 MHz	.110	---	2.883	.005	
	.1075	.0025	2.884	.001	
	.109	.0015	2.885	.001	
	.110	.001	2.885	---	
	.1085	.0015	2.883	.002	
	.109	.0005	2.880	.003	
	.1085	.0005	2.883	.003	
	.108	.0005	2.886	.003	
	.1085	.0005	2.883	.003	
	.105	.0035	2.880	.003	
	WORST Δ	.004	WORST Δ	.005	

FIGURE 4

4CT CONNECTOR REPEATABILITY MEASUREMENTS

(S-BAND)

2297.9 MHz

4CT AND ASSOCIATED COMPONENTS		4CT ALONE	
VALUE	Δ	VALUE	Δ
.038	---	3.429	---
.038	---	3.432	.003
.045	.007	3.434	.002
.046	.001	3.434	---
.047	.001	3.434	---
.053	.006	3.434	---
.055	.002	3.431	.003
.050	.005	3.433	.002
.053	.003	3.430	.003
.057	.004	3.431	.001
.059	.002	3.431	---
.0655	.0065	3.433	.002
.065	.0005	3.431	.002
.0665	.0005	3.4315	.0005
.059	.0075	3.4325	.001
WORST Δ	.0075	WORST Δ	.003

FIGURE 5

4 CT CONNECTOR REPEATABILITY MEASUREMENTS

(X-BAND)

8415 MHz

4CT AND ASSOCIATED COMPONENTS

VALUE	Δ
3.866	---
3.851	.015
3.851	---
3.857	.006
3.848	.009
3.859	.011
3.849	.010
3.845	.004
3.851	.006
3.838	.013
3.844	.006
3.850	.006
3.856	.006
3.859	.003
3.852	.007
WORST Δ	.015

4CT ALONE

VALUE	Δ
3.889	---
3.894	.005
3.896	.002
3.891	.005
3.894	.003
3.891	.003
3.897	.006
3.905	.008
3.903	.002
3.907	.004
3.910	.003
3.903	.007
3.906	.003
3.900	.006
3.908	.008
WORST Δ	.008

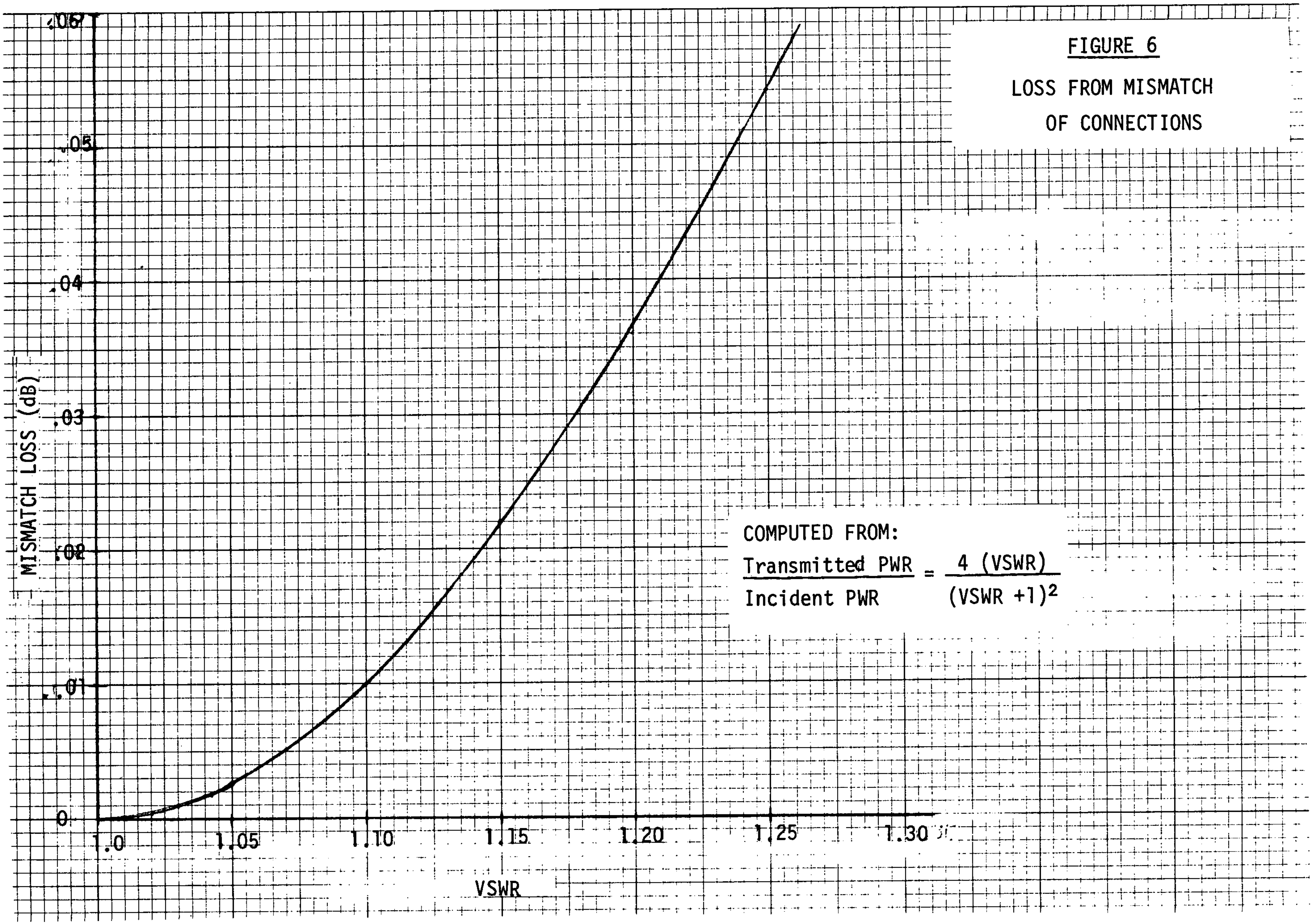


FIGURE 6

LOSS FROM MISMATCH OF CONNECTIONS

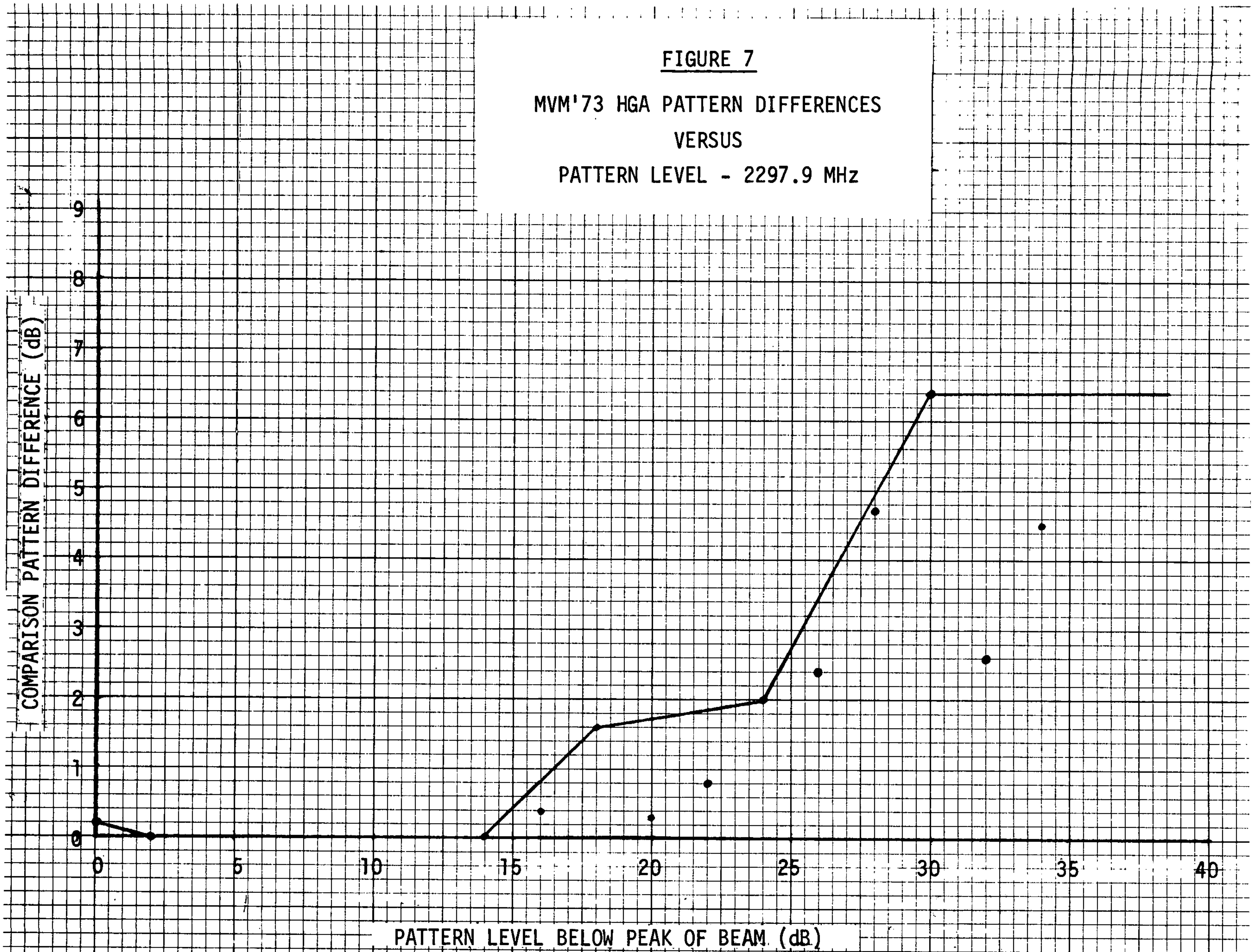


FIGURE 7

MVM'73 HGA PATTERN DIFFERENCES

VERSUS

PATTERN LEVEL - 2297.9 MHz

FIGURE 8

MVM'73 HGA PATTERN DIFFERENCES
VERSUS
PATTERN LEVEL - 8415 MHz

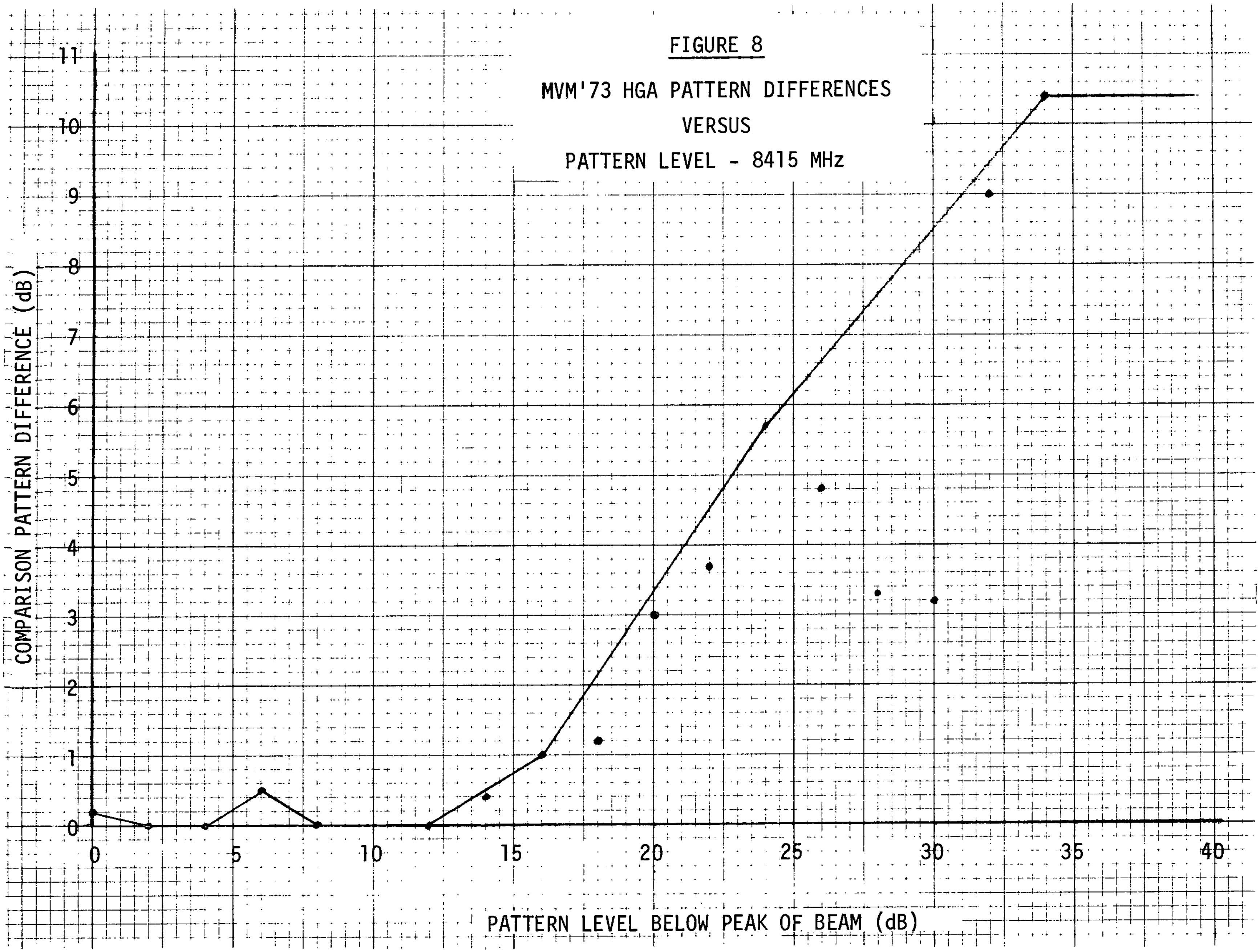


FIGURE 9

MVM'73 LGA COMPARISON PATTERN DIFFERENCES
VERSUS
CONE ANGLE AT S-BAND

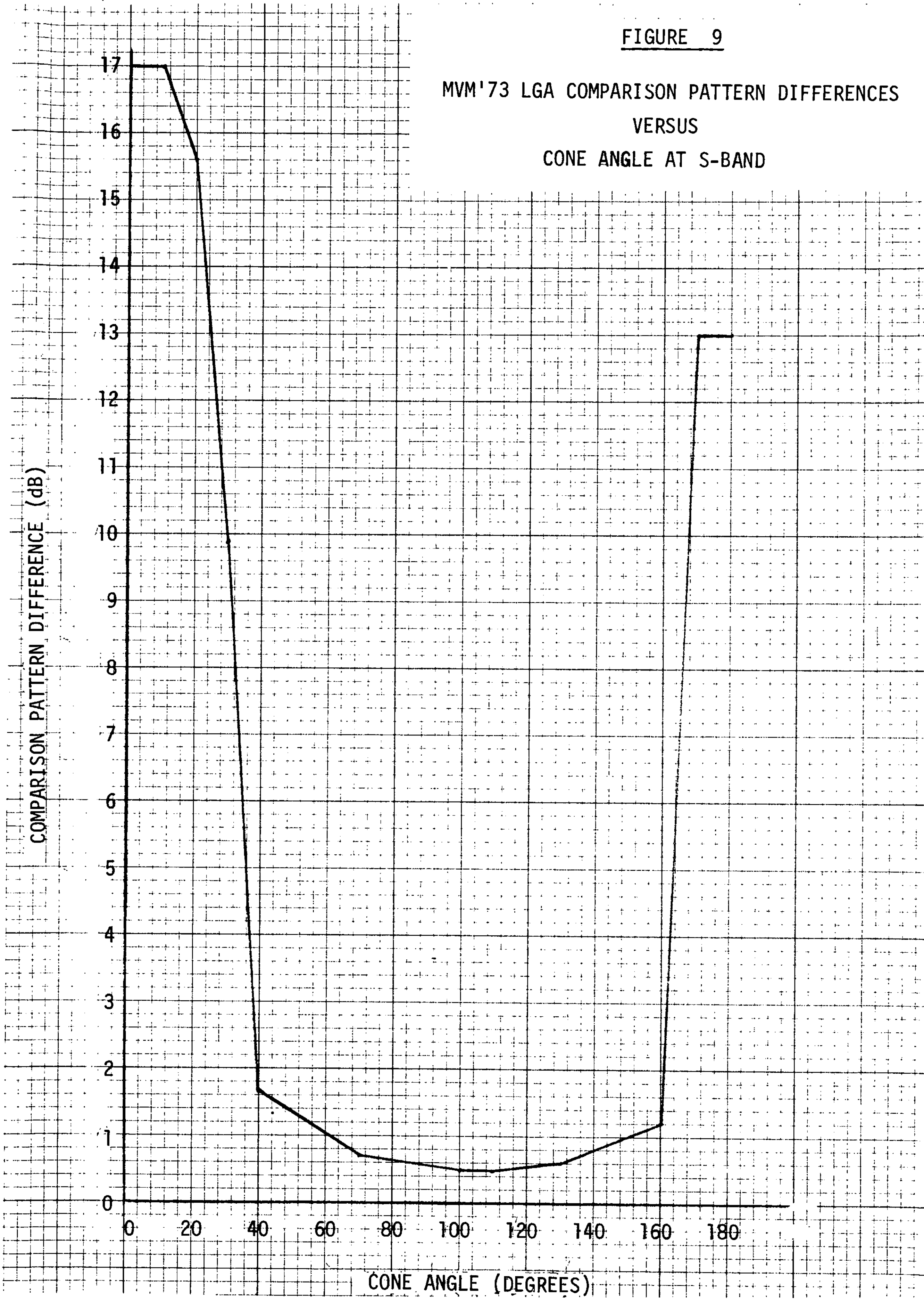


FIGURE 10

PAD ERRORS - S-BAND

RANGE (dB)	0 - 1	1 - 5	5 - 10	10 - 15	15 - 20	20 - 25
DB 3000 INHERENT	±.007	±.017	±.017	±.050	±.050	±.100
DB 3000 REPEATABILITY	±.002	±.004	±.005	±.005	±.017	±.018
TYPE N REPEATABILITY	±.008	±.008	±.008	±.008	±.008	±.008
SECTION VSWR	±.016 / ±.008	±.016 / ±.008	±.016 / ±.008	±.016 / ±.008	±.016 / ±.008	±.016 / ±.008
BOLOMETER NONLIN.	±.020	±.020	±.020	±.020	±.020	±.020
TOTAL (dB) $\left(\frac{B_2 \text{ to Pad}}{\text{Pad to Pad}}\right)$	±.053 / ±.045	±.065 / ±.057	±.066 / ±.058	±.099 / ±.091	±.111 / ±.103	±.162 / ±.154

All 1.02 VSWR (Except B_2 = 1.10)

1.01 Residual

FIGURE 11

PAD ERRORS - X-BAND

RANGE (dB)	0 - 1	1 - 5	5 - 10	10 - 15	15 - 20	20 - 25
DB 3000 INHERENT	±.007	±.017	±.017	±.050	±.050	±.100
DB 3000 REPEATABILITY	±.002	±.004	±.005	±.005	±.017	±.018
TYPE N REPEATABILITY	±.010	±.010	±.010	±.010	±.010	±.010
SECTION VSWR	±.026 / ±.020	±.026 / ±.020	±.026 / ±.020	±.026 / ±.020	±.026 / ±.020	±.026 / ±.020
BOLOMETER NONLIN.	±.020	±.020	±.020	±.020	±.020	±.020
TOTAL (dB) $\left(\frac{B_2 \text{ to Pad}}{\text{Pad to Pad}}\right)$	±.065 / ±.059	±.077 / ±.071	±.078 / ±.072	±.111 / ±.105	±.123 / ±.117	±.174 / ±.168

All 1.04 VSWR (Except B_2 = 1.08)

1.01 Residual

FIGURE 12

CABLE ERRORS (S-BAND)

RANGE (dB)	0 - 1	1 - 5	5 - 10	10 - 15	15 - 20	20 - 25
DB 3000 INHERENT	±.007	±.017	± 017	±.050	±.050	±.100
DB 3000 REPEATABILITY	±.002	±.004	±.005	±.005	±.017	±.018
4CT REPEATABILITY	± .015 / ±.003	±.015 / ±.003	±.015 / ±.003	±.015 / ±.003	±.015 / ±.003	±.015 / ±.003
SECTION VSWR	±.022	±.022	±.022	±.022	±.022	±.022
BOLOMETER NONLIN.	±.020	±.020	±.020	±.020	±.020	±.020
TOTAL (dB) BASE / PER 4CT INTERFACE	± .062 / ±.003	±.078 / ±.003	±.079 / ±.003	±.112 / ±.003	±.124 / ±.003	±.175 / ±.003

FIGURE 13

CABLE ERRORS (X-BAND)

RANGE (dB)	0 - 1	1 - 5	5 - 10	10 - 15	15 - 20	20 - 25
DB 3000 INHERENT	±.007	±.017	±.017	±.050	±.050	±.100
DB 3000 REPEATABILITY	±.002	±.004	±.005	±.005	±.017	±.018
4CT REPEATABILITY	±.030 / ±.008	±.030 / ±.008	±.030 / ±.008	±.030 / ±.008	±.030 / ±.008	±.030 / ±.008
SECTION VSWR	±.051	±.051	±.051	±.051	±.051	±.051
BOLOMETER NONLIN.	±.020	±.020	±.020	±.020	±.020	±.020
TOTAL (dB) BASE / PER 4CT INTERFACE	±.110 / ±.008	±.122 / ±.008	±.123 / ±.008	±.156 / ±.008	±.168 / ±.008	±.219 / ±.008