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16. Abstract

The use of phased arrays for the proposed landing system (MLS) is discussed. Studies relating to ground reflections, near field focusing, and phased-array errors are presented. Two experimental antennas are described which were fabricated and tested. Complete component specifications are included, as well as test results.

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PREFACE

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APPENDIX A

EVALUATION OF AN R-2R LENS AS A COMPONENT IN A C-BAND PHASED ARRAY

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

$$2R_1\cos\left(\frac{\phi_1}{2}\right) + L + R_2(1-\cos\ \phi_2) = 2R_1 + L$$

or

$$R_2(1-\cos\ \phi_2) = 2R_1\left(1-\cos\left(\frac{\phi_1}{2}\right)\right) \qquad (A.1)$$

If $R_2 = 2R_1$, and if the lens probe spacing is chosen to give $\phi_1 = 2\ \phi_2$, this becomes an identity. The antenna has thus twice the radius of the lens (hence the name R-2R lens), and the lens probe spacing is twice the spacing (in angle) of the antenna elements. The probe spacing in units of electrical length are approximately the same for lens and antenna. The size of the lens can be reduced with the addition of dielectric material if this is necessary from the point of view of size.

If the input probe at an angle $\Delta\phi$ clockwise from the initial probe is excited instead, the beam will move an angle $\Delta\phi/2$ clockwise in space. If this process is continued, eventually the input probe will be an output probe for one of the prior beam positions. If coverage this wide were necessary, a signal routing problem would occur, since the lens probe would be connected to both an antenna element and the source network, necessitating either a switch or circulator. This is to be avoided if possible in order to keep insertion loss and complexity down. Quantitatively, the coverage limits imposed by this criterion can be calculated from the active sector angle ϕ_a. If the antenna active sector is ϕ_a, the lens active sector must be $2\ \phi_a$. Moving the input probe clockwise, it can go no further than $180° - \phi_a$.

Thus, the scan coverage in space must be $(1/2)(180° - \phi_a)$, or

$$\phi_c \leq 90° - \frac{\phi_a}{2}$$

Thus, for an active sector of 60°, the scan limits are $\pm 30°$. In order to achieve a coverage of $\pm 60°$, the active sector would have

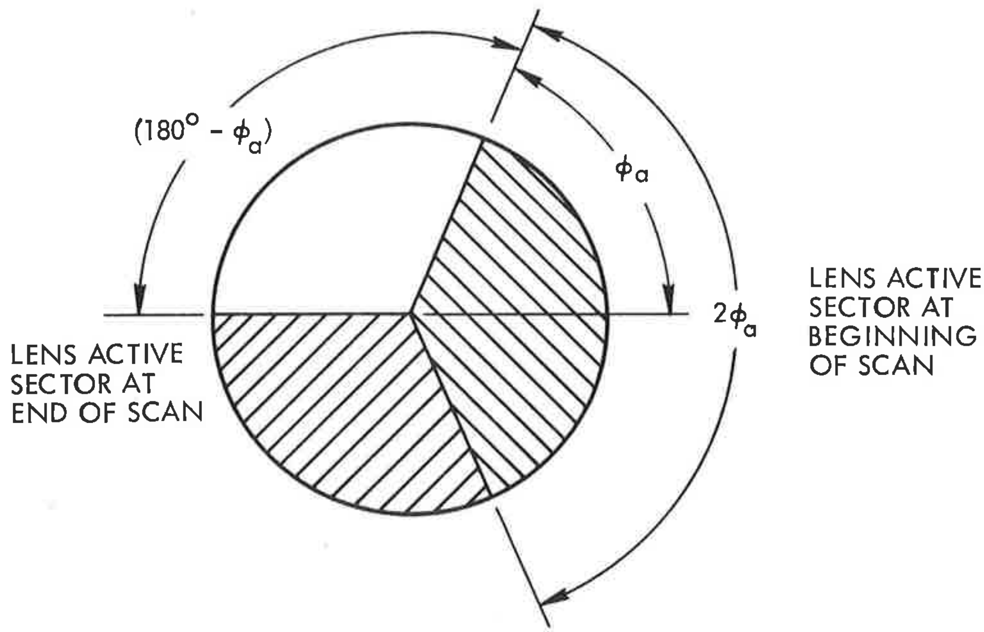


Figure A.2 Lens Geometry for Determining Scanning Limits for a Given Active Sector

to be 30° or less, which would constitute an inefficient use of aperture, and require a large radius antenna. This does not rule it out as a possibility, but it is a significant cost disadvantage.

Another feature of the independent input and output probes is that the spacings can be different: the output probe spacing is dictated by the antenna spacing, but the input probe spacing can be chosen to optimize the aperture taper and sidelobe level.

If the same antenna is to be used for front and back course azimuth guidance, input and output probes must overlap and the discussion above does not apply.

Used in the landing system context, there are two methods of achieving fine steering. One is by "center-of-gravity" steering, wherein some form of variable power division network is used between source and lens so that the signal appears to emanate from a position between the actual probe positions. The second method is by fine steering with phase shifters placed after the lens (i.e., between lens and radiating elements). In a full circular R-2R lens, this would require a large number of phase shifters, since there must be one per radiating antenna element. For limited scan, this is not so serious. The disadvantage of the variable power division method is that more highly critical components are placed between source and load, increasing the probability of catastrophic failure. For these reasons the second method has been chosen for this application. It is shown in Figure A.3 for symmetrical sum-beam patterns.

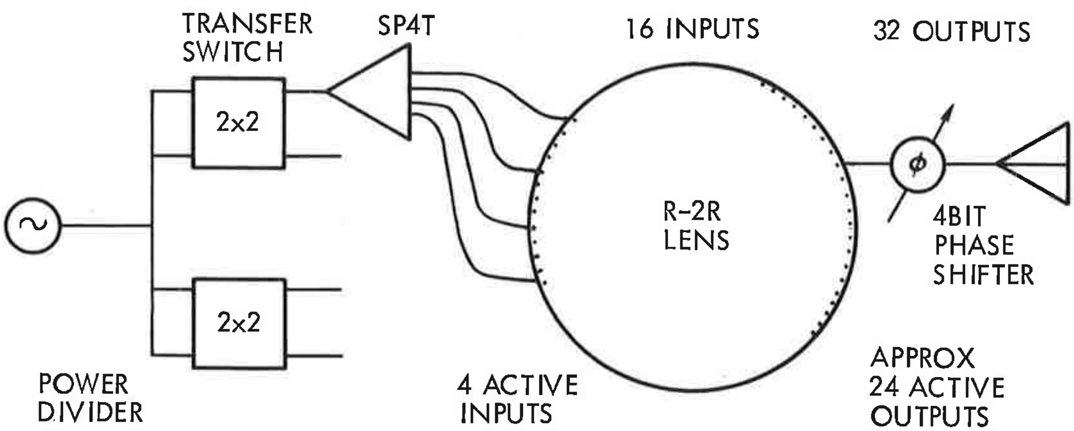


Figure A.3 R-2R Antenna System Configuration

The system shown in the figure has four inputs, while the discussion considered only one. The reason for this is that exciting one input probe results in an aperture distribution which does not have sufficient taper to it, and as a result, has unacceptably high side lobes. This can be seen with reference to Figure A.4. Also, probes at the side of the lens receive too much signal, and aggravate the defocusing problem. By simultaneously exciting several adjacent probes, the input pattern can be tapered to some extent to increase the signal to the center output probes, decrease that to the side probes, increase the aperture taper, and reduce sidelobes.

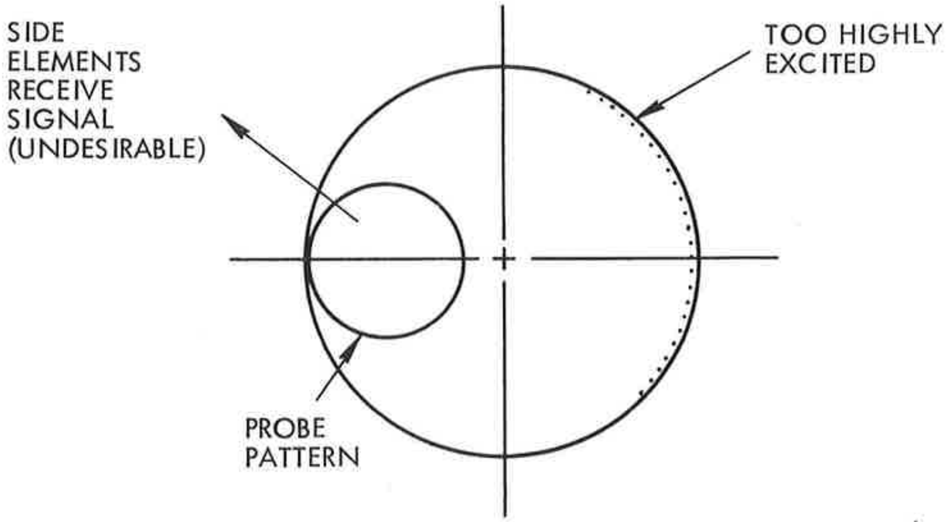


Figure A.4 Lens Illumination with One Probe Exicted

In order to test the lens technique, a small lens antenna scanning system design was fabricated using λ/4 vertical monopoles on a ground plane as the radiating elements. The parameters of the antenna are as follows:

Lens Diameter: 33.662"
Active Sector: 60° (33.662" aperture ≈ 15λ)
Probes in Active Sector: 24
Total Number of Output Probes: 32
Scan Limits: ±10°
Coarse Scan Interval: 2.61°
Coarse Beam Positions: ±4 either side of 0°
Half-Power Beamwidth: 4.0°-5.0° depending on radiating aperture distribution and frequency.

It is described in detail in section A.10.

A.3 CALCULATED PHASE AND AMPLITUDE DISTRIBUTIONS OF LENS OUTPUT PROBES

If a single input probe is fed with a signal, all output probes are excited, and the amplitude of excitation depends on the input probe pattern (see Figure A.4); the phase of excitation depends on the location of both the input and output probe phase centers. The most logical starting approximation is to use the pattern of a dipole in front of a flat ground plane; if the radius of curvature of the lens is large in terms of wavelengths, it can be expected that the resulting probe pattern will be similar.

A dipole in front of a flat conducting plane can be thought of as a two-element array. If the origin is chosen as the

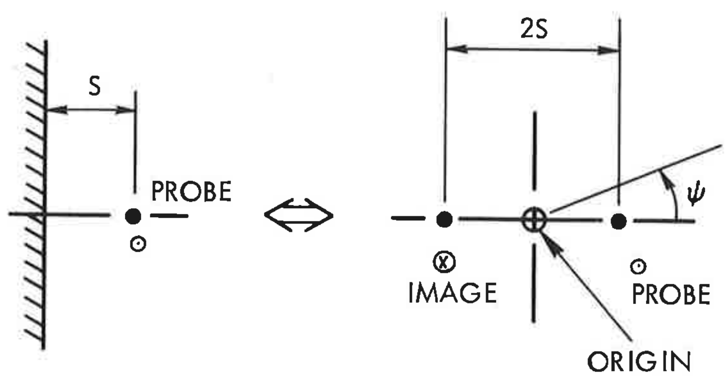


Figure A.5 Equivalence of Dipole Pair to Dipole in Front of a Ground Plane

center point between the dipole and its image, the far-field pattern for a two-dimensional geometry is given by

$$g(\psi) = \frac{\sin(ks\ \cos\psi)}{\sin(ks)} \qquad (A.2)$$

If another point were chosen as the origin, $g(\psi)$ would not be real. The fact that it is real means the phase is either zero or 180°. Thus it can be said that the probe phase center is at the center point between the dipole and its image. (This assumption does not bear up under experimental evidence; this is discussed in section A.6.2, along with a modification to the argument which allows the following formulas to hold.) The electrical radius of the lens is the radius to the conducting wall shown in Figure A.5. The probe pattern is given by equation (A.2).

In a cylindrical environment like the lens, the power falls off as $1/r$ so that the amplitude falls off as $1/\sqrt{r}$. The modal configuration of the field is essentially TEM, so that the phase velocity of propagation is the same as that of air. Thus, the behavior of the excitation of the n-th output probe obtained by exciting the p-th input probe is given by

$$f_n(p) = g(\psi_{np}/2)e^{-jkr_{AB}} \Big/ F_n\sqrt{r_{AB}} \qquad \text{(A.3)}$$

where r_{AB} and ψ_{np} are the interprobe distance and angle, respectively, (see Figure A.6), and F_n is the normalizing factor. The normalizing factor is obtained by evaluating (A.3) at the probe at B', and is given by $F_n = e^{-j2kR_1}/\sqrt{2R_1}$. Using equation (A.2) and the fact that $r_{AB} = 2R_1\cos(\psi_{np}/2)$, (A.3) becomes

$$f_n(p) = \frac{\sin[ks\cos(\psi_{np}/2)]}{\sin(ks)\sqrt{\cos(\psi_{np}/2)}}\, e^{j2kR_1[1 - \cos(\psi_{np}/2)]} \qquad \text{(A.4)}$$

It can be seen that at B', $\psi_{np} = 0$, and thus that $f_n(p) = 1$. Over the range of ψ_{np} where $ks\cos(\psi_{np}/2) < 180°$, the amplitude is given by the fraction in (A.4), and the phase is the exponent of the exponential. This covers the angular region in and near the main beam.

If more than one input probe is excited, the output is given by b_n, where

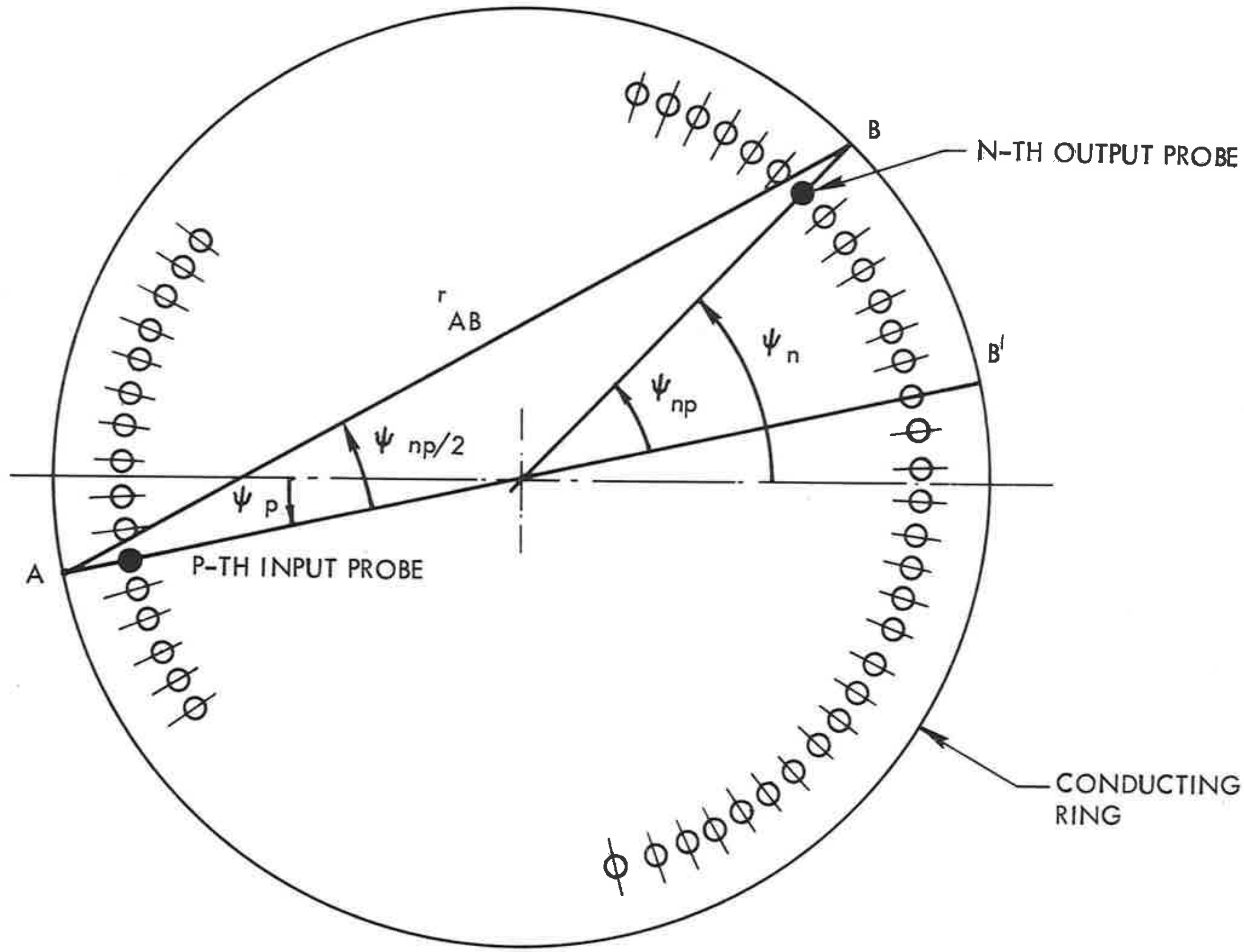


Figure A.6 Interprobe Parameters of Lens

$$b_n = \sum_{p=p_1}^{p_2} a_p f_n(p) \tag{A.5}$$

where a_p is the excitation coefficient of the p-th input probe. A computer program which calculates the lens output probe amplitude and phase distribution is given in section A.8.

A.4 CALCULATION OF THE FAR-FIELD PATTERN DUE TO A GIVEN INPUT PROBE EXCITATION

Cables of equal length connect the lens output probes to the antenna elements. If ϕ_n is the angular location of the n-th antenna element, the n-th probe is connected to it in such a way that $\phi_n = \psi_n/2$ from Figure A.6. The amplitude and phase distribution on the lens output probes thus appears on the antenna elements (the constant phase added to each element by the cable is of no consequence). The antenna elements are mounted in front of a ground plane, and thus are assumed to have a pattern given by equation (A.2). The field pattern due to exciting the n-th input probe is given by

$$E_p(\phi) = \sum_{n=1}^{N} f_n(p) g(\phi - \phi_n) e^{jkR_2 \cos\theta \, \cos(\phi - \phi_n)} \tag{A.6}$$

where ϕ is the azimuth angle, and θ is the elevation angle. Assuming $g(\phi - \phi_n)$ is real over the azimuth angles of interest, the far-field phase is given by

$$\Phi_n = kR_2 \cos\theta \, \cos(\phi - \phi_n) + 2kR_1[1 - \cos(\psi_{np}/2)] \tag{A.7}$$

The antenna is perfectly focused when the far-field phase is independent of the element number. This occurs when the following conditions apply:

$$R_2 \cos\theta = 2R_1 \tag{A.8}$$

$$\phi = \phi_n - \psi_{np}/2 \tag{A.9}$$

The last equation can be shown to be independent of n, since from Figure A.6, $\psi_{np} = \psi_n - \psi_p$, and since $\phi_n = \psi_n/2$,

$$\phi_n - \psi_{np}/2 = \psi_p/2$$

Thus it can be said that the antenna is in focus when

$$\theta = \cos^{-1}(2R_1/R_2) = \theta_f \tag{A.10}$$

and

$$\phi = \psi_p/2 = \phi_b \tag{A.11}$$

That is, the antenna beam is pointed at ϕ_b and is focused at θ_f. At other elevation angles, the antenna is defocused, but is still pointed at ϕ_b. If the lens radius is exactly half the antenna radius, the antenna is focused at the horizon, where $\theta = 0$. A computer program which calculates the antenna pattern due to a given input probe distribution is given in section A.9.

The pattern is given by the superposition of patterns from equation (6):

$$E(\phi) = \sum_{p=p_1}^{p_2} a_p E_p(\phi) \tag{A.12}$$

Where a_p is the excitation coefficient of the p-th input probe.

A.5 DETERMINATION OF INPUT PROBE EXCITATION

The input probe excitation is determined by examining the far-field amplitude and phase caused by individually exciting adjacent input probes, and adjusting the relative amplitude and phase of a group of adjacent inputs until the desired far-field pattern is attained. This appears at first to involve a great deal of trial-and-error, but in fact is relatively quick. Since a symmetric beam is desired, a symmetric distribution must be used. A single probe results in approximately uniform probe excitation which results in about -12 dB sidelobes, which is too high. Exciting two probes equally results in -17 dB sidelobes as shown in Figure A.7, which is still inadequate. The feed network for three probes is just as complicated as for four, so there is little reason for not considering four. With four probes, the outer probes are equally excited, so that there only remains to determine the relative amplitude and phase of outer to inner probes. By comparing the far-field phase resulting from inner-probe-only excitation to those resulting from outer-probe-only excitation, it is apparent that in-phase excitation of all four probes is desirable. Thus, only relative amplitude needs to be determined.

Figure A.7 shows the amplitude of the far-field resulting when two adjacent input probes (e.g., 8 and 9) are excited. The next pair (e.g., 7 and 10) result in a pattern which is tri-lobed (see Figure A.8). By adjusting the relative amplitudes of the two pairs of patterns, the combined patterns can be varied. Figure A.9 shows the variation in sidelobe level as the ratio of outer-to-inner probe excitation is varied. Throughout the program, -26.5 dB has been chosen as the design goal for calculated patterns. It is anticipated that phase and amplitude errors will result in a degradation to 23-24 dB in practice. From the figure, the peak voltage ratio which yields -26.5 dB sidelobes are .28, 1, 1, .28 in voltage, or -11 dB, 0 dB, 0 dB, -11 dB. The resulting output probe excitation is shown in Figure A.10. The edge taper (ratio of excitation at the active sector edge to excitation at the center) is about 14 dB. The resulting antenna pattern has a 3 dB beam width of 4.3°. (Figure A.11)

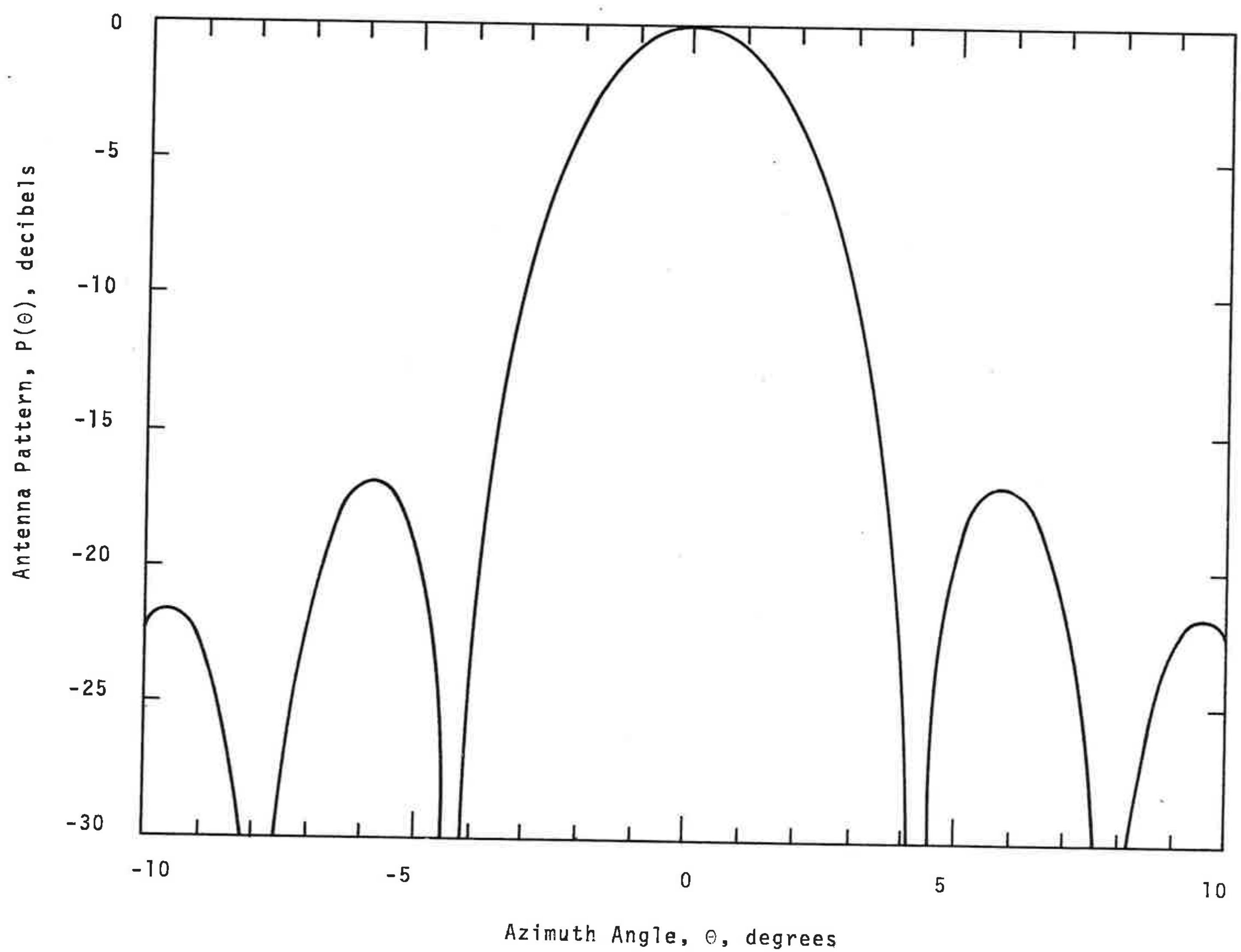


Figure A.7 -17 dB Sidelobes Resulting from Two Equally Excited Probes

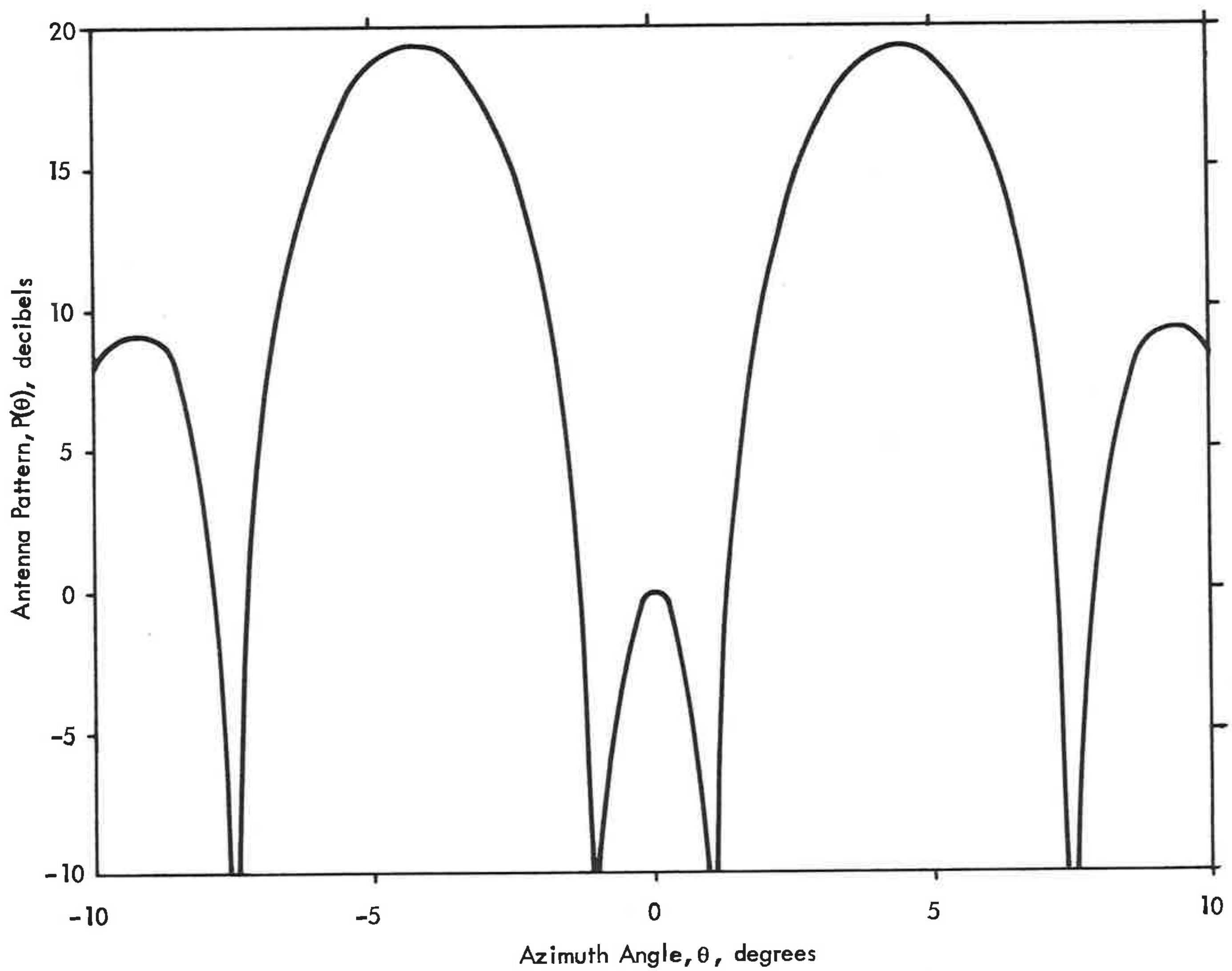


Figure A.8 Calculated Antenna Patterns Resulting from Equal Excitation of Two Input Probes with Two Non-Excited Probes Between

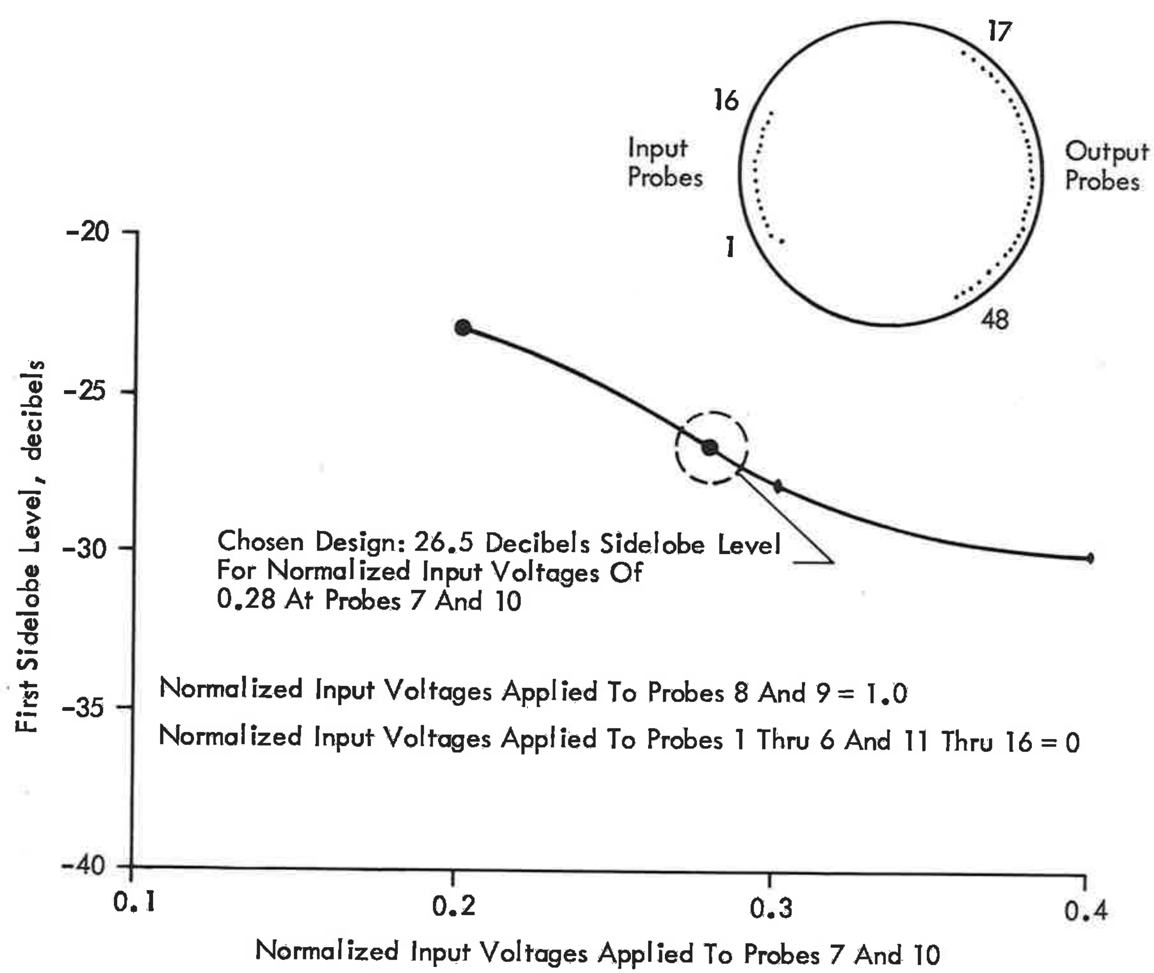


Figure A.9 First Sidelobe Level vs Voltage Ratio of Outer-to-Inner Input Probes

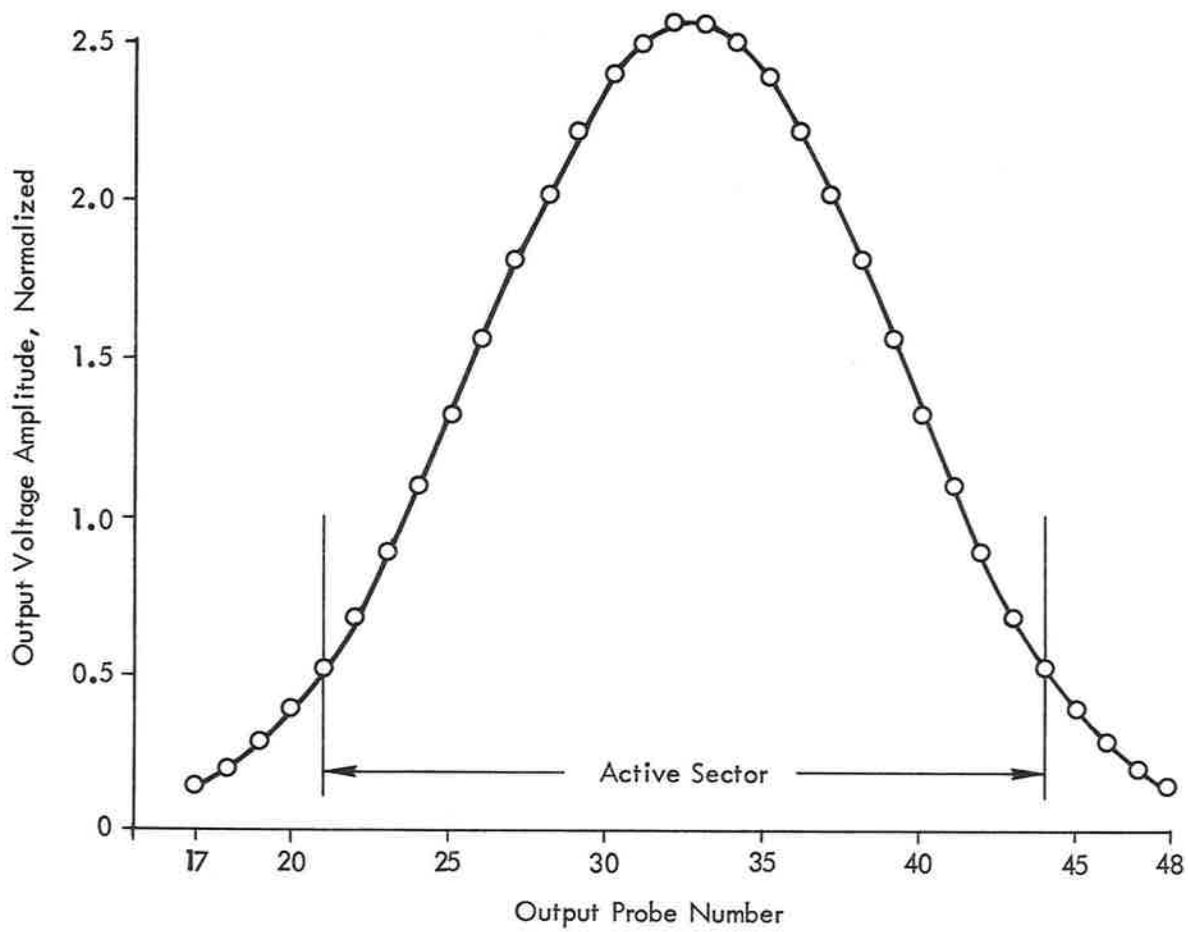


Figure A.10 Lens Output Probe Amplitude Excitation

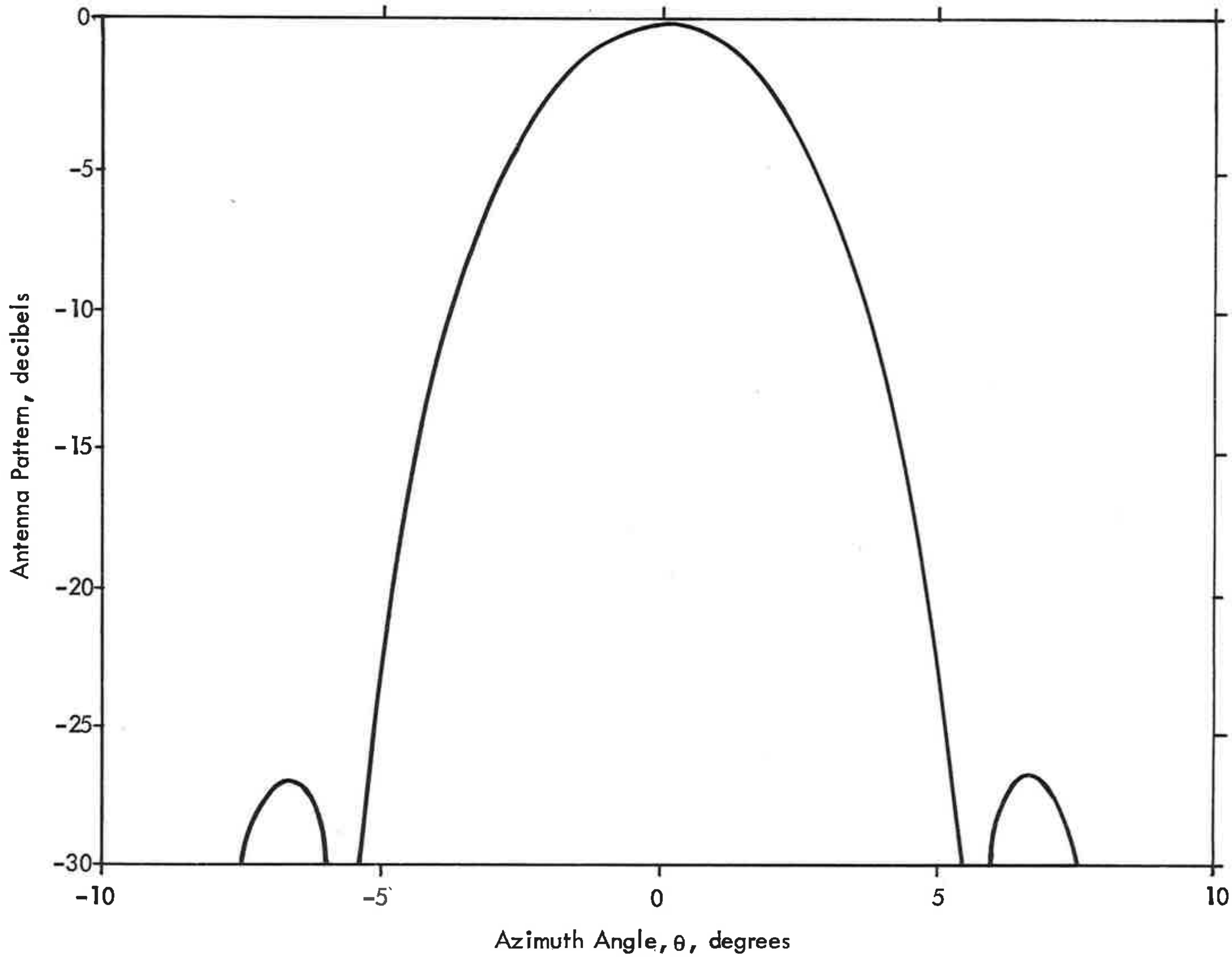


Figure A.11 Calculated Antenna Patterns Resulting from Excitation of Four Adjacent Input Probes in the Current Ratio 0.28:1.0; 1.0:0.28

A.6 EXPERIMENTAL TEST RESULTS

The Hewlett-Packard Network Analyzer was used to perform the various tests on the lens: VSWR, amplitude and phase distributions, and insertion loss. The estimated maximum uncertainties in the measurements are: VSWR: $\pm.05$; amplitude deviation: $\pm.1$ dB; phase deviation: $\pm1°$; insertion loss: $\pm.25$ dB. The measurement setups are shown in Figures A.12 and A.13 in block diagram form.

A.6.1 VSWR

Input and output probes were tested for VSWR over the MLS frequency band, 5.0 - 5.25 GHz. The lens, being a large cavity, exhibits a high probe interaction, so that the removal of one probe causes severe changes in the VSWR of other probes. Similarly, the areas around the edge not filled with probes caused high reflections and high probe VSWR's in initial tests. Subsequently, absorbing material was placed in those regions; the effect of this is much the same as if probes had been placed continuously around the edge. The ultimate effect of the absorbing material on the insertion loss is expected to be minimal, since the final input probe excitation concentrates the energy in the region of the probes (active sector).

The resulting VSWR varied from 1.41 to 1.72 with an average of 1.52 over the band. This means that on the average, 96 percent of the incident energy is absorbed by a probe, and 4 percent scattered into the other probes. This results in phase and amplitude variations, which are discussed below.

A.6.2 Phase Errors

Tests involving the excitation of one input probe showed phase deviations from the calculated values on the output probes which were systematic: i.e., the phase lags at the edges of the active sector were consistently low. The implication of this is that the effective radius of the lens is smaller than anticipated. It was assumed that the phase center of each probe is at the

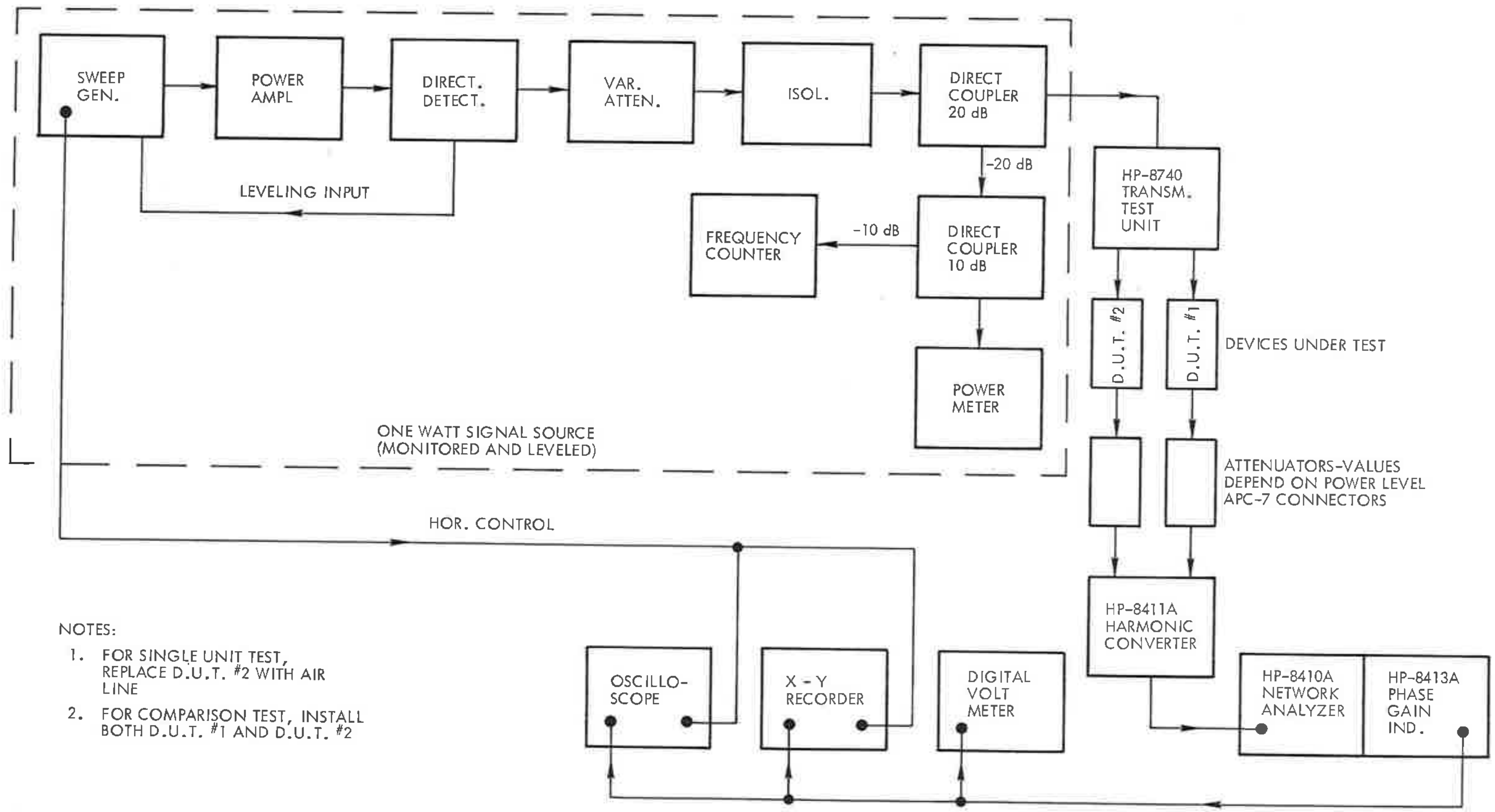


Figure A.12 Block Diagram - Insertion Loss Measurement - Amplitude & Phase, Swept Frequency Technique

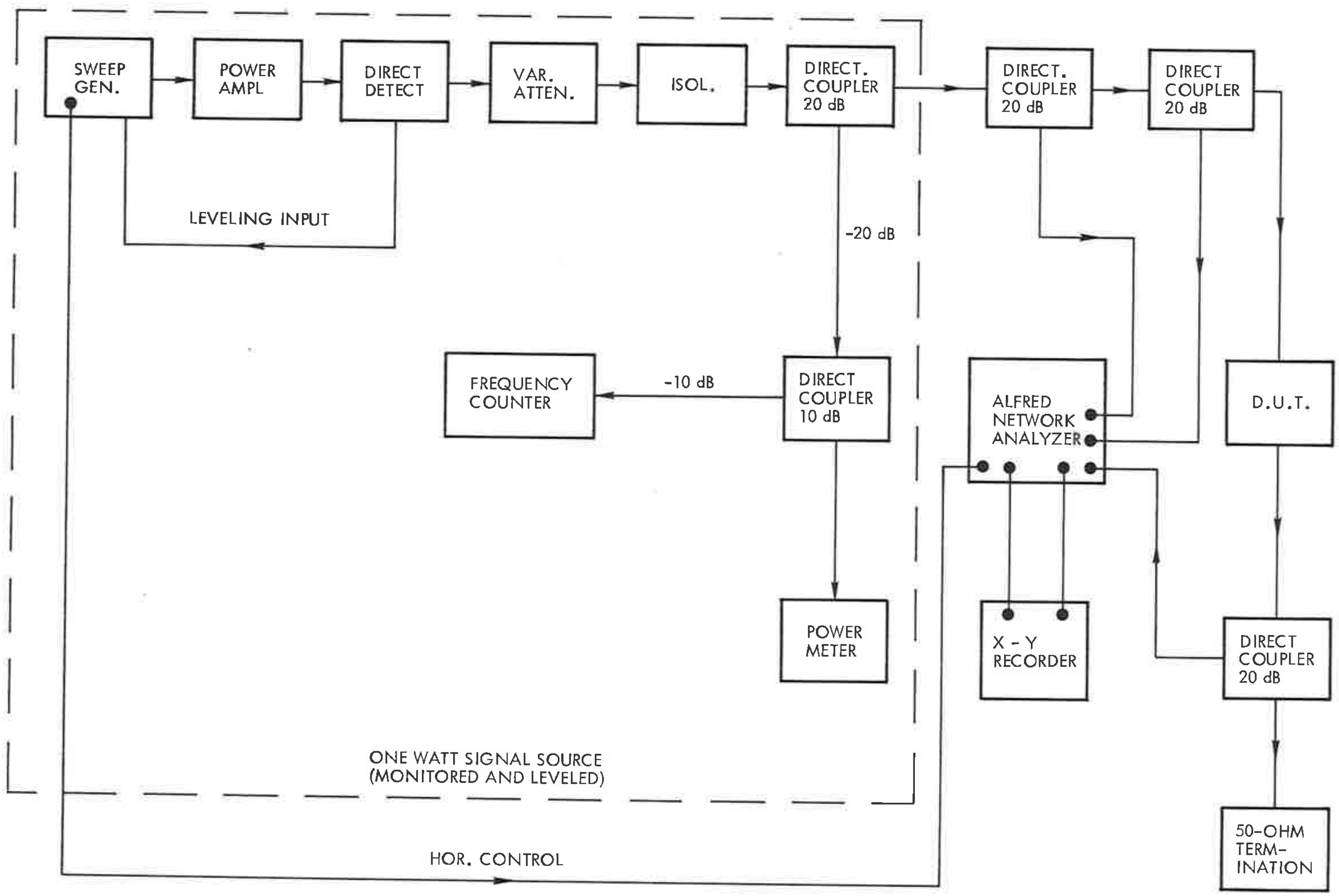


Figure A.13 Block Diagram - VSWR and Isolation - Swept Frequency Technique reflecting surface, which is the case for an isolated probe in front of a flat sheet. Subsequent calculations indicate that the probe phase center is located approximately at the probe itself. Whether this is due to lens curvature or to mutual coupling is not known. It means that the effective lens diameter is smaller than anticipated by about 3cm. Since the lens was originally designed to be focused at the horizon, it will actually focus at about 15° elevation. While this does not require a new lens to be fabricated, it is a phenomenon which must be considered when scaling this approach to other beamwidths.

Table A.1 shows the phase deviations resulting from exciting input probe number 8 by itself. The RMS deviation is 6.3°. Table A.2 shows the same errors for input probe number 9; the RMS phase error is 5.8°. Exciting an adjacent pair of input probes results in smaller phase errors. This is because the energy is concentrated in a narrower angular sector so that stray reflections are reduced. Table A.3 shows the phase deviations resulting from exciting probes 8 and 9. The RMS deviation is 4.3°. Table A.4 shows them for input probe pair 1 and 2; the RMS deviation is 3.9°.

The final tests involve the excitation of four adjacent probes. For probes 7-10, the errors are indicated in Table A.5; the RMS error is 6.7°. For probe 2-5, Table A.6 applies; the RMS error is 4.5°. These errors are considered to be quite low, and the assessment of the performance, excellent.

A.6.3 Amplitude Errors

The amplitude errors are tabulated in Tables A.7-A.12. The final performance figure of .5 dB RMS amplitude variation is considered good. In Tables A.7 and A.8 it can be seen that the predicted amplitude distribution is approximately uniform, but that beyond the active sector the measured amplitudes are less than the predicted amplitudes. The reason for this is attributed to mutual coupling effects, in that the predicted distribution is based on an isolated probe. In practice, the adjacent input probes are parasitically excited and re-radiate; this alters the distribution

TABLE A.1 OUTPUT PHASE DATA, PROBE 8 EXCITED

Probe Excited: 8	Reference Probe: 32	Frequency: 5.125 GHz	
Probe No.	Calculated Phase, Degrees	Measured Phase, Degrees	Phase Error, Degrees
17	64.88	45.28	-19.60
18	282.36	282.90	.54
19	148.35	144.54	-3.81
20	23.12	23.71	.59
21	266.92	256.56	-10.36
22	160.01	158.77	-1.24
23	62.59	60.38	-2.21
24	334.89	242.88	-92.01*
25	257.06	253.14	-3.92
26	189.29	203.18	13.89
27	131.70	135.87	4.17
28	84.42	81.94	-2.48
29	47.54	50.82	3.28
30	21.15	21.06	-.09
31	5.29	8.33	3.04
32	0	0	0
33	5.29	8.39	3.10
34	21.15	23.45	2.30
35	47.54	53.40	5.86
36	84.42	83.45	-.97
37	131.70	117.91	-13.79
38	189.29	198.76	9.47
39	257.06	245.07	-11.99
40	334.89	334.24	-.65
41	62.59	61.82	-.77
42	160.01	160.47	.46
43	266.92	260.00	-6.92
44	23.12	21.20	-1.92
45	148.35	139.82	-8.53
46	282.36	279.42	-2.94
47	64.88	37.52	-27.36
48	215.61	188.68	-26.93

RMS Phase Error (Probes 21 to 43) = 6.30
*Apparent Measurement Error - Not Repeatable

TABLE A.2 OUTPUT PHASE DATA, PROBE 9 EXCITED

Probe Excited: 9	Reference Probe: 33	Frequency: 5.125 GHz	
Probe No.	Calculated Phase, Degrees	Measured Phase, Degrees	Phase Error, Degrees
17	215.61	190.50	-25.11
18	64.88	39.52	-25.36
19	282.36	280.62	-1.74
20	148.35	141.21	-7.14
21	23.12	23.48	.36
22	266.92	257.15	-9.77
23	160.01	156.14	-3.87
24	62.59	58.82	-3.77
25	334.89	338.40	3.51
26	257.06	249.20	-7.86
27	189.29	201.41	12.12
28	131.70	130.37	-1.33
29	84.42	77.98	-6.44
30	47.54	48.56	1.02
31	21.15	17.57	-3.58
32	5.29	3.42	-1.87
33	0	0	0
34	5.29	8.55	3.26
35	21.15	17.37	-3.78
36	47.54	48.46	.92
37	84.42	76.99	-7.43
38	131.70	131.13	-.57
39	189.29	201.60	12.31
40	257.06	251.38	-5.68
41	334.89	339.80	4.91
42	62.59	58.13	-4.46
43	160.01	157.55	-2.46
44	266.92	256.65	-10.27
45	23.12	26.49	3.37
46	148.35	139.18	-9.17
47	282.36	278.56	-3.80
48	64.88	39.26	-25.62
RMS Phase Error (Probes 21 to 44) = 5.80			

TABLE A.3 OUTPUT PHASE DATA, PROBES 8 AND 9 EXCITED

Probes Excited: 8 and 9	Reference Probe: 33		Freq: 5.125 GHz
Probe No.	Calculated Phase, Degrees	Measured Phase, Degrees	Phase Error, Degrees
17	139.76	115.85	-23.91
18	353.38	328.33	-25.05
19	215.25	205.45	-9.80
20	85.71	81.97	-3.79
21	325.04	317.28	-7.76
22	213.50	209.45	-4.05
23	111.35	109.88	-1.47
24	18.79	23.10	4.31
25	296.02	299.25	3.23
26	223.21	228.45	5.24
27	160.52	161.23	0.71
28	108.08	107.76	-.32
29	66.00	63.19	-2.81
30	34.35	36.11	1.76
31	13.22	13.96	0.74
32	2.65	2.55	-0.10
33	2.65	2.65	0
34	13.22	14.75	1.53
35	34.35	35.85	1.50
36	66.00	65.55	-.45
37	108.08	109.60	1.52
38	160.52	159.52	-1.00
39	223.21	229.71	6.50
40	296.02	299.55	3.53
41	18.79	21.60	2.81
42	111.35	108.55	-2.80
43	213.50	207.25	-6.25
44	325.04	311.45	-13.59
45	85.71	78.25	-7.46
46	215.25	203.65	-11.60
47	353.38	325.44	-27.94
48	139.76	112.65	-27.11
RMS Phase Error (Probes 21 to 44) = 4.32			

TABLE A.4 OUTPUT PHASE DATA, PROBES 1 AND 2 EXCITED

Probes Excited: 1 and 2		Reference Probe: 25	Freq: 5.125 GHz
Probe No.	Calculated Phase, Degrees	Measured Phase, Degrees	Phase Error, Degrees
17	18.79	18.76	0.03
18	296.02	296.25	0.23
19	223.21	223.95	0.74
20	160.52	161.20	0.68
21	108.08	105.49	-2.59
22	66.00	62.80	-3.20
23	34.35	33.32	-1.03
24	13.22	11.46	-1.76
25	2.65	2.65	0
26	2.65	357.82	-4.83
27	13.22	12.97	-.25
28	34.35	36.09	1.74
29	66.00	60.73	-5.27
30	108.08	105.73	-2.35
31	160.52	166.74	6.22
32	223.21	223.20	-.01
33	296.02	296.81	.79
34	18.79	23.38	4.59
35	111.35	103.16	-8.19
36	213.50	205.42	-8.08
37	325.04	315.36	-9.68
38	85.71	78.00	-7.71
39	215.25	197.02	-18.23
40	353.38	326.24	-27.04
41	139.76	102.43	-37.33
42	293.98	168.99	-124.99
43	95.36	19.32	-76.04
44	261.81	236.16	-25.65
45	334.83	241.35	-93.48
46	95.48	109.85	14.37
47	282.41	83.14	160.73
48	117.26	350.55	-126.71
RMS Phase Error (Probes 17 to 37) = 3.90			

TABLE A.5 OUTPUT PHASE DATA, PROBES 7 TO 10 EXCITED

Probes Excited: 7 to 10		Reference Probe: 33	Freq: 5.125 GHz
Probe No.	Calculated Phase, Degrees	Measured Phase, Degrees	Phase Error, Degrees
17	115.22	78.74	-36.48
18	332.83	289.06	-39.19
19	198.64	185.86	-8.20
20	72.69	62.54	-10.15
21	315.15	291.74	-23.41
22	206.26	190.94	-15.32
23	106.29	100.84	-5.45
24	15.51	18.34	2.83
25	294.19	295.74	1.55
26	222.54	222.34	-.20
27	160.78	158.34	-2.44
28	109.06	106.44	-2.62
29	67.52	64.14	-3.38
30	36.27	34.09	-2.23
31	15.39	13.94	-1.45
32	4.94	4.04	-.90
33	4.94	4.94	0
34	15.39	15.64	.25
35	36.27	36.74	.47
36	67.52	66.94	-.58
37	109.06	110.04	.98
38	160.78	159.84	-.94
39	222.54	227.64	5.10
40	294.19	301.94	7.75
41	15.51	22.74	7.23
42	106.29	107.74	1.45
43	206.26	208.24	1.98
44	315.15	302.74	-12.41
45	72.69	74.24	1.55
46	198.64	261.94	63.30
47	332.83	314.94	-17.89
48	115.22	99.44	-15.78
RMS Phase Error (Probes 21 to 44) = 6.72			

TABLE A.6 OUTPUT PHASE DATA, PROBES 2 TO 5 EXCITED

Probes Excited: 2 to 5	Reference Probe: 28		Freq: 5.125 GHz
Probe No.	Calculated Phase, Degrees	Measured Phase, Degrees	Phase Error, Degrees
17	206.25	211.64	5.38
18	106.29	110.84	4.55
19	15.51	22.44	6.93
20	294.19	297.44	3.25
21	222.54	226.14	3.60
22	160.78	160.24	-.54
23	109.06	108.14	-.92
24	67.52	66.84	-.68
25	36.27	34.44	-1.83
26	15.39	14.94	-.45
27	4.94	4.64	-.30
28	4.94	4.94	0
29	15.39	14.74	-.65
30	36.27	33.04	-3.23
31	67.52	64.94	-2.58
32	109.06	107.94	-1.12
33	160.78	158.34	-2.44
34	222.54	225.54	3.00
35	294.19	295.64	1.45
36	15.51	15.54	.03
37	106.29	107.44	1.15
38	206.26	196.84	-9.42
39	315.15	300.14	-15.01
49	72.69	70.44	-2.25
41	198.64	187.44	-11.20
42	332.83	312.84	-19.99
43	115.22	64.94	-51.28
44	265.80	274.94	9.14
45	64.28	22.94	-41.34
46	228.03	274.94	46.93
47	289.91	285.94	-3.97
48	69.32	23.94	-45.38
RMS Phase Error (Probes 17 to 39) = 4.54			

TABLE A.7 OUTPUT AMPLITUDE DATA, PROBE 8 EXCITED

Probe Excited: 8	Reference Probe: 32	Frequency: 5.125 GHz	
Probe No.	Calculated Amplitude dB	Measured Amplitude dB	Amplitude Error dB
17	.09	-2.46	-2.55
18	.12	-2.77	-2.89
19	.13	-1.42	-1.55
20	.14	-1.33	-1.46
21	.13	.60	.46
22	.12	-.17	-.29
23	.11	.34	.23
24	.09	-.59	-.68
25	.08	-.61	-.68
26	.06	-2.31	-2.37
27	.04	1.33	1.28
28	.03	-1.32	-1.35
29	.02	-.70	-.71
30	.01	-.33	-.34
31	.00	.57	.57
32	0	0	0
33	.00	-.72	-.73
34	.01	-.80	-.80
35	.02	.63	.61
36	.03	-1.07	-1.10
37	.04	.72	.67
38	.06	-1.98	-2.04
39	.08	-.52	-.60
40	.09	.22	.12
41	.11	-.31	-.42
42	.12	.17	.04
43	.13	-.51	-.64
44	.14	-.44	-.58
45	.13	-2.90	-3.03
46	.12	-2.36	-2.48
47	.09	-5.68	-5.77
48	.06	-2.40	-2.46
RMS Amplitude Error (Probes 21 to 43) = 0.84 dB			

TABLE A.8 OUTPUT AMPLITUDE DATA, PROBE 9 EXCITED

Probe Exicted: 9	Reference Probe: 33		Frequency: 5.125 GHz
Probe No.	Calculated Amplitude dB	Measured Amplitude dB	Amplitude Error dB
17	.06	-2.87	-2.93
18	.09	-5.60	-5.69
19	.12	-2.36	-2.48
20	.13	-2.66	-2.79
21	.14	-.38	-.52
22	.13	-.61	-.74
23	.12	.07	-.06
24	.11	-.55	-.66
25	.09	.36	.27
26	.08	-.59	-.67
27	.06	-2.04	-2.10
28	.04	-.24	-.28
29	.03	-.48	-.51
30	.02	-.28	-.29
31	.01	-.78	-.79
32	.00	-.68	-.68
33	0	0	0
34	.00	.39	.38
35	.01	-.66	-.67
36	.02	-.44	-.45
37	.03	-1.70	-1.73
38	.04	1.32	1.27
39	.06	-2.34	-2.40
40	.08	-.69	-.77
41	.09	-.72	-.81
42	.11	.38	.27
43	.12	.01	-.11
44	.13	.74	.61
45	.14	-1.74	-1.88
46	.13	-1.55	-1.68
47	.12	-3.34	-3.46
48	.09	-2.50	-2.59
RMS Amplitude Error (Probes 22 to 44) = 0.81 dB			

somewhat. This phenomenon is of little effect in the active sector. In Tables A.9 and A.10 the two-probe distribution is given; at the edge of the active sector the output probe excitation is reduced, and larger deviations can be anticipated. From Tables A.11 and A.12 there are some probes which have predicted amplitude levels - 25 dB or more down, whereas the measured values do not drop below about -25 dB. This is due to reflections within the lens caused by imperfect absorption by the probes of the incident energy. The effect will be to raise sidelobes somewhat. This is treated further in the discussion about Figures A.14 and A.15.

A.6.4 Insertion Loss

The insertion loss is determined by adding up the powers in the output probes in the active sector, and comparing the total with the total input powers. The amplitudes are measured by using one output probe as a reference. Additionally, the power in the reference probe must be known. That is, the measurements result in the ratio $|b_n/b_{ref}|$. The additional measurements of $|b_{ref}/c|$ and $|a_p|/c$ must be made, where the a_p's are the input probe excitations, and c is some reference signal. The insertion loss is given by

$$I.L. = 1 - \frac{\sum_n |b_n|^2}{\sum_p |a_p|^2} \qquad (A.13)$$

or

$$I.L. = 1 - \frac{|b_{ref}/c|^2 \sum_n |b_n/b_{ref}|^2}{\sum_p |a_p/c|^2} \qquad (A.14)$$

In this form all the terms are measured quantities.

TABLE A.9 OUTPUT AMPLITUDE DATA, PROBES 8 AND 9 EXCITED

Probes Excited: 8 and 9	Reference Probe: 33	Freq: 5.125 GHz	
Probe No.	Calculated Amplitude dB	Measured Amplitude dB	Amplitude Error dB
17	-11.86	-12.06	-.20
18	-9.75	-8.58	1.17
19	-8.03	-9.00	-.97
20	-6.60	-6.56	.04
21	-5.40	-5.40	-.01
22	-4.37	-2.91	1.46
23	-3.49	-2.48	1.01
24	-2.73	-2.02	.71
25	-2.08	-1.93	.16
26	-1.54	-1.32	.22
27	-1.09	-.82	.27
28	-.72	-.73	-.02
29	-.43	-.03	.40
30	-.21	.64	.85
31	-.07	.74	.81
32	0	.48	.48
33	0	0	0
34	-.07	.61	.68
35	-.21	.20	.42
36	-.43	-.32	.11
37	-.72	-1.24	-.52
38	-1.09	-.64	.45
39	-1.54	-1.62	-.08
40	-2.08	-2.65	-.57
41	-2.73	-2.24	.49
42	-3.49	-3.82	-.33
43	-4.37	-4.40	-.03
44	-5.40	-6.96	-1.56
45	-6.60	-7.78	-1.18
46	-8.03	-12.14	-4.11
47	-9.75	-10.60	-.85
48	-11.86	-15.04	-3.18
RMS Amplitude Error (Probes 21 to 44) = 0.60 dB			

TABLE A.10 OUTPUT AMPLITUDE DATA, PROBES 1 AND 2 EXCITED

Probes Excited: 1 and 2	Reference Probe: 25	Freq: 5.125 GHz	
Probe No.	Calculated Amplitude dB	Measured Amplitude dB	Amplitude Error dB
17	-2.73	-2.56	.17
18	-2.08	-2.67	-.59
19	-1.54	-2.40	-.86
20	-1.09	-1.94	-.85
21	-.72	-1.39	-.67
22	-.43	-.56	-.14
23	-.21	-.66	-.45
24	-.07	-.13	-.06
25	0	0	0
26	0	-.18	-.18
27	.07	.21	.28
28	-.21	-.50	-.29
29	-.43	-1.10	-.67
30	-.72	-.55	.17
31	-1.09	-2.17	-1.09
32	-1.54	-3.13	-1.59
33	-2.08	-2.58	-.50
34	-2.73	-3.52	-.79
35	-3.49	-3.94	-.45
36	-4.37	-5.38	-1.01
37	-5.40	-7.30	-1.90
38	-6.60	-10.40	-3.80
39	-8.03	-11.08	-3.05
40	-9.75	-10.68	-.93
41	-11.86	-19.58	-7.72
42	-14.59	-16.30	-1.71
43	-18.42	-14.10	4.31
44	-24.87	-22.88	1.99
45	-43.15	-15.14	28.01
46	-24.85	-20.56	4.29
47	-19.49	-20.16	-.67
48	-16.53	-17.68	-1.15
RMS Amplitude Error (Probes 17 to 37) = 0.55 dB			

TABLE A.11 OUTPUT AMPLITUDE DATA, PROBES 7 TO 10 EXCITED

Probes Excited: 7 to 10 (.28-1-1-.28)	Reference Probe: 33	Freq: 5.125 GHz	
Probe No.	Calculated Amplitude dB	Measured Amplitude dB	Amplitude Error dB
17	-25.60	-21.18	4.42
18	-22.24	-18.42	3.82
19	-19.17	-20.80	-1.63
20	-16.34	-17.62	-1.28
21	-13.75	-14.04	-.29
22	-11.38	-10.38	1.00
23	-9.25	-8.76	.49
24	-7.36	-7.70	-.34
25	-5.69	-6.26	-.57
26	-4.24	-5.10	-.86
27	-3.02	-3.64	-.62
28	-2.00	-2.78	-.78
29	-1.20	-1.54	-.34
30	-.60	-.50	.10
31	-.20	-.14	.06
32	0	.08	.08
33	0	0	0
34	-.20	.26	.46
35	-.60	-.40	.20
36	-1.20	-1.32	-.12
37	-2.00	-2.64	-.64
38	-3.02	-3.80	-.78
39	-4.24	-4.70	-.46
40	-5.69	-6.12	-.43
41	-7.36	-7.26	.10
42	-9.25	-8.84	.41
43	-11.38	-10.76	.62
44	-13.75	-14.42	-.67
45	-16.34	-17.00	-1.06
46	-19.17	-21.06	-1.89
47	-22.24	-20.54	1.70
48	-25.60	-24.18	1.42
RMS Amplitude Error (Probes 21 to 44) = 0.49 dB			

TABLE A.12 OUTPUT AMPLITUDE DATA, PROBES 2 TO 5 EXCITED

Probes Excited: 2 to 5	Reference Probe: 28	Freq: 5.125 GHz	
Probe No.	Calculated Amplitude dB	Measured Amplitude dB	Amplitude Error dB
17	-11.38	-12.30	-.92
18	-9.25	-10.44	-1.19
19	-7.36	-8.40	-1.04
20	-5.69	-6.42	-.73
21	-4.24	-5.66	-1.42
22	-3.12	-3.98	-.96
23	-2.00	-2.92	-.92
24	-1.20	-1.42	-.22
25	-.60	-1.02	-.42
26	-.20	-.04	.16
27	0	-.04	-.04
28	0	0	0
29	-.20	-.12	.08
30	-.60	-.78	-.18
31	-1.20	-1.34	-.14
32	-2.00	-1.86	.14
33	-3.02	-3.66	-.64
34	-4.24	-4.86	-.62
35	-5.69	-5.92	-.23
36	-7.36	-6.30	1.06
37	-9.25	-7.06	2.19
38	-11.38	-9.70	1.68
39	-13.75	-12.40	1.35
40	-16.34	-16.56	-.22
41	-19.17	-17.60	1.57
42	-22.24	-15.92	6.32
43	-25.60	-23.40	2.20
44	-29.42	-21.92	7.50
45	-34.14	-20.60	13.54
46	-41.43	-23.40	18.03
47	-55.65	-23.80	31.85
48	-40.58	-26.16	14.42
RMS Amplitude Error (Probes 17 to 39) = 0.91 dB			

Table A.13 shows the insertion loss figures obtained at several frequencies and input probe configurations. The insertion loss varies between 0.91 dB and 1.13 dB. This compares favorably with the anticipated 1.0 dB insertion loss.

TABLE A.13 INSERTION LOSS MEASUREMENTS

Frequency GHz	Input Probes	Insertion Loss dB
5.000	7-10	1.10
5.125	7-10	0.94
5.250	7-10	0.91
5.125	7-10	0.94
5.125	2-5	1.13

A.7 CONCLUSIONS ON PERFORMANCE OF THE LENS

The actual amplitudes and phases resulting from exciting probes 7-10 were used as the excitation coefficients of a cylindrical array, and the associated patterns computed. They are shown in Figures A.14 and A.15, and should be compared with the predicted pattern of Figure A.11. Figure A.14 shows the pattern resulting with only the active sector probes being excited; this corresponds to the performance that would be obtained if SP2T switches were used at the probe outputs to switch the other probe energy into terminations. The beamwidth is 4.3°, as predicted, but the sidelobes have shifted somewhat. The second sidelobes have risen to -24 dB, whereas the first sidelobes were predicted to be at -27 dB. Figure A.15 shows the pattern obtained when all 32 output probes are considered. The beam actually narrows to 4.0°, and the sidelobes are reduced somewhat. It thus appears that the lens may be somewhat overdesigned. When the switching feed network (see Figure A.3) is added on the lens input, the performance will be degraded, depending on the amplitude and phase imbalances introduced by the components. As a component, however, the lens is considered satisfactory.

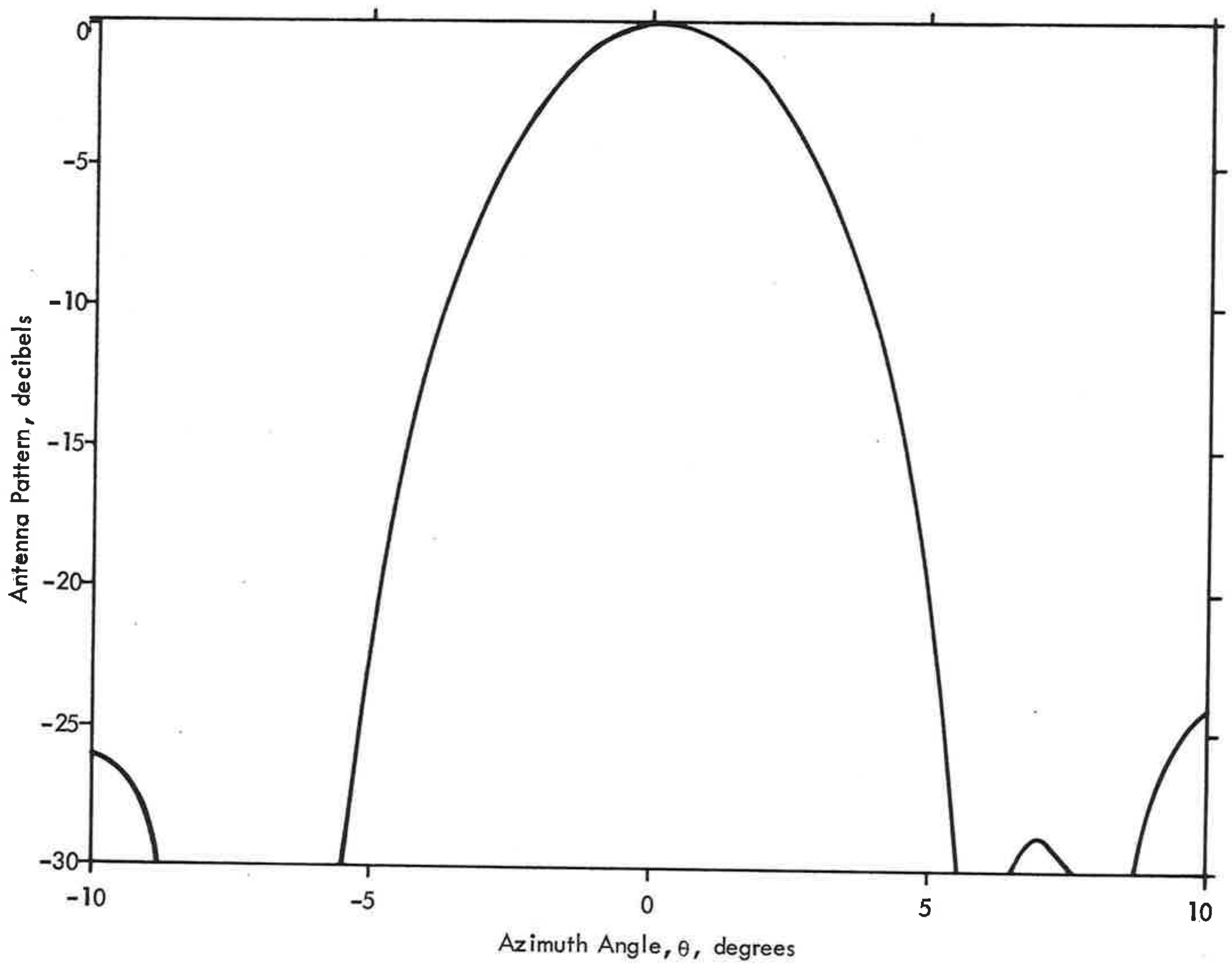


Figure A.14 Calculated Patterns Based on Measured Values of Probe Amplitudes and Phases, 24 Elements Active, Remainder Off

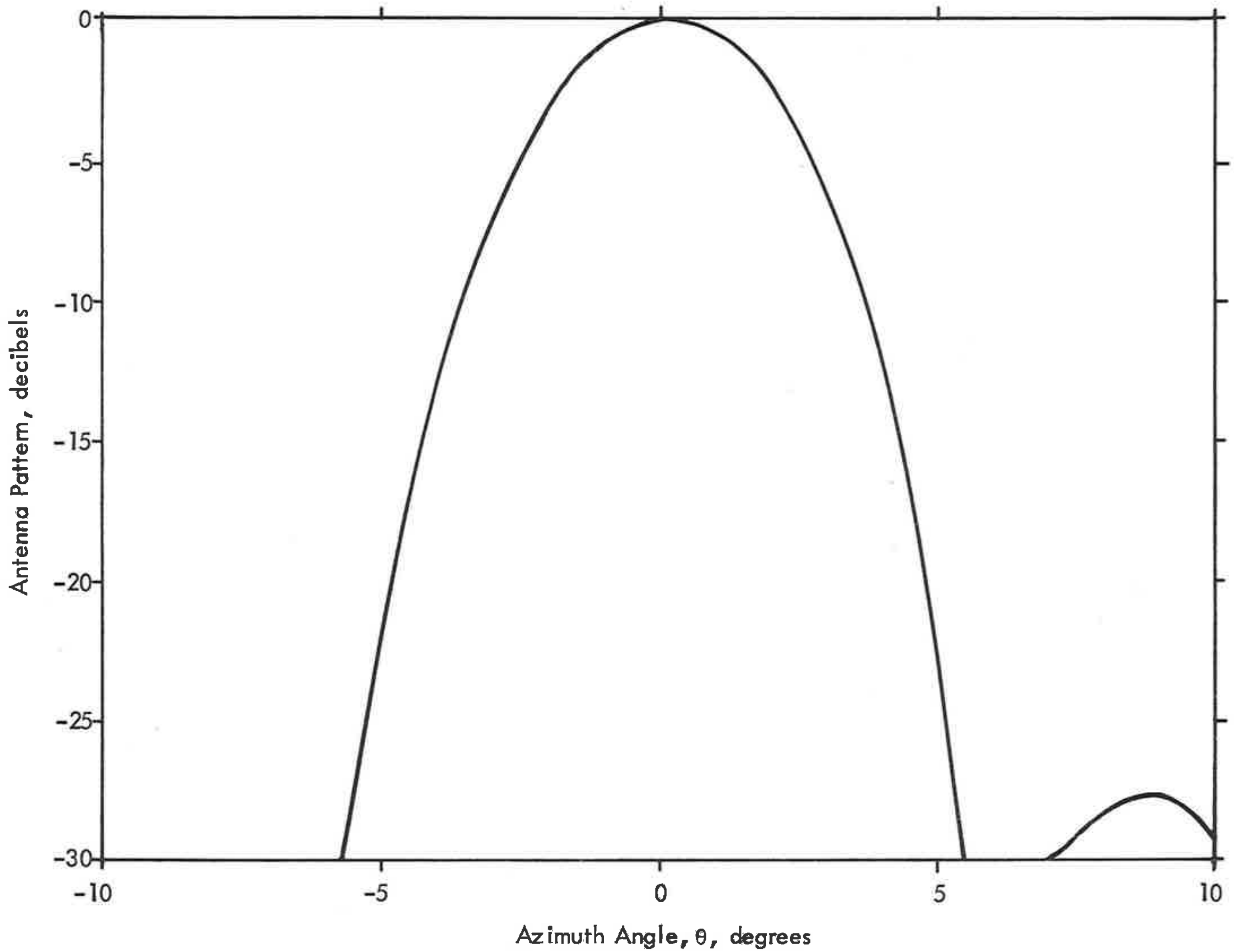


Figure A.15 Calculated Patterns Based on Measured Values of Probe Amplitudes and Phases, 32 Elements Active

The beam squint which is observed in Figures A.14 and A.15 deserves some attention. The beam squint is based on the motion of the halfway point between the 10 dB points on the pattern. With 24 probes excited the beam squint is .09° while with 32 probes, it is .08°. These are less than 2.5% of the beamwidth. This is considered good performance. It is believed that the squint which exists is due to the presence of the absorbing material, which was not placed with the high degree of accuracy as the rest of the structure. It is planned to continue the probes around the lens to give ±30° coverage, so that even better performance is anticipated when this is done.

As pointed out earlier, the lens is restricted to ±30° of scan using a 60° active sector. It is not advisable to use a narrower active sector, so that the only way to increase coverage beyond ±30° is to overlap input and output probes. This requires circulators or additional transfer switches, which is undesirable.

Another conclusion is that the electrical radius is not at the reflecting ring surface, as was expected, but in fact is approximately equal to the probe radius. The effect of this is that the antenna is focused at about 15° in elevation, rather than at the horizon.

The lens offers a large bandwidth so that only one lens and phase shifter control table (see Figure A.3) are necessary to cover the entire 5.0-5.25 GHz band. It also offers the option (not investigated here) of incorporating an omni-directional antenna pattern by inserting a feed probe at the lens center. For application where ±30° of scan is sufficient, it provides a relatively inexpensive solution to the beam steering problem. Narrowing the beamwidth to 2° or 1° will require a doubling or quadrupling of size, with the concomitant fabrication difficulties.

A.8 PROGRAM FOR CALCULATION OF OUTPUT PROBE DISTRIBUTION

Language: CAL (Conversational Algebraic Language)

Meaning of Terms:

P1	First input probe number
P2	Last input probe number
AAMP(J)	Amplitude of j-th input probe (voltage)
APH(J)	Phase of j-th input probe (radians)
R	Radius (electrical) of lens (centimeters)
F	Frequency
DPHI	Angular spacing between probes (degrees)
SPWL	Spacing between probe and ring, in wavelengths.

Program:

```
1.1 DEMAND P1,P2
1.2 DEMAND AAMP(P) FOR P=P1 TO P2
1.3 DEMAND APH(P) FOR P=P1 TO P2

2.1 DEMAND R,F,DPHI,SPWL
2.2 TYPE "
    N    AMPLITUDE     PHASE"
2.3 DO PART 3 FOR N=17 TO 48

3.1 DO PART 4 FOR P=P1 TO P2
3.2 GR=SUM(P=P1 TO P2:TAMP(P)*COS(TPH(P)))
3.3 GI=SUM(P=P1 TO P2:TAMP(P)*SIN(TPH(P)))
3.4 GAMP=SQRT(GR*GR+GI*GI)
3.5 GPH=ATN[GR,GI]*180/PI
3.6 GPH =GPH+360 UNLESS GPH>0
3.7 TYPE IN FORM 10:N,GAMP,GPH

4.1 CS=COS((N-24-P)*DPHI*PI/360)
4.2 TAMP(P)=AAMP(P)*SIN(2*PI*SPWL*CS)/SQRT(CS)/SIN(2*PI*SPWL)
4.3 TPH(P)=4*PI*F/30*R*(1-CS)+APH(P)
```

```
1408.05 RETURN PI/2 IF A=0 AND B>0
1408.07 RETURN -PI/2 IF A=0 AND B<0
1408.1 Z=B/A
1408.2 TO 1408.5 IF ABS Z<.41421356
1408.3 TO 1408.6 IF ABS Z>2.41421356
1408.4 TO 1408.46 IF Z>=0
1408.45 KON=-PI/4, T=(A+B)/(A-B)
1408.455 TO 1408.8
1408.46 KON=PI/4, T=(B-A)/(B+A)
1408.48 TO 1408.8
1408.5 KON=0, T=Z
1408.55 TO 1408.8
1408.6 T=-1/Z, KON=IF Z>0 THEN PI/2 ELSE -PI/2
1408.8 T2=T*T, KON=KON+IF A>=0 THEN 0 ELSE IF B>=0 THEN PI ELSE -PI
1408.9 RETURN T*(1+T2*(-.01558537-.58531513/(T2+2.1005540-.41900300/
 (T2+1.6210238))))+KON

FORM 10:
  %%%    %%%%.%%%%    %%%%.%%

DEFINE ATN[A,B,Z,T,T2,KON]: TO PART 1408
DEFINE FAC[J]=2*PI*RLAM*COS(PI/180*(PHI-PHL(J)))-PI*PSI(J)/180
```

A.9 PROGRAM FOR CALCULATION OF FAR-FIELD PATTERNS

Language: CAL

Meaning of Terms:

N	Number of radiating elements
RAD	Radius of antenna (centimeters)
FRQ	Frequency (GHz)
PHA	Active sector (degrees)
S	Lens probe-to-ring spacing, wavelengths
D	Antenna element-to-reflector spacing, wavelengths

Program:

```
1.1 DEMAND N,RAD,FRQ,PHA,S,D
1.2 PHA=PHA*PI/180

2.1 DEMAND P1,P2
2.2 DEMAND AAMP(P),APH(P) FOR P=P1 TO P2
2.3 TYPE "
     PHI      AMPL,DB      AMPLITUDE    PHASE"
2.4 DO PART 3 FOR M=0 TO N-5
2.5 FAC=1
2.55 DO PART 4 FOR GAM=0
2.56 FAC=FAMP
2.6 DO PART 4 FOR GAM=-.50 BY .50 TO 10

3.1 PSI=PHA*M/(N-1)
3.2 ANG=2*PI*RAD/30*FRQ*COS(PSI)
3.3 BR=TP[S,PSI]/SQRT(COS(PSI))*TP[D,PSI]*COS(ANG)
3.4 BI=BR*TAN(ANG)
3.5 BAMP(M)=SQRT(BR*BR+BI*BI)
3.6 BPH(M)=ATN[BR,BI]

4.1 PHI=GAM*PI/180
4.2 DO PART 5 FOR P=P1 TO P2
4.3 FR=SUM(P=P1 TO P2:AAMP(P)*EAMP(P)*COS(APH(P)+EPH(P)))
4.4 FI=SUM(P=P1 TO P2:AAMP(P)*EAMP(P)*SIN(APH(P)+EPH(P)))
4.5 FAMP=SQRT(FR*FR+FI*FI)/FAC
4.55 FDB=20*LOG10(FAMP)
4.6 FPH=ATN[FR,FI]*180/PI
4.65 FPH=360+FPH UNLESS FPH>0
4.7 TYPE IN FORM 10:GAM,FDB,FAMP,FPH
```

```
5.1 DO PART 6 FOR I=1 TO N
5.2 ER=SUM(I=1 TO N:DR(I))
5.3 EI=SUM(I=1 TO N:DI(I))
5.4 EAMP(P)=SQRT(ER*ER+EI*EI)
5.5 EPH(P)=ATN[ER,EI]

6.1 PHN=((I-1)/(N-1)-.5)*PHA
6.2 ANG=2*PI*RAD*FRQ/30*COS(PHI-PHN)
6.3 J=ABS(I-P-4)
6.4 DR(I)=BAMP(J)*COS(BPH(J)-ANG)
6.5 DI(I)=BAMP(J)*SIN(BPH(J)-ANG)

1408.05 RETURN PI/2 IF A=0 AND B>0
1408.07 RETURN -PI/2 IF A=0 AND B<0
1408.1 Z=B/A
1408.2 TO 1408.5 IF ABS Z<.41421356
1408.3 TO 1408.6 IF ABS Z>2.41421356
1408.4 TO 1408.46 IF Z>=0
1408.45 KON=-PI/4, T=(A+B)/(A-B)
1408.455 TO 1408.8
1408.46 KON=PI/4, T=(B-A)/(B+A)
1408.48 TO 1408.8
1408.5 KON=0, T=Z
1408.55 TO 1408.8
1408.6 T=-1/Z, KON=IF Z>0 THEN PI/2 ELSE -PI/2
1408.8 T2=T*T, KON=KON+IF A>=0 THEN 0 ELSE IF B>=0 THEN PI ELSE -PI
1408.9 RETURN T*(1+T2*(-.01558537-.58531513/(T2+2.1005540-.41900300/
 (T2+1.6210238))))+KON

FORM 10:
   ZZZZ.ZZ    ZZZZ.ZZZ    ZZZ.ZZZZ    ZZZZ.ZZ

DEFINE ATN[A,B,Z,T,T2,KON]: TO PART 1408
DEFINE TP[X,BETA]=SIN(2*PI*X*COS(BETA))/SIN(2*PI*X)
```

A.10 MECHANICAL DESIGN OF LENS

The assembly drawing for the lens is given in Figure A.16. The lens consists of two 1/4 inch aluminum plates spaced 0.875 inches apart by an annular ring of aluminum. The assembly is 37.0 inches in diameter. The inside diameter of the lens is 33.662 inches. The probes are mounted on a circle 32.662 inches in diameter, and spaced 5.22° apart. The ring-to-probe spacing is .500 inches. This was determined by trying several spacings with a jig plate consisting of 5 probes, and adjusting probe length and ring-to-probe spacing to achieve a good VSWR over the frequency band.

The probe design is shown in Figure A.17. SMA female connectors are used. As mentioned above, the probe length was chosen to achieve a good electrical match.

In the drawing, 16 input probes and 32 output probes are used. The spacing is an even divisor of 360°, so that the probes can be continued until 69 equally spaced probes result, which gives the full $\pm 30°$ scan.

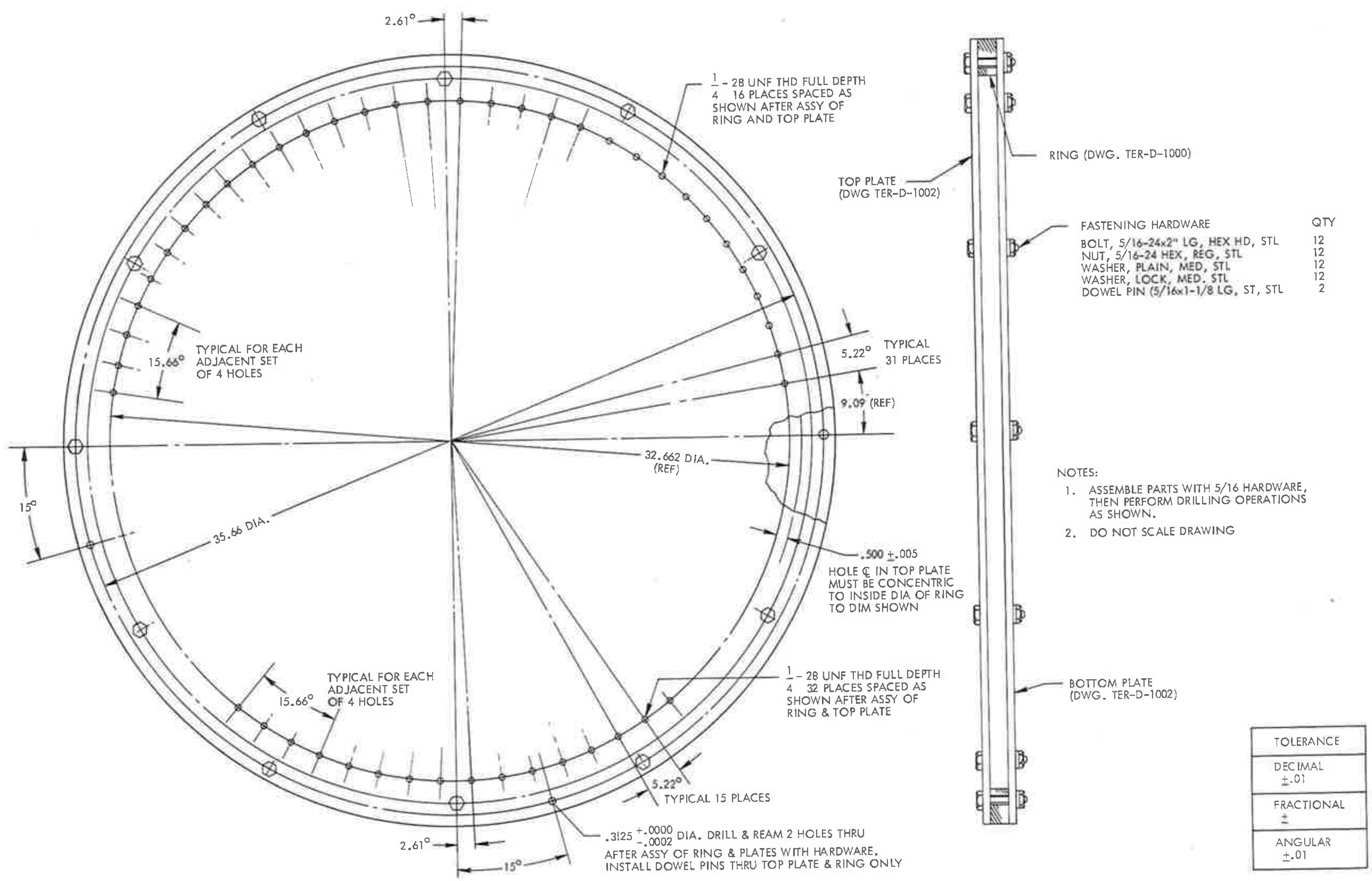
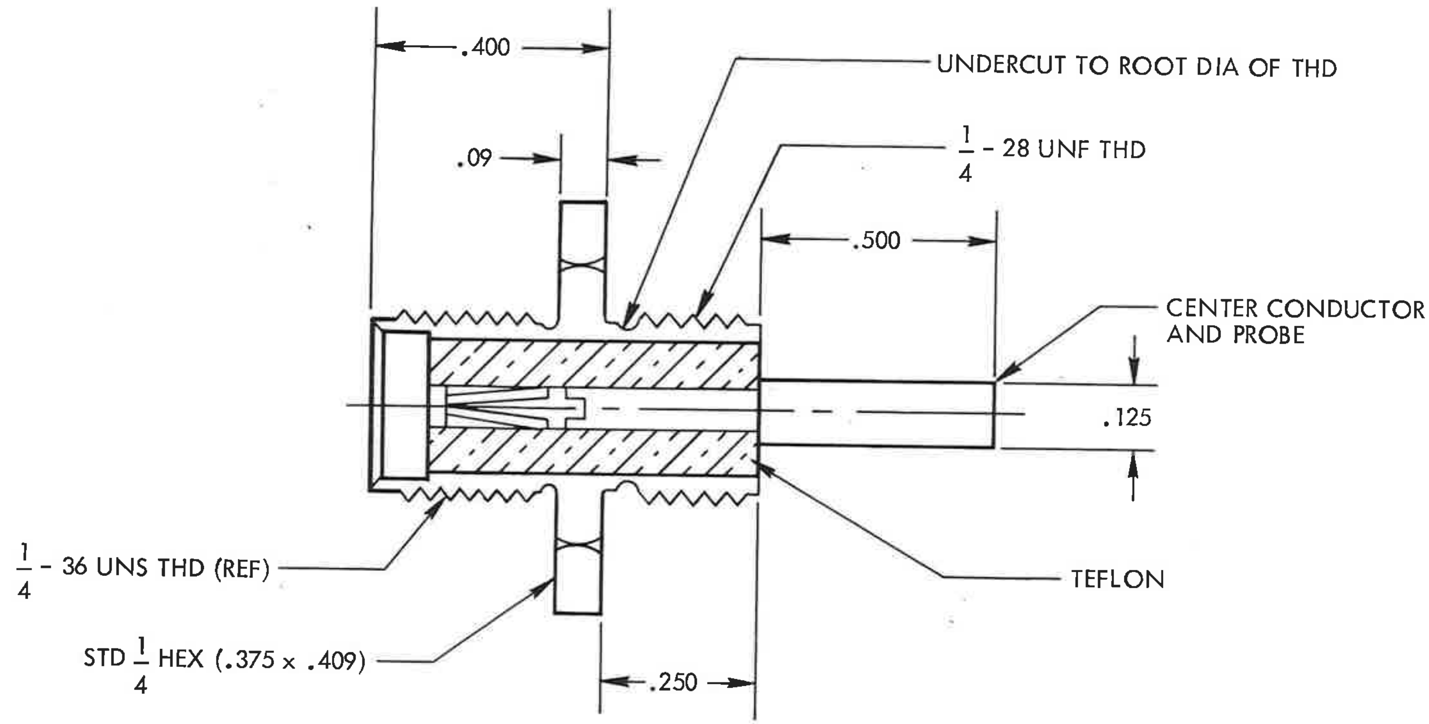


Figure A.16 Lens Assembly Drawing



NOTES:

1. USE DIMENSIONS AND CONSTRUCTION FROM STANDARD SMA SERIES JACK UNLESS OTHERWISE SHOWN
2. FINISH: GOLD PLATE METAL PARTS OF PROBE CONNECTOR ASSEMBLY IN ACCORDANCE WITH MIL-C-39012A
3. TEFLON INSULATOR AND CENTER CONDUCTOR PROBE MUST BE CAPTIVATED WITHIN CONNECTOR SHELL
4. UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
   TOLERANCES:
   DEC $\pm$.01 - 2 PLACES
   $\pm$.005 - 3 PLACES

Figure A.17 Probe Design Drawing

APPENDIX B

AZIMUTH COMPONENT SPECIFICATIONS AND TEST RESULTS

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (CONTINUED)

ILLUSTRATIONS (CONTINUED)

ILLUSTRATIONS (CONTINUED)

TABLES

TABLES (CONTINUED)

B.1 INTRODUCTION

During FY72, several contracts and purchase orders were awarded to procure nine types of components to be used on the phased-array azimuth antenna subsystems. Three of the contracts were re-awards made to a second source when the first source was unable to deliver the required components. The nine types of components obtained are the following:

a. SPDT diode switch

b. SP4T diode switch

c. 2 X 2 Phase-balanced diode transfer switch

d. Constant phase, electrically variable attenuator

e. 4 bit digital phase shifter

f. 8-way and 4-way power dividers

g. Mechanically variable phase shifter

h. Mechanically variable attenuator

i. Phase matched RG 141 semi-rigid cables

The final specifications to which the components were designed and fabricated are included in section B.1.1. Block diagrams and pertinent information related to the DOT/TSC component evaluation Test Set-Ups are given in section B.2. Performance data obtained on the components are presented in sections B.3.1 through B.3.9.

A 4 X 4 phase-balanced diode transfer switch is being procured for feasibility evaluations for an azimuth antenna subsystem. The specifications are included in section B.1.2.

Several components have been procured for use in the transmitter subassembly of the test system. The specifications of the components are presented in section B.1.3. Some data is presented in section B.4.

Five types of components were purchased for inclusion in the Dynamic Performance Test Receiver. Their specifications are included in section B.1.4.

B.1.1 Specifications of Components Used in Azimuth Antenna Subsystem

Nine types of components were procured for use in one of the azimuth antenna subsystems. The table numbers under which their specifications are presented are listed as follows:

Component	Table No.
Single Pole Double Throw Switch (SPDT Sw)	B.1
Single Pole Four Throw Switch (SP4T Sw)	B.2
2 X 2 Transfer Switch (XFER Sw)	B.3
Digitally Controlled, Constant Phase, Electrically Variable Attenuator	B.4
4-Bit Diode Phase Shifter	B.5
4-Way and 8-Way Power Dividers	B.6
Continuously Variable Coaxial Attenuator	B.7
Continuously Variable Coaxial Phase Shifter	B.8
RG-141 Semi-rigid Phase Matched Coaxial Cables	B.9

Twenty-six single pole double throw (SPDT) switches were purchased from American Electronic Laboratories (AEL) in Colmar, Pa. Twenty four of these are to be used in the distribution matrix of the Azimuth No. 2 Antenna Subsystem. The switches have integral drivers compatible with TTL logic and are compact high performance microwave integrated circuit (MIC) devices.

Five single pole four throw (SP4T) switches were also purchased from AEL. Four of these have been incorporated into the lens input component matrix of Azimuth No. 1 Antenna Subsystem. The SP4T switches also have integral drivers compatible with TTL logic and are MIC devices using alumina substrates.

Four 2 X 2 transfer switches with integral drivers were purchased from Hyletronics Corporation, Littleton, Mass. Two of these were incorporated into the lens input component matrix of Azimuth No. 1 Antenna Subsystem. The status of each diode in a switch can be monitored from test points on a multi-pin connector.

These switches are fabricated on standard dielectric material using a two-level stripline configuration. One level contains the basic double pole throw switch. The other level contains transmission line lengths of equal electrical length to provide inputs on one side and outputs on the other side of the switch as shown in Figure B.C. The two levels are interconnected by low loss feed-throughs which could serve as an excellent crossover mechanism as required in a phased array system. The stripline configurations were designed to be expandable, as required, to a 4 X 4 matrix which has been ordered and will be made using a 3-level stripline system.

Twenty-six digitally controlled, constant phase, electrically variable attenuators were obtained from Hyletronics Corporation. Twenty-four of these are to be used in the distribution matrix of the Azimuth No. 2 Antenna Subsystem. As implied by their title, the switches directly interface with TTL logic. The units are designed to provide 0 to 9.8 dB attenuation (exclusive of the insertion loss) in 1.4 dB steps under 3-bit logic control. A fourth logic input connection has been provided to set the attenuator to maximum attenuation for channel isolation purposes.

A contract for thirty-four state-of-the-art digitally controlled, 4-bit diode phase shifters was awarded to Microwave Associates, Burlington, Mass. Included as Table B.5 are the amended specifications to which the phase shifters were manufactured. A new procurement for fifty-two phase shifters has been awarded to Microwave Associates wherein the specifications have been reworked to be compatible with the antenna subsystem needs and the current implementable state-of-the-art. Twenty-four of the original units are to be used in the distribution matrix of the Azimuth No. 2 Antenna Subsystem.

Two 8-way and nine 4-way power dividers were procured during FY72. One 8-way and six 4-way power dividers are to be used in the distribution matrix of the Azimuth No. 2 Antenna Subsystem. The specifications of both the 8-way and the 4-way power dividers are included as Table B.6. The specifications primarily stress amplitude and phase balance at the output ports.

Thirty mechanical, continuously variable coaxial attenuators, which are basically catalog items, were purchased from Weinschel Engineering Co., Gaithersburg, Md. Their specifications are included as Table B.7. These units were obtained for manual setting of amplitude distributions, primarily for laboratory work associated with the antenna subsystems prior to the delivery of the electronic attenuators. Four mechanical coaxial attenuators were used on the R-2R lens evaluation work and also in the lens-input-component-matrix of Azimuth No. 1 Antenna Subsystem for setting the required amplitude distributions instead of unequal power dividers which would normally be used in such a matrix.

Forty mechanical, continuously variable coaxial phase shifters were purchased from Sage Laboratories, Natick, Mass. The specifications are included as Table B.8. These units were obtained for manually adjusting phase distributions in the R-2R lens evaluation, in the lens-input-component-matrix, and at the output of R-2R lens of the Azimuth No. 1 Antenna Subsystem. Although these phase shifters can be used to provide small incremental phase adjustments for each antenna input line, in a final system such a usage is economically unfeasible, and the function is more effectively performed with small "tweakers" or by "planned phasing" of the antenna connection cables discussed next.

Forty-eight RG-141 semi-rigid coaxial cables were purchased for the Azimuth No. 1 Antenna Subsystem utilizing the R-2R lens. Thirty-two of the cables used to interconnect the output of the lens to the antenna were purchased from one vendor. The delivered items yielded poor phase performance wherein the difference in electrical phase between any two cables was 44 degrees. This necessitated the use of the aforementioned mechanical phase shifters. The next 16 cables used to interconnect to the lens input were purchased from Phelps Dodge Communications Corp., North Haven, Conn. and met the specifications of Table B.9. One of the prime points demonstrated was that "planned phasing" of cables to within ± 3 degrees can be achieved at reasonable cost.

B.1.2 Specifications of 4 X 4 Phase-Balanced Diode Transfer Switch

Table B.10 presents the technical specifications of 4 X 4 phase-balanced diode transfer switch. The 4 X 4 switch is basically constituted of four 2 X 2 switches, the design of which is described by the specifications of Table B.3. The projected design of the 4 X 4 switch including the 16 operational matrix states is included in Table B.10.

B.1.3 Specifications of the Transmitter Subassembly Components

The transmitter subassembly used for antenna test range work consisted of a 108 MHz crystal oscillator and a times 48 multiplier capable of producing two watts at 5.19 GHz. The multiplier has a bandwidth of ±20 MHz centered at that frequency.

A broadband times 48 multiplier producing 1 watt from 5.0 to 5.25 GHz has been procured and is available. The multiplier input can, of course, be any single crystal oscillator or switched crystal type oscillator. If, for test purposes, high level stability is not essential, a voltage controlled oscillator (VCO) can be effectively utilized as the VHF input to either multiplier. Pertinent specifications of the existing and ordered transmitter subassembly components are listed in the tables as follows:

Component	Table No.
108 MHz Crystal Oscillator	B.11
Narrowband times 48 multiplier (2 watt output)	B.12
Wideband times 48 multiplier (1 watt output)	B.13
Impatt Amplifier, 8 watt output	B.14
Impatt Amplifier, 16 watt output	B.15

The crystal oscillators (108, 75 and 380 MHz) for both the transmitter and the receiver subassemblies were purchased from Greenray Industries, Inc., Mechanicsburg, Pa. The units listed here were satisfactory for the functions required on the MLS test system and are representative of what is generally available on a 30 day delivery. Units with more rigid specifications, as required, are available at somewhat higher cost and longer delivery schedule.

The narrowband multiplier with a bandwidth of 5190 MHz ±20 MHz and 2 watts output was purchased from Microwave Associates, Burlington, Mass., and is a high performance unit available on 30 to 60 days delivery. The broadband multiplier with a bandwidth of 5125 MHz ±125 MHz and 1 watt output which was purchased from the Joseph Standley Corporation, Burlington, Mass., is a moderate performance unit.

Higher solid state C-band power levels have been achieved with an unconditionally stable Impatt Amplifier following the 2 watt multiplier. A prototype amplifier with approximately 8 watts output and 10 percent instantaneous bandwidth has been designed and built by Stanford Research Institute (SRI) on Contract DOT-TSC-158 using 4 Impatt diodes and power-divider-combiner technique. A block diagram of a typical presently available multiplier-Impatt Amplifier C-band solid state transmitter subassembly is shown in Figure B.1. This is a forerunner of a 16 to 20 watt subassembly having greater than 5% instantaneous bandwidth. An extension of DOT-TSC-158 has been implemented to achieve between 16 and 20 watts over the MLS bandwidth of 5.0 to 5.25 GHz. Such an achievement will fulfill an important and ultimate necessity in future all solid state microwave landing systems.

B.1.4 Specifications of Components Used in the Dynamic Performance Test Receiver

A dynamic performance test receiver was assembled for detecting, processing, and recording the time coded phased array information available from the Azimuth No. 1 Antenna Subsystem. It is shown in block diagram form in Figure B.2. A block diagram of the test receiver to be used with the Azimuth No. 2 Antenna is shown in Figure B.3. Components were designed and fabricated, or purchased as required, and then assembled with laboratory equipment such as oscilloscopes to form a complete test receiver system adequate to perform the required tasks. The specifications of the individual components are listed in the tables as follows:

Component	Table No.
C-band Mixer Preamp, 410 MHz output	B.16
Linear IF Amplifier and Detector	B.17
UHF Local Oscillator	B.18
C-band Local Oscillator Subassembly	B.19
UHF Mixer, Relcom Model M1	
VHF Attenuators, Hewlett Packard Models 355C and 355D	
CRT Display Converter, Pacific Measurements Model 1005	
Signal Timer Subassembly, DOT/TSC	
Pulse Width Discriminator and Receiver Sync Generator, DOT/TSC	

The test receiver subsystem basically consists of double down conversion from C-band to 410 MHz to 30 MHz with intermediate attenuators used for appropriate level setting and calibration purposes. The second attenuation is followed by a 30 MHz linear IF amplifier and detector. The detector output is connected to a Tektronix 547 delayed sweep scope with Type W plug-in to view the time and amplitude inputs in a "delayed expanded" basis. The detector output is fed to an HP 180 scope with a delayed sweep horizontal input and connected to a CRT Display Converter which permits X-Y plotting of the time scan phased array system responses. This instrument provides large scale permanent plots of any response displayed on the oscilloscope. It may also be useful for interfacing between the receiver system and a magnetic recorder. The beam steering computer controls the microwave beam steering components and, in the configuration depicted, provides the sync signal for the oscilloscopes and the sync timer subassembly.
The system configuration of Figure B.2 can only be used when the test receiver is at the phased array antenna. When the transmitter is conventionally placed at the phased array antenna and the receiver at the other end of the range, the system configuration of Figure B.3 will be used. This configuration includes the pulse width discriminator and receiver sync generator, which was designed and built at DOT/TSC. In both B.2 and B.3 the sync timer subassembly designed and built at DOT/TSC must be used for time frame calibration which is necessary for angle position calculation.

B.2 COMPONENT EVALUATION TEST SET-UPS

Test set-ups for evaluating the components, intended for use in the phased array antenna subsystems, were assembled at DOT/TSC. These test set-ups were used to evaluate each type of component received. All types were sample tested at room temperature and the temperature extremes. Those types which yielded failures were further tested as required. One type was tested 100 percent to provide necessary justification for having the vendor open and rebuild all units to eliminate inherent defects which develop at temperatures below +15°C.

Insertion loss and isolation measurements were made on the non-computer controlled test set-up depicted in the block diagram of Figure B.4. Accuracies of better than 0.2 dB and 1 electrical degree were achieved and correlated with measurements made on a computer controlled network analyzer. Amplitude and phase balance measurements are easily made on this test system. Reflection coefficient measurements, both magnitude and phase were obtained on a test set-up represented by the block diagram form in Figure B.5. Required accuracies were readily achievable. Spurious responses and intermodulation products were observed and recorded on the test system shown in block diagram form in Figure B.6. Switching measurements were made at the vendors locations only, thus a block diagram for this function is not included.

B.3 COMPONENT EVALUATION TEST RESULTS

Nine types of components listed in section B.1.1 were evaluated. Data describing their performance is presented in the following sections.

B.3.1 Single Pole Double Throw (SPDT) Switch

Twenty-six SPDT switches were purchased from AEL on contract DOT-TSC-276. A photograph of one is included in Figure B.7. As required by the contract the vendor supplied data on isolation, insertion loss, and VSWR for all units. Per a special request of DOT/TSC, they also supplied relative phase data on all units for correlation with TSC data taken on a sampling basis. The AEL and TSC data correlated well. For the first article, AEL supplied the data required by the contract. Included among the data were excellent photographs of switching speed taken with a sampling scope. They are included here as Figure B.8. Data was taken at TSC of the insertion loss amplitude and phase balance at room temperature, -30°C, and +70°C from 5.0 to 5.25 GHz. Representative data on IL amplitude and transmission phase are presented in Figures B.9 and B.10 respectively. The results indicate compliance with both the insertion loss and phase requirements of the specification. Due to overall subsystem requirements future procurements will probably require a phase balance smaller than the present 10 degrees.

B.3.2 Single Pole Four Throw (SP4T) Switch

Five SP4T switches were procured from AEL on Contract DOT-RSC-276. A photograph of one is also included in Figure B.7. The vendor supplied data similar to that on the SPDT switches. The insertion loss and transmission phase characteristics for all output ports in a typical switch are presented in Figures B.11 and B.12. The test results indicate compliance with the insertion loss requirements of the specification. Although the unit meets the port-to-port differential insertion phase requirement, the specification would probably be tightened for future procurements. The switch-to-switch differential insertion phase requirements would also be tightened to reduce the problems in assembling an antenna feed network and because TSC's experience with the other components indicates that tighter phase limits can be met with minimal additional effort by the designer-manufacturer.

There are three separate techniques which can be used to obviate the need for tighter specifications on each component. They are: (1) design and build "phase tweakers" to be placed in each channel; (2) measure the phase of each channel, then design and build the interconnecting semi-rigid cables to the required compensating phase lengths; both techniques (1) and (2) imply that the control components are assembled in the most judicious manner to reduce overall phase variations; (3) ultimately, design and build all components of a channel on a single substrate and apply one set of amplitude and phase balance requirements per channel; unavoidable but much smaller phase differences could then be corrected for by specifying compensating cable lengths; this would probably not be necessary. Technique number (3) would probably have one very important additional advantage in that elimination of the connectors on individual components would result in lower overall insertion loss, VSWR, and reduced variation of insertion loss, VSWR and phase across the frequency band.

B.3.3 2 X 2 Phase-Balanced Diode Transfer Switch

Four 2 X 2 transfer switches were procured from Hyletronics Corporation, Littleton, Mass. on Contract DOT-TSC-283. The basic design philosophy of dual stripline levels and feed-throughs to accomplish crossovers was specified by DOT/TSC. This was done to permit expansion from 2 X 2 to 4 X 4 or 8 X 8, if required, at minimal additional non-recurring engineering (NRE) charges but primarily to provide best performance within the required physical configuration. A photograph of one of the units is presented in Figure B.13. The vendor supplied copies of data obtained on a computer controlled network analyzer and also pertinent tabulations per an approved data format. Figures B.14 and B.15 illustrate the insertion loss and transmission phase characteristics, respectively, over the frequency band from 5.0 to 5.25 GHz. All units easily met the phase balance specifications. Some units exceeded the absolute insertion loss and VSWR specifications at the upper band edge with maximum values of 1.4 dB and 1.8 VSWR, respectively. Delivery of the units was accepted when the vendor guaranteed in writing to rework the units, if requested, within one year at no cost to DOT/TSC.

B.3.4 Digitally Controlled Constant Phase Attenuator

Twenty-six attenuators were procured on Contract DOT-TSC-355. The microwave portion of the unit which was an extension of a standard design previously developed by Hyletronics was coupled to a current driver and a D to A Converter to from the final unit. A great deal of effort was of course required to interface the separate segments to meet the required specifications. The photograph of the attenuator is presented in Figure B.16. The vendor supplied a copy of all the computer measurement data. He also supplied an excellent set of tabulated data at 5.1 GHz delineating the parameters of insertion loss, attenuation, VSWR, isolation, and switching characteristics at room temperature. Also provided on all units were transmission phase data at room ambient and the temperature extremes. Included were phase data at +24 and +27 dBm for two units.

The majority of the vendor's data at 5.1 GHz is summarized in this report in Tables B.20 through B.23 inclusive. Table B.20 presents a comparison of both insertion loss and maximum 3-bit attenuation at room ambient and the temperature extremes. Ninety five percent of the units meet the room temperature insertion loss spec. Just one unit exceeds the IL spec by only 0.1 dB. Eighty percent of the units meet all of the insertion loss and maximum 3-bit attenuation specifications at all three temperatures. Considering that the specifications are stringent, the attenuators are excellent in the areas of matched insertion loss and accurate attenuation levels.

Table B.21 presents a comparison of phase and amplitude responses of two attenuators at low (≈ -20 dBm) and high (+24 and +27 dBm). There is absolutely no change in phase at power levels of -20, +24, and +27 dBm. The change in insertion loss when increasing input power from -20 dBm to +27 dBm is a maximum of 0.1 dB.

Table B.22 presents the insertion phase characteristics of each unit at room ambient and the temperature extremes. The table includes the difference between maximum and minimum of all units at each temperature and the RMS of the insertion phases of all units at each temperature. Ninety percent of the units have phase changes less than four degrees over the full temperature range.

Table B.23 lists the RMS phase deviations of each digital attenuator overall settings at room ambient and the temperature extremes at room temperature and +70°C, none of the units exceeds 2 degrees RMS. At -30°C, only two units exceed 3 degrees RMS.

Figures B.17 and B.18 present swept frequency room temperature responses of one attenuator picked at random from the entire group. Figure B.17 indicates the attenuation accuracy and Figure B.18 displays the transmission phase characteristics. The attenuation accuracy is excellent relative to the specifications. The phase characteristics meet the requirements of the specifications at the lower end of the band and are well within spec in the upper half of the frequency band.

Figures B.18 and B.19 represent the spurious and intermodulation product responses, respectively, of the attenuator. Four components in all (SPDT and SP4T switches, phase shifter and attenuator) were checked for performance in this regard. None produced spurii. Only the attenuator produced any intermodulation products and that was well within specification. The attenuator of course is the most susceptible to produce intermodulation products since the diodes are in an intermediate bias state between zero bias and the full forward condition. In such a case large RF voltage swings produce non-linearities which are manifested as intermodulation products.

All the data taken on the attenuators and presented in this report indicate that they are well designed, high performance, state-of-the-art constant phase attenuators well suited for use in phased array system applications.

B.3.5 4-Bit Digital Phase Shifter

Thirty-five digitally controlled 4-bit diode phase shifters were procured on Contract DOT-TSC-277. A photograph of one is shown in Figure B.21. This unit was developed by Microwave Associates specifically for DOT for use in phased array applications. After several iterations of designs, including mechanical and thermal, the final product performs well on all the tests to which it was subjected. Table B.24 is a sample format of the comprehensive computer controlled network analyzer data supplied on all units at center band and at 50 MHz increments from 5.0 to 5.25 GHz.

Table B.25 lists the RMS phase errors of the 35 phase shifters at random frequencies in the frequency band. Although a few units slightly exceed the 5 degree specification, ninety percent are within it. The RMS specification for the new phase shifter procurement has been held to 5 degrees because it is considered to be with the state-of-the-art.

Figure B.22 presents the phase accuracy of a typical phase shifter across the 5.0 to 5.25 GHz frequency range. The total variation is ± 7 degrees from a reference. This is the operating tolerance picked for the new phase shifter procurement. The RMS values plotted as circles at 50 MHz increments are relatively constant across the band at just under 4 degrees RMS. Figure B.23 presents the insertion loss levels for the same phase shift states. The average insertion loss values plotted as circles across the band range from 1.27 to 1.4 dB.

Figures B.24, B.25, and B.26 are reprints of data obtained from the vendor. Figure B.24 presents the average and maximum insertion loss characteristics of 14 phase shifters across a frequency band from 4.85 to 5.4 GHz. Within the required band of 5.0 to 5.25 GHz only one unit exceeds 1.7 dB (the maximum on the new specification) at the lower band edge. Figure B.25 presents the average and maximum VSWR characteristics of the 14 phase shifters. All units are below the new specification of 1.8 dB in the required band. Microwave Associates, who has been awarded the new contract on a competitive procurement Contract DOT-TSC-491, is attempting to improve the microwave circuit. If successful, VSWR's well below 1.8 in the required band will be achievable with accompanying reductions in the maximum insertion loss of about 0.2 dB compared to existing units. The VSWR bandwidth characteristics will also be improved. These improvements will lead to greater base of production and larger quantity yield. Figure B.26 presents average and maximum phase shift errors for the same 14 phase shifters across a frequency band exceeding 4.2 to 5.4 GHz. The data illustrates the relatively broadband phase characteristics inherent in the presently available units. This type of broadband performance projects relatively stable phase performance with temperature.

Figures B.27 and B.28 illustrate the "clean" responses of the phase shifter relative to spurious and intermodulation product requirements. The same type of responses were obtained on the SPDT and SP4T switches.

The data obtained on the 35 phase shifters indicates that they are adequately designed, moderate performance, state-of-the-art 4-bit digital diode phase shifters suitable for use in phased array systems applications.

B.3.6 8-Way and 4-Way Power Dividers

Two 8-way and nine 4-way power dividers have been procured on Contract DOT-TSC-352 for use on both Azimuth Antenna subsystems. While Azimuth No. 1 system used one 4-way power divider, Azimuth No. 2 antenna subsystem uses one 8-way and six 4-way power dividers. Consequently for these applications, only six 4-way power dividers must meet controlled phase and amplitude balance requirements.

Relative to the 8-way power divider, Figures B.29 and B.30 present the amplitude and phase responses of one of the units. The 8-way power dividers do not meet either the insertion loss or amplitude balance or the phase balance specifications. Of all the components described in this report the power dividers are, on a relative scale, the simplest components to design and fabricate on a quantity basis because they contain no active elements such as diodes and with reasonable care are batch processed from a single piece of art work. Thus, with nominal attention to engineering design detail and with reasonable care in processing and fabrication, performance meeting the required specifications can be achieved.

Relative to the 4-way power dividers, Figures B.31 and B.32 illustrate the relative amplitude and phase of six units. The power dividers do not meet the port-to-port specifications. Figures B.33 and B.34 illustrate the insertion loss and transmission phase characteristics of a single 4-way power divider. Some of the delivered units do not meet the insertion loss, amplitude or phase balance requirements. The units were accepted to permit continuance of work on the antenna subsystem, but are being selectively utilized.

Since the power dividers are considerably less complex than components such as digital attenuators, and since excellent insertion loss, and amplitude and phase balance performance has been achieved on the other components, it can confidently be assumed that much improved performance can and will be obtained on the newer procurement of power dividers on Contract DOT-TSC-475.

B.3.7 Phase-Matched RG-141 Semi-Rigid Cables

Semi-rigid cables are used on both antenna subsystems. Lens input and lens output cables were used on the Azimuth No. 1 subsystem. The lens output cables obtained from Americom Corporation were less than high performance units. The total spread in insertion loss was 0.5 dB. Cable evaluations showed the RMS error to be 17 degrees with a total spread of 44 degrees. Since this was considered excessive, one Sage Model FS-478 continuously variable coaxial phase shifter was used in tandem with each cable to compensate for the phase spread of the cables.

Precision, high quality, high performance RG-141 semi-rigid cables were subsequently obtained from Phelps Dodge Communications Co., North Haven, Conn. to interconnect the lens input component matrix to the lens input. The total phase spread was 4.2 degrees and RMS phase errors were 2.5 degrees. The total spread in insertion loss was less than 0.05 dB at 5.0 GHz. Figure B.35 illustrates typical phase and amplitude flatness from 5.0 to 5.25 GHz. These cables are highly recommended not only for phase matched interconnections but for phase matching channels by selective choice of phase.

B.3.8 Continuously Variable Coaxial Phase Shifter

Forty Sage Laboratories Model FS-478 phase shifters have been pruchased for controlled experiment use in conjunction with the Azimuth Antenna Subsystem. They have been evaluated to determine their performance relative to the specifications. The phase shift through the unit is varied mechanically by means of a micrometer control. The total travel of the micrometer control is 1.0 inches. The total electrical phase shift for the one inch of travel is 415 degrees. Thus, 360 degrees of phase shift is achieved over any 0.87 inch traversal of the micrometer.

The insertion loss over all micrometer setting is equal to or less than 0.8 dB for all units. The insertion loss over the entire frequency band for micrometer settings of 0.4 to 0.6 inches is equal to or less than 0.5 dB. Typical insertion loss responses of the phase shifters are shown in Figure B.36. The units are used near the 0.40-0.60 micrometer setting whenever possible. The phase variation at any frequency across the frequency band from 5.0 to 5.25 GHz is within ± 2 degrees for the change of 415 degrees insertion phase. A typical series of responses for the phase shifters is shown in Figure B.37.

The VSWR of all the units was equal to or less than 1.7 for a 360 degree phase shift over the frequency band of 5.0 to 5.25 GHz. For micrometer settings in the range of 0.4 to 0.6, the VSWR was less than 1.4 over the frequency band.

The phase shift and amplitude variations of ten percent of the units were evaluated relative to room temperature settings over the temperature range of -30 to +70°C. The units exhibited the following characteristics:

Temp	Δ Phase	Δ Amplitude
C	degrees	dB
-30	-11.6±0.9	<0.1
0	-6.9±1.1	<0.1
+70	+2.0±0.4	<0.1

The above data illustrates that, although the phase shift of the units changes with temperature, the variation from unit to unit is within acceptable limits.

Although these units would not be used in a final system, they are useful for an experimental work requiring manually adjusted phase setting and were used in the Az No. 1 antenna set-up.

B.3.9 Continuously Variable Coaxial Attenuator

As a matter of general interest, some data on mechanically variable attenuators purchased from Weinschel Engineering Company is included in this appendix. These units are excellent for controlled experiments wherein the phase variation is small as a function of attenuator setting. Figure B.38 presents the swept frequency transmission phase characteristics from 5.0 to 5.5 GHz for 1 dB changes in attenuation up to the maximum of 11 dB.

B.4 TRANSMITTER SUBASSEMBLY COMPONENT DATA

Two moderate-power solid state sources were purchased for use on the antenna tests. Both were times 48 multipliers and purchased to a one watt minimum specification. All the specifications are listed in Tables B.13 and B.14. The wideband unit produces one watt and is certainly not exceptional. The narrowband unit produces in excess of two watts over a 50 MHz bandwidth and in excess of 1.5 watts over a bandwidth of 85 MHz as indicated in Figure B.39. Both the harmonically and non-harmonically related spurs are greater than 60 dB below the RF output level. The times 48 multipliers are driven by VHF oscillators in the 107 MHz region. Antenna range tests were conducted using a 108.125 MHz crystal oscillator (specifications listed in Table B.12) to drive the narrowband times 48 multiplier. This combination, which is shown in the photograph of Figure B.40, produced 2 watts at 5.19 GHz.

This combination can also be used to drive an 8 watt C-band Impatt Amplifier obtained on Contract DOT-TSC-158 from Stanford Research Institute, Menlo Park, California and shown in Figure

B.41. The amplifier configuration uses a hybrid-circuit power combiner scheme to combine the outputs from four individual avalanche diodes, each mounted in its own coaxial matching circuit and heat sink. The 4-diode amplifier produced 6 dB gain and 5 percent power-add efficiency at an output power level of 8 watts in the 5.20 GHz frequency range. Output powers of nearly 10 watts were obtainable with better power-added efficiency; however the amplifier gain dropped to 4.9 dB for this power level.

The result of a swept frequency output power versus input power measurement for the four diode amplifier is shown in Figure B.42. The three upper curves display the input power to the amplifier while the lower curves give the corresponding output power levels. The 1 dB bandwidth of the amplifier is given in the insert and shows the expected bandwidth expansion from 350 MHz for a 2-watt input to 400 MHz at 3 watts. The ripple at 5.26 Hz in both input and output signals is due to inadequate power leveling and should not be as apparent in a more level test set-up. The gain response of the 4-diode amplifier is shown in Figure B.43. The input-output power curves are displayed for several frequencies in the range of interest. The highly non-linear amplifier characteristics inherent in high power Impatt Amplifiers are evident from these curves.

The noise characteristics of the amplifier are presented in Figures B.44 through B.46. Figure B.44 is a comparison of the input and output frequency spectrums as observed on a large dynamic range spectrum analyzer. At rated output, the noise visible over a 30 MHz range centered at 5.20 GHz was more than 60 dB below the main signal. Swept frequency measurements made on the unit revealed that the amplifier output signal was clean and free of any unwanted "jumps" or triggered responses present in some avalanche diode amplifiers. Figure B.45 is a plot of FM noise displaced from 2 to 100 kHz from the carrier. Figure B.46 is a plot of AM noise relative to the carrier also from 2 to 100 kHz displacement from the carrier. These results show the IMPATT amplifier to have very little FM noise over this range and slightly more AM noise than the klystron from ≈6 kHz down. It should be noted the measurement bandwidth is 1000 Hz and thus yields ≈10 dB more noise than if the more standard 100 Hz bandwidth had been used. Still the AM noise is more than 88 dB below the carrier at more than 2 kHz from the drive frequency. The test equipment (klystron source, power supplies, etc.) did not allow the avalanche amplifier to be tested at its full 8 watts output power. However, these measurements (at more than 6 watts) demonstrate the noise behavior to be quite satisfactory. The final amplifier design used four commercially available Hewlett Packard high power silicon avalanche diodes. These diodes have a reverse breakdown voltage of ≈120 volts which corresponds to an optimum operating frequency of 5.6 GHz. However by proper impedance matching, satisfactory results were obtained at 5.2 GHz, the frequency of interest. If this type of amplifier were utilized in an MLS System, there would be no problem in getting manufacturers to provide the optimum diode.

Each diode used was individually tested as an oscillator. Typical test results for the single diode amplifiers operated near 5.2 GHz are summarized below:

Single Diode Amplifier Results

Amplifier Number	Output Power (watts)	Power Added (watts)	Gain dB	Power Added Efficiency (%)
1	2.28 watts	1.73 watts	6.17 dB	5.15%
2	2.21 watts	1.66 watts	6.04 dB	5.18%
3	2.44 watts	1.90 watts	6.57 dB	6.07%
4	2.27 watts	1.72 watts	6.16 dB	6.04%

The results suggest that single diode amplifiers could be considered in each channel of a phased array antenna system if the phase tracking of all units is satisfactory. It would be possible, if desired, to conduct phase tracking experiments on the four individual single diode amplifiers to verify the phase and amplitude balance characteristics.

An extension of Contract DOT-TSC-158 is being implemented to use the same approach with 8 diodes to produce 16 watts minimum from a single output port. This type of development would fulfill several required functions of the MLS while providing solid-state reliability and long life.

TABLE B.1

Specification: Single Pole Double Throw Diode Switch

1. Scope: This document defines the performance and data requirements for a single pole double throw (SPDT) switch to be used in controlling RF energy in a phased array antenna.

2. Applicable Documents:

   MIL-I-6181D Interference Control Requirements, Aircraft Equipment

3. Requirements:

   3.1 Summary: This document defines the requirements for SPDT switches and associated test data. The switch will be a reciprocal device that can be used for transmit and receive operation.

   3.2 Drawing Applicability:

      1. Figure B.A is provided for terminology reference.

      2. The vendor shall supply a schematic diagram, parts list and assembly drawings suitable for engineering use and analyses.

      3. The vendor will supply an outline drawing of the switch within 30 days ARO.

   3.3 Electrical Requirements:

      1. Frequency: 5.0 to 5.25 GHz

      2. RF Power Input: Thermal noise to 0.5 w max. C.W.

      3. Insertion Loss: 1.2 dB max.

      4. Insertion Loss Variation:

         Port-to-Port: Maximum and minimum insertion losses shall not differ by more than 0.4 dB between switch positions.

         Switch-to-Switch: Maximum and minimum insertion loss shall not differ by more than 0.3 dB between switches (with the same positions used).

5. Differential Insertion Phase:

Port-to-Port: The insertion phase difference between switch ports will not exceed ten deg.

Switch-to-Switch: The insertion phase difference between switches (same switch position) shall not exceed ten deg.

6. Isolation: 30 dB min from any selected "on" port to "off" port.

7. Impedance: 50 ohms, VSWR 1.5 max at input port when other ports are terminated in a 50 ohm load having a VSWR of 1.1

8. Switching Characteristics:

Speed: $\leq$ 500 nanosec max (full on to full off and full off to full on)

Repetition rate: 0 to 40 kHz max

Delay: $\leq$ 200 nanoseconds

Delay Variation: $\leq$ 100 nanoseconds

Control: Drive circuitry shall be designed to interface with TTL logic, with 2.5 to 5 volts representing a "1", and 0 to 0.8 volts representing a "0".

Switching Transients ("Dribble"): Care will be taken to minimize the generation of energy on the RF input and output ports commonly caused by the switch control signals. Maximum advantage will be taken of the slow switching time requirement in achieving this requirement.

RF Isolation: C-band energy on the switch control leads shall be at least 30 dB below the RF input signal under any test condition.

9. RFI: (Interference Control) - The generation of radio-frequency interference by the network and the vulnerability of the network to radio-frequency interference shall be controlled within the limits of Specification MIL-I-6181D.

3.4 Mechanical Requirements:

1. Connectors

   RF Input: SMA female

   RF Output: SMA male

   Control: Vendor standard, mating connector should readily permit the use of shielded cable.

2. Weight: ≤ 8 oz

3. Size: ≤ 6 cubic inches excluding connectors. Vendor will supply outline drawing within 30 days after award of contract. The RF ports will be generally located as shown in Figure B.A.

4. Mounting: Shall mount to a flat surface with 4-40 hardware.

5. Finish: Corrosion resistant, the assembly will be suitably finished to prevent deterioration of the switch housing material over the operating conditions and environmental conditions called out in this specification.

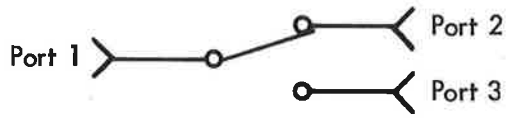
6. Cooling: The switch shall be designed to be cooled solely by natural convection.

7. Marking: All units shall have a label that contains at least the following information:

   1. Manufacturer
   2. Model No.
   3. Serial No.
   4. TSC contract no.
   5. Device nomenclature

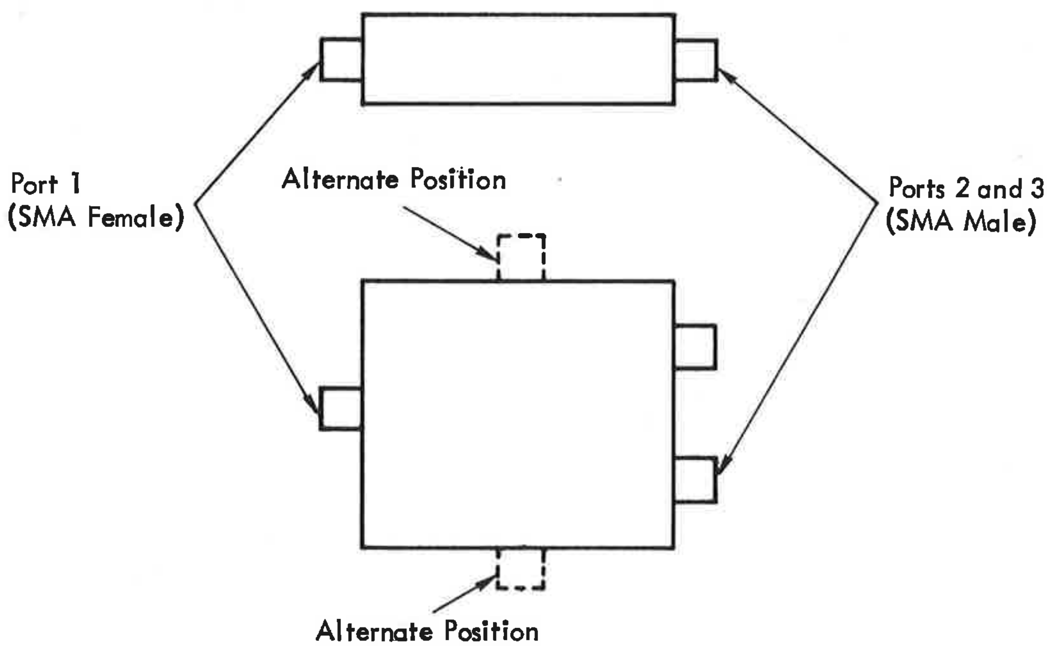
3.5 Operational Effectiveness

Operating Life - The switch shall have a minimum total operating life of 20,000 hrs. of continuous operation.



(a)

SPDT Functional Diagram



(b)

SPDT General Physical Layout

Figure B.A SPDT General Physical Layout

3.6 Environmental Requirements

a. Temperature: -30°C to +70°C

b. Humidity: 0 to 100%

c. General: The design and fabrication should consider a weatherized approach. Condensation is expected within the temperature range of +70°C to -30°C. A salt laden moisture is to be considered also. Sand, dust and wind loading are not directly applicable.

3.7 Design and Construction

This specification is not intended to define the internal structure of the network. Any reasonable configuration is acceptable as long as overall spec is maintained, but efforts should be oriented to a minimal size where possible. The design approach shall be amenable to large quantity production.

4. Quality Assurance Provisions

4.1 Test Data

The vendor shall supply the following test data at 5.0 GHz, 5.250 GHz and over the band (at intervals of 50 MHz if a swept-frequency measurement is not used).

1. All Units:

   a. Isolation
   b. Insertion Loss
   c. VSWR

4.2 Temperature Cycling:

All units shall be temperature cycled over the temperature extremes a minimum of two times with switch control signals applied to lock the switch in one position. The units shall soak for a minimum of two hours at each temperature extreme.

5. First Article Testing - Minimum Requirements

1. Isolation, insertion loss, and VSWR over the frequency band 5.0 GHz to 5.250 GHz (at intervals of 50 MHz if a swept frequency measurement is not used).

2. Test(s) specified in (1) above at temperature extremes cited under paragraph 3.6 of the specification.

3. Maximum insertion differential phase over the frequency band 5.0 GHz to 5.250 GHz as determined from a room ambient reference (70°F).

4. Port-to-port differential phase over the aforementioned frequency band.

5. Maximum switching speed.

TABLE B.2

Specification: Single Pole Four Throw Diode Switch

1. Scope: This document defines the performance and data requirements for a single pole four throw (SP4T) switch to be used in controlling RF energy in a phased array antenna.

2. Applicable Documents:

   MIL-I-6181D Interference Control Requirements, Aircraft Equipment

3. Requirements:

   3.1 Summary: This document defines the requirements for SP4T switches and associated test data. The switch will be a reciprocal device that can be used for transmit and receive operation.

   3.2 Drawing Applicability:

      1. Figure B.B is provided for terminology reference.

      2. The vendor shall supply a schematic diagram, parts list and assembly drawings suitable for engineering use and analyses.

      3. The vendor will supply an outline drawing of the switch within 30 days ARO.

   3.3 Electrical Requirements

      1. Frequency: 5.0 to 5.25 GHz

      2. RF Power Input: thermal noise to 3.0 watts max, CW

      3. Insertion Loss: 1.8 dB Max

      4. Insertion Loss Variation:

         Port-to-Port: Maximum and minimum insertion losses shall not differ by more than 0.4 dB between switch positions. (Port 1 - Port 2 path used as reference)

         Switch-to-Switch: Maximum and minimum insertion loss shall not differ by more than 0.3 dB between switches (with the same switch positions used).

5. Differential Insertion Phase:

Port-to-Port: The insertion phase difference between switch ports will not exceed ten deg (Port 1 - Port 2 path used as reference).

Switch-to-Switch: the insertion phase difference between switches (same switch position) shall not exceed ten deg.

6. Isolation: 30 dB min from any selected "on" port to any "off" port.

7. Impedance: 50 ohms, VSWR 1.5 Max, at input port when other ports terminated in 50 ohms, VSWR=1.1.

8. Switching Characteristics:

Speed: ≤500 nano sec max. (Full on to full off and full off to full on)

Repetition rate: 0 to 40 kHz max

Delay: ≤200 nano seconds

Delay Variation: ≤ 100 nano seconds

Control: Drive circuitry shall be designed to interface with TTL logic, with 2.5 to 5 volts representing a "1", and 0 to 0.8 volts representing a "0".

Switching Transients ("Dribble"): Care will be taken to minimize the generation of energy on the RF input and output ports commonly caused by the switch control signals. Maximum advantage will be taken of the slow switching time requirement in achieving this requirement.

RF Isolation: C-band energy on the switch control leads shall be at least 30 dB below the RF input signal under any test condition.

9. RFI: (Interference control) - The generation of radio-frequency interference by the network and the vulnerability of the network to radio-frequency interference shall be controlled within the limits of Specification MIL-I-6181D.

3.4 Mechanical Requirements

1. Connectors:

   RF Input: SMA female

   RF Output: SMA male

   Control: Vendor standard, mating connector should readily permit the use of shielded cable.

2. Weight: ≤ 16 oz.

3. Size: ≤ 10 cubic inches excluding connectors.

4. Mounting: Shall mount to a flat surface with 4-40 hardware.

5. Finish: Corrosion resistant, the assembly will be suitably finished to prevent deterioration of the switch housing material over the operating conditions and environmental conditions called out in this specification.

6. Cooling: The switch shall be designed to be cooled solely by natural convection.

7. Marking: All units shall have a label that contains at least the following information:

   1. Manufacturer
   2. Model No.
   3. Serial No.
   4. TSC Contract No.
   5. Device Nomenclature

3.5 Operational Effectiveness

Operating life - the switch shall have a minimum total operating life of 20,000 hrs. of continuous operation.

3.6 Environmental Requirements

a. Temperature: -30°C to +70°C

b. Humidity: 0 to 100%

c. General: The design and fabrication should consider a weatherized approach. Condensation is expected within the temperature range of +70°C to -30°C. A salt laden moisture is to be considered also. Sand, dust, and wind loading are not directly applicable.

3.7 Design and Construction

This specification is not intended to define the internal structure of the network. Any reasonable configuration is acceptable as long as overall spec is maintained, but efforts should be oriented to a minimal size where possible. The design approach shall be amenable to large quantity production.

4. Quality Assurance Provisions

4.1 Test Data

The vendor shall supply the following test data at 5.0 GHz, 5.250 GHz and over the band, at intervals of 50 MHz if a swept-frequency measurement is not used.

1. All Units:

    a. Isolation
    b. Insertion loss
    c. VSWR

4.2 Temperature Cycling

All units shall be temperature cycled over the temperature extremes, a minimum of two times with switch control signals applied to lock the switch in one position. The units shall soak for a minimum of two hours at each temperature extreme.

5. First Article Testing - Minimum Requirements

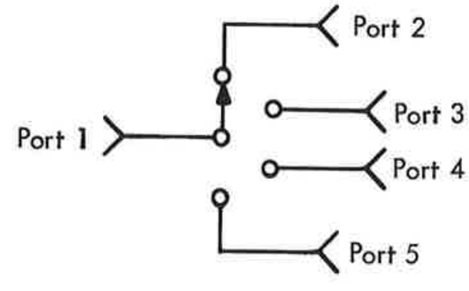
1. Isolation, insertion loss, and VSWR over the frequency band 5.0 GHz to 5.250 GHz (at intervals of 50 MHz if a swept frequency measurement is not used).

2. Test(s) specified in (1) above a temperature extremes cited under paragraph 3.6 of the specification.

3. Maximum insertion differential phase over the frequency band 5.0 GHz to 5.250 GHz as determined from a room ambient reference (70°F).

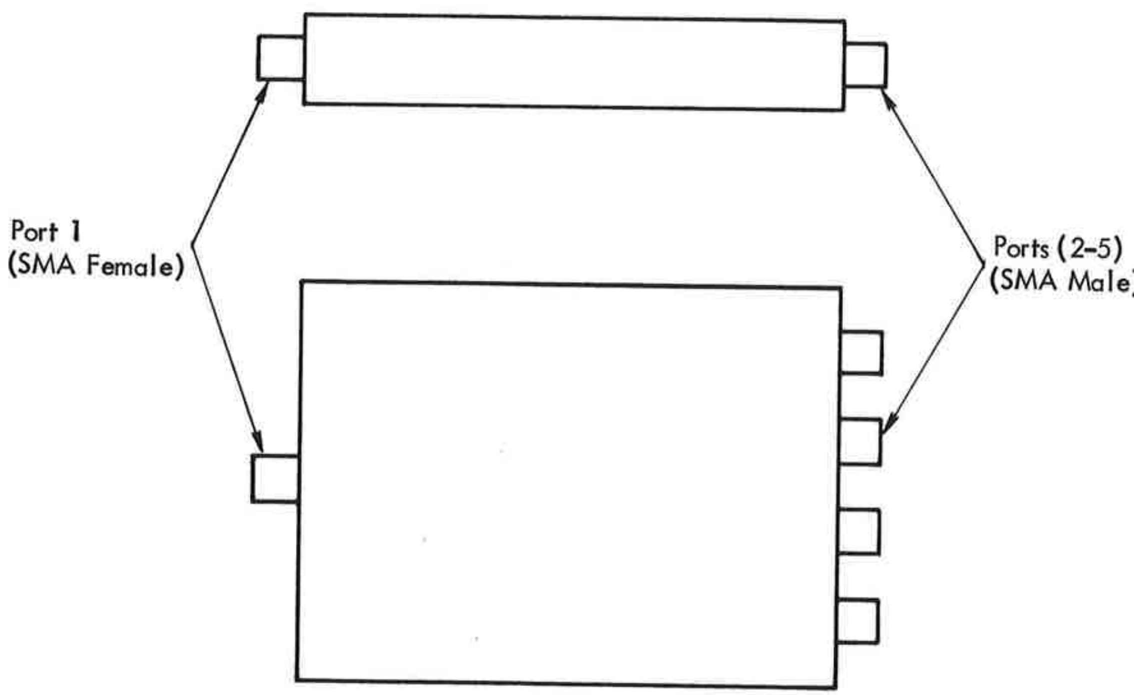
4. Port-to-port differential phase over the aforementioned frequency band.

5. Maximum switching speed.



(a)

SP4T Functional Diagram



(b)

SP4T General Physical Layout

Figure B.B SP4T General Physical Layout

TABLE B.3

Specification: Phase-Balanced Transfer Switch

1. Scope: This document defines the performance and data requirements for a phase balanced transfer switch (double pole double throw switch) to be used in controlling RF energy in a phased array antenna.

2. Applicable Documents:

   Military: MIL-I-6181D Interference Control Requirements, Aircraft Equipment

3. Requirements:

   3.1 Summary: This document defines the requirements for for four phase-balanced transfer switches and associated test data.

   3.2 Drawing Applicability:

      1. Figures B.C, B.D, and B.E are provided for terminology reference and clarification of device operation and construction.

      2. The vendor shall supply: a schematic diagram showing all characteristic impedances, electrical lengths, dielectric and ground plane thicknesses and other critical circuit dimensions; a parts list; and assembly drawings suitable for switch repair by a skilled technician if the unit is repairable. Assembly drawings are not required if the unit is non-repairable.

   3.3 Electrical Requirements:

      1. Frequency: 5.0 to 5.25 GHz

      2. RF Power Input: 20 dB variation typical, 1.0 watt (cw) maximum at each input terminal.

      3. Switch Routing: (refer to Figure B.C)

         Position 1: Terminal 1 connected to Terminal 3.
         Terminal 2 connected to Terminal 4.

         Position 2: Terminal 1 connected to Terminal 4.
         Terminal 2 connected to Terminal 3.

4. Insertion Loss: 1.1 dB maximum, 0.9 dB average, (0.7 dB average desired)

5. Insertion Loss Variation:

   a. The maximum and minimum insertion losses for different units, (input applied at the corresponding terminal and the switch being set to the same position in each case), shall not differ by more than 0.3 dB.

   b. The maximum and minimum insertion losses for any one unit shall not differ by more than 0.3 dB.

6. Amplitude Balance: With equal amplitude signals applied at terminals 1 & 2, the difference in amplitude between the output signals shall not exceed 0.3 dB in either switch position.

7. Phase Balance: With in-phase signals applied at terminals 1 and 2, the phase difference between the signals measured at ports 3 and 4 shall not exceed 5° in either switch position.

8. Insertion Phase Variation:

   a. The maximum and minimum electrical path length for different units, (input applied at the corresponding terminal and the switch being set to the same position in each case), shall not differ by more than ten degrees.

   b. The maximum and minimum electrical path length for any one unit shall not differ by more than ten deg

9. Impedance: 50 ohms

10. VSWR: All terminals not greater than 1.5 (when other terminals are terminated with 50 ohms (VSWR $\leq$1.05)).

11. Isolation: The power measured at either of the two terminals not designated as input or output shall be down by at least 30 dB from the power measured at the designated output terminal - for the input located at either input terminal and for either position of the switch.

12. Switching Characteristics:

    Speed: $\leq$500 nanoseconds maximum (Full On to Full Off and Full Off to Full On)

Repetition Rate: 0 to 40 kHz maximum

Delay: ≤200 nanoseconds

Delay Variation: ≤100 nanoseconds

Control: Drive circuitry shall be designed to interface with TTL logic, with 2.5 to 5 volts representing a "1", and 0 to 0.8 volts representing a "0".

13. RFI: (Interference Control) - The generation of radio frequency interference by the network and the vulnerability of the network to radio frequency interference shall be controlled within the limits of Specification MIL-I-6181D.

3.4 Mechanical Requirements:

1. Connectors: RF input: SMA female

   RF output: SMA male

   Control: Vendor standard, mating connector should readily permit use of shielded cable.

2. Size: On-center distance between inputs and on-center distance between outputs shall be two inches. The inputs are both to be located on one side of the switch (shown as the left side in Figure B.D) and the outputs are both to be located on the opposite side of the switch (shown as the right side in Figure B.D). Thickness of entire board assembly shall be ≤0.75 inches (≤0.5 inches desired). See Figure B.D.

3. Board Construction: Shall be on two boards (see Figure B.D and note of Figure B.E) with right angle connections between them. Entire assembly must be within the required thickness dimension, and must meet the insertion loss, VSWR, and other requirements.

4. Finish: Corrosion resistant, the assembly will be suitably finished to prevent deterioration of the switch housing material over the operating conditions and environmental conditions called out in this specification.

5. Cooling: The switch shall be designed to be cooled solely by natural convection.

6. Marking: All units shall have a label that contains at least the following information:

    1. Manufacturer's Name
    2. Model No.
    3. Serial No.
    4. TSC Contract No.
    5. Device Nomenclature

3.5 Operational Effectiveness: The switch shall have a minimum total operating life of 20,000 hours of continuous operation.

3.6 Environmental Requirements:

a. Temperature: -30° to +70°C

b. Humidity: 0 to 100%

c. General: The design shall consider a weatherized approach. Condensation and salt-laden moisture are to be considered.

3.7 Design Requirement: The design approach shall be amenable to large quantity production.

4. Quality Assurance Provisions:

4.1 Test Data: The vendor shall supply the following test data at 5.0 GHz, 5.25 GHz and over that band at intervals of 50 MHz if a swept frequency measurement is not used.

All Units:

a. Isolation
b. Insertion loss
c. Insertion phase variation
d. VSWR
e. Switching speed

4.2 Temperature Cycling: All units shall be temperature cycled over the temperature extremes a minimum of two times with switch control signals applied to lock the switch in one position. The units shall soak for a minimum of two hours at each temperature extreme.

5. First Article Testing: Minimum Requirements

1. Isolation, insertion loss, insertion phase variation, and VSWR over the frequency band 5.0 GHz to 5.250 GHz (at intervals of 50 MHz if a swept frequency measurement is not used).

2. Test(s) specified in (1) above at temperature extremes cited under paragraph 3.6 of the specification.

3. Maximum insertion differential phase over the frequency band 5.0 GHz to 5.250 GHz as determined from a room ambient reference (70°F).

4. Port-to-port differential phase over the aforementioned frequency band.

5. Maximum switching speed.

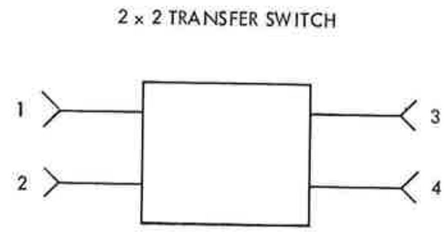


Figure B.C 2 x 2 Transfer Switch

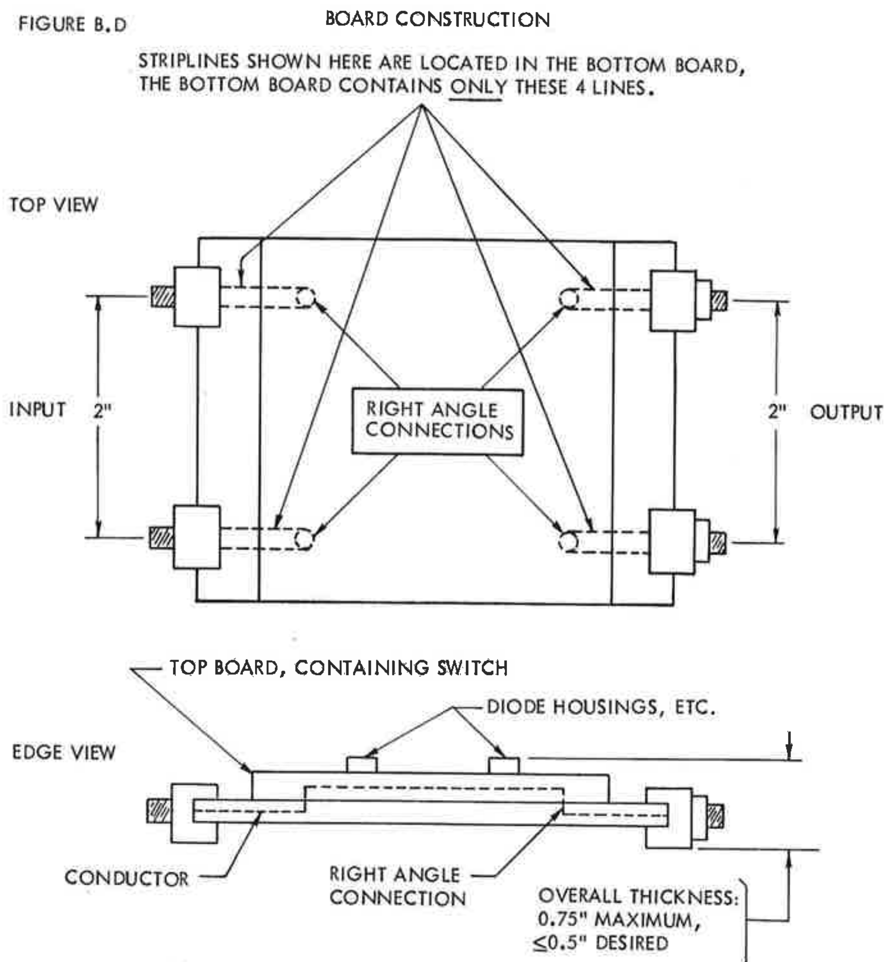


Figure B.D Board Construction

FIGURE B.E ALTERNATE CONSTRUCTION SCHEMES

NOTE: IF THE VENDOR BELIEVES HE CAN CONSTRUCT THE ABOVE SWITCH (FIGURES B.C & B.D) USING A DIFFERENT BOARD CONSTRUCTION, THAT WOULD BE PERMISSIBLE PROVIDED:

(1.) THE SWITCH MEETS THE DIMENSION SPECIFICATIONS SHOWN IN FIGURE B.D.

(2.) THE VENDOR PROVIDES, WITH HIS PROPOSAL, HIS SPECIFICATIONS FOR BUILDING THE FOLLOWING TWO SWITCHES, EACH MEETING THE DIMENSION SPECIFICATIONS IN FIGURE B.D AND PARAGRAPH 3.4(2).

THE INSERTION LOSS AND ISOLATION CHARACTERISTICS FOR THESE TWO SWITCHES MUST BE NO WORSE THAN THOSE WHICH WOULD BE OBTAINED BY CONSTRUCTING THESE SWITCHES FROM SEPARATE 2 x 2 TRANSFER MODULES.

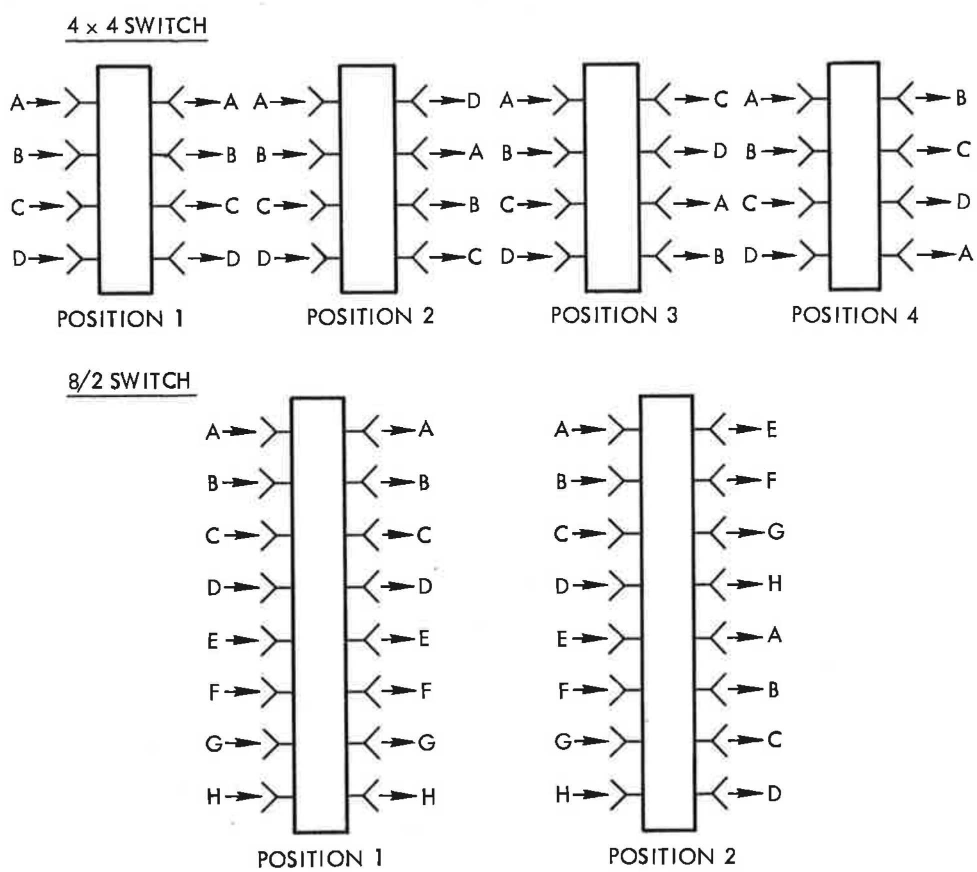


Figure B.E Alternate Construction Schemes

TABLE B.4

Specification: Digitally Controlled, Constant Phase, Electrically Variable Attenuator

1. Scope: This document defines the performance and data requirements for a digitally controlled, constant phase, electrically variable attenuator to be used to control power level to a phased array antenna.

2. Applicable Documents:

   MIL-I-6181D Interference control requirements, aircraft equipment.

3. Requirements:

   3.1 Summary: This section defines the requirements for a variable attenuator. The units shall be reciprocal in order to be used in a transmit or receive mode.

   3.2 Drawings:

      1. The vendor shall supply a schematic diagram, parts list, and assembly drawings (if unit is repairable at a location other than the factory) suitable for engineering use and analysis. Preliminary information due thirty (30) days ARO; finalized information due with delivery of first article.

      2. The vendor shall supply an outline drawing of the devices, showing mounting holes and dimensions, within thirty (30) days ARO.

   3.3 Electrical Requirements:

      1. Type: Absorptive Variable Attenuator

      2. Frequency Range: 5.0 - 5.25 GHz

      3. Input Power: 0.5 watt CW maximum (1.0 watt CW maximum, desirable)

      4. VSWR: 1.5 max referred to 50 ohm coaxial line at any attenuation setting and any input power level up to the maximum

      5. Attenuation Range: 0 to 9.8 dB per binary code table

      6. Attenuation Accuracy: Per binary code table

7. Resettability: Per binary code table

8. Insertion Loss at Binary Setting of 0000: 1.2 dB maximum

   a. Insertion loss of any two units at binary setting of 0000: shall not differ by more than 0.3 dB.

   b. Attenuation values of any two units having the same binary input: shall be within the tolerances specified in the binary code table.

9. Variation of Phase with Attenuation, Power, and Temperature:

   a. Each Unit: Over all possible 3 dB ranges of power up to +27 dBm (+30 dBm desirable), variation of phase, over the entire attenuation range of each unit, shall be within a total of 4 deg at any temperature within the required temperature range with input power to the attenuator varied over the entire 3 dB range.

   b. Unit to Unit: Over all possible 3 dB ranges of power up to +27 dBm (+30 dBm desirable), any two units at the same attenuator setting shall not differ in insertion phase by more than a total of 6 deg at any temperature (both units simultaneously at the same temperature) within the required temperature range when the difference in input power levels to the units under test is varied from 0 to 3 dB.

10. Switching Characteristics:

   a. Speed: 1.0 microsecond max total switching time between any two attenuation settings, per 3.3.10(b) from the binary command to 90% of the RF attenuation change in dB.

   b. Maximum change of attenuation at any given time to be limited to two steps (2.8 dB) over the range of 0 to 9.8 dB.

   c. Rep. Rate: 0 - 40 kHz

   d. Control: Each attenuator to be controlled with a 4-bit Input Binary Code (see Table B.4.1) from TTL Logic drive units capable of sinking 16 ma in the "zero" logic state and sourcing 400 microamps in the "one" logic state.

e. Switching Transients ("Dribble"): Care will be taken to minimize the generation of RF energy on the attenuator input and output ports. Such energy may be caused by the attenuator control signals as attenuation levels are changed. Maximum advantage will be taken of the slow switching time requirement in achieving this goal. The attenuator shall meet the following requirements:

   1. Above 2.0 GHz, power density to be less than -85 dBm/MHz.

   2. Video Signal Levels: Video switching transient signals present on the RF ports as observed with a suitable broadband oscilloscope shall not exceed an amplitude of 1.0 volt peak maximum.

   The above requirements will be obtained under the following conditions:

   1. No RF present

   2. Input and output ports terminated in specified impedances

   3. Attenuation level variation: one or two Binary step levels, up or down

   4. Control signal characteristics: per paragraph 3.3 (10) a, c, d of this Exhibit

f. Third Order Intermodulation Products: When the attenuator is driven by two test signals of equal amplitude within the specified operating bandwidth it shall have the following third order performance characteristics:

   1. With two test signal levels less than +27 dBm. Third order products shall be equal to or greater than 20 dB below test signal levels.

   2. With two test signal levels less than +20 dBm. Third order products shall be equal to or greater than 30 dB below test signal levels.

   3. With two test signal levels below 0 dBm. Third order products shall be equal to or greater than 40 dB below test signal levels.

NOTE: The above specification shall be met with the test signals injected at either RF port and with the attenuator set at any value within its specified operating range. Test signal frequency separation shall be such that third order intermodulation products fall "in-band".

g. RF Isolation: C-band power on the switch control leads shall be at least 30 dB below the RF input signal under any test condition.

11. RFI: (Interference Control) The generation of radio-frequency interference by the network and the vulnerability of the network to radio-frequency interference shall be controlled within the limits of Specification MIL-I-6181D.

3.4 Mechanical Requirements:

1. RF Connectors - stainless steel

   Input: SMA Female
   Output: SMA Female

2. RF input and output connectors shall lie at opposite ends of the long dimension. Positions of any non-RF connectors to be within shaded areas indicated in Figure B.F of this Exhibit.

3. Maximum Dimensions: Not to exceed 1 in. x 2 1/2 in. x 4 1/2 in. excluding connectors

4. Weight: Not to exceed 1 lb

5. Mounting: Shall mount to a flat surface with 4-40 hardware

6. Finish: Corrosion resistant. The assembly will be finished to prevent deterioration of the attenuator housing material over the operating conditions and environmental conditions called out in this specification.

7. Cooling: The attenuator shall be cooled solely by natural convection.

8. Marking: All units shall have a label that contains at least the following information.

   1. Manufacturer's Name
   2. Model No.
   3. Serial No.
   4. TSC Contract No.
   5. Device Nomenclature

3.5 Operational Effectiveness: The attenuator shall have a minimum total operating life of 20,000 hours of continuous operation.

3.6 Environmental Requirements:

a. Temperature: -30°C to +70°C

b. Humidity: 0 to 100%, including salt-laden atmosphere

The attenuators are required to meet all operating requirements, as prescribed in this specification, over the full temperature and humidity ranges of this Exhibit. Sand, dust and wind loading are not directly applicable.

3.7 Design and Construction: The design approach shall be amenable to large quantity production.

3.8 Shock and Vibration: The units must withstand normal handling procedures involved in shipment and laboratory work.

4. Quality Assurance Provisions

4.1 Test Data: The vendor shall supply the following test data at 5.0 GHz, 5.25 GHz, and over the band (at 50 MHz intervals if a swept-frequency measurement is not used).

1. All Units: Insertion loss, VSWR, attenuation, and transmission phase characteristics.

4.2 Temperature Cycling: All units shall be temperature cycled over the temperature extremes a minimum of two (2) times. The units shall soak for a minimum of two (2) hours at each temperature extreme.

TABLE B.4.1 BINARY CODE TABLE

BINARY CODE	NOM. ATTEN., dB (above IL)	ATTEN. TOL. ± dB
0000	0	See para. 3.3(8)
0001	1.4	0.20
0010	2.8	0.20
0011	4.2	0.21
0100	5.6	0.28
0101	7.0	0.35
0110	8.4	0.42
0111	9.8	0.49
1000	>20.0	None

NOTES:

1. The attenuation levels and tolerances listed in the above table are required to be met over all conditions specified in this exhibit including frequency range, accuracy, resettability, power input, temperature, and humidity.

2. An attenuation level greater than 20 dB will be presented to a signal within the required frequency range when a logic "one" is applied to a fourth logic terminal located on the non-RF connector. When a logic "zero" is applied to the same terminal, the required attenuation values listed above will be available.

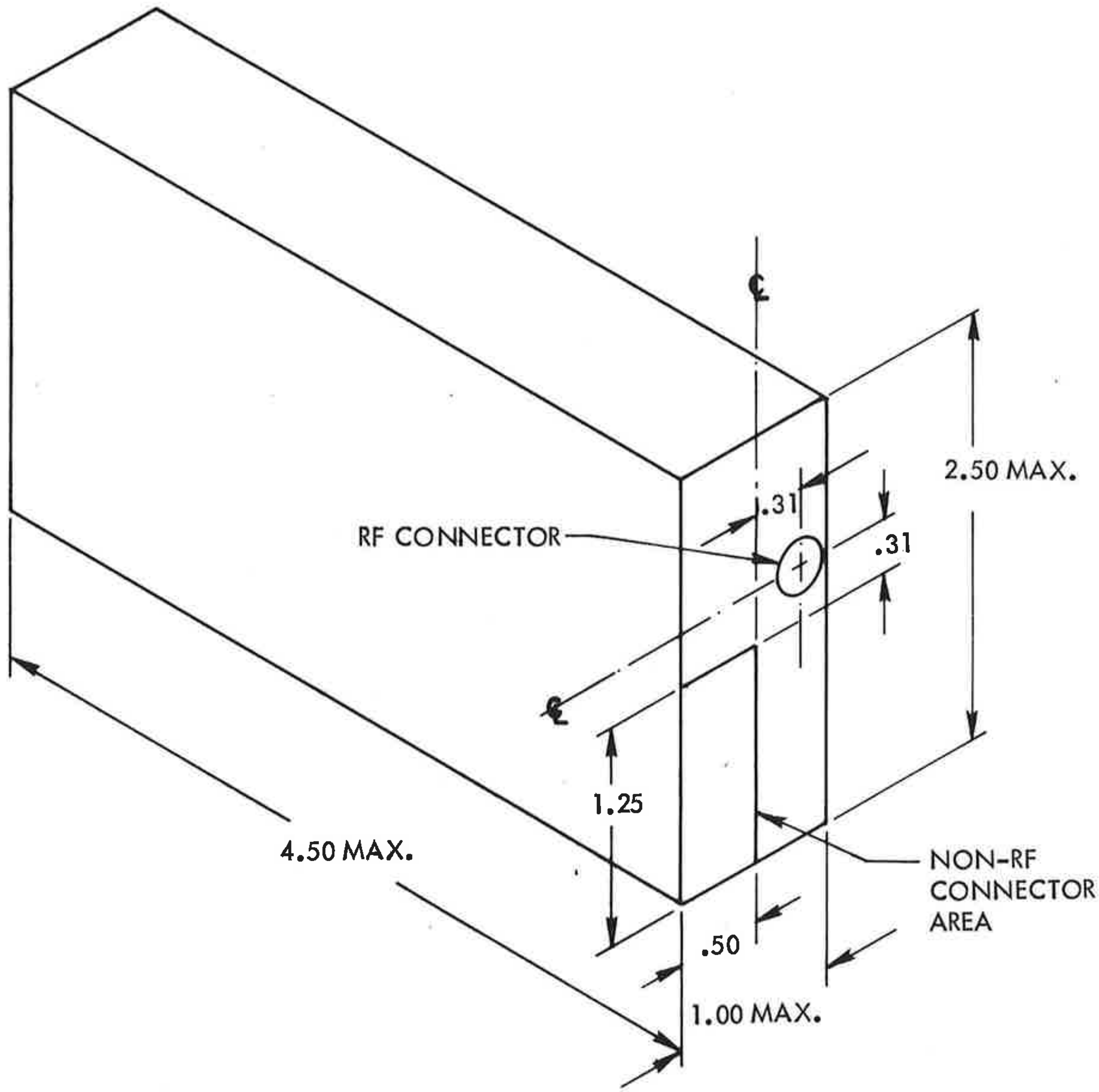


Figure B.F Digital Attenuator, Physical Configuration

TABLE B.5

Specification: 4-Bit Digital Phase Shifter

1. Scope: This document contains the performance and data rements for a four-bit digital diode phase shifter to be used for fine phasing in a phased array antenna.

2. Applicable Documents:

   MIL-I-6181D Interference Control Requirements, Aircraft Equipment

3. Requirements:

   3.1 Summary: This section defines the requirements for the digital diode phase shifter. The device shall be reciprocal in order to be used in either a transmit or receive mode.

   3.2 Drawings:

   1. The vendor shall supply a schematic diagram, parts list, and assembly drawings suitable for engineering use and analysis.

   2. The vendor shall supply an outline drawing of the attenuator within 30 days ARO. Mounting holes, dimensions and connector locations shall be clearly indicated.

   3.3 Electrical Requirements:

   1. Frequency Range: 5.0 - 5.25 GHz

   2. VSWR: Average for all bias states at each frequency not to exceed 1.40. Absolute maximum to be 1.8, with not more than 2 of the 16 bias states at each frequency to exceed 1.6.

   3. Insertion Loss: Maximum shall not exceed 1.7 dB for 14 of the 16 bias states at each frequency. Absolute maximum of 1.8 dB for all bias states at all frequencies from 5.0 to 5.25 GHz. Average for all bias states at each frequency not to exceed 1.6 dB. Insertion loss variations for one unit shall not exceed ±0.3 dB over all bias states at each frequency. At each frequency, insertion loss variations between units at the same bias state shall not exceed ±0.3 dB.

   4. Power Handling Capability: Shall be 700 mW minimum, with one watt desired, with no deterioration of electrical performance.

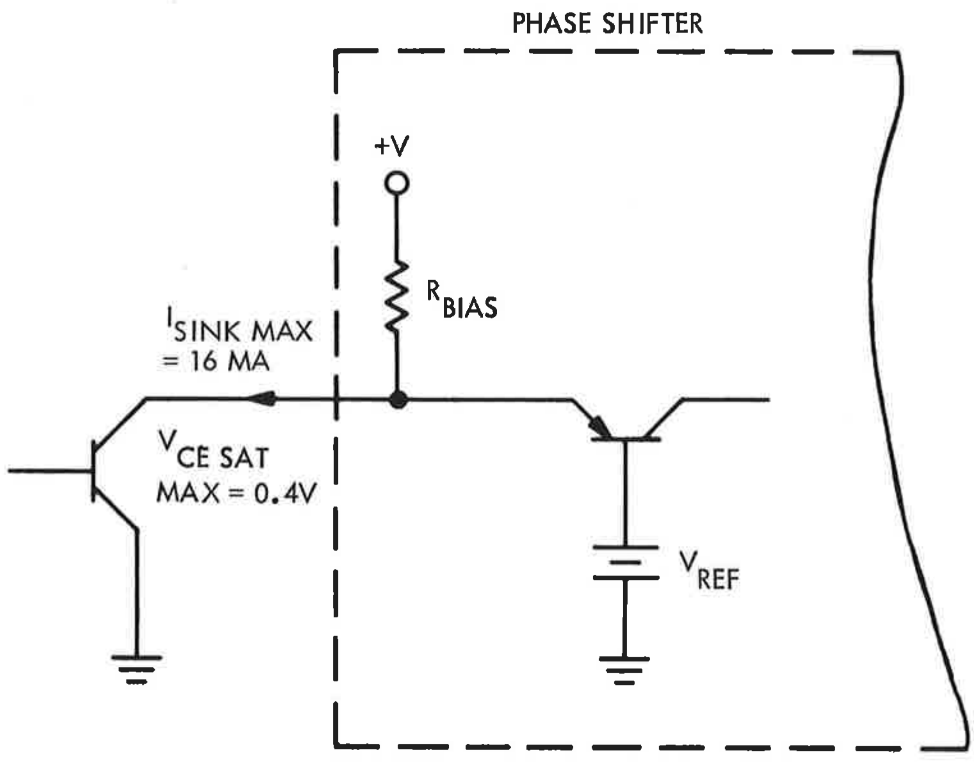


Figure B.G Schematic Diagram of Control Circuit per Paragraph 3.3 (8) of Table B.5

5. Phase Shift: 0 deg to 337.5 deg in steps of 22.5 deg. RMS phase error at various settings: 5 deg or less. Unit-to-unit variations shall be within ± 5 deg at each setting.

6. Insertion Phase: Unit-to-unit variations at zero phase shift setting shall be within ± 5 deg.

7. Switching Time: Total switching time shall not exceed 700 nanoseconds under all operating conditions required by this specification and under a single set of bias levels to be specified by the Contractor. Total switching time to be measured from 90 percent of final level of pulse voltage applied at driver in phase shifter - to - 90 percent of the RF bias state change. RF switching time from one bias state to any other (10 to 90 percent of RF bias state change) shall not exceed 400 nanoseconds. Delay time variations to be less than 100 nanoseconds. Delay time to be measured from 90 percent of final level of pulse voltage applied at driver in phase shifter - to - 10 percent of the RF bias state change. Repetition rate: up to 40 kHz.

8. Control: Drive circuitry shall be designed in accordance with the schematic in Figure B.G of this specification to interface with an open collector of a transistor capable of sinking a maximum of sixteen milliamps at a voltage of 0.4 volts $V_{CE\ Sat}$ during a logic "zero". Responsibility for meeting the temperature provisions of the specification remains with the Contractor.

9. Switching Transients ("Dribble"): Care will be taken to minimize the generation of energy on the RF input and output ports commonly caused by the switch control signals. Maximum advantage will be taken of the relatively slow switching time to achieve this end.

10. RF Isolation: C-band energy on the switch control leads shall be down by at least 30 dB below the RF input signal under any test condition.

11. RFI: The generation of RFI by the network and the vulnerability of the network to RFI shall be controlled within the limits of specification MIL-I-6181D.

3.4 Mechanical Requirements:

1. Connectors:

   RF input: SMA female, end launch
   RF output: SMA male, end launch
   Control: Vendor standard; mating connector should permit the use of shielded cable.

2. Weight: Less than 1 lb

3. Size: Length 7.00 ±.050 inches preferred. Height and width should be small enough, including drive unit, to allow connectors to feed into a 2 inch by 2 inch grid (approximately 1.5 inches by 1.75 inches).

4. Mounting: Shall mount to a flat surface with 4 -40 hardware.

5. Finish: Corrosion resistant. The assembly shall be suitable finished to prevent deterioration of the housing material over the operating and environmental conditions in the specification.

6. Cooling: The phase shifter shall be designed to be cooled solely by natural convection.

7. Marking: All units shall have a label that contains at least the following information:

   1. Manufacturer's Name
   2. Model No.
   3. Serial No.
   4. TSC Contract No.
   5. Device Nomenclature

3.5 Operational Effectiveness: These phase shifters shall have a minimum total operating life of 20,000 hours of continuous operation.

3.6 Environmental Requirements:

1. Temperature -30°C to +70°C.

2. Humidity: 0 to 100%

3. General: The design should consider a weatherized approach. Condensation and a salt-laden moisture are expected within the stated temperature.

3.7 Design Requirements: The design approach shall be amenable to large quantity production.

4. Quality Assurance Provision:

4.1 Test Data: The vendor shall supply the following test data at 5.0 GHz, 5.25 GHz, and over the band (at intervals of 50 MHz if swept frequency techniques are not used):

1. All Units: Insertion loss, insertion phase; VSWR, phase shifts at all settings.

4.2 Temperature Cycling: All units shall be temperature cycled over the temperature extremes a minimum of 2 times. The units shall soak for a minimum of two hours at each temperature extreme.

5. First Article Testing: Minimum Requirements

1. Insertion loss, insertion phase, VSWR and phase shift at all steps over the frequency band 5.0 GHz to 5.250 GHz (at intervals of 50 MHz if a swept frequency measurement is not used).

2. Test(s) specified in (1) above at temperature extremes cited under paragraph 3.6 of the specification.

3. Maximum switching speed

4. Phase shifts at all settings at maximum power

TABLE B.6

Specification: Power Dividers, 1 to 8 and 1 to 4

1. Scope: This document defines the performance and data requirements for two types of power dividers, a one input-eight output type, and a one input-four output type.

2. Applicable Documents:

   MIL-I-6181D Interface Control Requirements, Aircraft Equipment

3. Requirements:

   3.1 Summary: This document defines the requirements for power dividers and associated test data. The power dividers will be reciprocal devices that can be used on transmit or receive operation.

   3.2 Drawings:

      1. The vendor shall supply a schematic diagram, parts list, and assembly drawings suitable for engineering use and analysis.

      2. The vendor will supply an outline drawing of each unit, showing dimensions and mounting holes within thirty (30) days ARO.

      3. Figure B.H is provided for clarification of the device configuration.

   3.3 Electrical Requirements:

   (Item 1: 8-way Power Divider)

      1. RF Power Input: Up to 30 watts CW. Outputs are anticipated to feed into components with VSWR's of 2.5 maximum, but power divider shall be able to dissipate the reflected signal from a VSWR of 3.5 at one output port without destruction.

      2. Coupling and Insertion Loss: Maximum insertion loss of 1.2 dB (the power level at any output port shall be between 9 and 10.2 dB down from the power level at the input port).

      3. Isolation: 20 dB minimum. Specifically this means that if the input port and all but two output ports are terminated in matched loads, and a signal fed into one of the two remaining ports,

the signal observed at the other port shall be down by 20 dB or more from the input signal.

4. Amplitude Balance between Output Ports: The signal at the maximum port and the minimum port shall not differ by more than 0.3 dB for any unit.

5. Phase Balance between Output Ports: The path length to any output port shall not differ from the path length to any other output port by more than 5 deg for any unit. The path length to any port of any unit shall not differ from the path length to the same port of any other unit by more than 10 deg.

6. VSWR: 1.5 max to 50 ohms, with matched terminations at output.

7. RFI: Shall meet the requirements of MIL-I-6181D.

8. Frequency: 5.0 to 5.25 GHz.

(Item 2: 4-Way Power Divider)

1. RF Power Input: Up to 5 watts CW. Outputs are anticipated to feed into components with VSWR's of 2.5 maximum, but power divider shall be able to dissipate the reflected signal from a VSWR of 3.5 at one output port without destruction.

2. Coupling and Insertion Loss: Maximum insertion loss of 0.8 dB (the power level at any output port shall be between 6 and 6.8 dB down from the power level at the input port).

3. Isolation: 20 dB minimum. Specifically this means that if the input port and all but two output ports are terminated in matched loads, and a signal fed into one of the two remaining ports, the signal observed at the other port shall be down by 20 dB or more.

4. Amplitude Balance between Output Ports: The signal at the maximum port and the minimum port shall not differ by more than 0.3 dB for any unit. The coupling to any port of any unit shall not differ from the coupling to the same port of any other unit by more than 0.3 dB.

5. Phase Balance between Output Ports: The path length to any output shall not differ from the path length to any other output port by more than 5 deg for any unit. The path length to any port of any unit shall not differ from

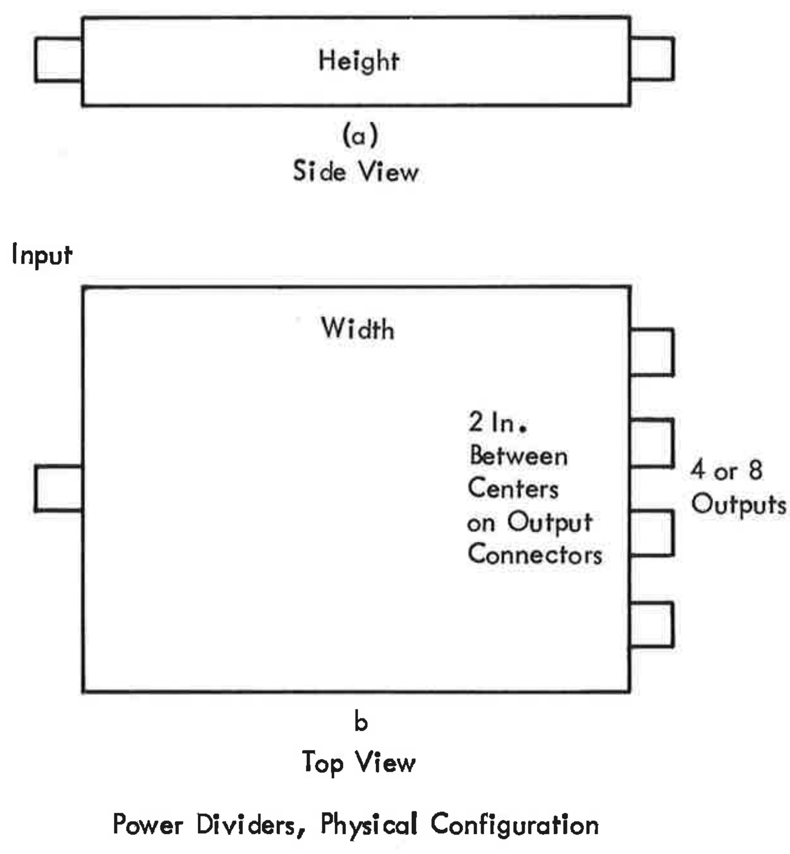


Figure B.H Power Dividers, Physical Configuration the path length to the same port of any other unit by more than 5 deg.

6. VSWR: 1.5 max to 50 ohms, with matched terminations

7. RFI: Shall meet the requirements of MIL-I-6181D.

8. Frequency: 5.0 to 5.25 GHz

3.4 Mechanical Requirements:

(Item 1: 8-way Power Divider)

1. RF Connectors: Stainless Steel

   Input: SMA Female, End Launch
   Output: SMA Male, End Launch

   Input and output connectors to be mounted on opposite sides of board. Output connectors to be mounted on 2.00 ±.016 inch centers (non-cumulative tolerance). Spacing between outer connectors: 14.00 ±.050 inches.

2. Size: Width - 18 in.; Depth - 14 in.; Height - 1 in. max

3. Weight: 5 lbs max

(Item 2 - 4-Way Power Divider)

1. RF Connectors: Stainless Steel

   Input: SMA Female, End Launch
   Output: SMA Male, End Launch

   Input and output connectors to be mounted on opposite sides of board. Output connectors to be mounted on 2.00 ±.016 inch centers (non-cumulative tolerance). Spacing between outer connectors: 6.00 ±.050 inches.

2. Size: Width - 10 in.; Depth - 10 in.; Height - 1 in. max

3. Weight: 3 lbs. max

The following mechanical requirements apply to both items:

4. Mounting: Shall mount to a flat surface with 4-40 hardware.

5. Finish: Corrosion resistant. Shall be able to prevent deterioration of the divider housing over the operating and environmental conditions stated herein.

6. Cooling: Natural convection shall be adequate.

7. Markings: All units shall have a label that contains at least the following information:

    1. Manufacturer's Name
    2. Model No.
    3. Serial No.
    4. TSC Contract No.
    5. Device Nomenclature

3.5 Operational Effectiveness: The dividers shall have a minimum total operating life of 20,000 hrs of continuous operation.

3.6 Environmental Requirements

1. Temperature: -30°C to +70°C

2. Humidity: 0 to 100%, salt-laden atmosphere

3. General: Sand, dust and wind loading are not directly applicable.

3.7 Design and Construction: The design approach shall be amenable to large quantity production.

3.8 Shock and Vibration: The units must withstand normal handling procedures involved in shipping and laboratory work.

4. Quality Assurance Provisions

4.1 Test Data: The vendor shall supply the following test data at 5.0 GHz, 5.25 GHz and over the band (at intervals of 50 MHz if swept-frequency measurements are not used).

1. All Units: Isolation, insertion loss or coupling, and VSWR. Insertion phase at each port.

4.2 Temperature Cycling: All units shall be temperature cycled over the temperature extremes a minimum of two (2) times. The units shall soak for a minimum of two (2) hours at each temperature extreme.

TABLE B.7

Specification: Continuously Variable Coaxial Attenuator

1. Frequency: 5.0 to 5.25 GHz
2. Type: Mechanical, direct reading
3. Range: 10 dB
4. VSWR: 1.3:1 maximum
5. Insertion Loss: 0.8 dB maximum
6. Accuracy: Within 0.2 dB of setting
7. Phase Shift Variation: Less than 1 deg/dB of attenuation
8. Connectors: Type N stainless steel, one male, one female
9. Size: Maximum dimensions in plane perpendicular to coaxial axis must be less than 1.5 x 1.5 inches.

TABLE B.8

Specification: Continuously Variable Coaxial Phase Shifter

1. Electrical:

   1.1 Frequency: 5.0 to 5.25 GHz

   1.2 Type: Mechanical, calibrated micrometer readout

   1.3 Range: 360 deg minimum

   1.4 VSWR: 1.5:1 maximum

   1.5 Insertion Loss: 0.7 dB maximum

   1.6 Accuracy of Setting Including Repeatability: Within ±2deg of calibration.

   1.7 Linearity of Phase with Micrometer Travel: ±2 deg

2. Mechanical

   2.1 Connectors:

   Input: OSM female
   Output: OSM male
   Input and output connectors are to be colinearly aligned.

   2.2 Size:

   Length: Distance between connector tips shall be 7.00 ±.050 inches.

   Width: Less than 1.5 inches to permit adjacent units to feed connectors spaced at 1.53 inch intervals.

   2.3 Micrometer Mounting: Micrometer heads shall be end mounted to allow convenient adjustment of phase shift when units are adjacent; dial should be visible from above, i.e., from output connector side for convenient readout.

3. Testing and Acceptance: Each unit shall be tested for insertion phase at 5.0, 5.10, and 5.25 GHz at zero setting of micrometer; data is to be included on the decal for 5.10 GHz. The prototype unit shall be thoroughly tested to meet all specifications. The final inspection and acceptance of the production units shall be accomplished at the Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge, Massachusetts.

TABLE B.9

Specification: RG-141 Semi-rigid Phase Matched Cables.

1. Frequency: 5.0 to 5.25 GHz

    1.1 RF Power Input: 0.5 Watt maximum

    1.2 Insertion Loss Balance: The insertion loss difference of one cable to any other of the same set shall be less than 0.1 dB.

    1.3 Phase Balance: The difference in electrical length of one cable to any other of the same set shall not exceed 5 electrical deg at 5 GHz.

    1.4 Impedance: 50 ohms

    1.5 Temperature: -30°C to +70°C

    1.6 Humidity: 0 to 100%

    1.7 Connectors: SMA (male or female as specified)

    1.8 Size and Shape: As specified in DOT/TSC drawing

    1.9 Flexure and Tensile Strength at Juncture of Cable and Connectors: .30 inch-pounds.

TABLE B.10

Specification: Phase-Balanced Four by Four Transfer Matrix

1. Scope: This document defines the performance and data requirements for a phase-balanced 4 x 4 (four input-four output) transfer matrix to be used in controlling RF energy in a phased array antenna.

2. Applicable Documents:

MIL-I-6181D	Interference Control Requirements, Aircraft Equipment
MIL-217A	Reliability Handbook
FAA-G-2100/1	Electronic Equipment, General Requirements

3. Requirements:

3.1 Summary: This document defines the requirements for one phase-balanced 4 x 4 transfer matrix and associated test data.

3.2 Drawing Applicability:

1. Figures B.I, B.J, B.K, and B.L are provided for terminology reference and clarification of device operation and construction.

2. The vendor shall supply: a schematic diagram showing all characteristic impedances, electrical lengths, line curvatures and corner angles, feed-through connections and associated pins or screws, dielectric and ground plane thicknesses and other critical circuit dimensions; a parts list, and assembly drawings suitable for switch repair by a skilled technician.

3.3 Electrical Requirements:

1. Frequency: 4.9 to 5.35 GHz

2. RF Power Input: 20 dB variation typical, 1.0 watt (cw) maximum at each input terminal

3. Matrix Design-Routing:

a. The 4 x 4 matrix shall route four distinct RF inputs between its inputs and outputs, identically as it would if it were constructed of individually controlled internal elements equivalent to four phase-balanced 2 x 2 transfer switches (see Contract DOT-TSC-283) and which are internally connected as shown in Figure B.I.

b. The matrix shall have sixteen distinct routing states (see Figure B.J) whose connectivity shall be:

State	Terminals (see Figure 1)	State	Terminals (see Figure 1)
1	1 - 5	9	1 - 5
	2 - 6		2 - 8
	3 - 7		3 - 7
	4 - 8		4 - 6
2	1 - 6	10	1 - 8
	2 - 5		2 - 5
	3 - 7		3 - 7
	4 - 8		4 - 6
3	1 - 5	11	1 - 5
	2 - 6		2 - 8
	3 - 8		3 - 6
	4 - 7		4 - 7
4	1 - 6	12	1 - 8
	2 - 5		2 - 5
	3 - 8		3 - 6
	4 - 7		4 - 7
5	1 - 7	13	1 - 7
	2 - 6		2 - 8
	3 - 5		3 - 5
	4 - 8		4 - 6
6	1 - 6	14	1 - 8
	2 - 7		2 - 7
	3 - 5		3 - 5
	4 - 8		4 - 6
7	1 - 7	15	1 - 7
	2 - 6		2 - 8
	3 - 8		3 - 6
	4 - 5		4 - 5
8	1 - 6	16	1 - 8
	2 - 7		2 - 7
	3 - 8		3 - 6
	4 - 5		4 - 5

c. The 4 x 4 transfer matrix shall be in stripline, constructed in three layers with the top and bottom layers containing switches and drivers and the center layer containing only stripline RF conductors. A suggested 3-layer stripline layout for the matrix is shown in Figure B.K.

d. The final matrix design shall have in each path the same number and type of angular stripline bends or curves as are incorporated in any other path.

4. Insertion Loss: 2.2 dB maximum

5. Insertion Loss Variation:

   a. At a given frequency for any given 4 x 4 matrix, over all paths for all states the largest insertion loss shall not differ from the smallest insertion loss by more than 0.4 dB.

   b. At a given frequency the largest insertion loss of any matrix shall not differ from the largest insertion loss of any other matrix by more than 0.3 dB.

6. Insertion Phase Variation:

   a. At a given frequency for any given 4 x 4 matrix, over all paths for all states, the longest electrical path length shall not differ from the shortest electrical path length by more than eight degrees.

   b. At a given frequency the longest electrical path length of any other matrix by more than four degrees.

NOTE: Since this procurement is for only one unit the design must be amenable to large quantity production which will meet specifications 3.3 (5) (b) and 3.3 (6) (b).

7. Impedance: 50 ohms

8. VSWR: No terminal greater than 1.5 (when all other terminals are terminated with 50 ohms, VSWR 1.10).

9. Isolation: The power measured at any of the six terminals not designated as input or output shall be down by at least 30 dB from the power measured at the designated output terminals - for the input located at any input terminal and for any state of the 4 x 4 matrix.

10. Switching Characteristics:

   a. Switching Time: Total switching time shall not exceed 700 nanoseconds under all operating conditions required by this specification and under a single set of power supply voltage levels to be specified by the vendor. Total switching time to be measured from 90% of final level of pulse logic voltage applied at driver to 90% of the RF path change, including ringing.

   b. Switching Rate: Up to 40 kHz maximum

11. Control: The transfer matrix driver shall be designed to interface, over the entire temperature range, with TTL logic, wherein a 0 to 0.8 volts represents a logic "zero" and 2.5 to 5.0 volts represents a logic "one". In no case shall the logic source be required to sink more than 16 ma per control bit in the logic "zero" condition or to source more than 400 microamps per control bit in the logic "one" condition. The steady state current through the microwave switching diodes shall not be dependent on the current gain (beta) of any of the transistors in the transfer matrix driver circuit.

12. Number of Drivers: Four (one for each 2 x 2 switch module), integral with transfer matrix.

13. Diode Voltage Monitor: A lead shall be brought out from each diode to permit remote monitoring of diode condition. The driver shall be so designed that failure of one diode will be detectable on its own monitor lead and will not significantly change the voltage on the other three leads to that switch module.

14. RF Isolation: C-band energy on the transfer matrix control leads shall be down by at least 30 dB below the RF input signal under any test condition.

15. RFI: (Interference Control) The generation of radio frequency interference by the network and the vulnerability of the network to radio frequency interference shall be controlled within the limits of Specification MIL-I-6181D.

3.4 <u>Mechanical Requirements</u>:

1. Connectors:

RF input: SMA female, end launch
RF output: SMA male, end launch, model number to be approved by TSC
Control, Power, and Monitoring: Multi-pin con- such as ITT Cannon P/N MDB1-9SH001 with mating connector supplied.

2. Size: On-center distance between inputs and on-center distance between outputs shall be two inches. The inputs are all to be located on one side of the switch (shown as the left side in Figure B.L) and the outputs are all to be located on the opposite side of the switch (shown as the right side of Figure B.L). Thickness of entire board assembly shall be no greater than 1.75 inches. See Figure B.L.

3. Board Construction: Shall be on three boards (see Figure B.K) with feed-through right angle connections between them. Entire assembly must be within the required thickness dimension, and must meet the insertion loss, VSWR, and other requirements.

4. Mounting: Shall mount to a flat surface with 4-40 hardware.

5. Finish: Corrosion resistant. The assembly shall be suitably finished to prevent deterioration of the housing material over the operating and environmental conditions in the specification.

6. Cooling: The transfer matrix shall be designed to be cooled solely by natural convection.

7. Marking: All units shall have a label that contains at least the following information:

   1. Manufacturer's Name
   2. Model Number
   3. Serial Number
   4. TSC Contract Number
   5. Device Nomenclature

3.5 <u>Reliability:</u>

1. Required MTBF of 20,000 hours

2. As a minimum, the transfer matrix and driver shall be designed for continuous operation for a period of one year with no more than minor maintenance.

3.6 <u>Environmental Requirements</u>:

1. Temperature: -30°C to +70°C

2. Humidity: 0 to 100%

3. Salt Atmosphere: As encountered in coastal service

4. Altitude:

   Non-operating: Sea Level to 30,000 ft.
   Operating: Sea Level to 10,000 ft.

5. Shock (non-operating): 10g any direction

6. Vibration (non-operating): 10 to 55 cps with a 0.03 inch total excursion

7. General: Since condensation and salt-laden atmospheres are expected within the stated temperature range, the transfer matrix shall be capable of operating under these conditions.

3.7 Design Requirements:

1. The design approach shall be amenable to large quantity production.

2. The transfer matrix shall be so shielded that its performance is not degraded by the proximity of adjacent transfer matrices spaced on 2 inch centers.

4. Quality Assurance Provisions:

4.1 Temperature Cycling: Prior to final evaluations for obtaining test data required by this specification, the unit shall be temperature cycled by the manufacturer over the temperature extremes a minimum of two times with the unit soaked for a minimum of one (1) hour at each temperature extreme. The Government reserves the right to temperature cycle the unit between the temperature extremes for the soak times specified, at least 25 times in the course of a year after final delivery. The manufacturer shall guarantee that the unit will operate in conformance with the technical requirements of this Exhibit at the end of each or any cycling segment, or at any temperature within the extremes.

4.2 Tests: The following tests will be performed on the unit by the manufacturer at his facility in the presence of a TSC representative. (Written notice must be received by the TSC Technical Monitor at least seven (7) days prior to the date of the test. TSC reserves the right to not witness the tests.) All results of these tests shall be submitted, in a format agreed upon between TSC and the vendor, no later than the date of delivery of the completed unit. These tests will be performed over the specified temperature and RF power ranges and over a frequency range from 4.9 to 5.35 GHz at intervals of 50 MHz if swept frequency techniques are not used. Tests shall be performed with the unit in states 1, 4, 5, 8, 9, 12, 13 and 16 as a minimum (see Figure 2). Tests shall all be performed at 25°C and at the temperature extremes of -30°C and +70°C. If these data are taken using a computer controlled Network Analyzer, the vendor shall provide copies of all computer data obtained with delivery of the unit.

a. Isolation shall be measured in the following states with the following designated inputs: state 1-terminal 1, state 1-terminal 4, state 16-terminal 1, state 16-terminal 4.

b. Insertion loss of all paths in states 1, 4, 5, 8, 9, 12, 13 and 16

c. Insertion phase of all paths in states 1, 4, 5, 8, 9, 12, 13, and 16

d. VSWR of all ports (input and output) in states 1, 4, 5, 8, 9, 12, 13 and 16

e. Switching speed

4.3 Acceptance: The vendor shall guarantee all performance requirements of this specification. TSC will also perform tests to verify that the units meet the requirements of this specification. Final acceptance shall be made only after the satisfactory completion of these tests.

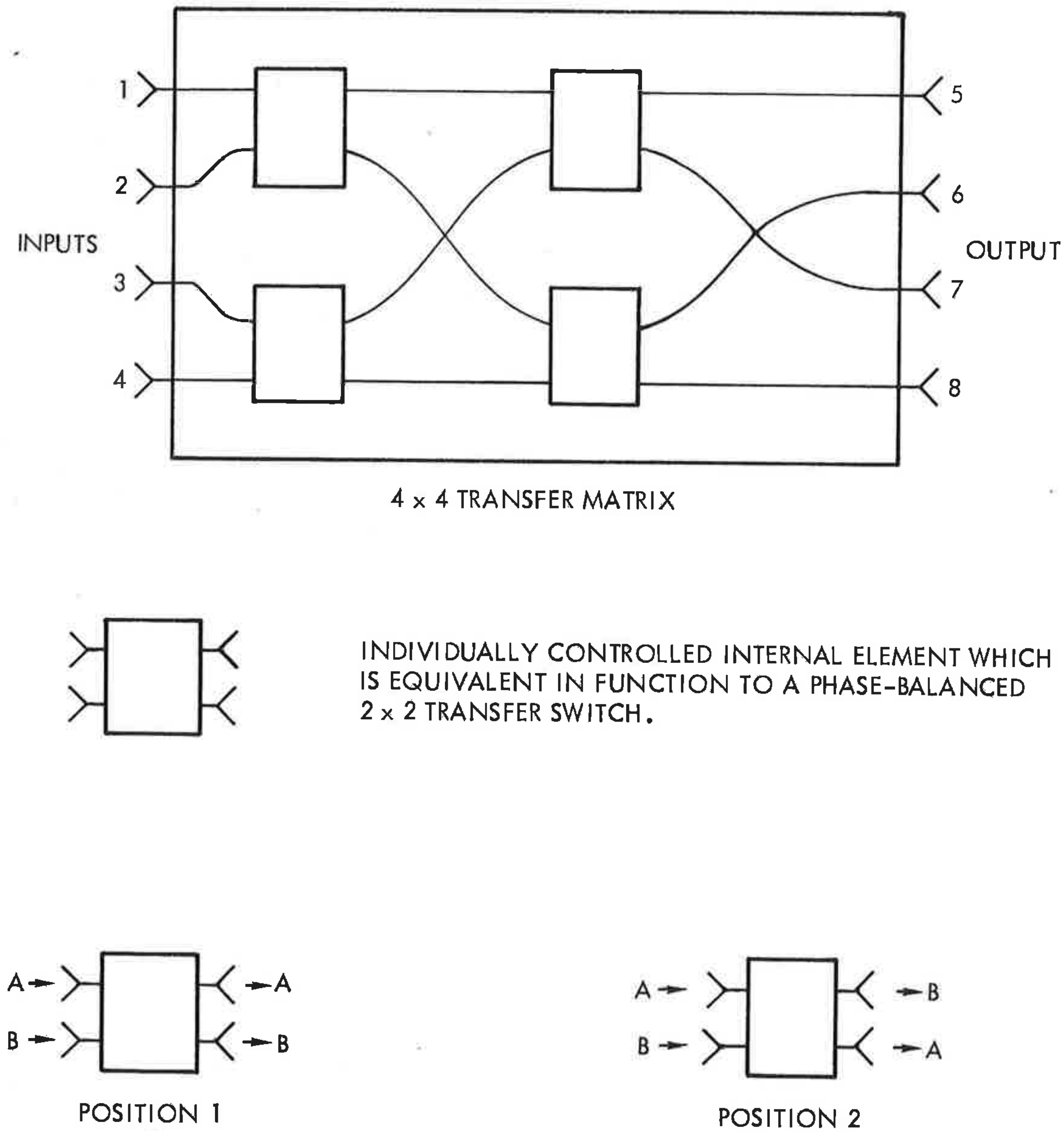


Figure B.I 4 x 4 Matrix Design - Routing

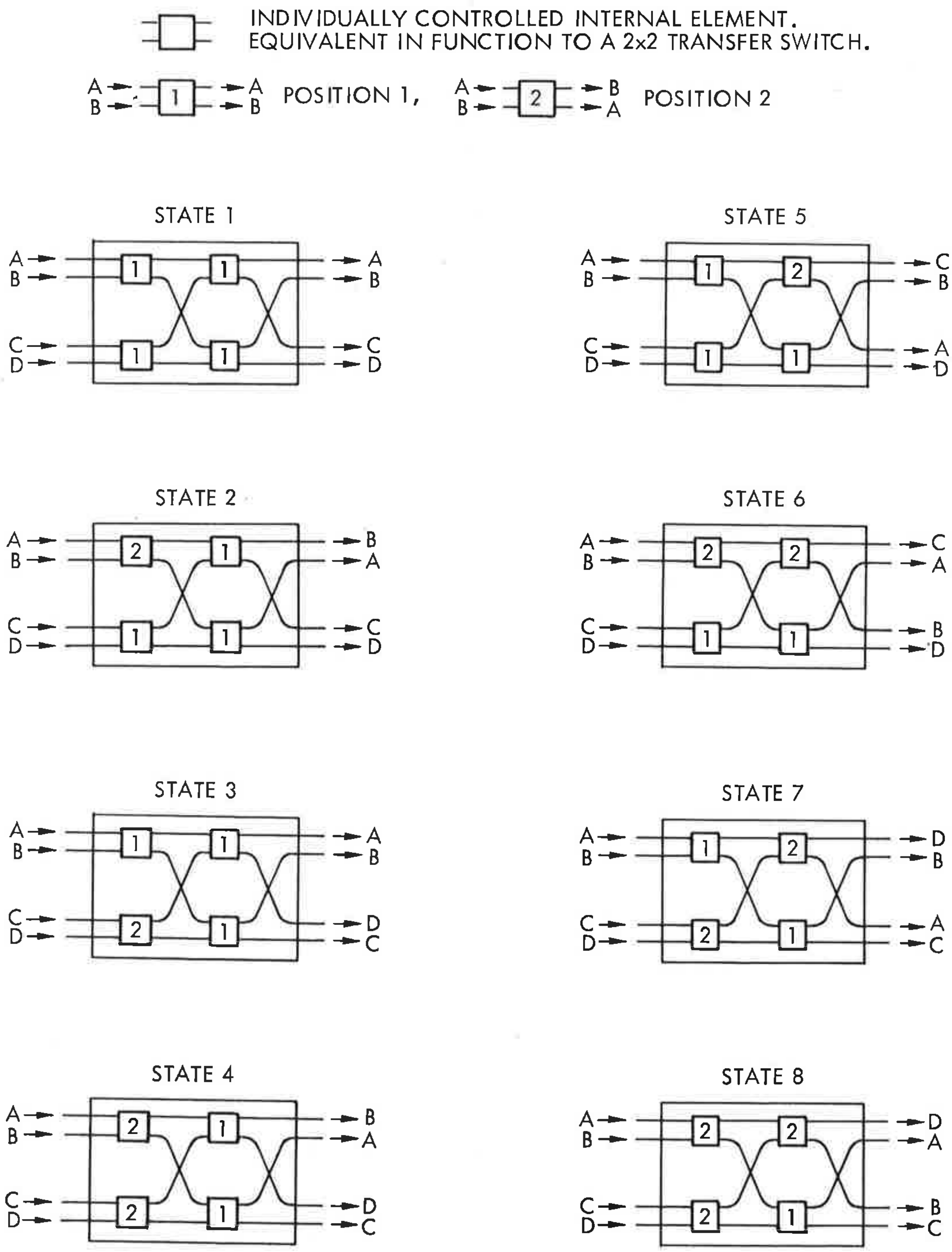


Figure B.J Diagram of Matrix States (Sheet 1 of 2)

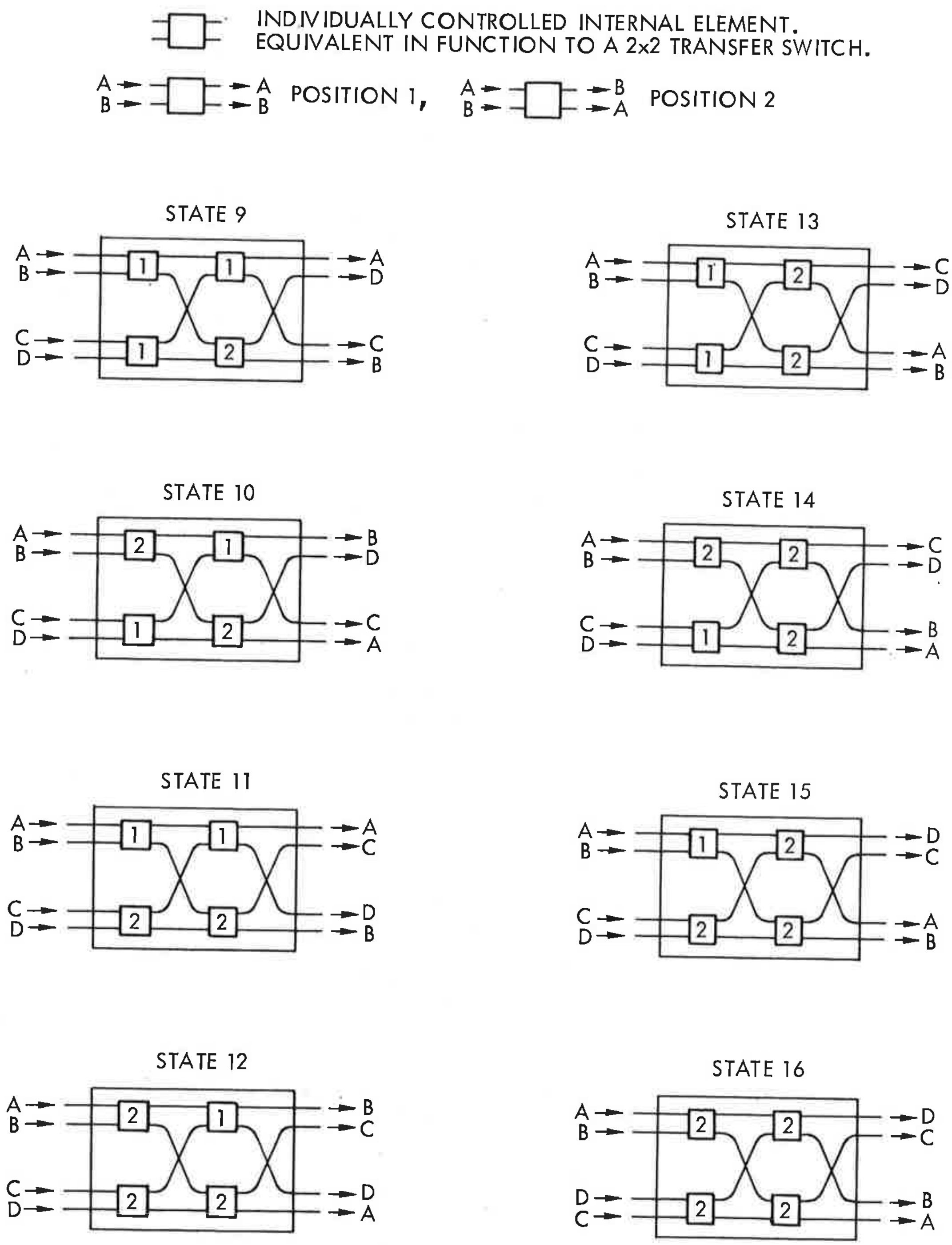


Figure B.J Diagram of Matrix States (Sheet 2 of 2)

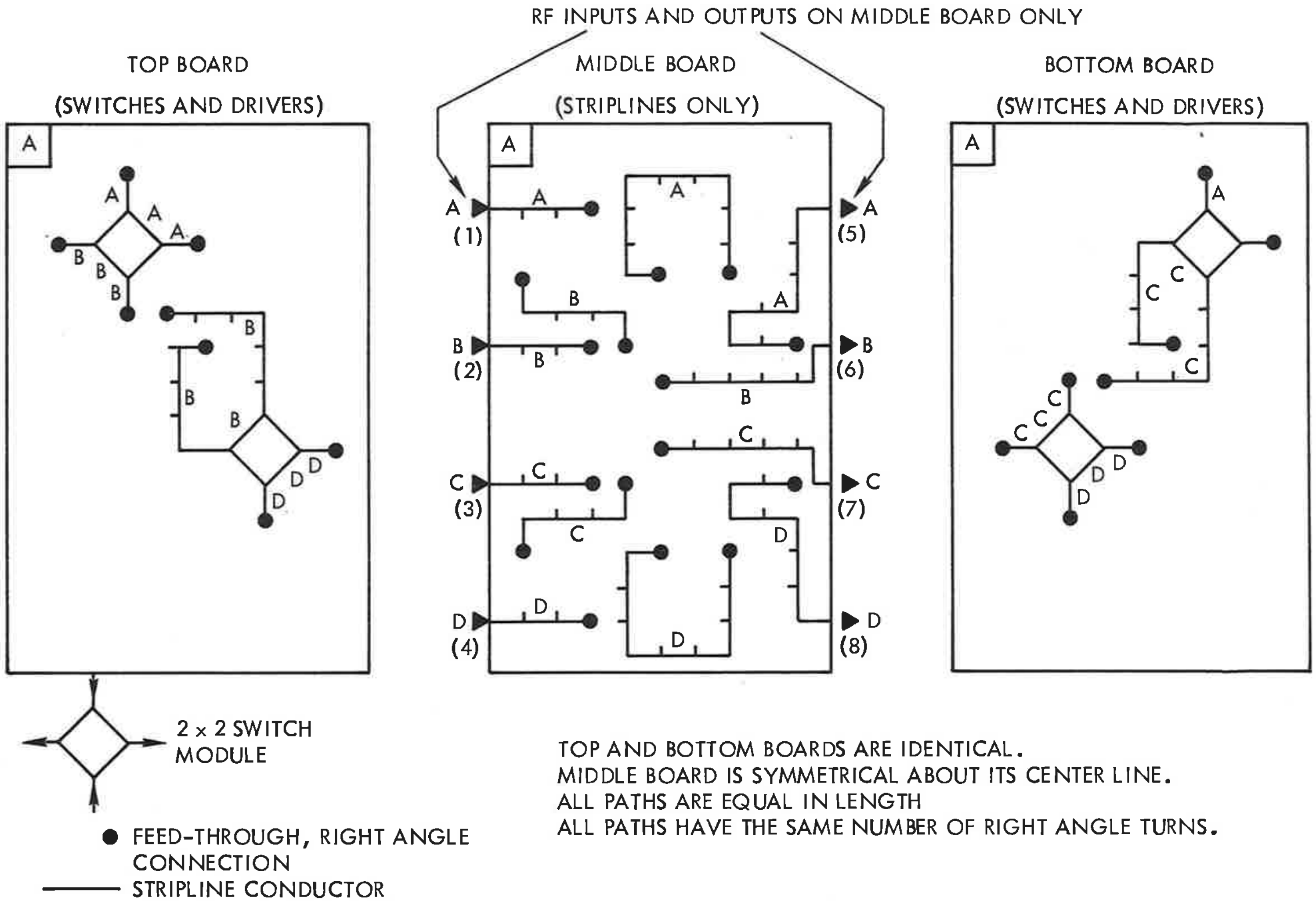


Figure B.K Suggested 3-Layer Stripline Layout for 4 x 4 Transfer Matrix

OVERALL DIMENSIONS OF 4 x 4 TRANSFER MATRIX

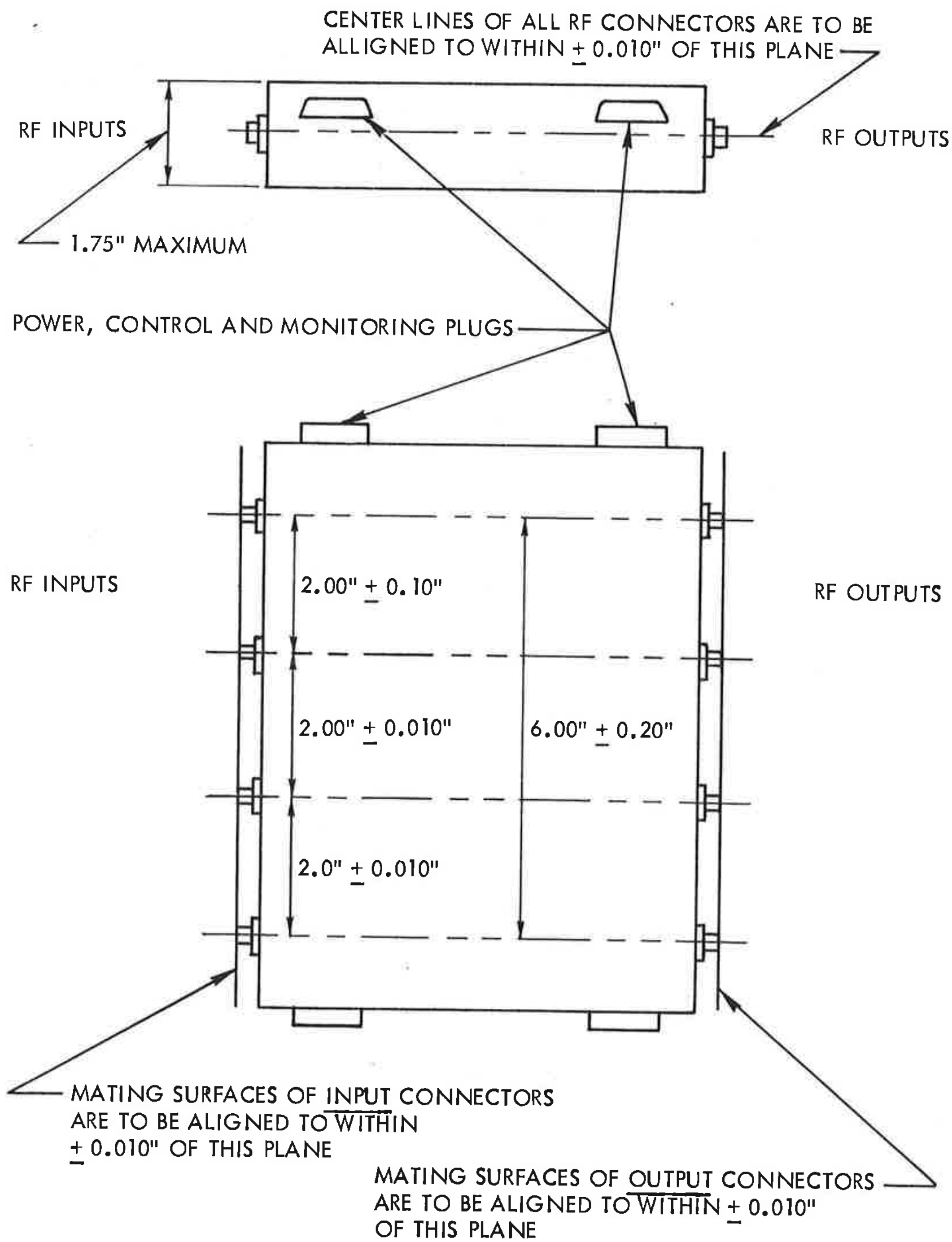


Figure B.L Overall Dimensions of 4 x 4 Transfer Matrix

TABLE B.11

Specification: Transmitter Crystal Oscillator

1. Electrical:

   1.1 Frequency: 108.125 MHz

   1.2 Frequency Stability over Temperature Range: 0.005%

   1.3 External Load: 50 ohms

   1.4 Power Output: 10 mw minimum

   1.5 Output Waveform: Sinewave

   1.6 Spurious Outputs: Harmonically related to be greater than 40 dB below signal level. Non-harmonically related to be greater than 50 dB below signal level.

   1.7 Input Voltage: +28 VDC ±1%

   1.8 Operating Temperature Range: -10°C to +60°C

2. Mechanical

   2.1 Size: 4 in. x 2 in. x 2 in. (L x W x H)

   2.2 Sealing: Hermetic

   2.3 Connectors: RF-SMA
   DC-Filtercon, Solder
   Ground-Solder terminal

TABLE B.12

Specification: Narrowband Times 48 Multiplier

1. Scope: The document defines the performance and data requirements for a X48 Amplifier-Multipler Assembly to be used to generate C-Band energy from amplitude (On/Off), frequency or frequency hopping modulated sources in the 100 Mhz frequency region, in accordance with the following specifications:

2. Applicable Documents:

   The following document forms a part of the technical requirements. In areas of conflict, the above specifications take precedence of the document listed below:

   MIL-I-6181D - Interference Control Requirements, Aircraft Equipment

3. Requirements

   3.1 Summary: This document defines the requirements for a X48 multiplier and associated test data.

   3.2 Drawing Applicability:

      1. The Contractor shall supply informal, non-proprietary block diagrams, parts list and assembly drawings suitable for engineering use and analyses.

      2. The Contractor shall supply an outline drawing of the amplifier multiplier within 30 days after receipt of order.

   3.3 Electrical Requirements:

      1. Operating Modes: CW, CW with narrow/wideband FM; up to 200 kHz, sequential frequency hopping, and pulsed.

      2. Output Frequency: 5190 $\pm$20 MHz min (instantaneous bandwidth)

      3. RF Power Output: 1 watt min

      4. Input Frequency: Output frequency/48

      5. RF Input Power: +10 dBm $\pm$3 dB

      6. Undesired Signal Levels: Output harmonics and signals related to the input frequency: > 40 dB below the fundamental C-band output

7. Broadband Noise: Not to exceed -60 dBm/MHz over the 5190 ±90 MHz frequency band. The noise shall roll off at least 6 dB/octave thereafter (5190 ±60 MHz shall be the reference bandwidth used).

8. Spurious Signals: Signals not related to the above shall be equal to or greater than 80 dB below the C-band output signal level.

9. Input Impedance: 50 ohms, VSWR < 1.5

10. Output Impedance (load): 50 ohms, VSWR < 2.0. The unit will not be damaged under "no load" operating conditions.

11. Power Source Requirements:

    a. Voltage: 28 ±0.5 VDC

    b. Current: < 1.3 amp, 500 ma desired

    c. The unit will not be damaged by operation from a power source voltage variation of 0 to 30 VDC. The unit will not exhibit any deterioration other than changes in output power and undesired signal levels when the power source voltage varied from 26 to 30 VDC. Undesired signal "break up", parasitic signals etc., will not be caused by such operation.

12. RFI: The generation of radio-frequency interference by the multiplier and the vulnerability of the multiplier to radio-frequency interference shall meet the limits of specification MIL-I-6181D.

3.4 Mechanical Requirements:

1. Connectors:

   RF, input/output: SMA female DC, Solder Terminal

2. Weight: < 5 lbs

3. Size: <150 cubic inches, excluding connectors

4. Mounting: The assembly shall hard mount to a flat surface with a surface tolerance of ±1/64 inch.

5. Finish: Corrosion resistant, the assembly will be suitable finished to prevent deterioration of the assembly housing material over the operating and environmental conditions called out in this specification.

6. Cooling: The unit shall be designed to be cooled by conduction to the mounting surface.

7. Marking: All units shall have a label that contains at least the following information:

   1. Manufacturer's Name
   2. Model No.
   3. Serial No.
   4. TSC Contract No.
   5. Device Nomenclature

3.5 Operational Effectiveness: The Contractor warrants the unit for a period of at least one year after final acceptance. Multiplier failures occurring during this period (when operated in accordance with this specification) shall be repaired by the vendor at no cost to the Government.

3.6 Environmental Requirements:

1. Ambient Temperature:

   a. Operational: -20°C to + 50°C, Mounting Surface Temp: -10°C to +60°C

   b. Degraded Performance: -30°C to -20°C and +50°C to +70°C

2. Humidity: 0 to 100%

3. Shock and Vibration: Must withstand normal handling procedures involved in shipment and laboratory work.

4. General: Condensation is expected within the temperature range of +70°C to -30°C. A salt laden moisture is to be considered. Sand, dust and wind loading are not directly applicable.

3.7 Design and Construction:

1. This specification is not intended to define the internal structure of the network. Any reasonable configuration is acceptable as long as overall specification is maintained, but efforts should be oriented to a minimal size where possible. The design approach shall be amenable to large quantity production. The design should feature modular construction and be readily maintainable by technicians skilled with these devices.

2. All components will be accessible, that is to say, potting will not be used, and components will not be epoxied in place, etc.

4. Quality Assurance Provisions:

4.1 Test Data:

1. The Contractor shall provide test data to show general specification compliance with paragraph (3) above.

2. Final Test Notification: The Contractor shall notify the Contracting Officer at least five (5) working days prior to the commencement of final tests.

TABLE B.13

Specification: Wideband Times 48 Multiplier

The specifications of this unit are the same as the narrow band unit given in Table B.13 except for the following:

3.3

2. Output Frequency: 5125 ±125 MHz Min (instantaneous bandwidth)

7. Broadband Noise: Not to exceed -60 dBm/MHz over the 5125 ± 125 MHz frequency band. The noise shall roll off at least 6 dB/octave thereafter (5125 ±125 MHz shall be the reference bandwidth used).

TABLE B.14

Specification: C-Band Impatt Amplifier

1. Scope: This document defines basic and minimal requirements for a C-band solid state Impatt Amplifier.

2. Electrical Requirements:

    1. Operating Mode: Unconditionally stable amplifier

    2. Frequency: 5.0 to 5.25 GHz, instantaneous bandwidth

    3. Output Power: 8 watts

    4. Input Power: 2 watts

    5. Gain: 6 dB

    6. Efficiency: 5%

    7. Noise Pedestal: From 5.0 to 5.25 GHz to be 60 dB below output signal

TABLE B.15

Specification: High Power C-Band Impatt Amplifier

1. Output Power: 16 watts minimum; 20 watts minimum design goal
2. Input Power: 2 watts maximum; 1.6 watts maximum design goal
3. Gain: 9 dB; 10 dB design goal
4. Bandwidth (1 dB points): 5.0 to 5.25 GHz; 4.9 to 5.35 GHz design goal
5. Parameter Optimization Frequency: 5.19 $\pm$0.02 GHz
6. Efficiency: 3.75% minimum; 5% design goal
7. Spurious:

   2nd Harmonic -- 40 dB down from maximum output signal level

   2nd Harmonic -- 60 dB down from maximum output signal level when a reduction of 0.25 dB is allocated for insertion loss of filtering

   Non-second Harmonic -- 60 dB down from maximum output signal level
8. Noise Pedestal: 60 dB down from the maximum output signal level
9. FM Noise: To be measured
10. AM Noise: To be measured
11. Ambient Operating Temperature Range: 0°C to +50°C; -30°C to +50°C design goal
12. Ambient Humidity: 0 to 95%; 0 to 100% design goal
13. DC Input Parameters: 100 volts maximum, 5 amps maximum
14. Reverse Polarity Protection: To be provided internally
15. Weight: Under 20 lbs

TABLE B.16

Specification: C-Band Mixer Preamplifier

1. Scope: This document defines the performance requirements for a mixer preamplifier to be used for the first down conversion in the Dynamic Performance Test Receiver.

2. Electrical Requirements:

   2.1 Input Frequency: 4 to 8 GHz min

   2.2 Noise Figure: 11 dB max

   2.3 IF Center Frequency: 410 MHz

   2.4 IF Bandwidth: 30 MHz min

   2.5 RF to IF Gain: 20 dB min

   2.6 Local Oscillator Power: 0 to +3 dBm min

   2.7 1 dB Compression Point: 0 dBm output min

   2.8 Supply Voltage: +12 VDC

3. Mechanical Requirements:

   3.1 RFI gasketing will be provided.

   3.2 Provisions for crystal current monitoring will be provided.

   3.3 Connectors:

   RF input/L.O. input-Type N female

   IF output-Type BNC female

4. Environmental Requirements

   4.1 Operating Temperature Range: -30°C to +70°C.

TABLE B.17

Specification: Linear IF Amplifier and Detector

1. Center Frequency: 30 MHz
2. Bandwidth: 4 MHz
3. Operating Temperature Range: -54°C to +71°C
4. MIL Spec Compliance: MIL-E-5400 and MIL-E-16400
5. MTBF: Greater than 25,000 hours
6. Rise Time: 0.25 microseconds
7. Gain to IF: 80 dB
8. Gain to Video: 90 dB
9. Noise Figure: 2.5 dB
10. 1 dB Compression: Greater than +15 dBm IF output into 50 ohms
11. VSWR: 1.5:1 into 50 ohms
12. Video Output: 5 volts into 93 ohms, emitter follower, direct coupled
13. AGC: Closed loop provision built in with AGC delay to establish desired output level. Compression ratio 60 dB input provides 3 dB output change. AGC may be disabled and MGC will provide 60 dB of manual control.
14. RFI Protection: Filtered power connector assembly and RFI gasketing
15. Power Requirements: +12 volts at 150ma (nom), -12 volts at 50ma (nom)
16. Recovery Time: 1 microsecond at 0 dBm input
17. Wide Range Linear Detector: Linear detected output of ± 0.5 dB with 30 dB input change
18. AGC Open Loop: 60 dB input range minimum with 0 to -5 VDC control. Response time to be 10 microseconds for 60 dB change.
19. Connectors: RF and Video connectors to be type BNC female

20. Compatibility: AGC input and output voltages must be compatible to provide AGC closed loop operation as provided by these specifications. Unit must be capable of pulse operation wherein the pulses are 15 microseconds minimum width.

21. Second Harmonic: With +10 dBm output power at the IF Output connector (30 MHz) the 60 MHz signal level shall be at least 30 dB down from the 30 MHz signal level.

TABLE B.18

Specification: UHF Local Oscillator

1. Frequency: 380 MHz

2. Settability: 0.0001% max

3. Stability: 0.0005% max over temperature and voltage variations per month

4. Frequency Trim Range: Sufficient to compensate for five years aging

5. Power Output: 10 milliwatts minimum

6. Load: Double-balanced mixer (50 ohms nominal)

7. Output Waveform: Sinewave

8. Spurious and Harmonic Content: 40 dB minimum below the output specified in (5) above

9. RF Connector: SMA or equivalent

10. D.C. leads will be filtered with miniature RFI filters.

11. Power Source: ±12 VDC available (±2% regulation)

12. Power Available: 3 watts max

13. Size: 2 in. X 2 in. X 4 in. nominal

14. Temperature: -10°C to +60°C

15. Shock and Vibration: Must withstand normal handling in a laboratory environment. Must be able to withstand 50 to 500 Hz at 10 G.

16. Design and Construction: The oscillator shall use fungus non-nutrient materials. The assembly shall be capable of disassembly with small standard tools. The unit shall not be hermetically sealed.

17. Drawings: An outline drawing and a schematic diagram of the oscillator shall be delivered to the government within 30 days ARO.

18. Operational Effectiveness: The Contractor shall guarantee the unit for a period of at least one year after final acceptance. Failures occurring during this period (when the oscillator is operated in accordance with this specification) shall be repaired by the Contractor at no cost to the Government.

TABLE B.19

Specification: C-Band Local Oscillator Assembly

1. Scope: This document defines the technical requirements of a C-band local oscillator assembly used in the Dynamic Performance Test Receiver. The VHF Crystal Oscillator is described in paragraph 2 and the C-band times 64 multiplier is described in paragraphs 3 and 4.

2. VHF Crystal Oscillator Requirements:

   2.1 Frequency: 74.68750 MHz

   2.2 Settability: 0.0001% max

   2.3 Stability: 0.0005% per month (including temperature and voltage variations)

   2.4 Frequency Trim Range: Sufficient to compensate for five years aging

   2.5 Power Output: One milliwatt min, into 50 ohms

   2.6 Harmonic Output: 40 dB minimum below the output specified in (2.5) above

   2.7 Output Waveform: Sinewave

   2.8 RF Connector: SMA

   2.9 D.C. leads shall be filtered with miniature RFI filters.

   2.10 Power Source: ±12 VDC (±2% regulation)

   2.11 Power Available: 2 watts max

   2.12 Size: 1.5 in. X 1.5 in. X 3 3/4 in. nominal

   2.13 Temperature: -10°C to +60°C

   2.14 Vibration: Shall operate to specification over 50 to 500 Hz at 10 G.

   2.15 Design and Construction: The oscillator shall use fungus non-nutrient materials. The assembly shall be capable of disassembly with standard small tools. The unit shall not be hermetically sealed.

   2.16 Drawings: An outline drawing and schematic diagram of the oscillator shall be delivered to the Government within 30 days ARO.

2.17 Operational Effectiveness: The Contractor shall guarantee the unit for a period of at least one year after final acceptance. Failures occurring during this period (when the oscillator is operated in accordance with this specification) shall be repaired by the Contractor at no cost to the Government.

3. C-Band Times 64 Multiplier:

3.1 Frequency Output: 4.76 to 4.80 GHz

3.2 Frequency Input: Frequency output/64

3.3 Output Power: +7 dBm minimum, +13 dBm maximum

3.4 Output Power Variation: 4 dB maximum

3.5 Input Power: 0 dBm ±1 dB

3.6 Input Impedance: 50 ohms; VSWR, 1.5 maximum

3.7 Output Impedance: 50 ohms; VSWR, 2.0 maximum

The unit will not be damaged under "no-load" operating conditions.

3.8 Undesired Discrete Signal Levels:

a. 30 dB Minimum: Below the desired C-band output signal, for output harmonics and signals related to the input frequency.

b. 60 dB Minimum: Below the desired C-band output signal, for any spurious signal not included in (a) above.

3.9 Broadband Noise: The multiplier assembly when used as a local oscillator shall not degrade the noise figure of a C-band receiver by more than one half dB from that receiver noise figure obtained using a C-band signal generator (Hewlett Packard model 618C, or equivalent) for the local oscillator.

The test receiver shall have a SSB noise figure of 8 dB nominally and utilize an IF of approximately 400 MHz.

3.10 Power Source:

a. Voltage: Plus and minus 12 VDC available

b. Power: 3 watts maximum

c. The unit will not be damaged by operation from a power source with a voltage variation of 0 to 20 VDC for both positive and negative supply voltages.

d. Signal break-up: Parasitic signal generation will not be caused when the multiplier is operated from plus and minus voltages over the range of 10 to 14 VDC.

3.11 Warm-up Time: The assembly shall meet the requirements of this specification within five seconds after application of DC voltages and RF drive.

3.12 Connectors:

a. RF input/output: SMA female

b. DC: Solder terminal(s)

3.13 Size: 20 cubic inches maximum

3.14 Weight: One pound maximum

3.15 Mounting: The assembly shall hard mount to a flat surface with a surface tolerance of $\pm 1/64$ in.

3.16 Finish: Corrosion resistant, the assembly will be suitably finished to prevent deterioration of the assembly housing material over the operating and environmental conditions specified herein.

3.17 Cooling: The unit shall be designed to be conduction cooled to the mounting surface.

3.18 Marking: The unit shall have a label that contains at least the following information:

a. Contractor Name
b. Model Number
c. Serial Number
d. TSC Contract Number
e. Device Nomenclature

3.19 Operational Effectiveness: The Contractor shall guarantee unit performance for a period of at least one year after final acceptance. Multiplier failures occurring during this period (when operated in accordance with this specification) shall be repaired by the Contractor at no cost to the Government.

4. Quality Assurance Provisions

4.1 Test Data: The Contractor shall provide test data to show general specification compliance with this specification.

4.2 Final Test Notification: The Contractor shall notify the contracting officer at least five (5) days prior to the commencement of final tests.

TABLE B.20 DIGITALLY CONTROLLED, CONSTANT PHASE ATTENUATOR, COMPARISON OF INSERTION LOSS AND MAXIMUM 3-BIT ATTENUATION AT ROOM AMBIENT AND TEMPERATURE EXTREMES

	+25°C	-30°C	+70°C	+25°C	-30°C	+70°C
15654	0.9	0.7	1.3	9.4	9.8	9.5
15655	0.9	0.8	1.1	9.5	9.8	9.8
15656	0.9	0.8	1.1	9.7	10.1	9.8
15657	0.9	0.7	1.2	9.4	9.7	9.4
15658	0.7	0.6	1.0	9.8	10.3	9.8
15659	1.0	0.9	1.3	9.6	10.0	9.6
15660	0.9	0.8	1.2	9.9	10.3	10.0
15661	1.0	0.8	1.3	9.7	10.1	9.7
15062	0.9	0.8	1.2	9.7	10.0	9.7
15663	1.0	1.1	1.3	9.9	10.3	9.8
15664	0.9	0.7	1.0	9.6	10.1	9.7
15665	0.8	0.7	1.1	9.5	9.6	9.7
15666	1.1	1.3	1.4	9.7	10.0	9.8
15667	1.0	0.8	1.2	9.8	10.0	10.0
15668	1.0	0.8	1.2	9.5	9.7	9.8
15669	1.0	1.0	1.3	9.7	9.7	9.8
15670	1.0	1.0	1.3	9.6	10.0	9.7
15671	1.1	0.9	1.4	9.8	10.4	9.7
15672	1.0	0.8	1.3	9.6	10.0	9.8
15673	1.1	0.9	1.2	9.5	9.8	9.7
15674	1.0	0.8	1.1	9.7	9.9	9.7
15675	1.1	1.3	1.2	9.6	10.0	9.8
15676	1.1	0.8	1.2	9.5	10.0	9.5
15677	1.1	0.8	1.2	9.8	10.2	9.9
15678	1.1	0.9	1.3	9.6	10.0	9.7
15679	1.1	0.8	1.2	9.4	9.8	9.6
SPEC	$1.2 {}^{+0.0}_{-0.3}$	$1.2 {}^{+0.0}_{-0.3}$	$1.2 {}^{+0.0}_{-0.3}$	9.8 ± 0.49	9.8 ± 0.49	9.8 ± 0.49
AVG	0.98	0.86	1.21	9.64	9.9	9.731
MEAN	0.9	0.95	1.2	9.65	10.0	9.7

f = 5.1 GHz

TABLE B.21 COMPARISONS OF DIGITAL ATTENUATOR ATTENUATION AND PHASE AT LOW AND HIGH POWER AT 5.1 GHz, AMPLITUDE PERFORMANCE

	SN 15659		SN 15661		SPECIFICATION	
NOM ATTEN	IL at -20 dBm	IL at +27 dBm	IL at -20 dBm	IL at +27 dBm	LIMIT, dB	TOL, dB
IL Level	1.0	1.1	1.0	1.1	1.2	+0.0,-0.3
0 REF level	0.0	0.0	0.0	0.0	-	-
1.4 dB	1.4	1.5	1.4	1.5	1.4	±0.2
2.8 dB	2.8	2.9	2.7	2.8	2.8	±0.2
4.2 dB	4.3	4.4	4.1	4.2	4.2	±0.2
5.6 dB	5.7	5.7	5.5	5.5	5.6	±0.28
7.0 dB	7.0	7.0	7.1	7.1	7.0	±0.35
8.4 dB	8.2	8.2	8.5	8.5	8.4	±0.42
9.8 dB	9.6	9.6	9.7	9.7	9.8	±0.49

Phase Performance:

No Change on Either Unit at -20, +24, and +27 dBm

TABLE B.22 DIGITALLY CONTROLLED CONSTANT PHASE ATTENUATOR, INSERTION PHASE CHARACTERISTICS

SN	Rel. phase, deg at +25°C	Rel. phase, deg at -30°C	Rel. phase, deg at +70°C	$\Delta\phi$
15654	+1.1	+1.5	-0.1	1.6
15655	+2.2	+3.1	+2.6	1.4
15656	+1.6	-0.6	+2.5	3.1
15657	-1.0	-1.3	-3.4	2.4
15658	-0.5	-2.6	-0.1	2.5
15659	-1.2	-2.2	-1.9	1.0
15660	-0.3	-1.8	+1.2	3.0
15661	-1.8	-2.9	-0.4	2.5
15662	+1.1	-1.0	+2.1	3.1
15663	-3.4	-5.6	-3.0	2.6
15664	+0.3	+0.7	+3.7	3.4
15665	-4.8	-4.7	-3.7	1.1
15666	-1.6	+1.6	0	3.2
15667	-2.7	+0.1	-1.7	2.8
15668	-4.4	-4.2	-2.6	1.8
15669	-4.4	-3.2	-4.7	1.5
15670	-1.1	+3.9	-1.8	5.0
15671	-1.0	-2.0	-2.5	1.5
15672	-2.2	+3.0	-1.8	5.2
15673	-2.0	+0.1	-1.6	1.9
15674	-1.9	+1.4	-2.2	3.6
15675	-1.5	+2.2	-1.3	3.7
15676	-4.7	-2.2	-3.9	2.5
15677	-1.7	+1.2	-1.0	2.9
15678	-5.2	-2.3	-7.9	5.6
15679	-0.8	+2.9	-0.6	3.7
Max Δ Ins. Phase (T = Const.)	7.4	9.5	11.6	2.6 average
Ins Phase RMS	2.55	2.73	2.80	

TABLE B.23 RMS PHASE DEVIATIONS AT 5.1GHz OVER ALL SETTINGS OF EACH DIGITAL ATTENUATOR AT ROOM AMBIENT AND TEMPERATURE EXTREMES

	RMS Phase Deviations		
SN	T = +25°C	T = -30°C	T = +70°C
15654	1.12	2.80	0.85
15655	1.01	2.45	0.95
15656	1.19	2.24	1.14
15657	1.41	2.80	1.07
15658	0.87	1.89	0.75
15659	0.79	1.42	0.53
15660	1.85	2.71	2.04
15661	0.40	0.63	0.71
15662	1.32	1.35	1.56
15663	0.67	0.84	0.69
15664	0.58	2.74	0.63
15665	1.11	2.41	1.66
15666	0.70	2.80	0.89
15667	1.16	2.84	1.14
15668	0.37	1.06	0.48
15669	0.95	1.61	0.75
15670	0.99	3.25	0.79
15671	1.42	2.88	1.23
15672	1.55	4.08	1.25
15673	0.71	2.11	0.66
15674	0.34	1.74	0.40
15675	0.74	3.03	0.78
15676	0.39	1.95	0.63
15677	0.76	2.53	0.67
15678	1.16	3.46	0.79
15679	1.13	2.97	0.96

TABLE B.24 PHASE SHIFTER DATA FORMAT SUPPLIED BY MANUFACTURER

Unit 5851-10
Freq 5125

Bias State	Phase Shift	Inser Loss	VSWR In	Phase Delta
1	.0	1.39	1.29	.00
2	-20.8	1.33	1.27	1.70
3	-46.8	1.33	1.29	-1.75
4	-67.5	1.32	1.25	.00
5	-91.9	1.34	1.08	-1.86
6	-112.7	1.37	1.11	-.22
7	-140.3	1.45	1.34	-5.29
8	-161.3	1.44	1.33	-3.78
9	-177.3	1.54	1.42	2.72
10	-198.1	1.48	1.39	4.37
11	-224.0	1.44	1.29	.96
12	-244.9	1.44	1.26	2.60
13	-268.7	1.33	1.09	1.27
14	-289.7	1.34	1.06	2.81
15	-316.9	1.36	1.13	-1.87
16	-337.9	1.34	1.13	-.36
	AVG=	1.39	1.23	.09
	MAX=	1.54	1.42	5.29

Avg. Delta Mag. 2.10
Insertion Phase -98.94

TABLE B.25 RMS PHASE ERRORS OF 35 PHASE SHIFTERS AT RANDOM FREQUENCIES

Unit S/N	Freq GHz	RMS Phase Degrees
001	5.00	2.23
009	5.05	2.55
010	5.10	2.82
013	5.125	5.75
014	5.15	2.69
015	5.20	3.93
016	5.25	3.04
020	5.00	3.04
022	5.05	2.41
026	5.10	5.56
028	5.125	3.35
025	5.15	2.32
029	5.20	3.10
017	5.25	2.54
033	5.00	2.57
035	5.05	2.81
007	5.10	4.22
018	5.125	2.95
023	5.15	5.16
024	5.20	3.62
030	5.25	4.45
031	5.00	1.30
032	5.05	4.48
034	5.10	3.91
036	5.125	2.78
130	5.15	2.60
027	5.20	2.67
005	5.25	4.17
126	5.00	4.53
004	5.05	4.92
002	5.10	3.14
011	5.125	2.25
012	5.15	4.19
019	5.20	2.39
006	5.25	4.39

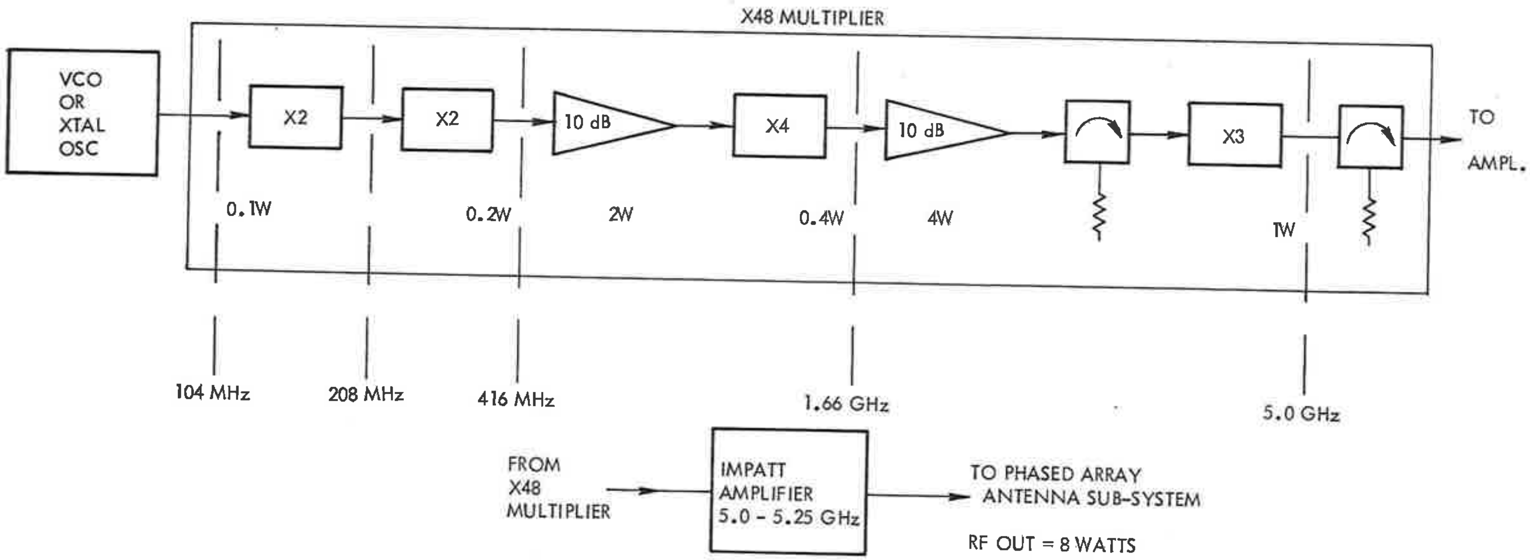


Figure B.1 8-Watt C-Band Solid State Transmitter Subassembly

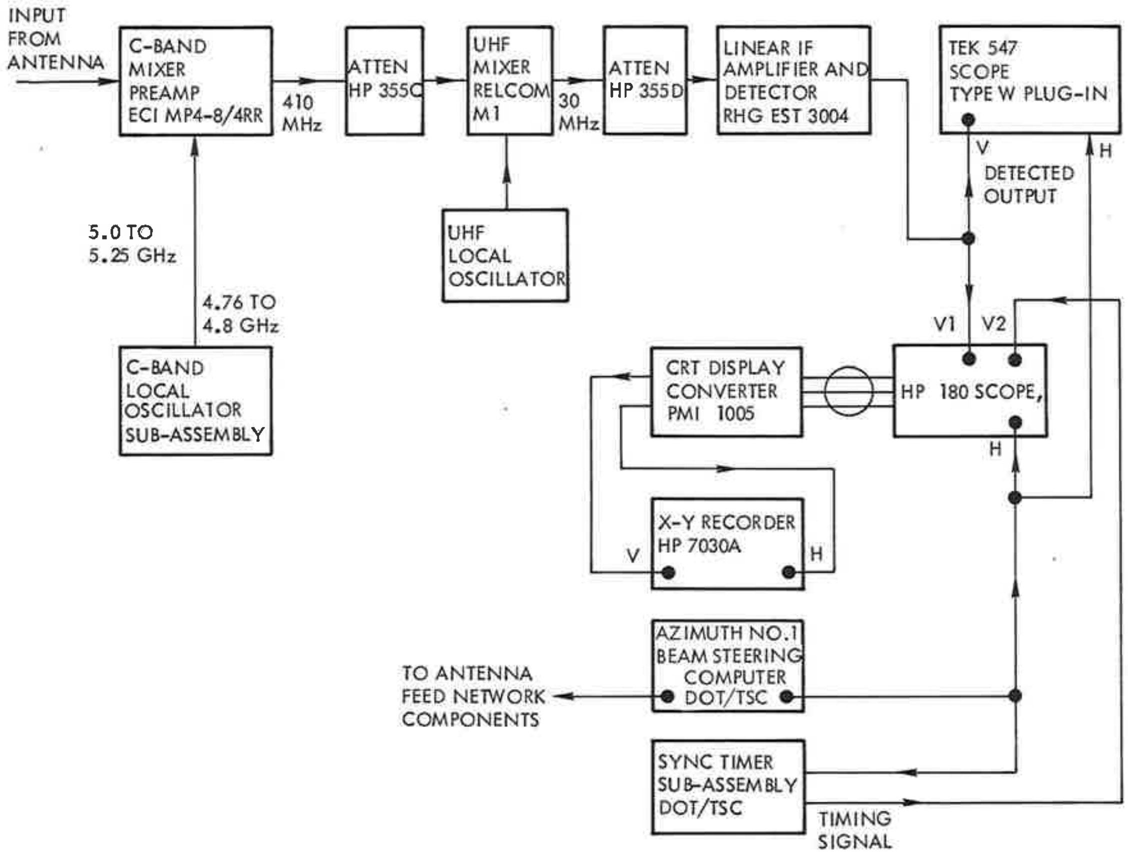
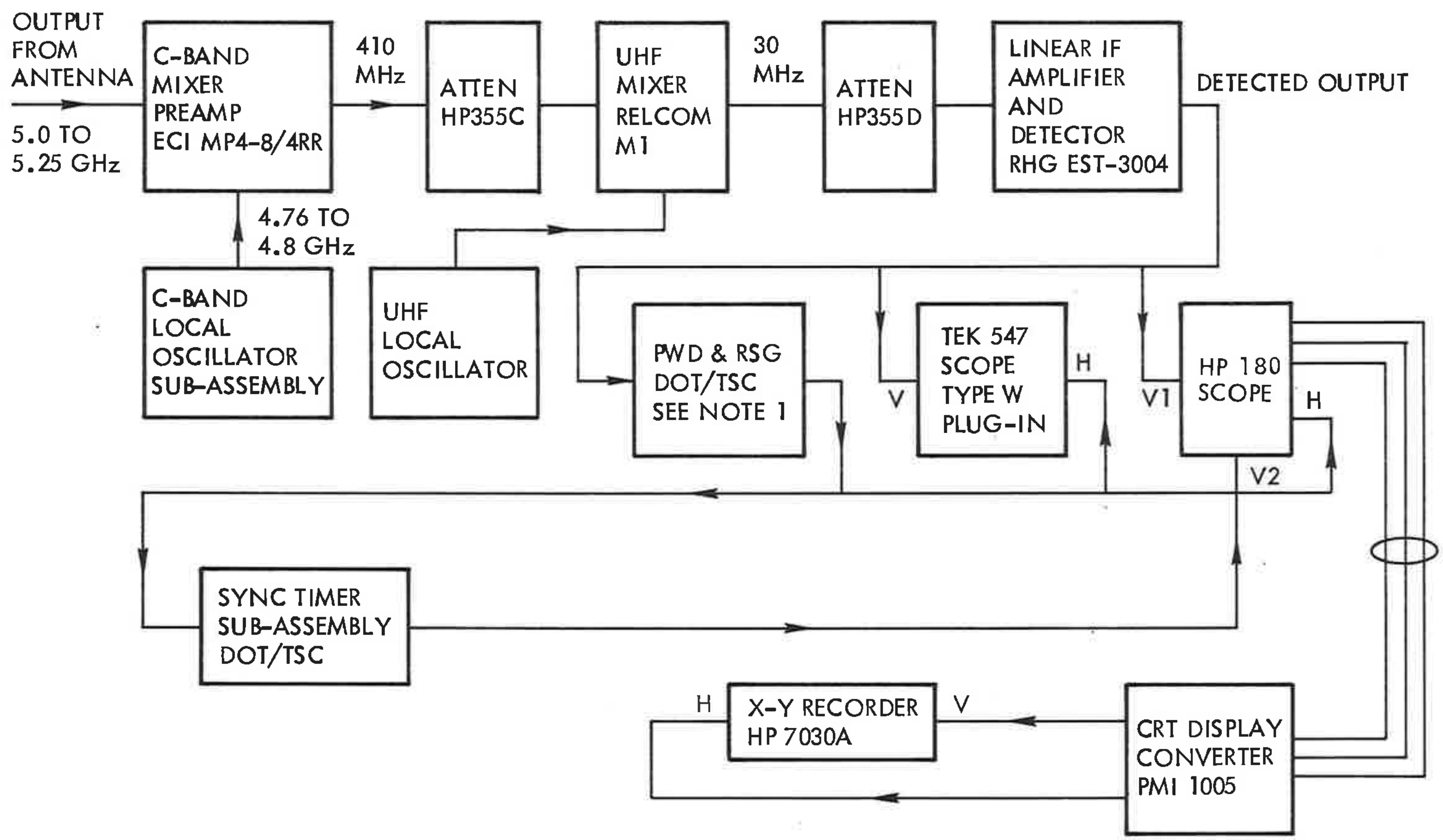


Figure B.2 Block Diagram-Azimuth No. 1
Dynamic Performance Test Receiver



NOTE: 1. PWD & RSG IS THE PULSE WIDTH DISCRIMINATOR AND RECEIVER SYNC GENERATOR DESIGNED AND BUILD AT DOT/TSC. IT IS REQUIRED BECAUSE THE BEAM STEERING COMPUTER IS AT THE TRANSMITTER END OF THE RANGE. IT IS USED TO RECOGNIZE THE OMNI SYNC SIGNAL AND THEN GENERATE A SYNC SIGNAL FOR THE SCOPES AND THE SYNC TIMER SUB-ASSEMBLY.

Figure B.3 Block Diagram-Azimuth No. 2
Dynamic Performance Test Receiver

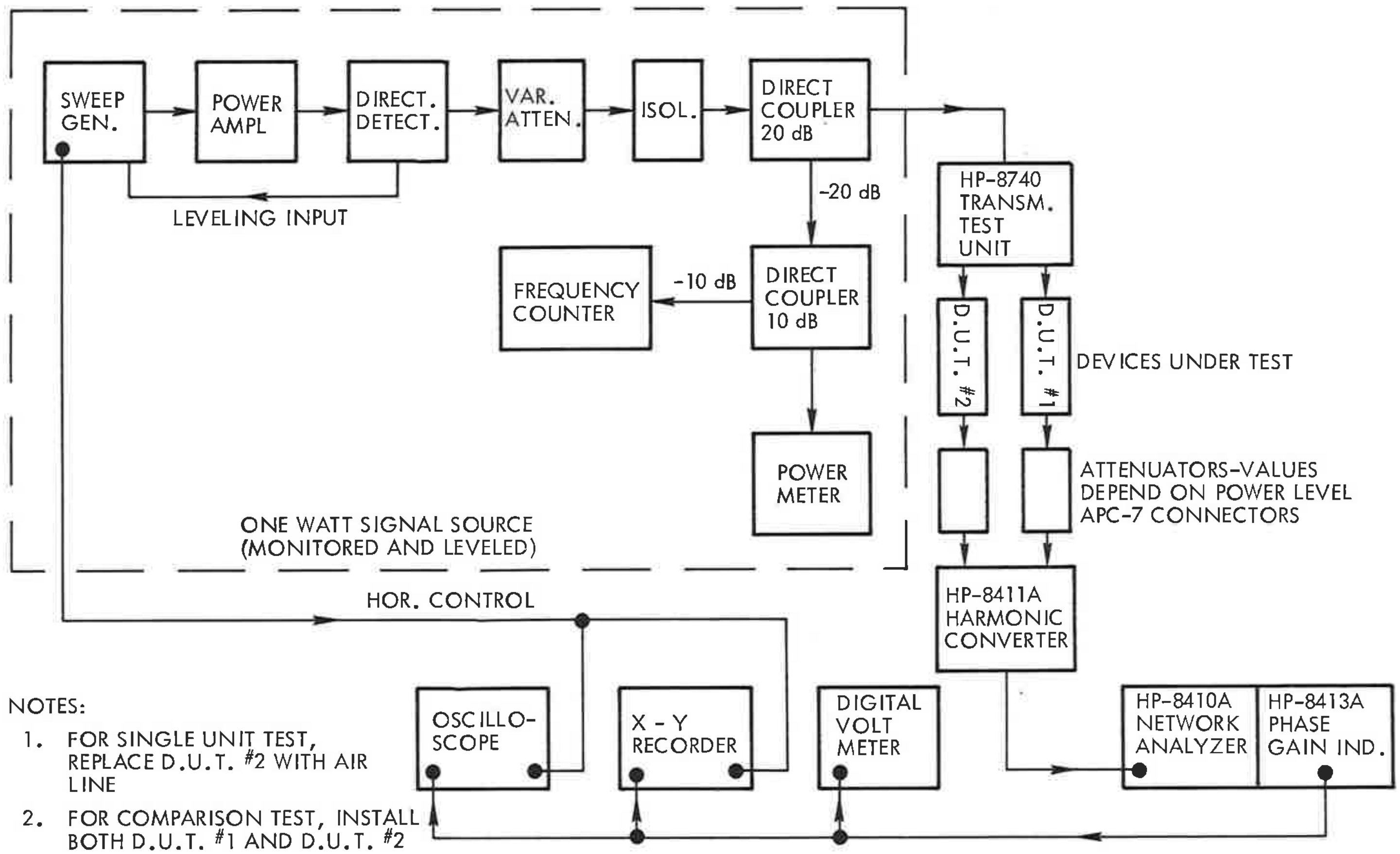


Figure B.4 Block Diagram - Insertion Loss and Isolation Measurements, Amplitude and Phase

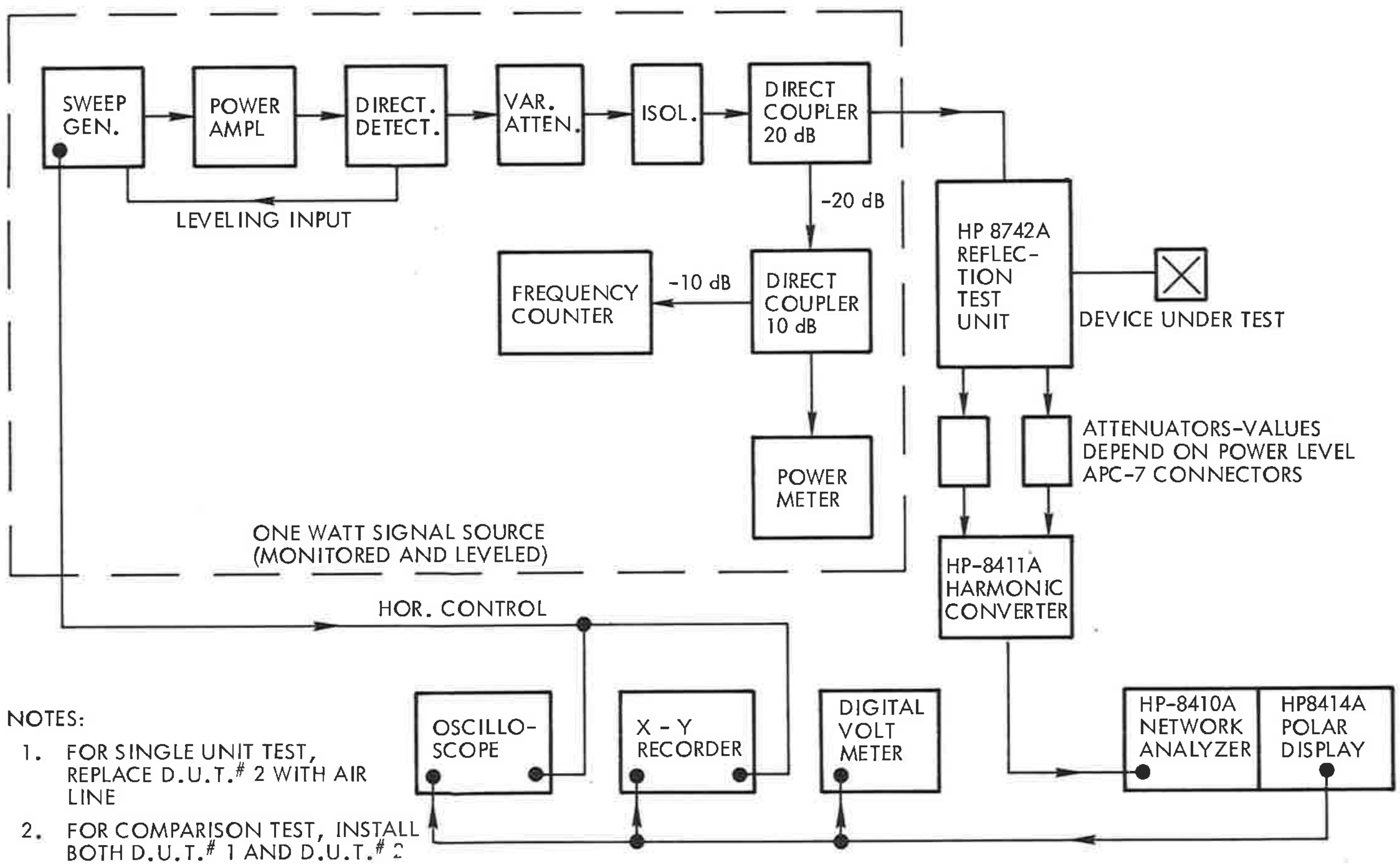


Figure B.5 Block Diagram - Reflection Coefficient Measurement, Amplitude and Phase

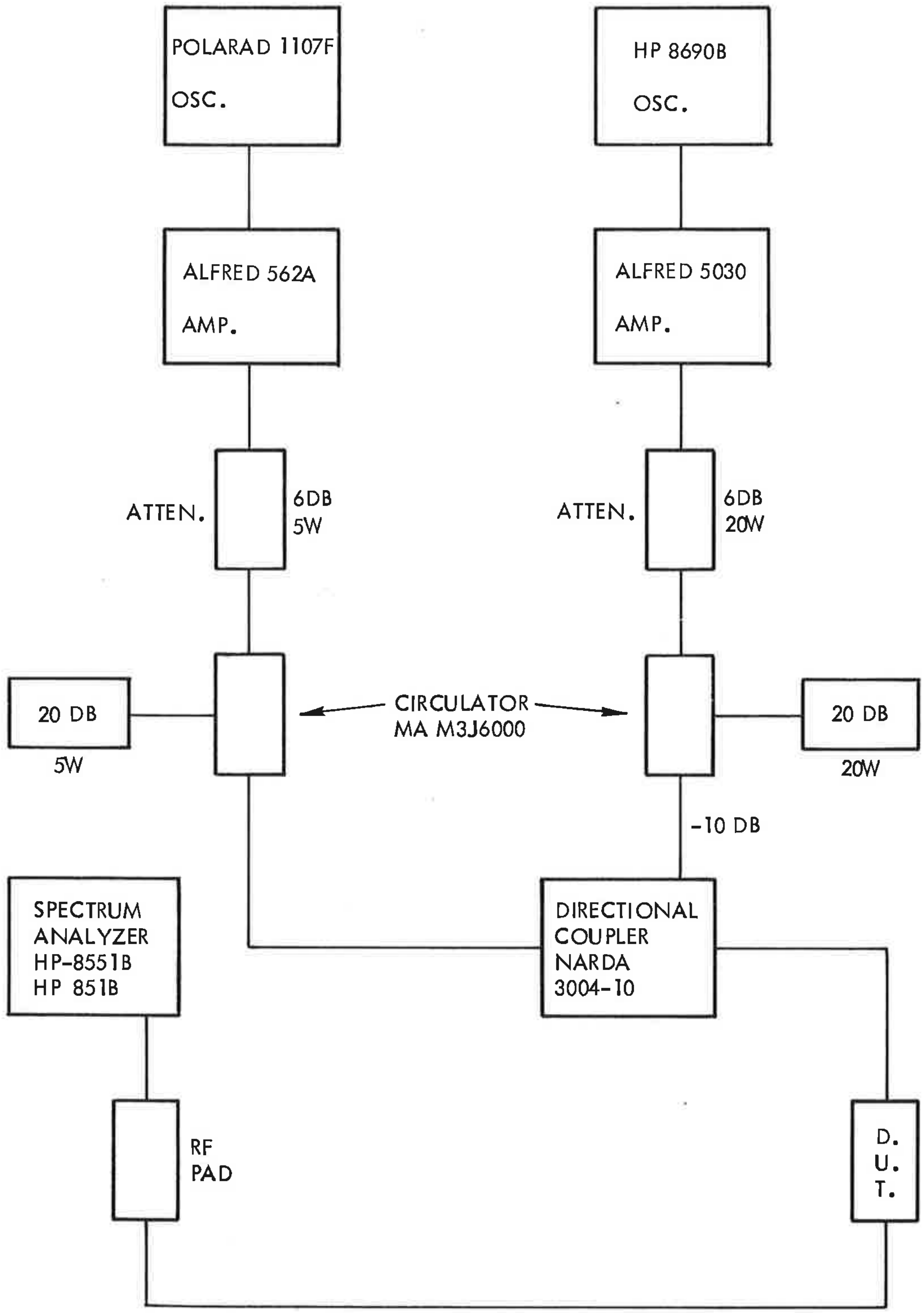


Figure B.6 Block Diagram - Spurious and Inter-modulation Products Measurements

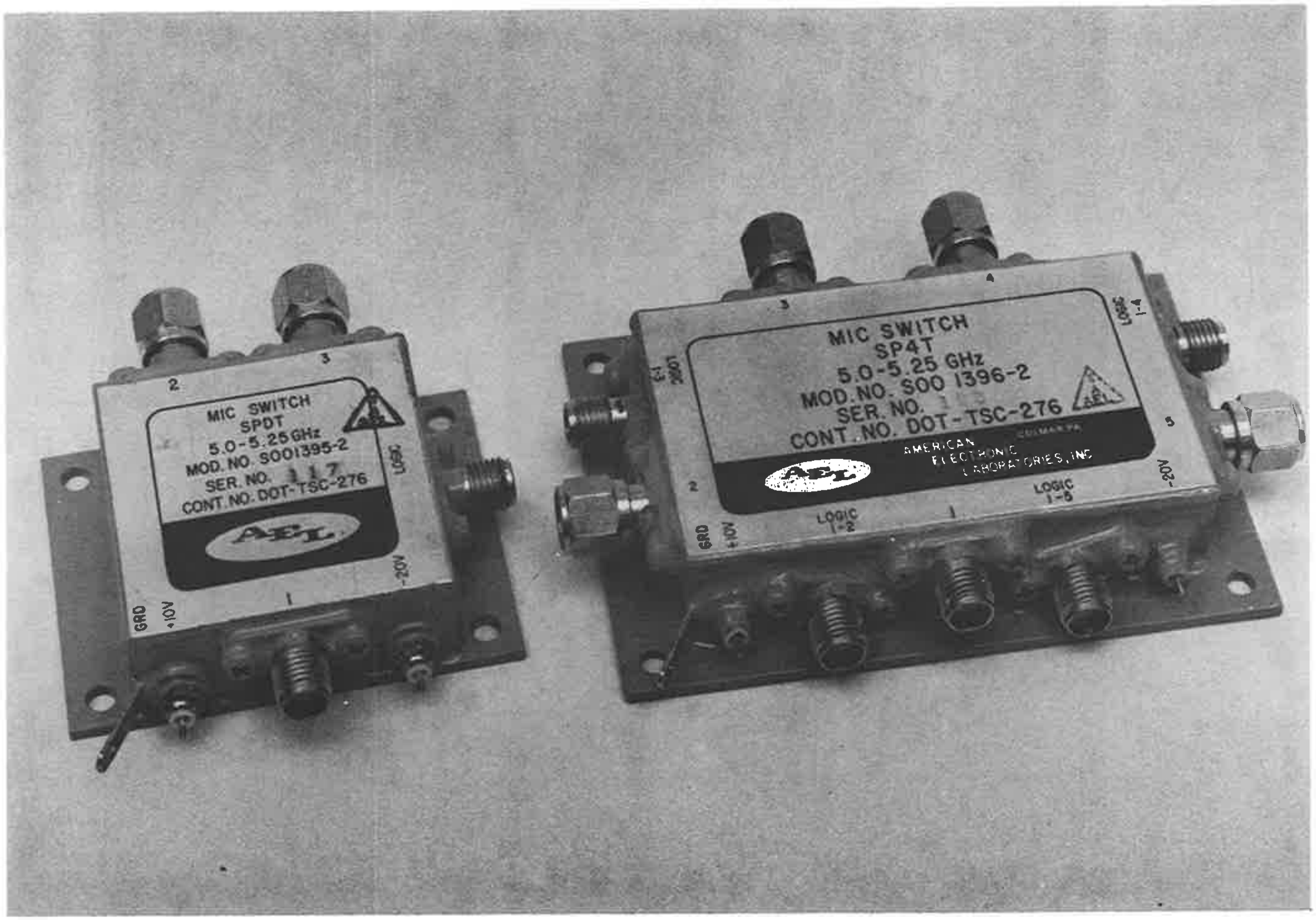


Figure B.7 Photograph of SPDT and SP4T Switches

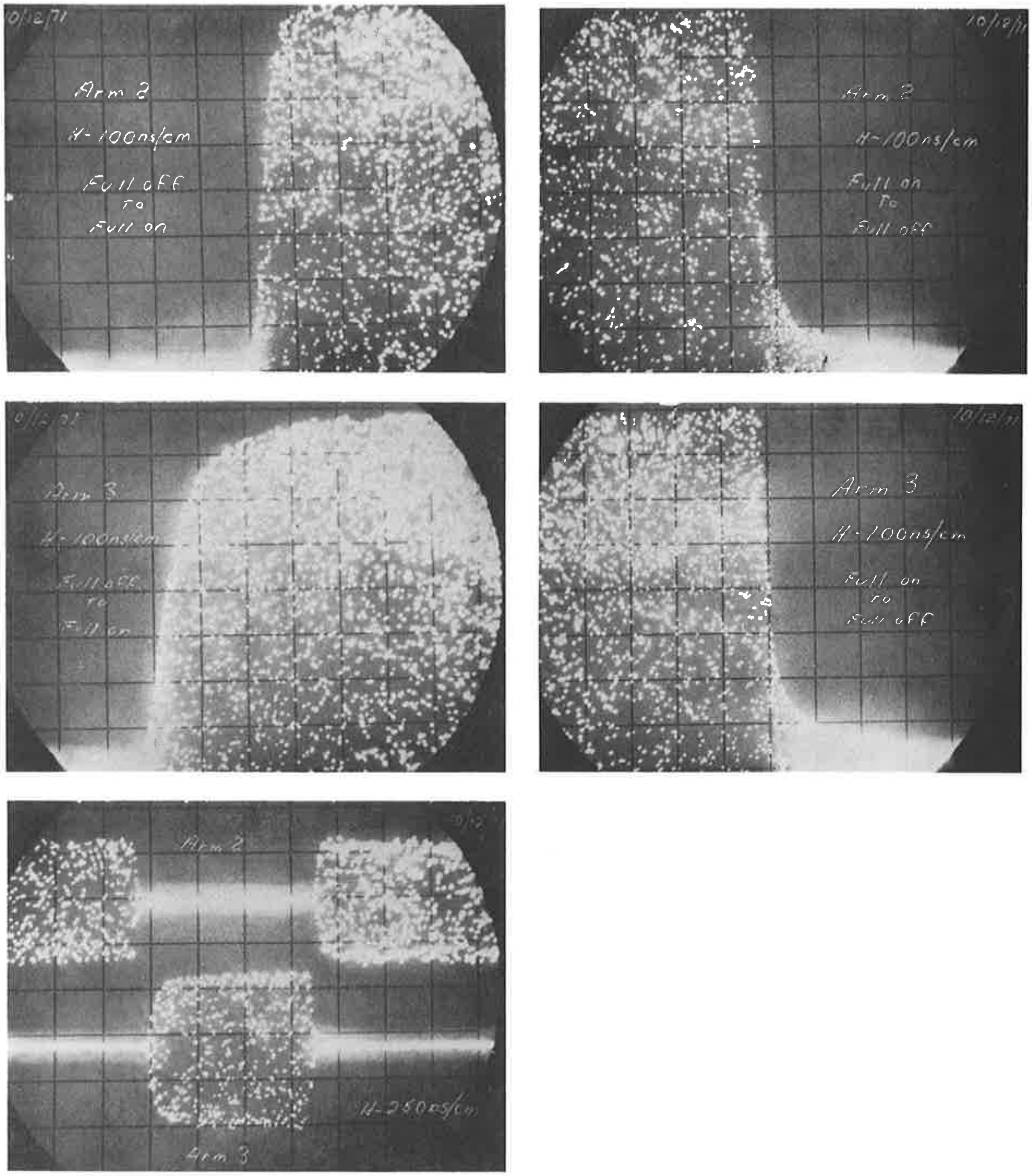


Figure B.8 SPDT MIC Switch Test Data

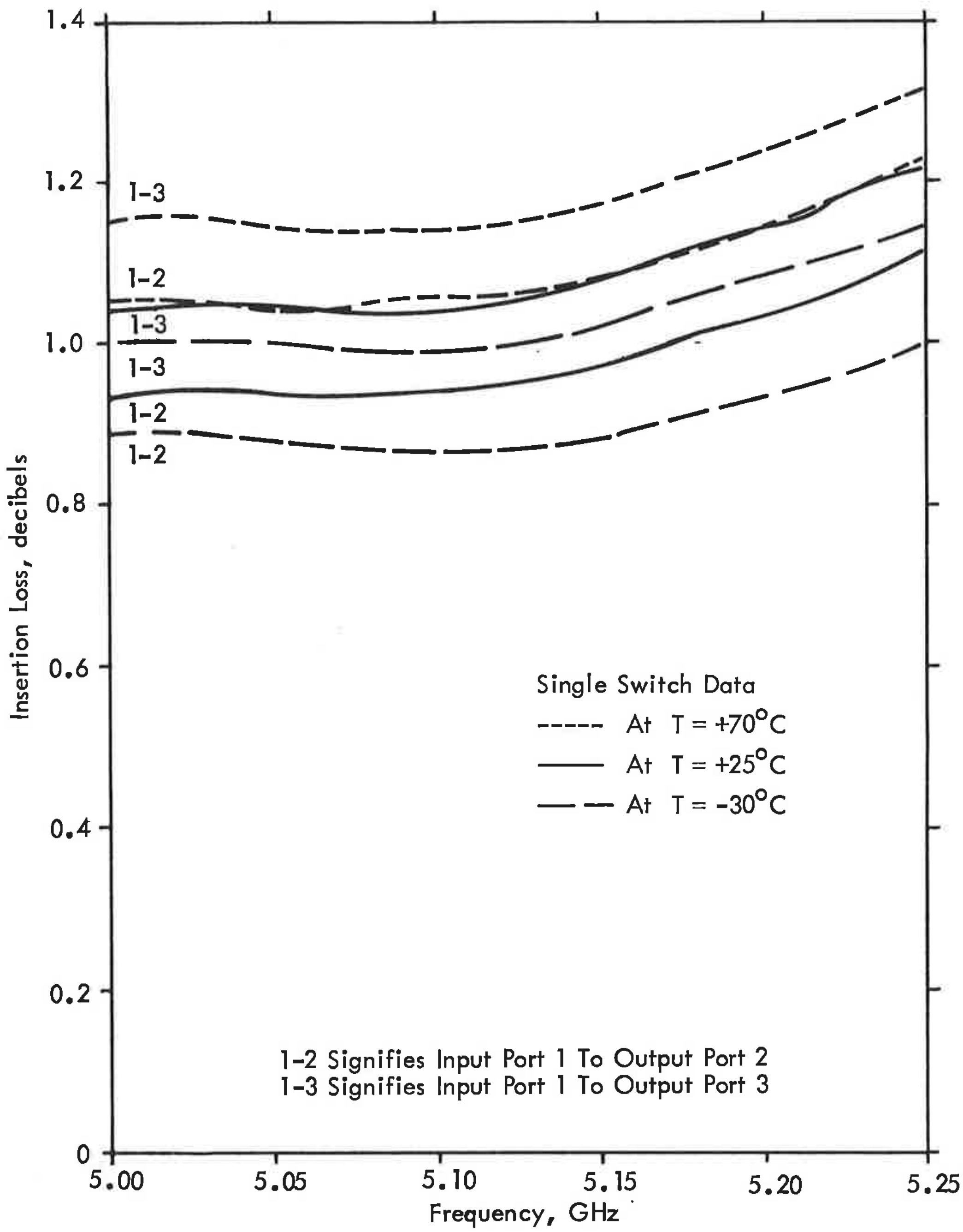


Figure B.9 SPDT Switch - Insertion Loss Variation with Temperature

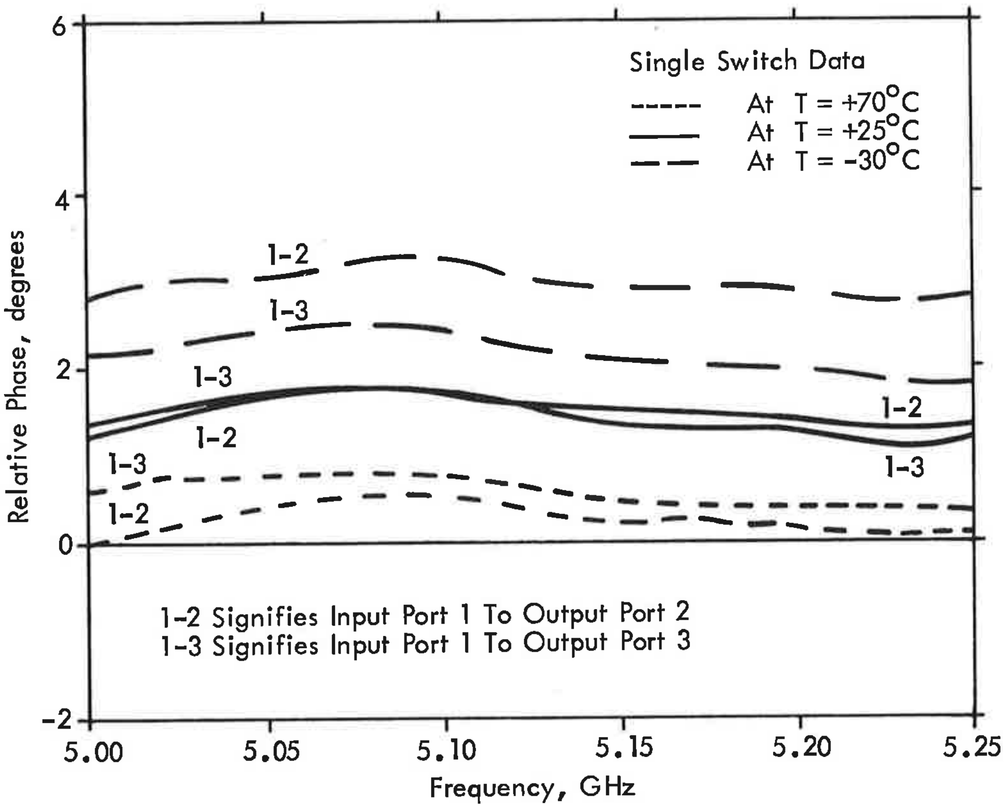


Figure B.10 SPDT Switch - Transmission Phase Variation with Temperature

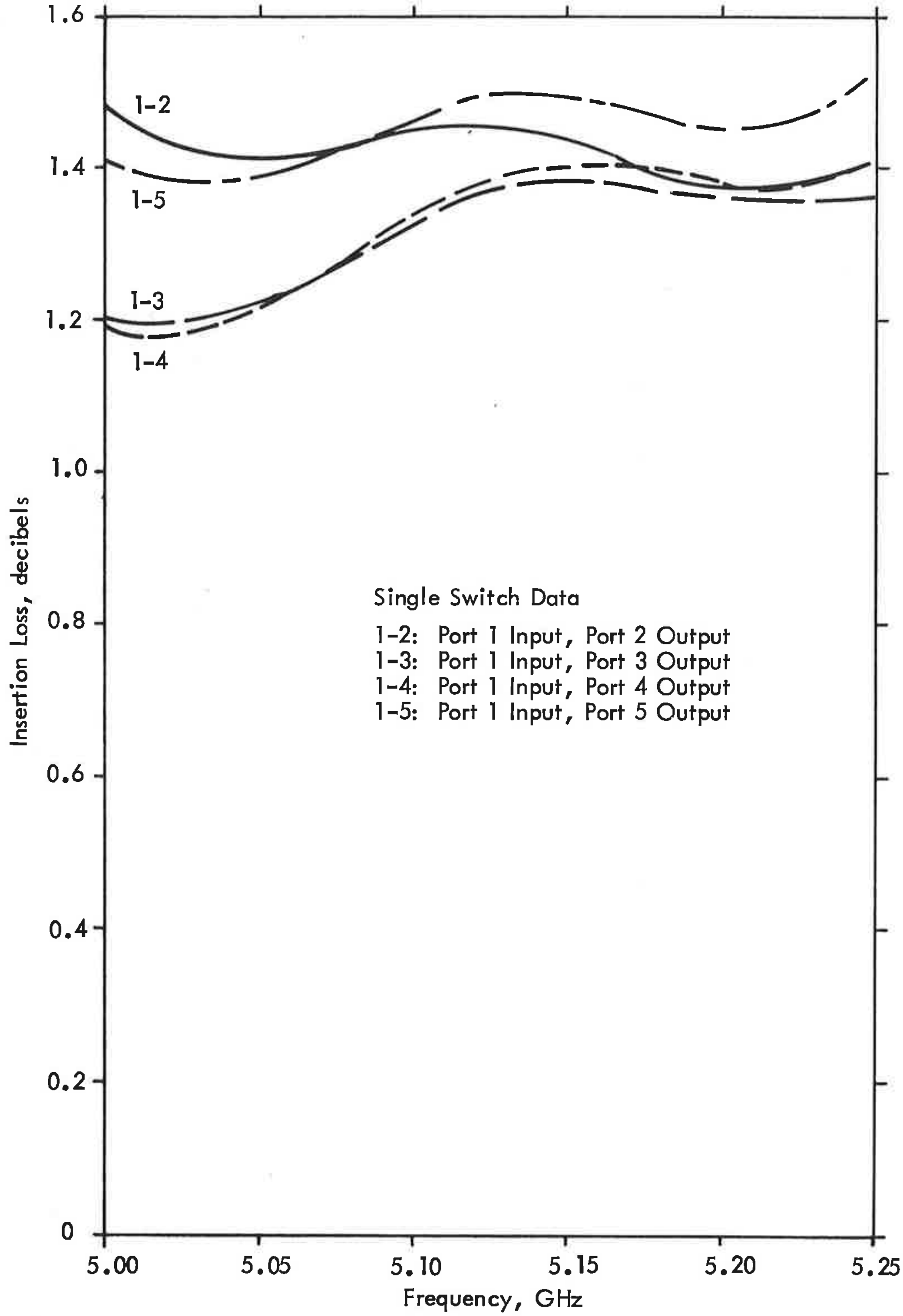


Figure B.11 SP4T Switch Insertion Loss Characteristics

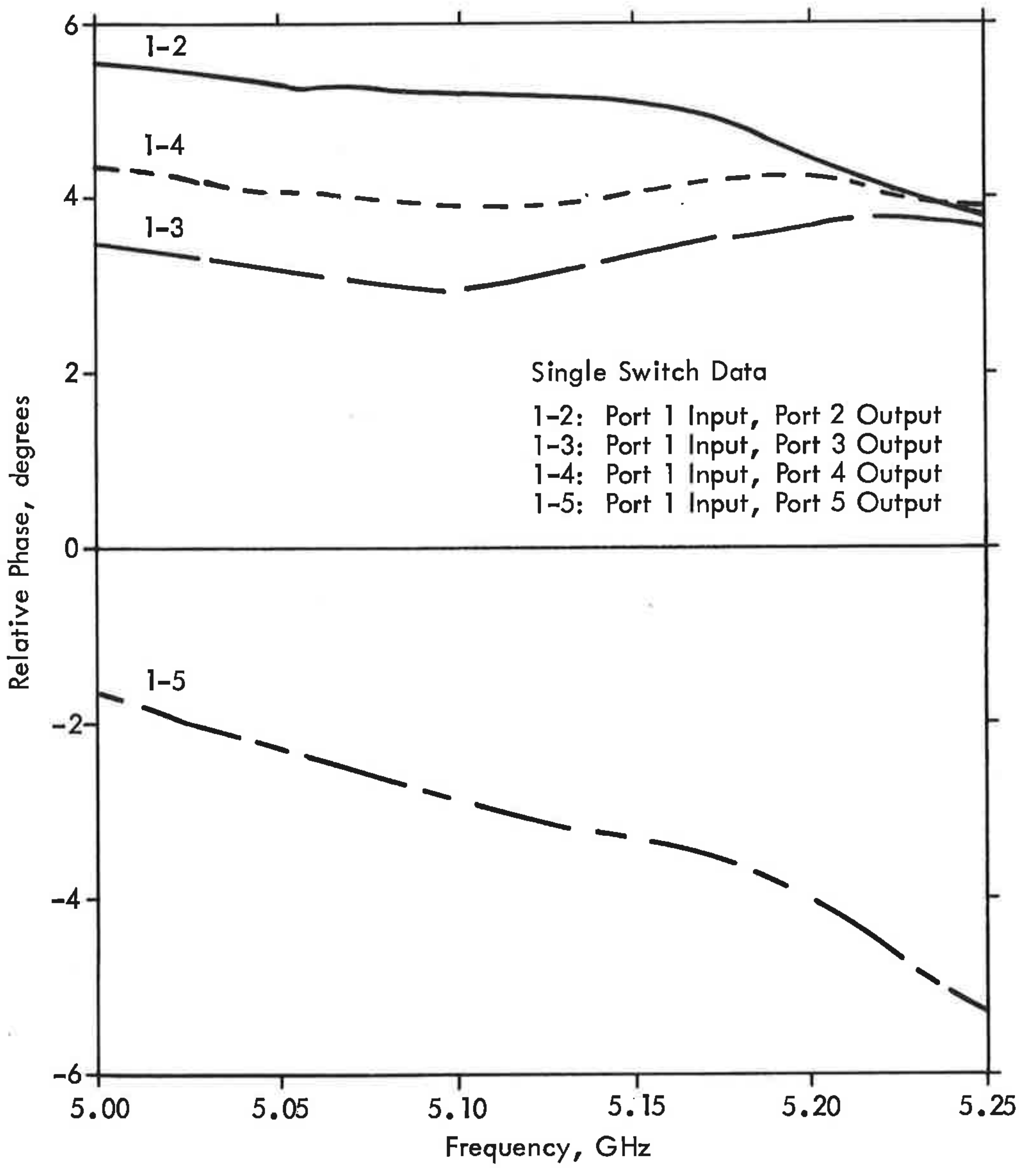


Figure B.12 SP4T Switch Transmission Phase Characteristics

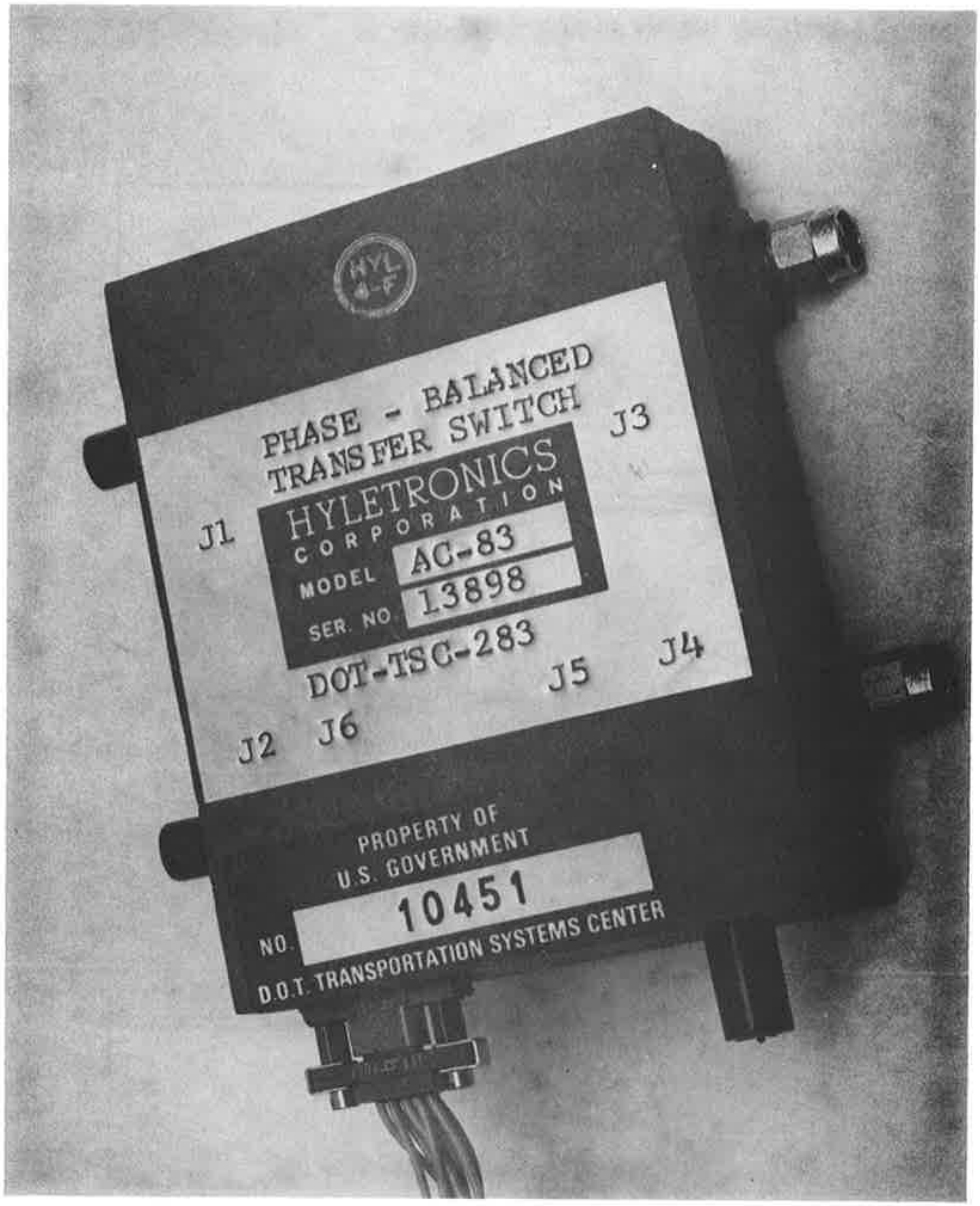


Figure B.13 Photograph of 2x2 Phase-Balanced Transfer Switch

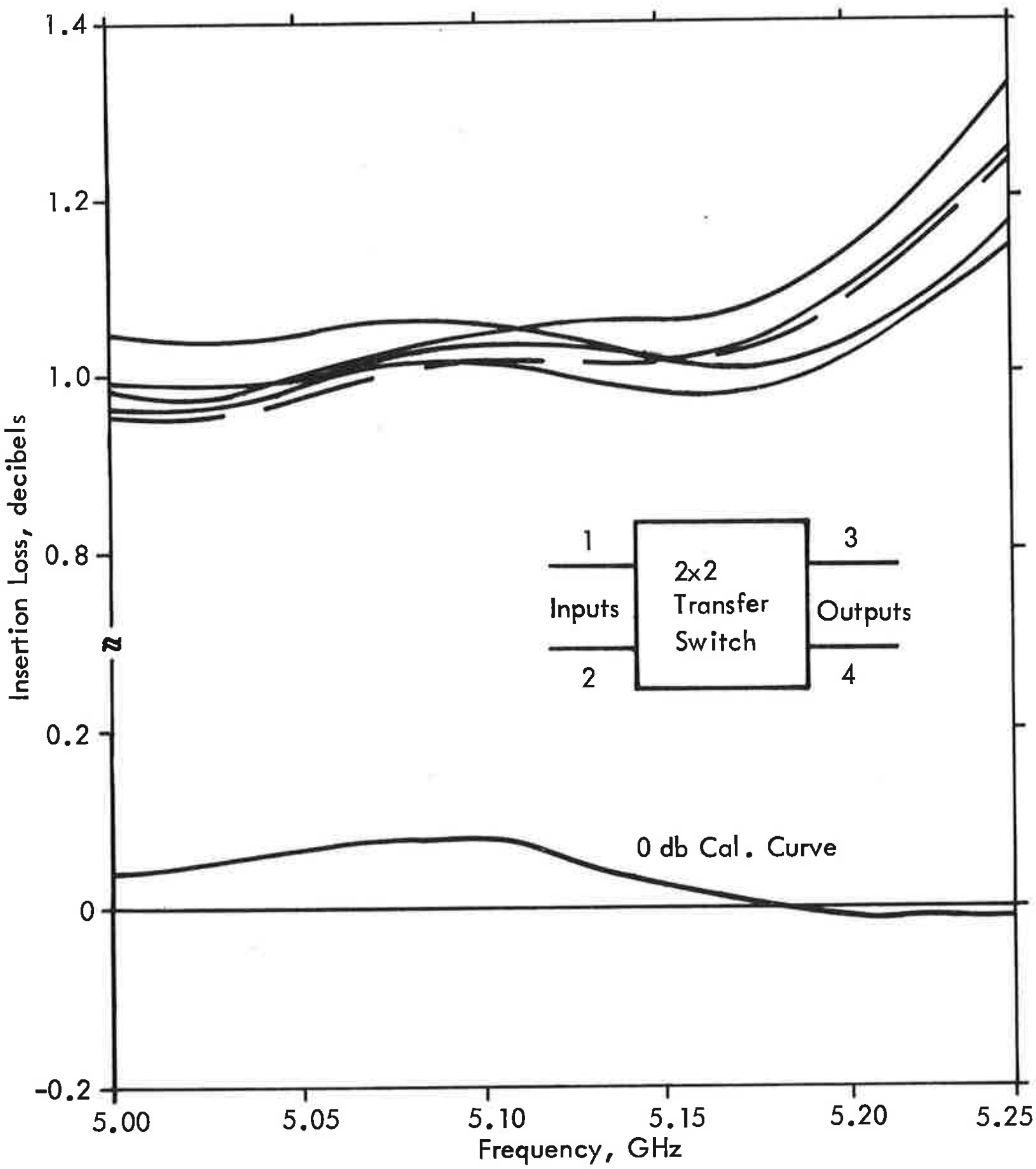


Figure B.14 2x2 Phase-Balanced Transfer Switch Insertion Loss Characteristics

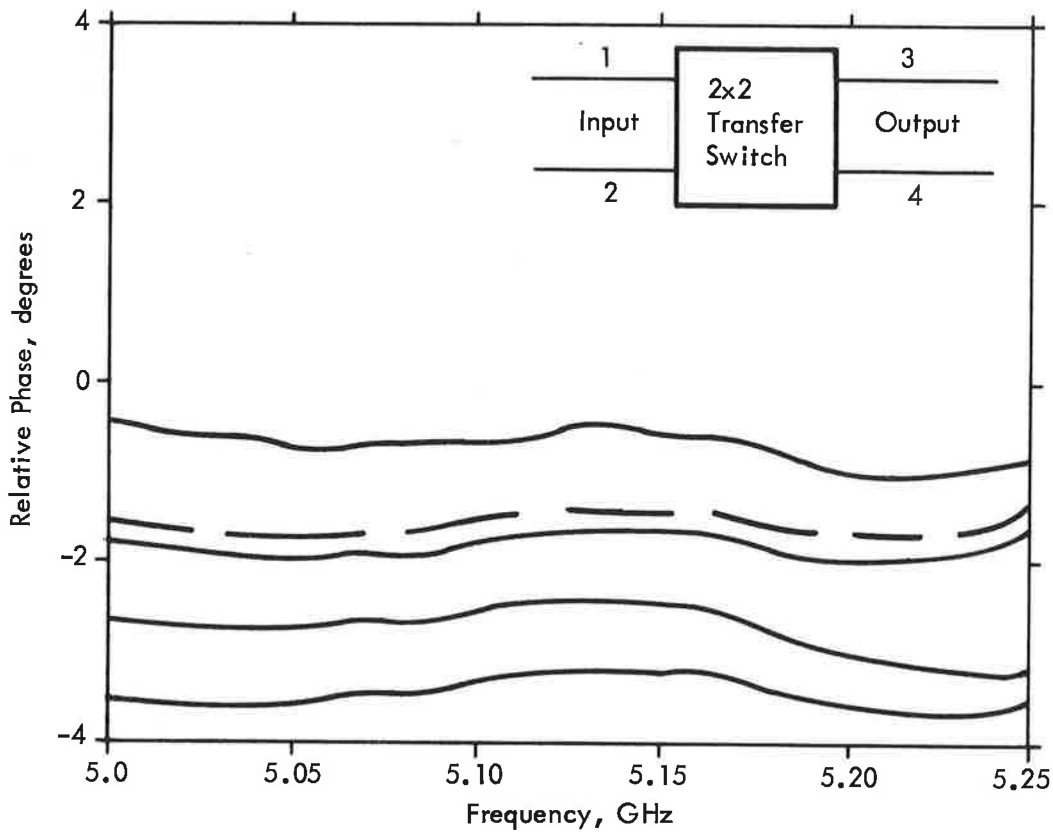


Figure B.15 2x2 Phase-Balanced Transfer Switch Transmission Phase Characteristics

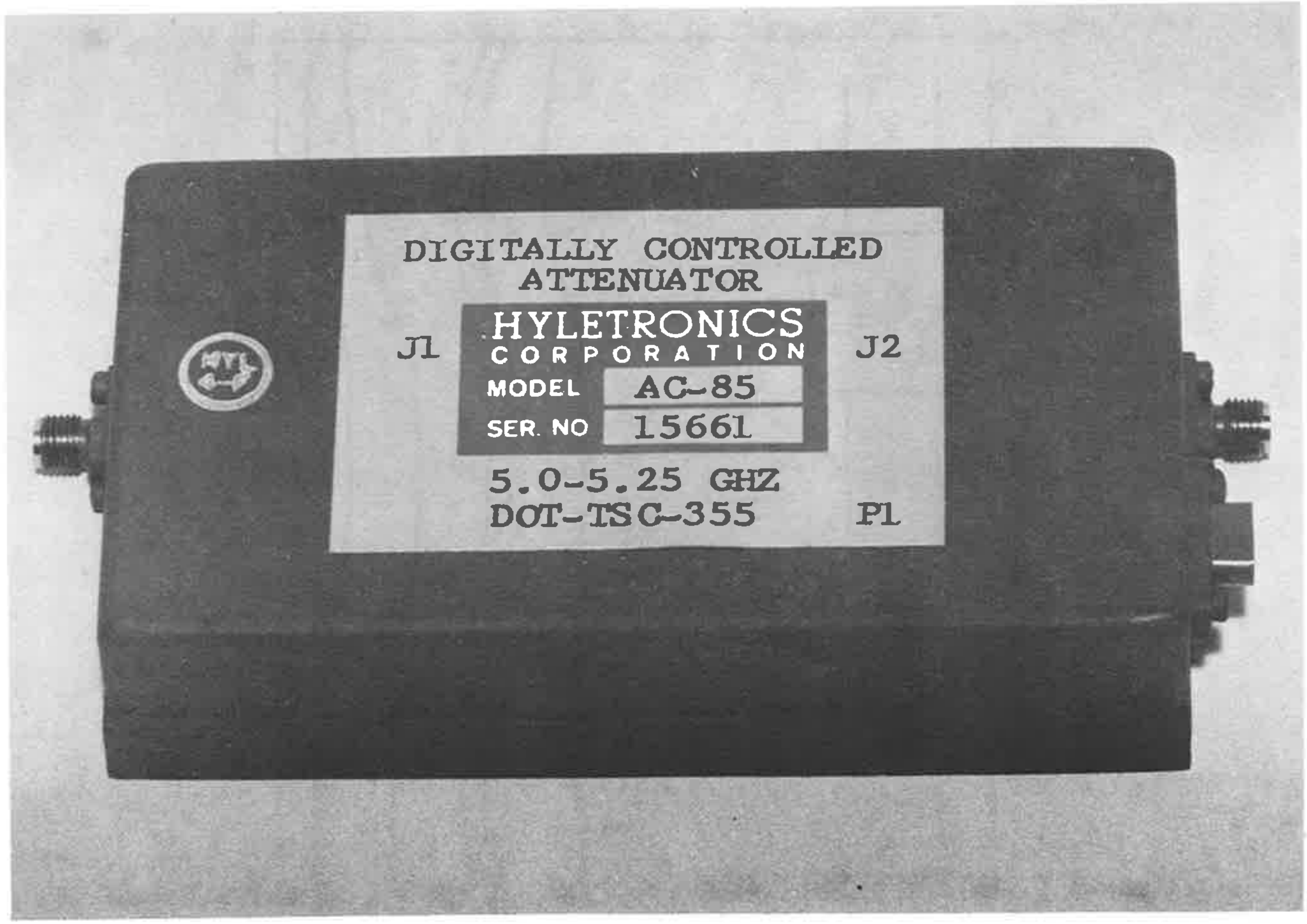


Figure B.16 Photograph of Digitally Controlled, Constant Phase Attenuator

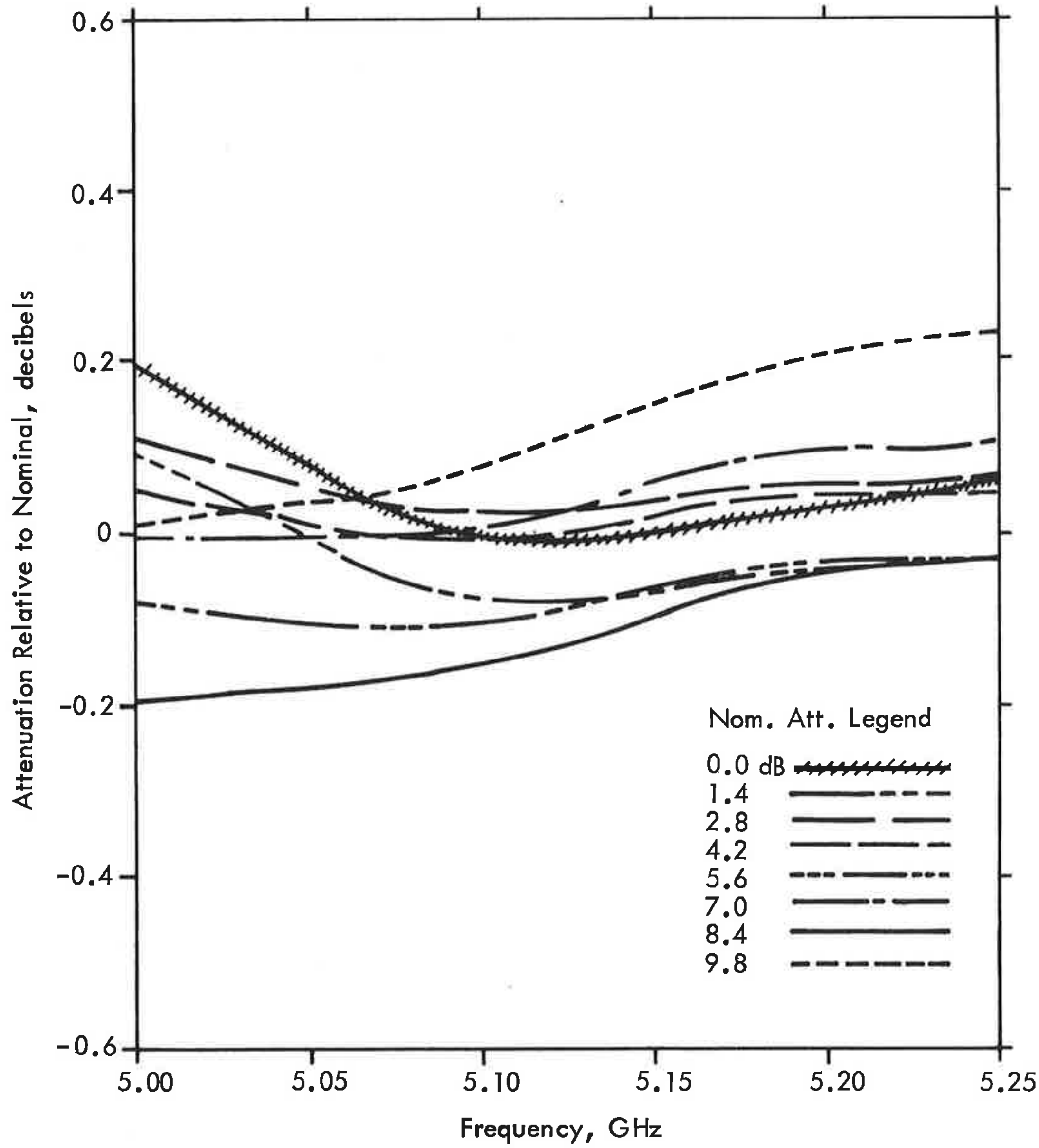


Figure B.17 Attenuation Accuracy of Digitally Controlled Constant Phase Attenuator

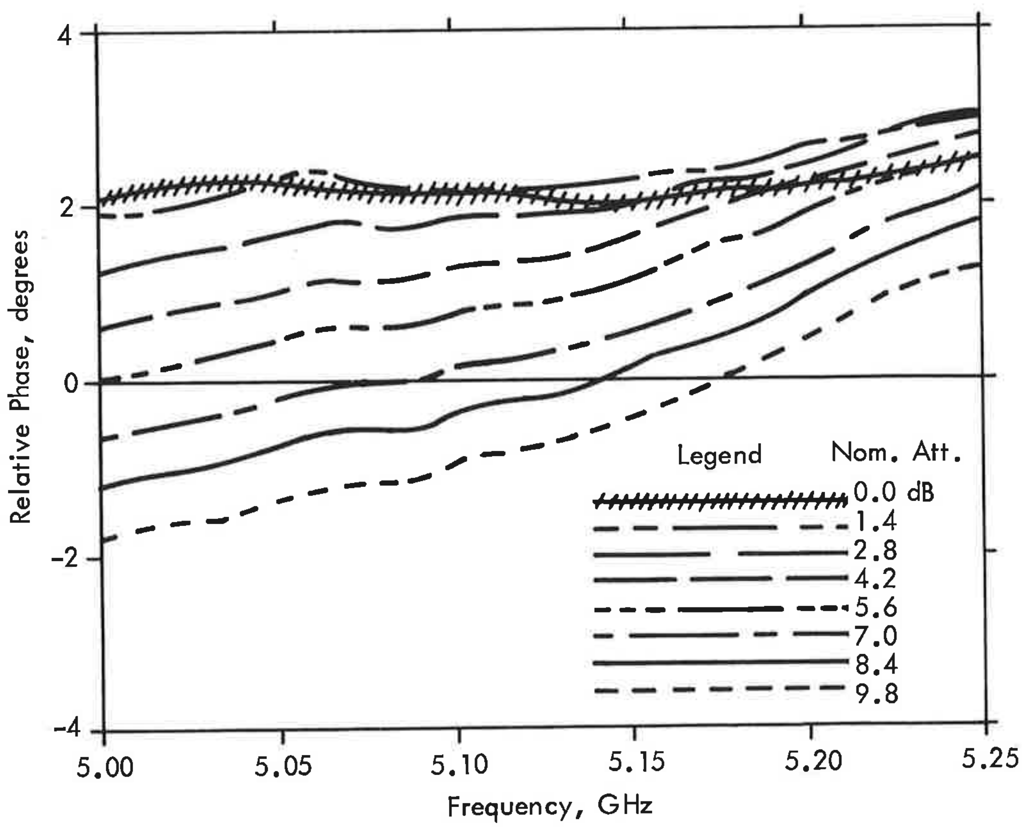
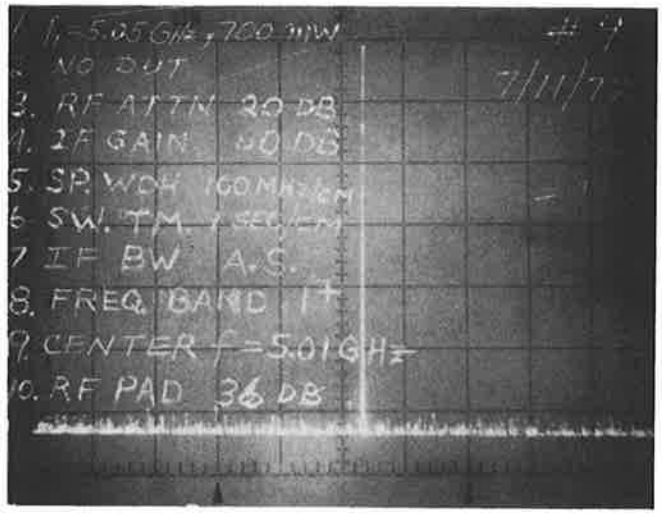


Figure B.18 Transmission Phase Characteristics of Digitally Controlled Constant Phase Attenuator



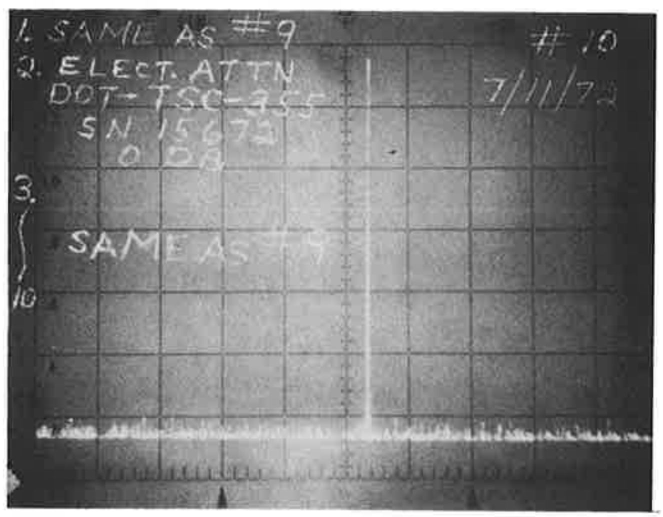
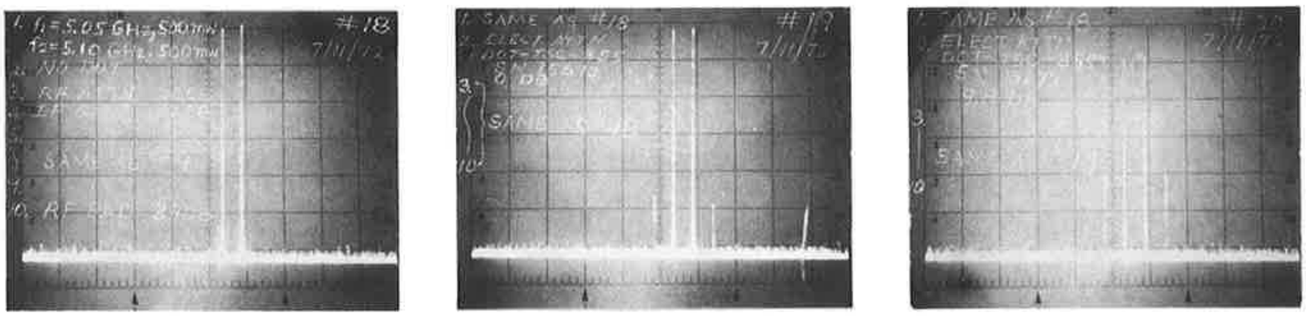
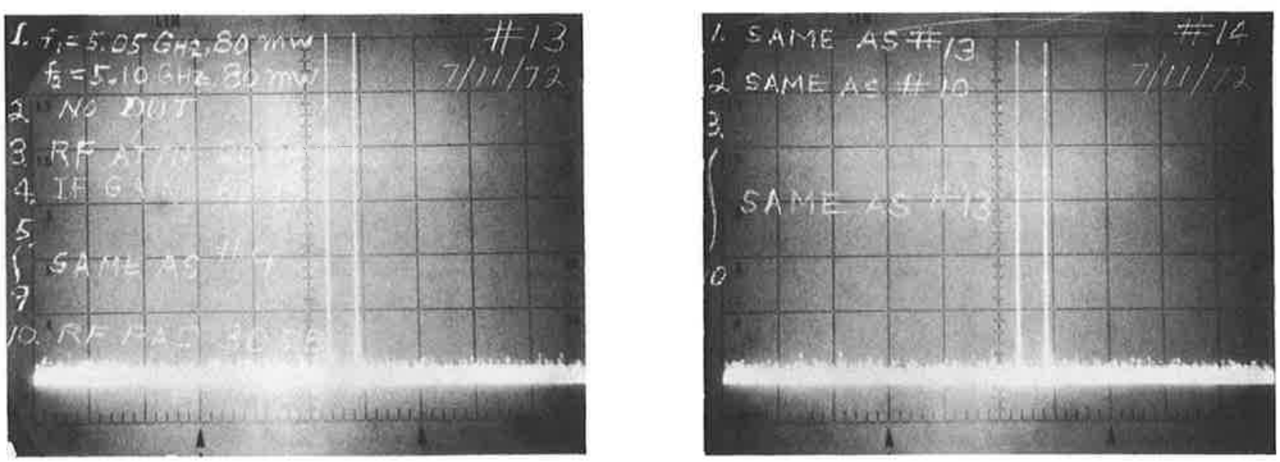


Figure B.19 Spurious Response of Digital Attenuator with Single Signal Input of 700 mw



(A) DUAL INPUT SIGNAL INPUTS OF 500 MW EACH



(B) DUAL SIGNAL INPUTS OF 500 MW EACH

Figure B.20 Intermodulation Products Response of Digital Attenuator

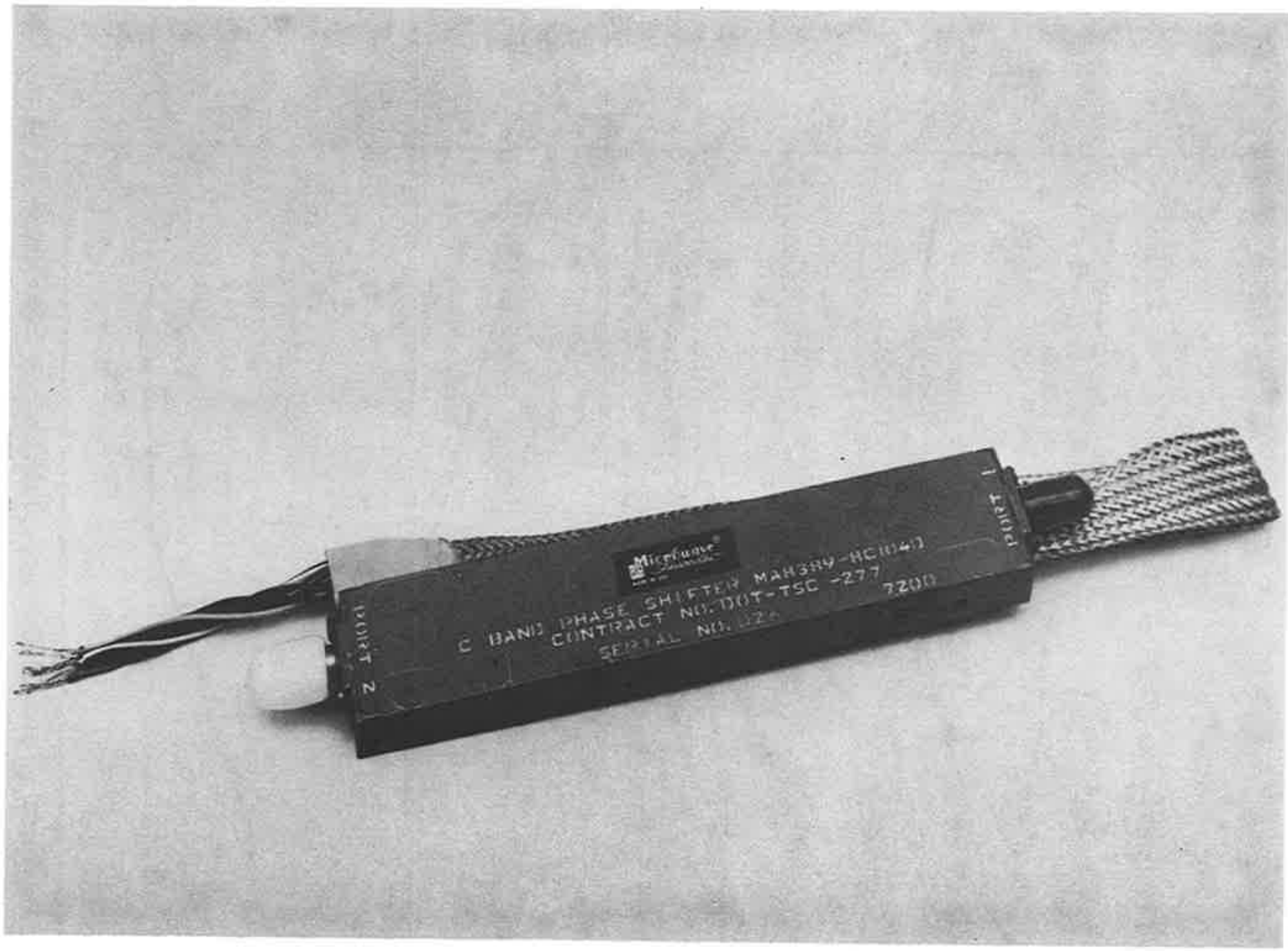


Figure B.21 Photograph of 4-Bit Digital Phase Shifter

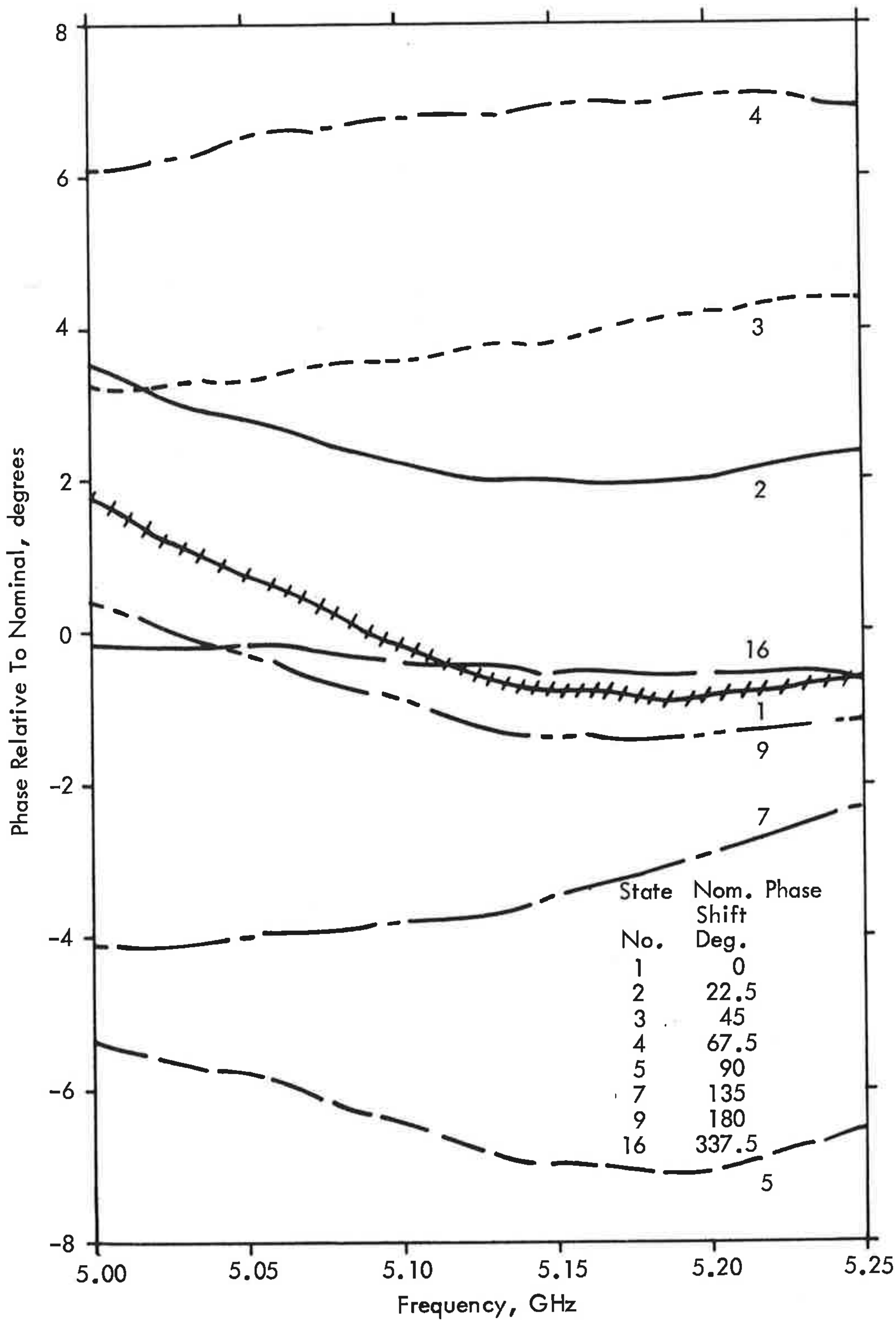


Figure B.22 Phase Accuracy of 4-Bit Digital Phase Shifter

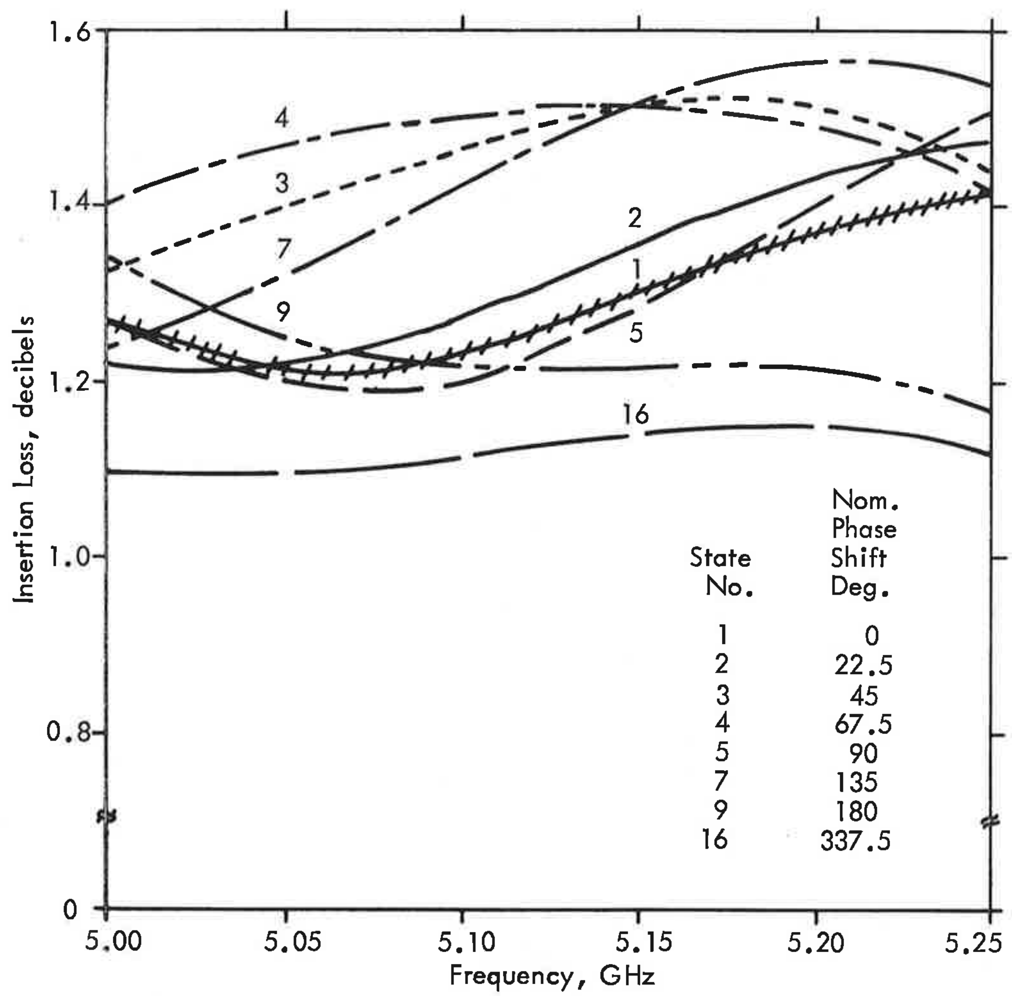


Figure B.23 Transmission Loss Characteristics of 4-Bit Digital Phase Shifter

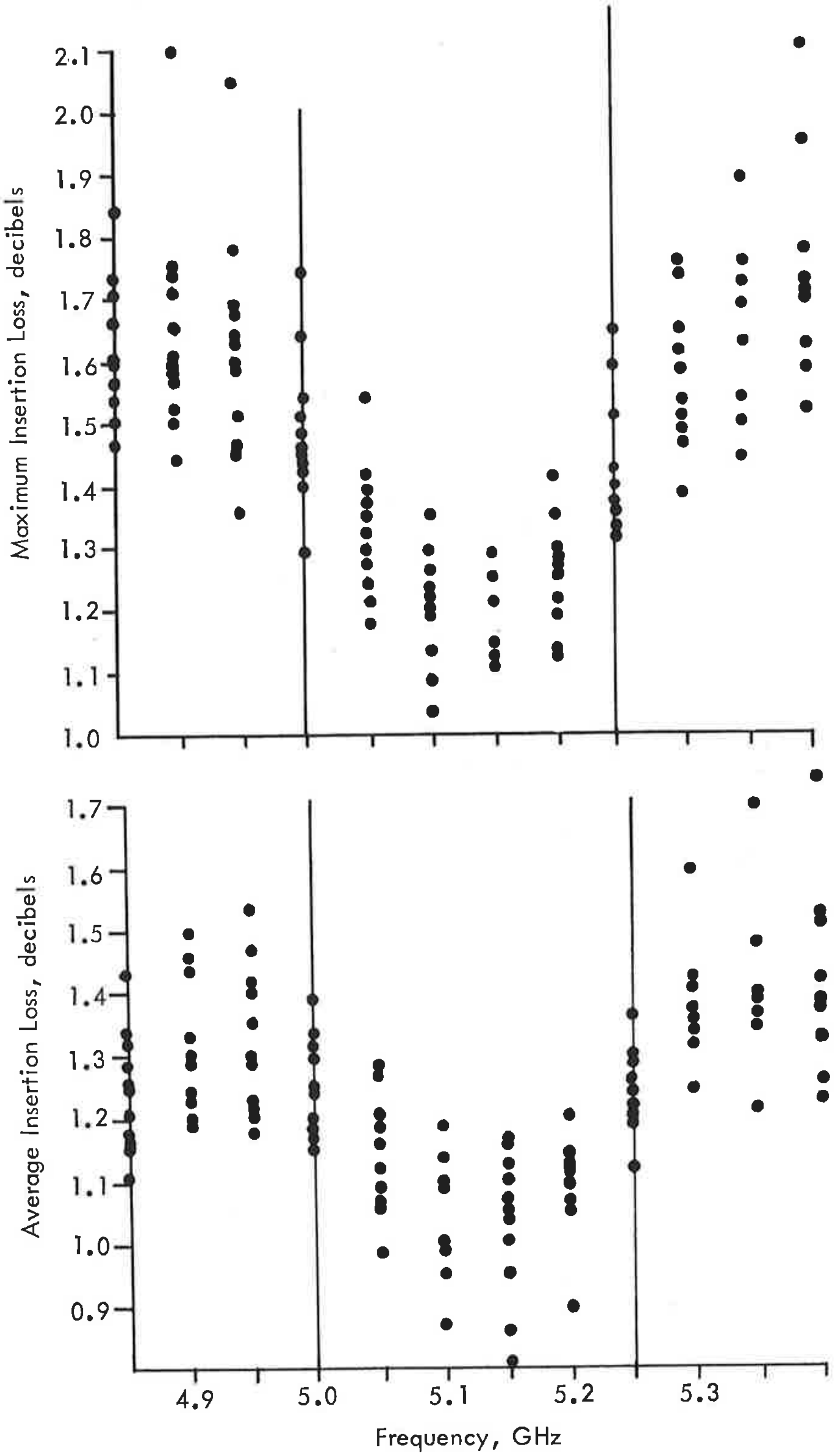


Figure B.24 Insertion Loss Characteristics of 14 Phase Shifters

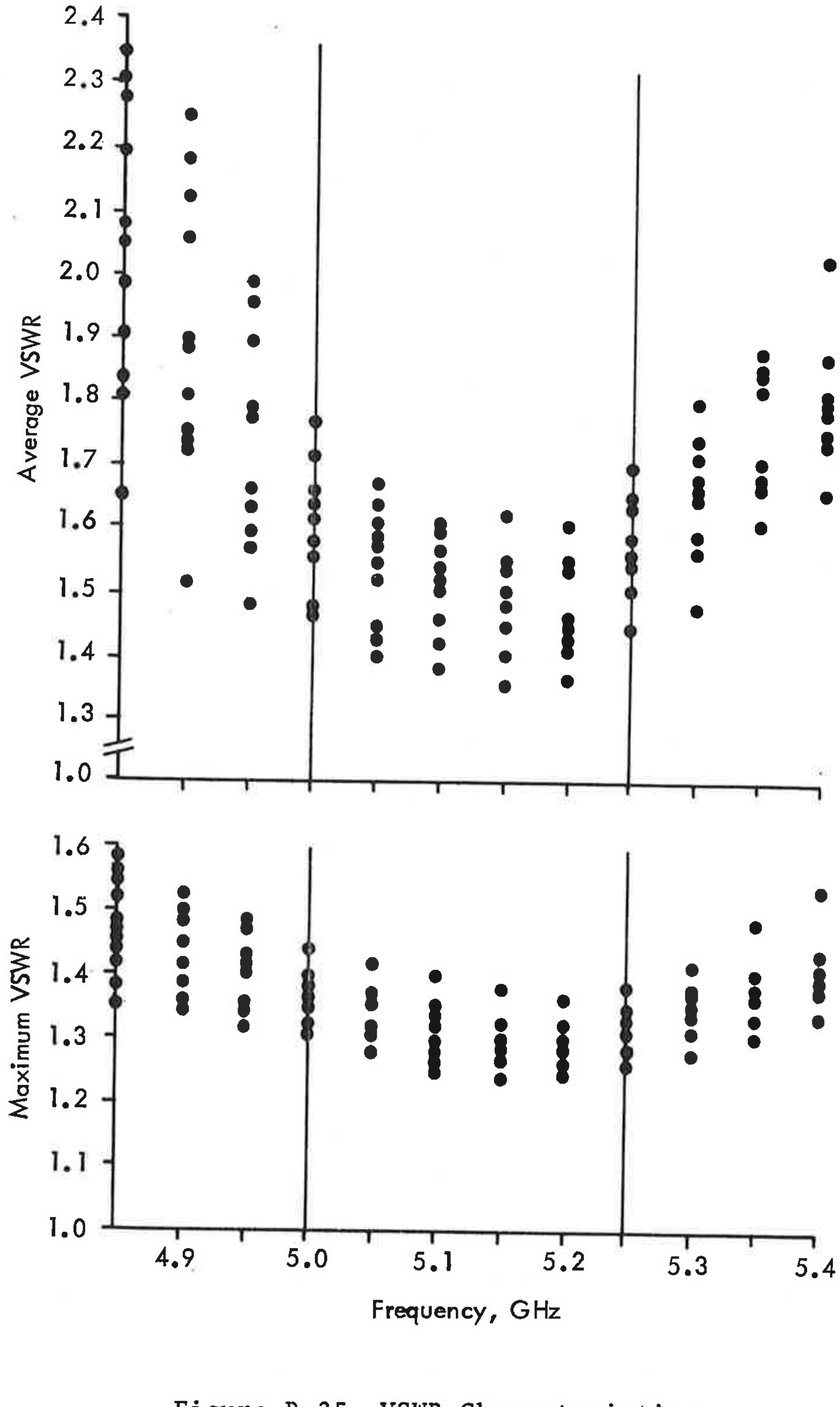


Figure B.25 VSWR Characteristics of 14 Phase Shifters

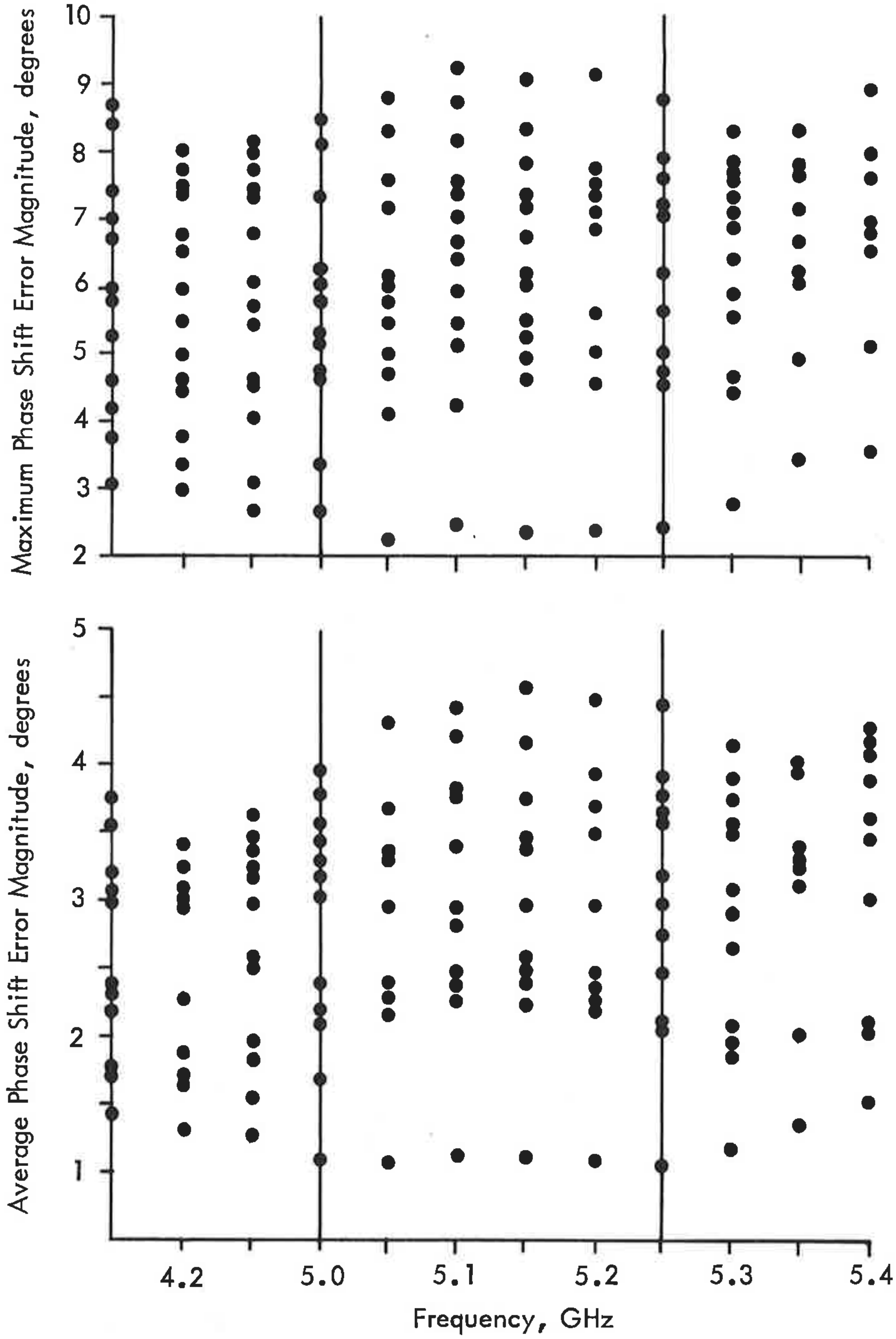
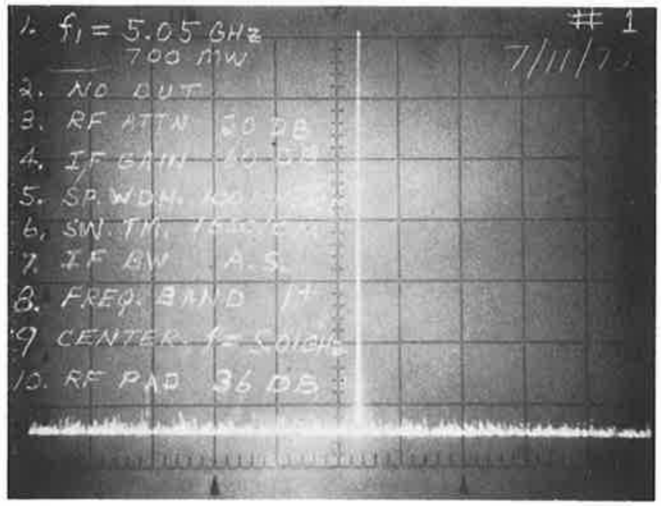
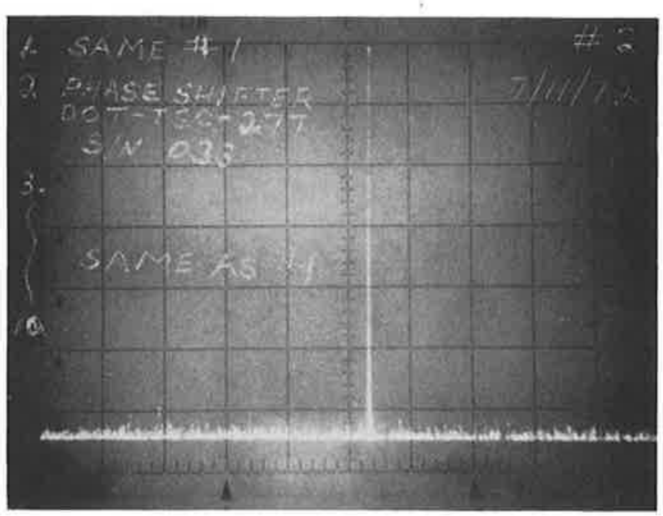


Figure B.26 Phase Shift Error Characteristics of 14 Phase Shifters

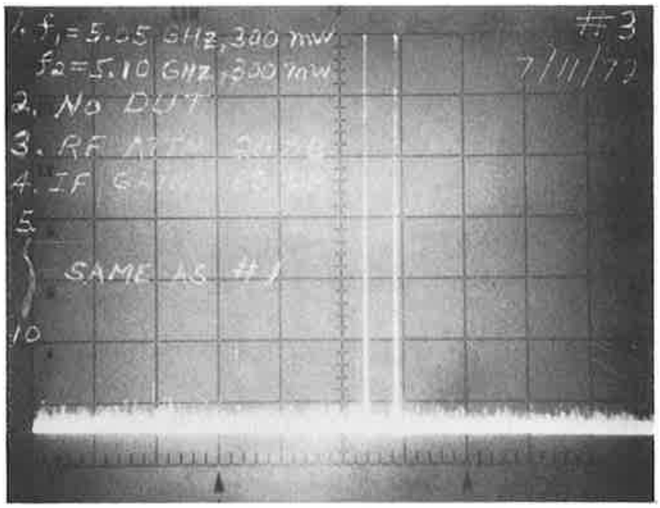


(A) SPECTRUM ANALYZER RESPONSE ONLY

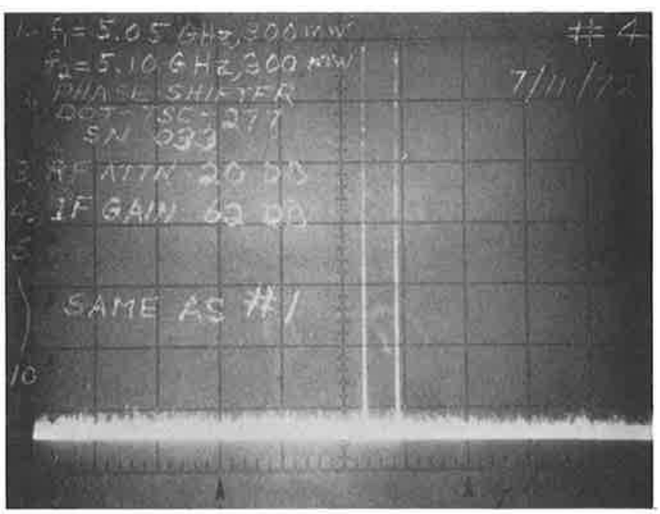


(B) PHASE SHIFTER RESPONSE

Figure B.27 Spurious Response of 4-Bit Phase Shifter with Signal Input of 700 mw



(A) SPECTRUM ANALYZER RESPONSE ONLY



(B) PHASE SHIFTER RESPONSE

Figure B.28 Intermodulation Products Response of 4-Bit Phase Shifter with Dual Signal Inputs of 300 mw Each

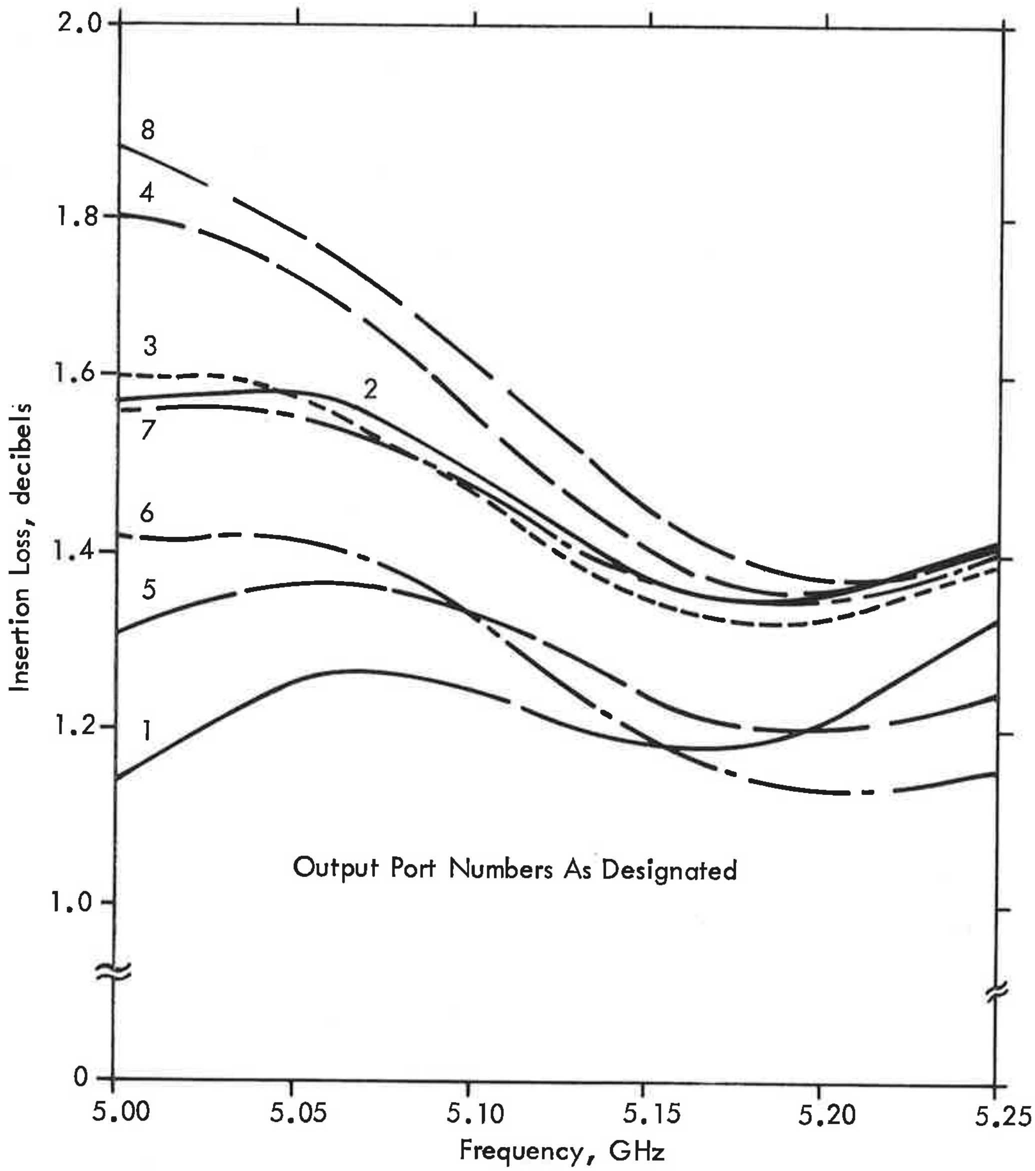


Figure B.29 Amplitude Responses of Output Ports of 8-Way Power Divider

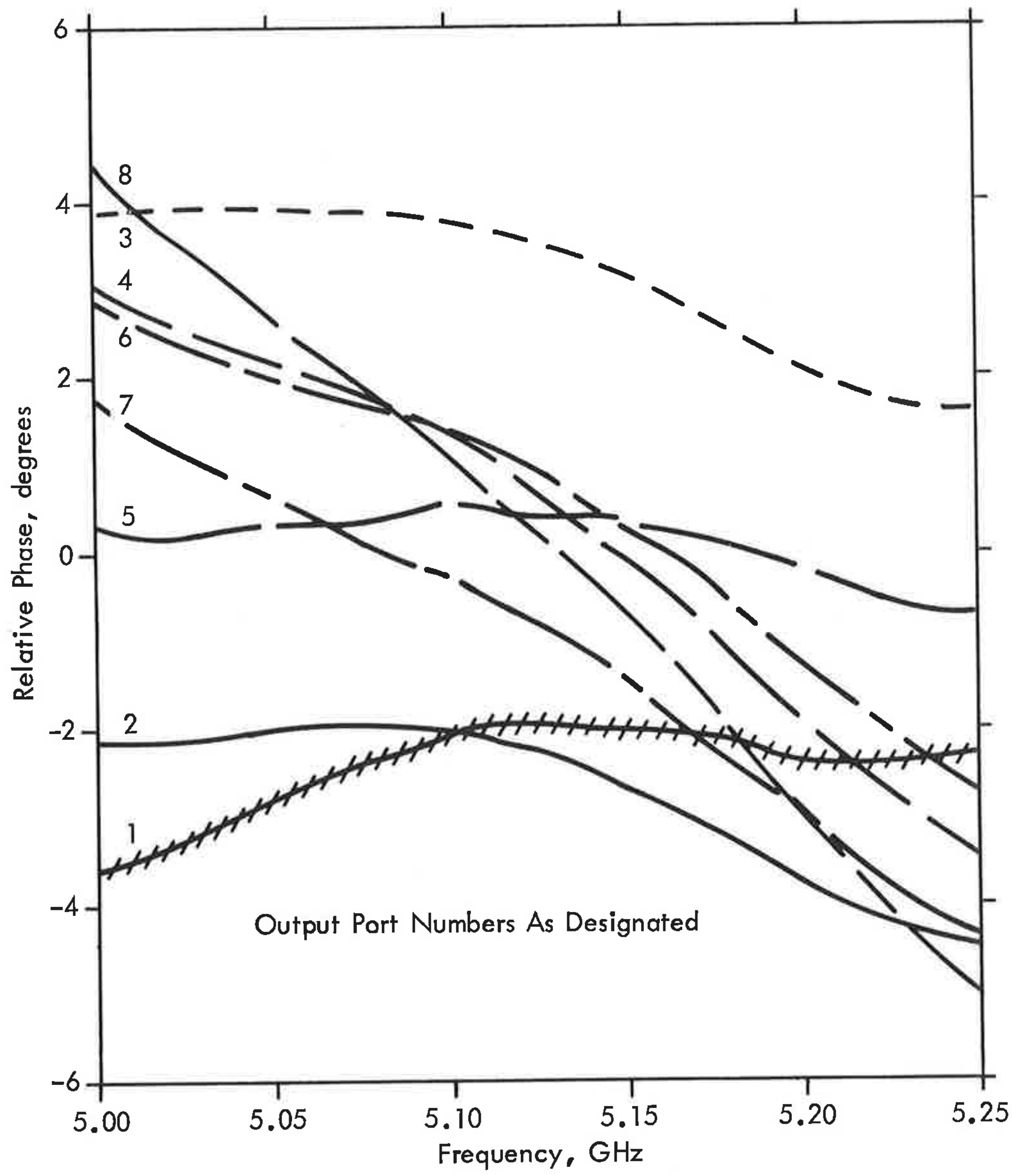


Figure B.30 Phase Responses of Output Ports of 8-Way Power Divider

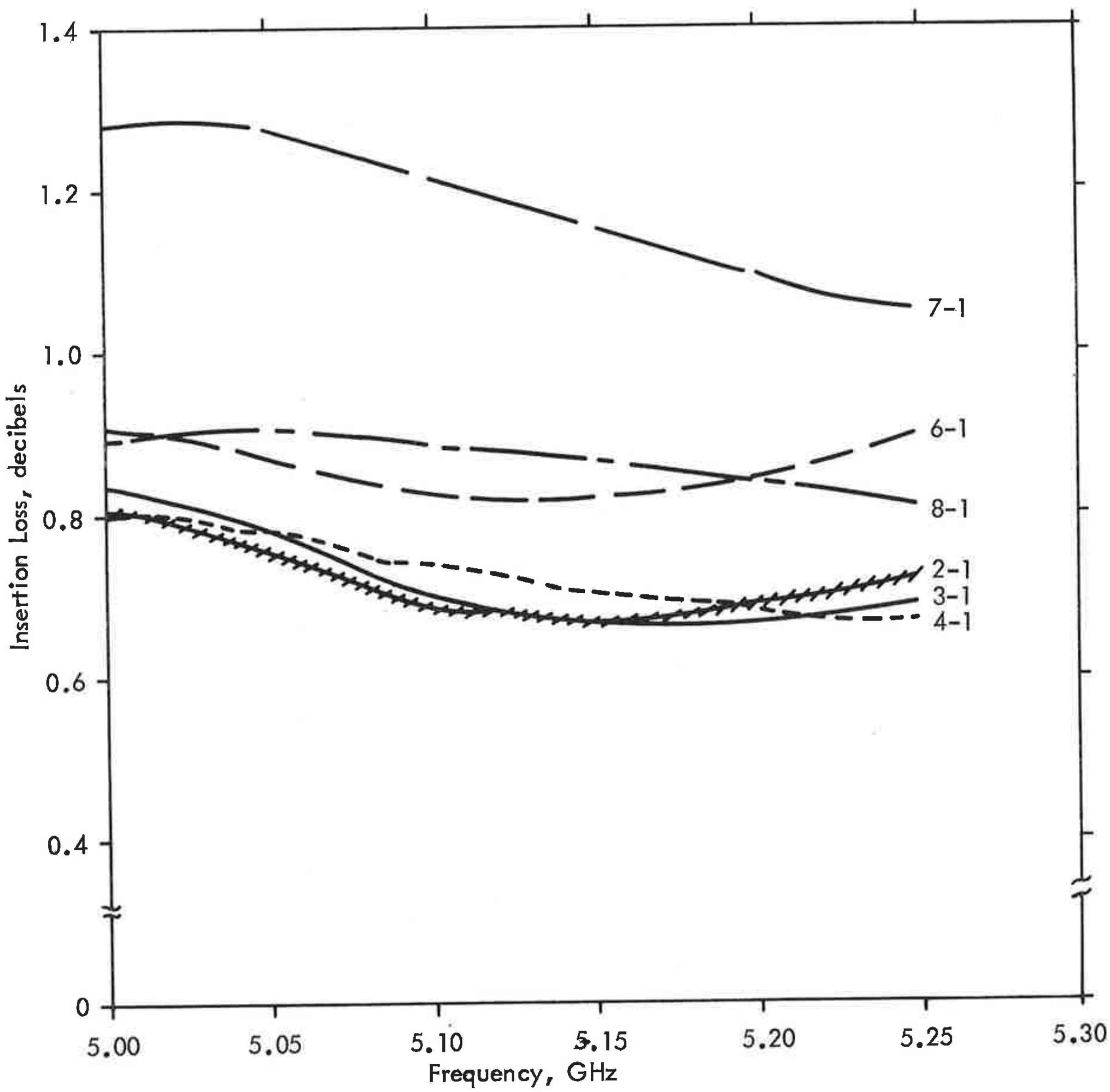


Figure B.31 Transmission Loss Variation of Six 4-Way Power Dividers

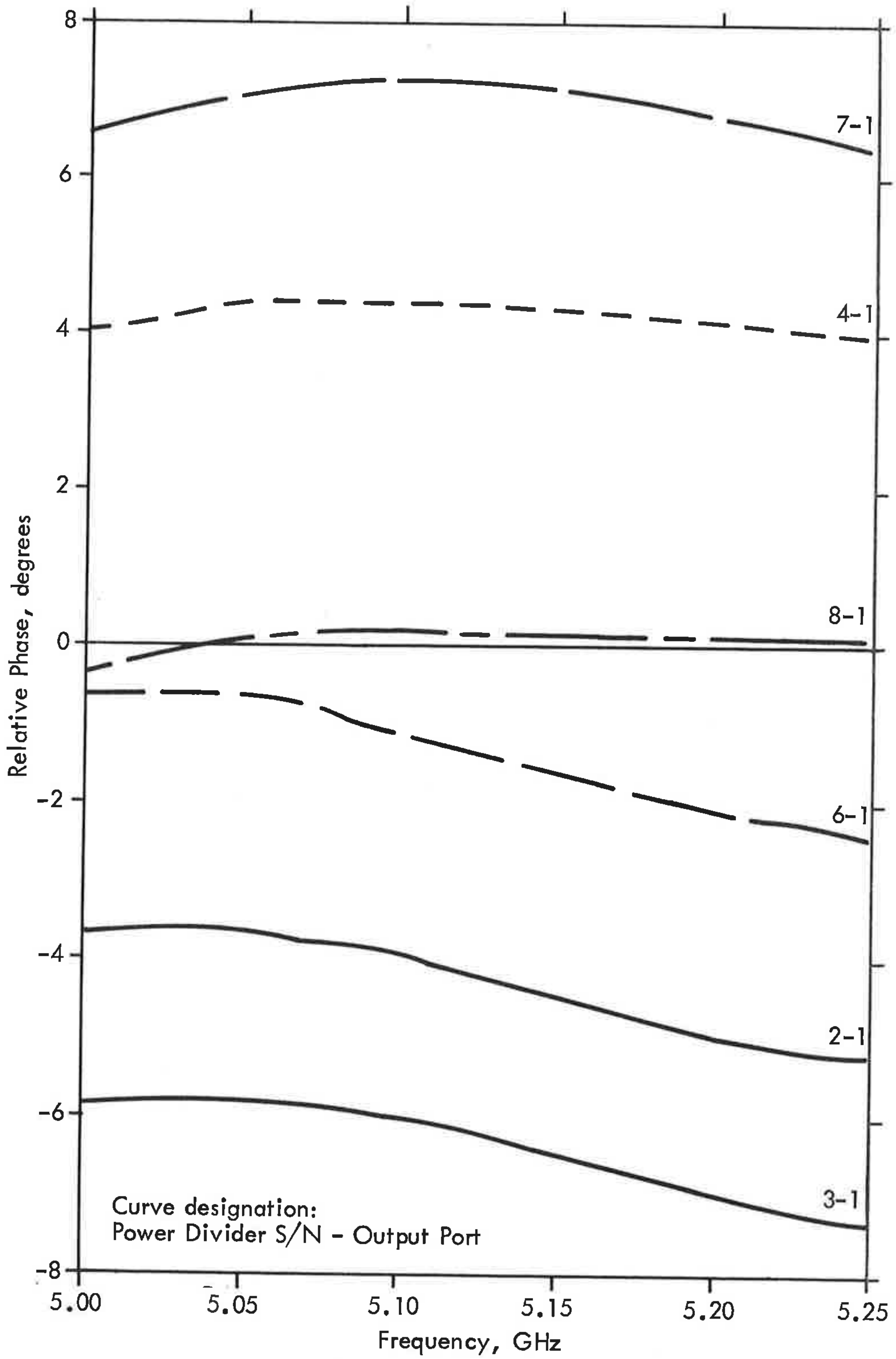


Figure B.32 Transmission Phase Variation of Six 4-Way Power Dividers

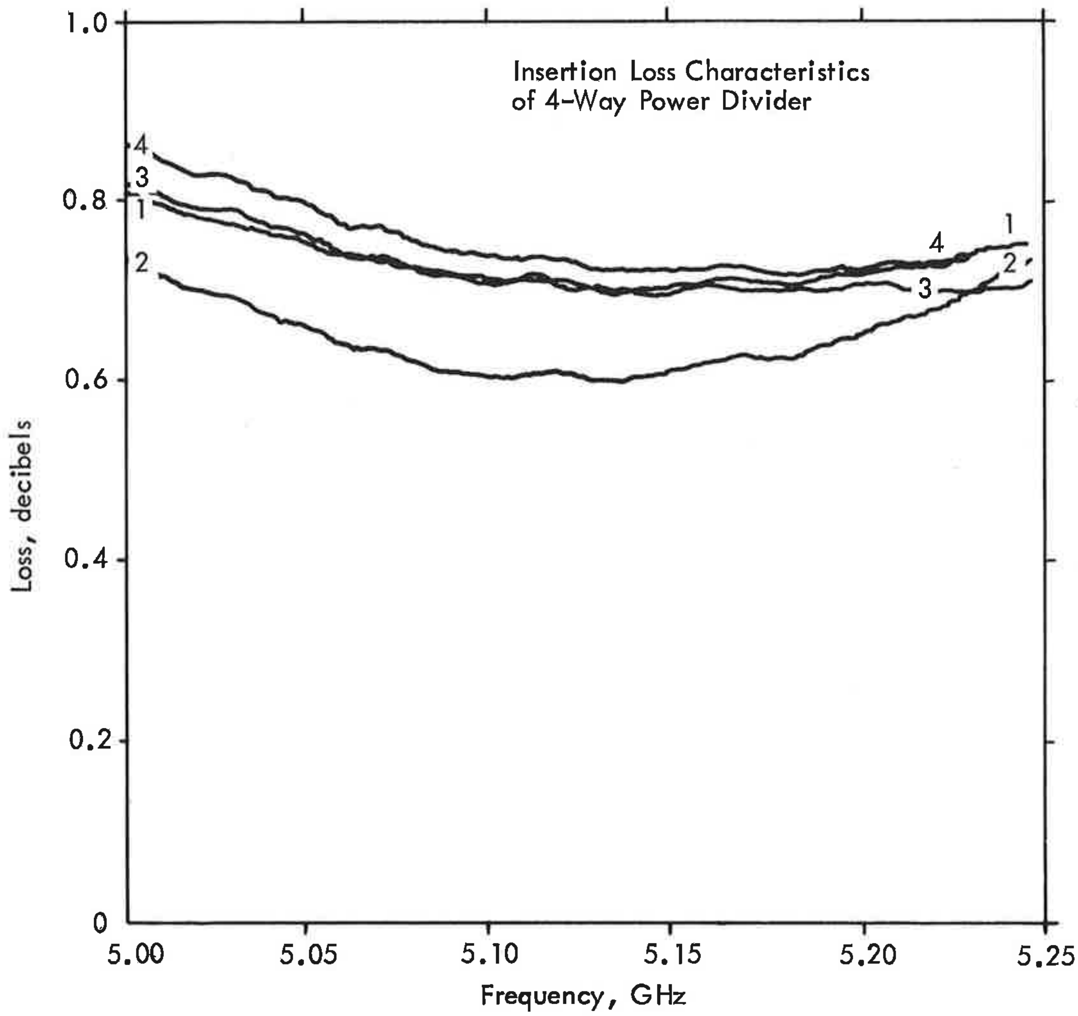


Figure B.33 Insertion Loss Characteristics of 4-Way Power Divider

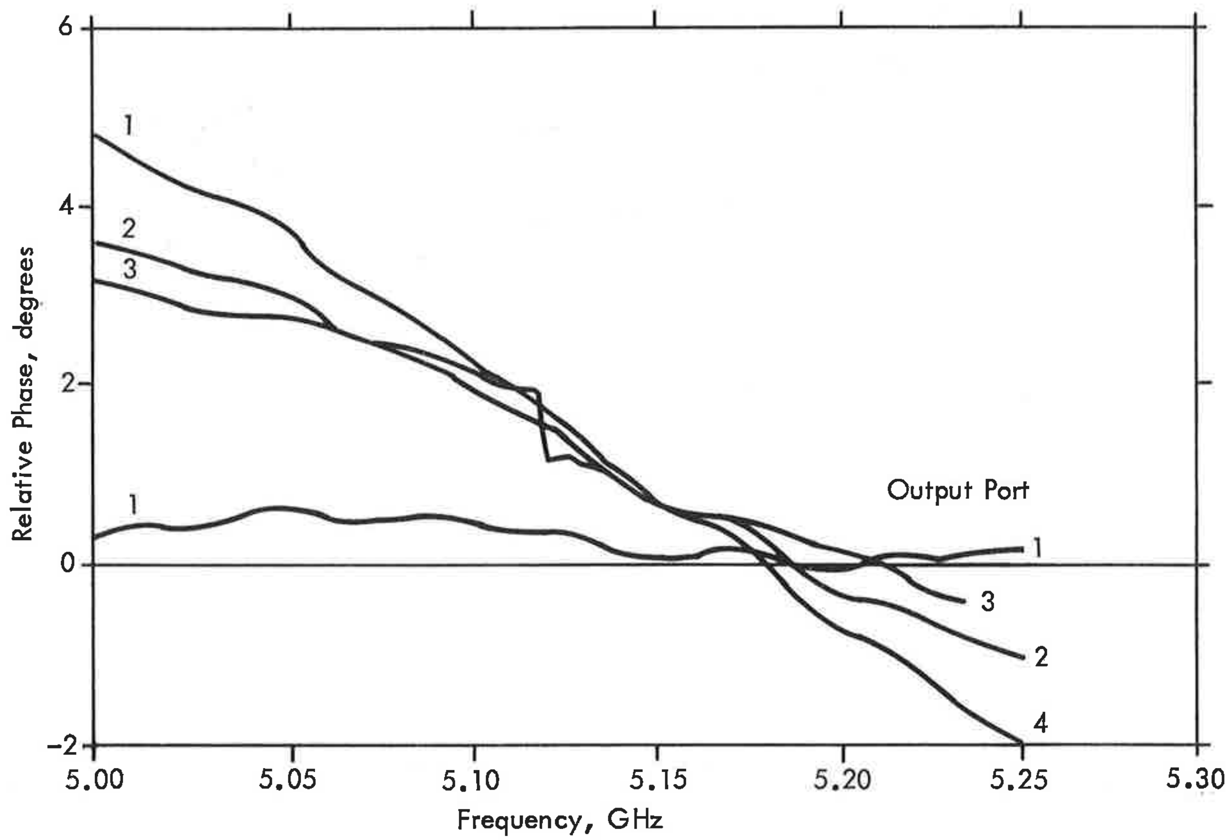


Figure B.34 Transmission Phase Characteristics of 4-Way Power Divider

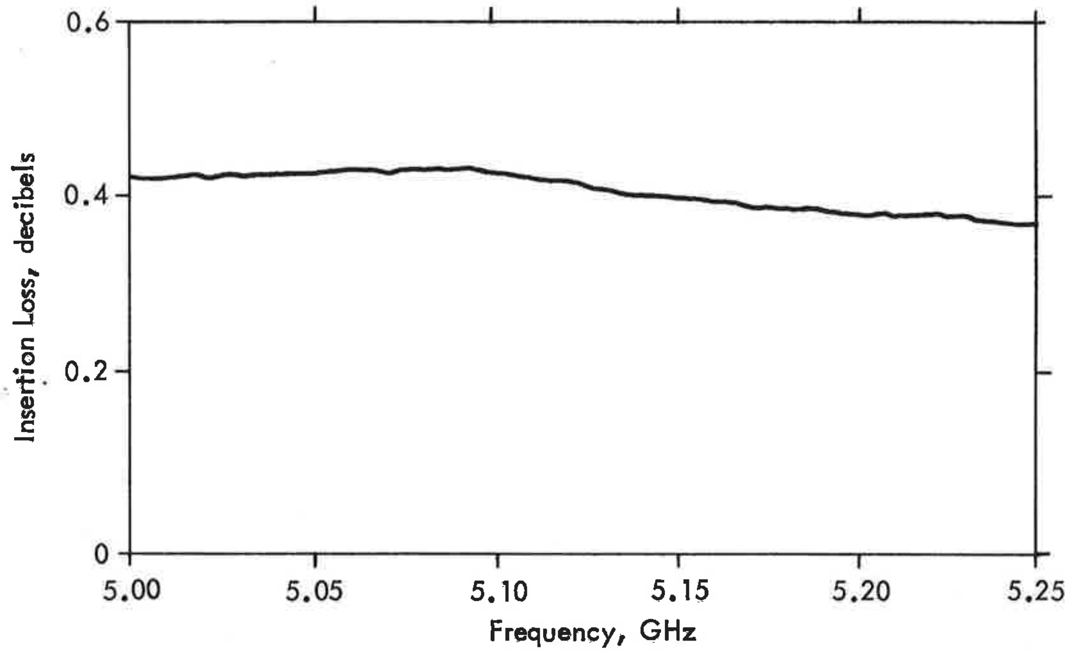


Figure B.35 Electrical Characteristics
RG-141 Semi-Rigid Cable
Subassemblies (Sheet 1 of 2)

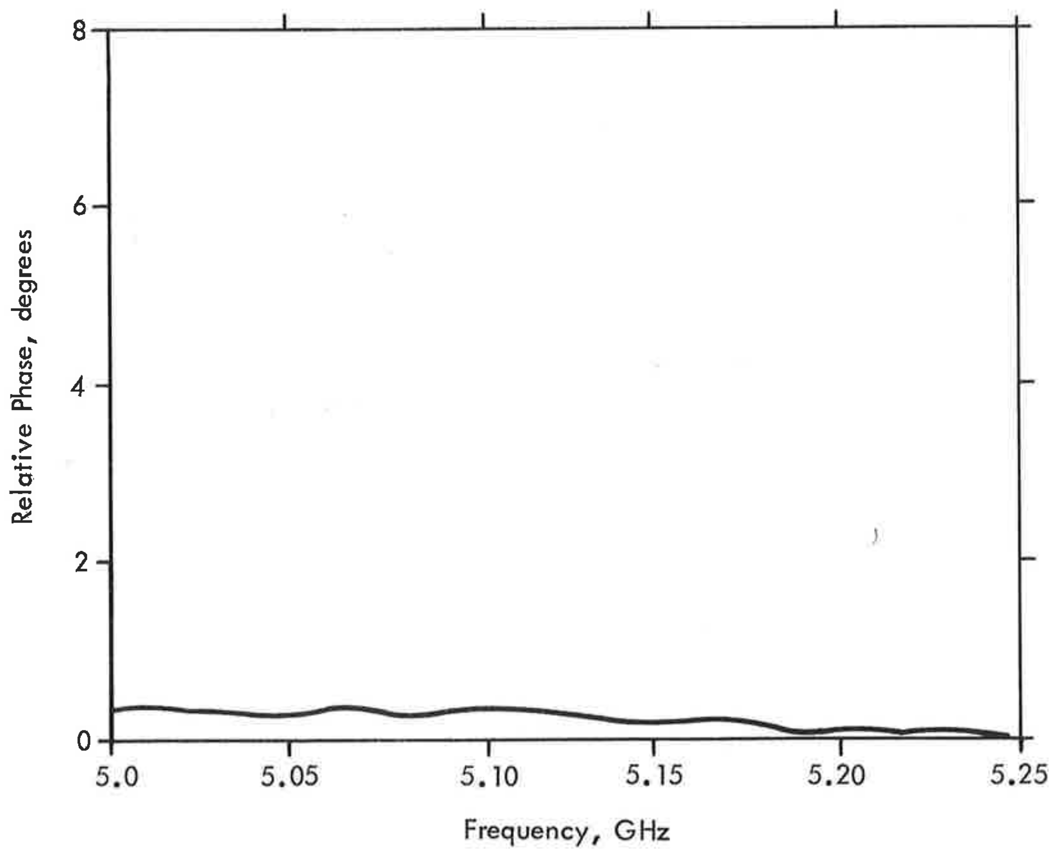


Figure B.35 Electrical Characterisitcs
RG-141 Semi-Rigid Cable
Subassemblies (Sheet 2 of 2)

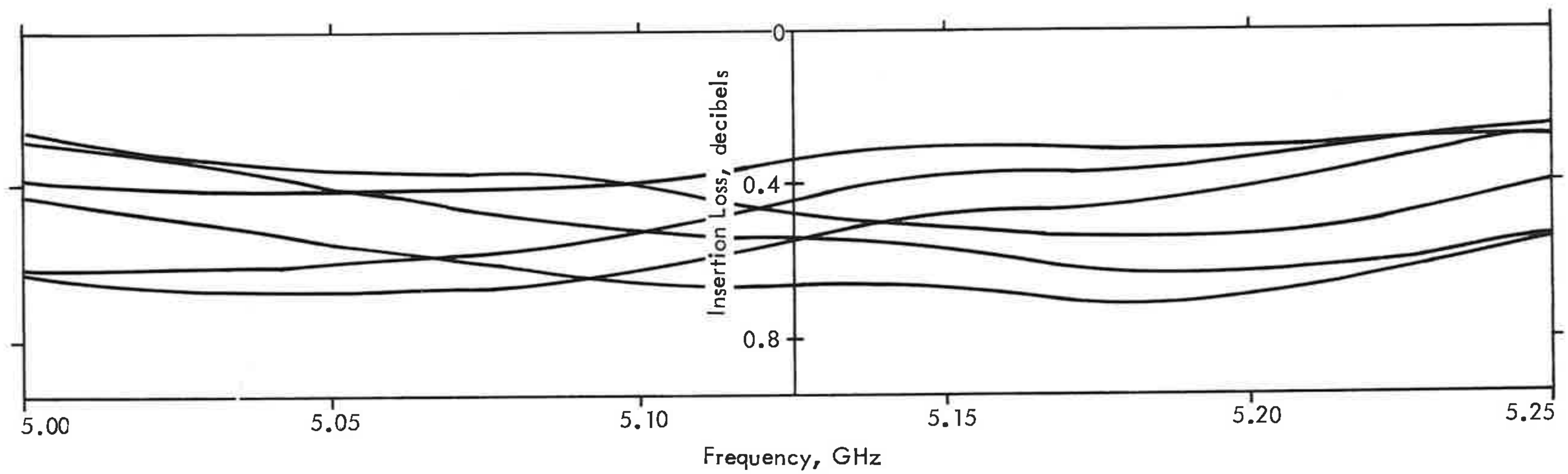


Figure B.36 Insertion Loss Variations vs Settability of Mechanical Phase Shifter

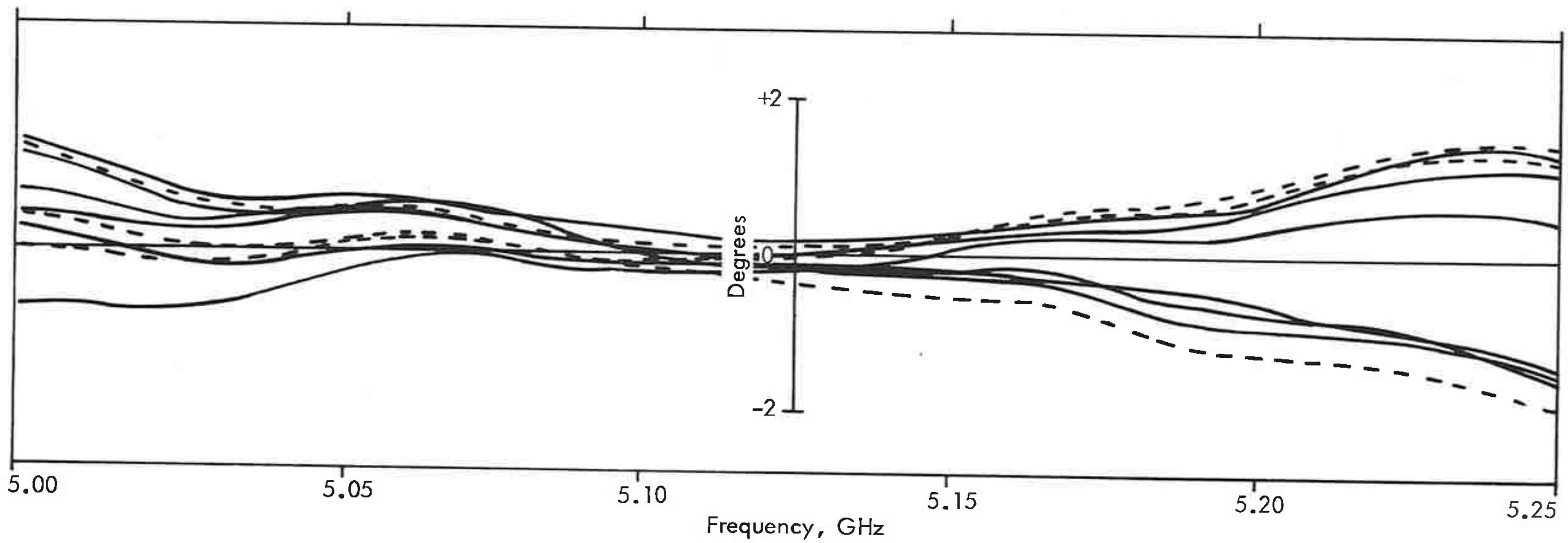


Figure B.37 Phase Shift Variations vs Settability of Mechanical Phase Shifter

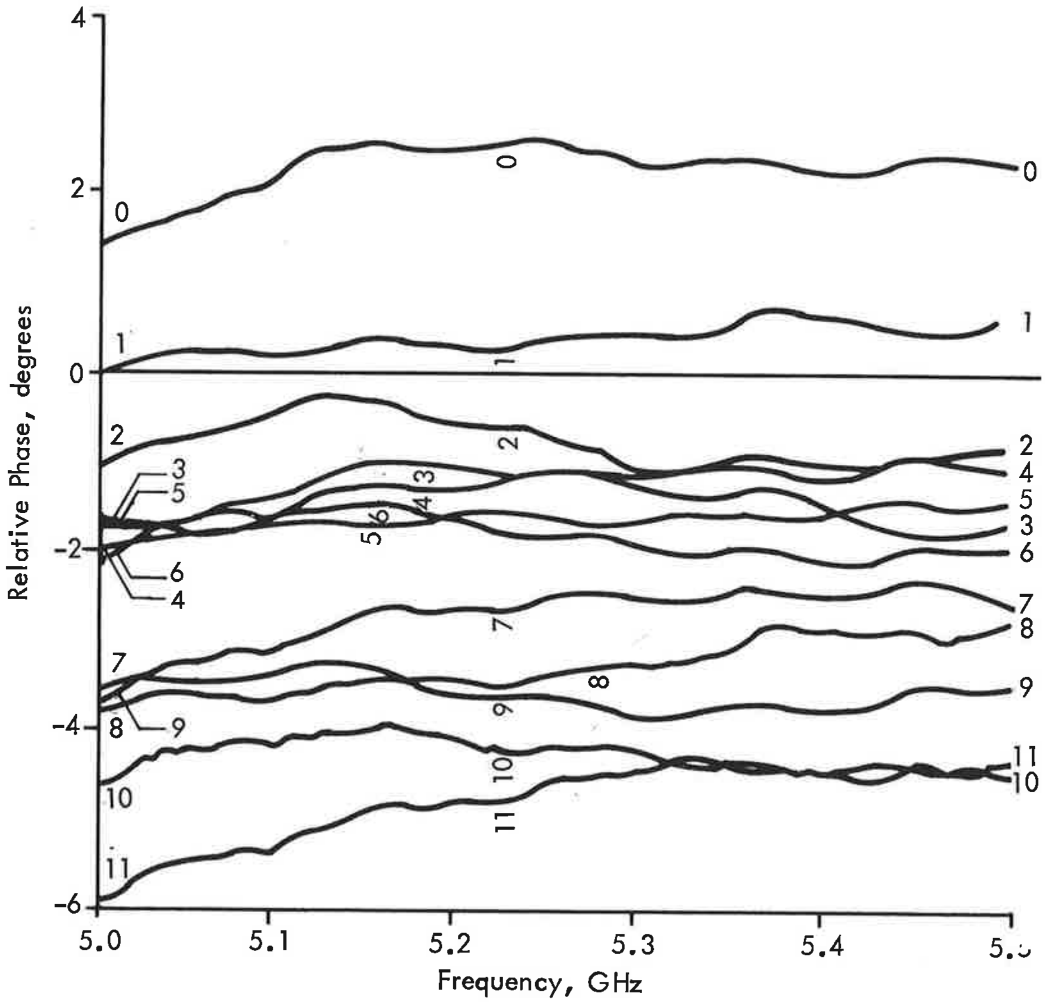


Figure B.38 Transmission Phase Characteristics of Mechanical Attenuator

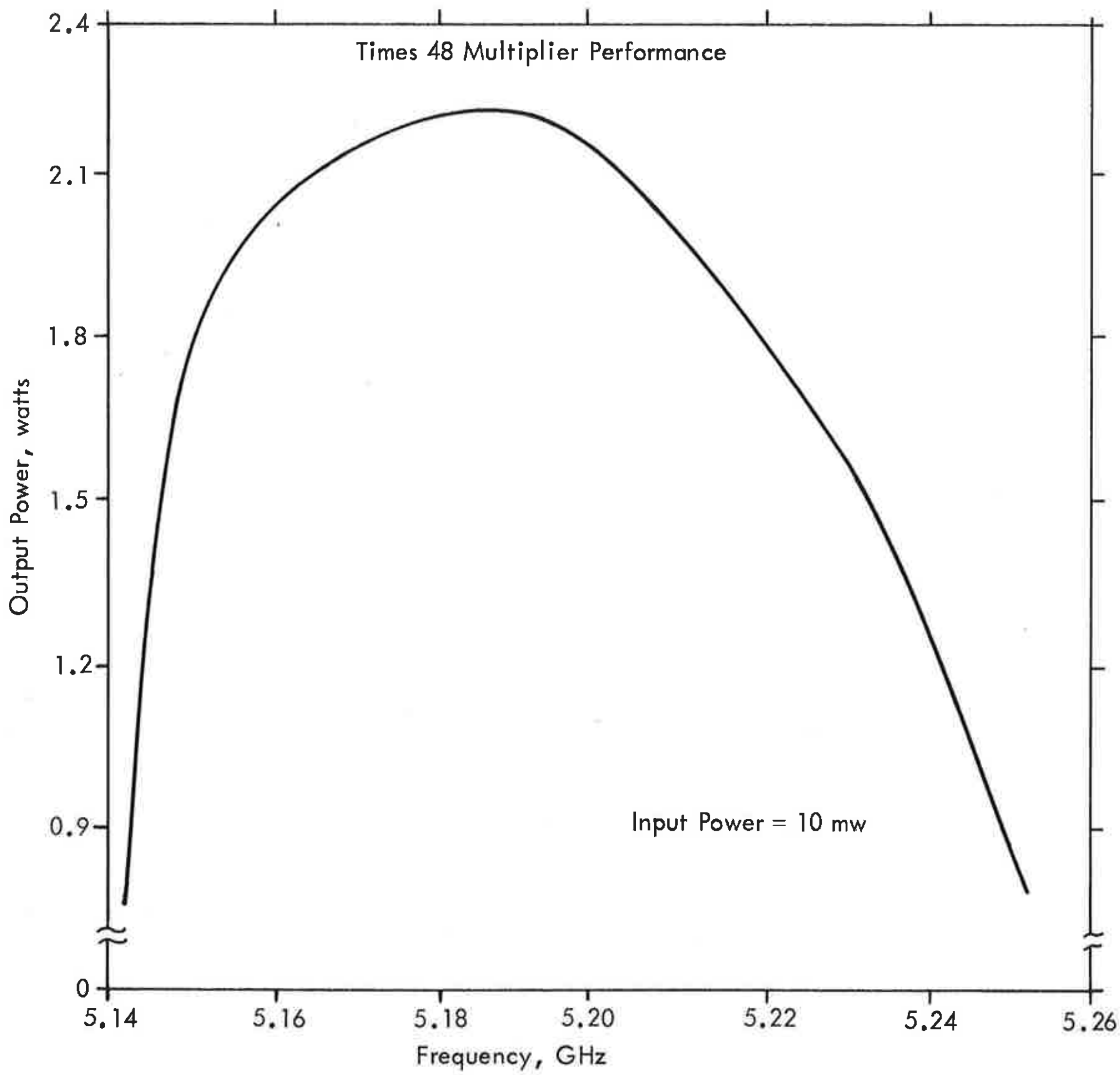


Figure B.39 Times 48 Multiplier Performance

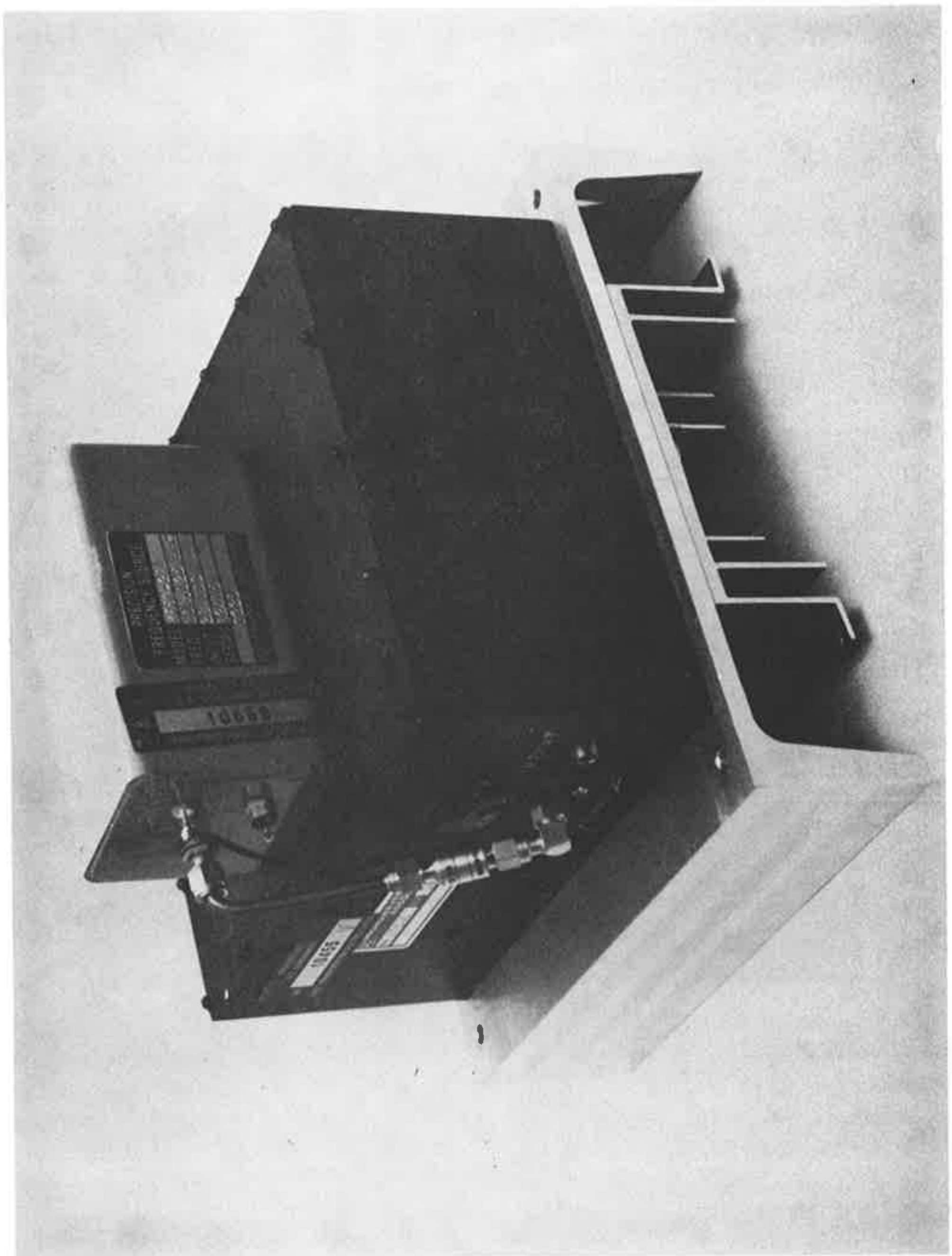


Figure B.40 Photograph of 2-Watt Transmitter Subassembly

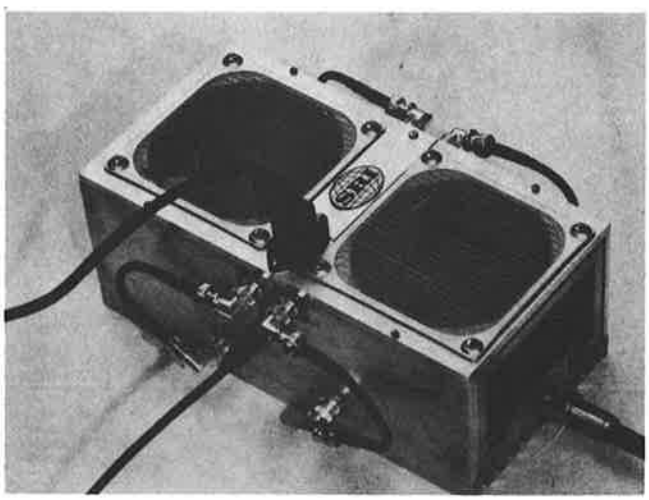


Figure B.41 4-Diode C-Band Impatt Amplifier

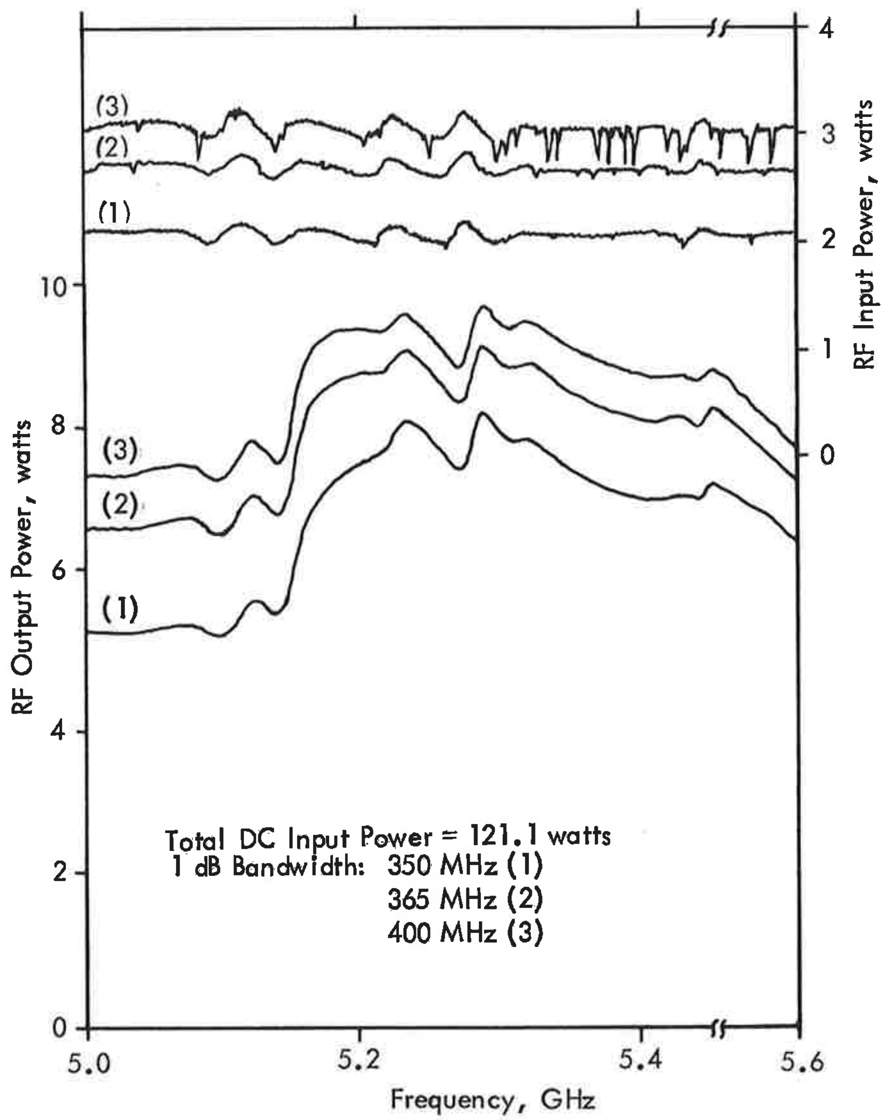


Figure B.42 Swept Frequency Response of 4-Diode C-Band Impatt Amplifier

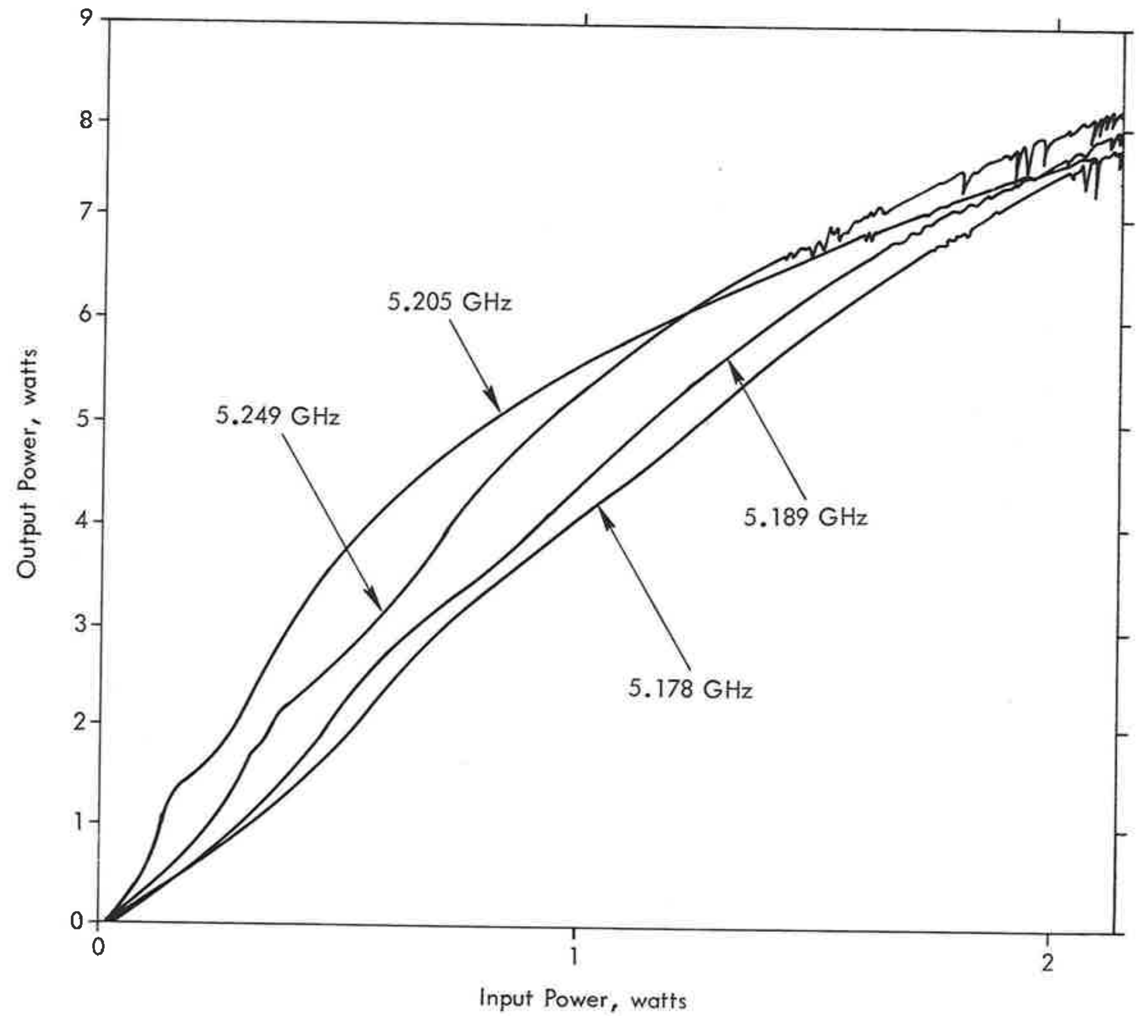
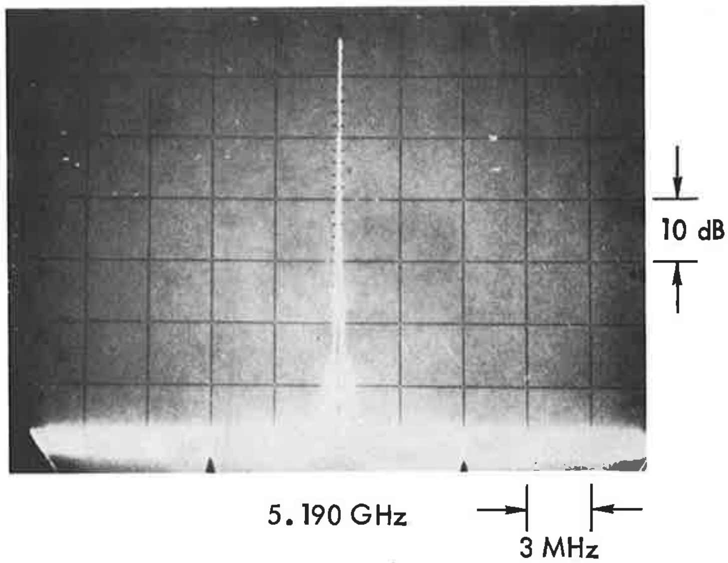
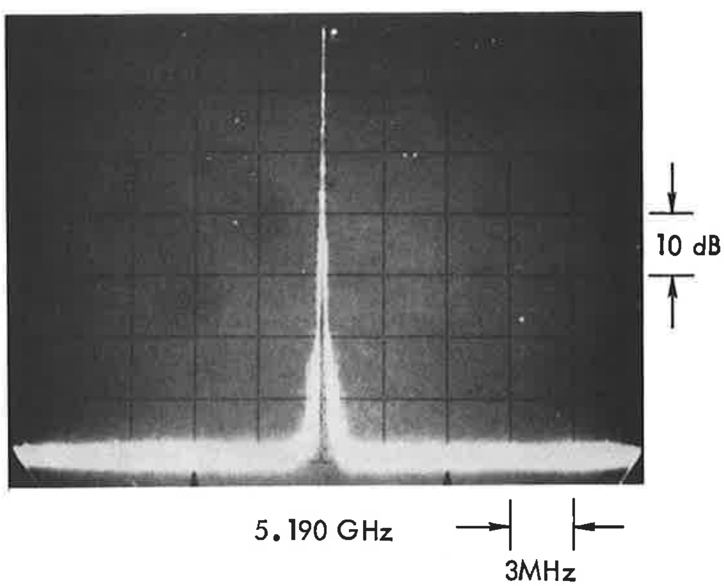


Figure B.43 Gain Response Measured on 4-Diode Amplifier



INPUT FREQUENCY SPECTRUM



OUTPUT FREQUENCY SPECTRUM

Figure B.44 Noise Characteristics of 4-Diode Impatt Amplifier

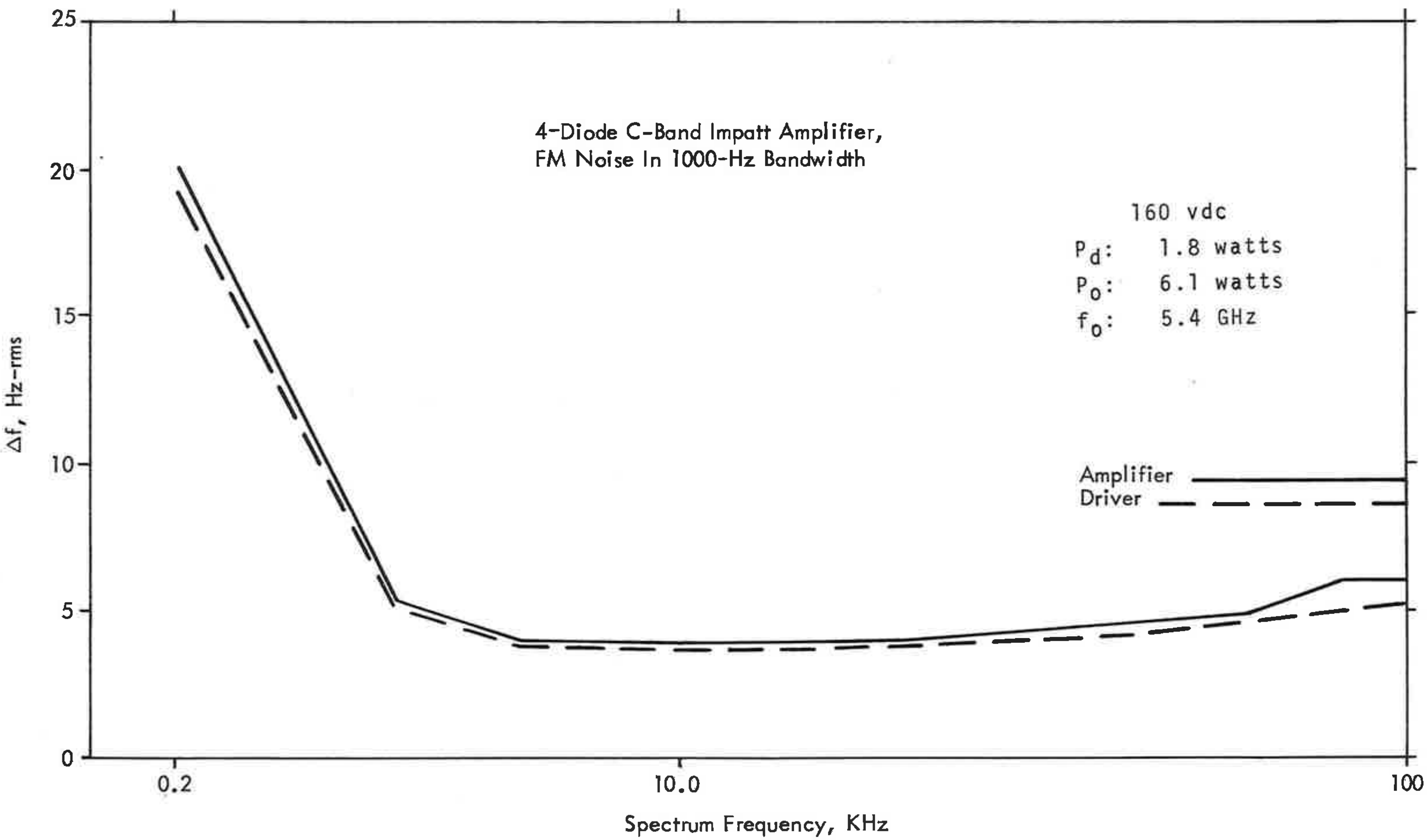


Figure B.45 4-Diode C-Band Impatt Amplifier FM Noise in 1000 Hz Bandwidth

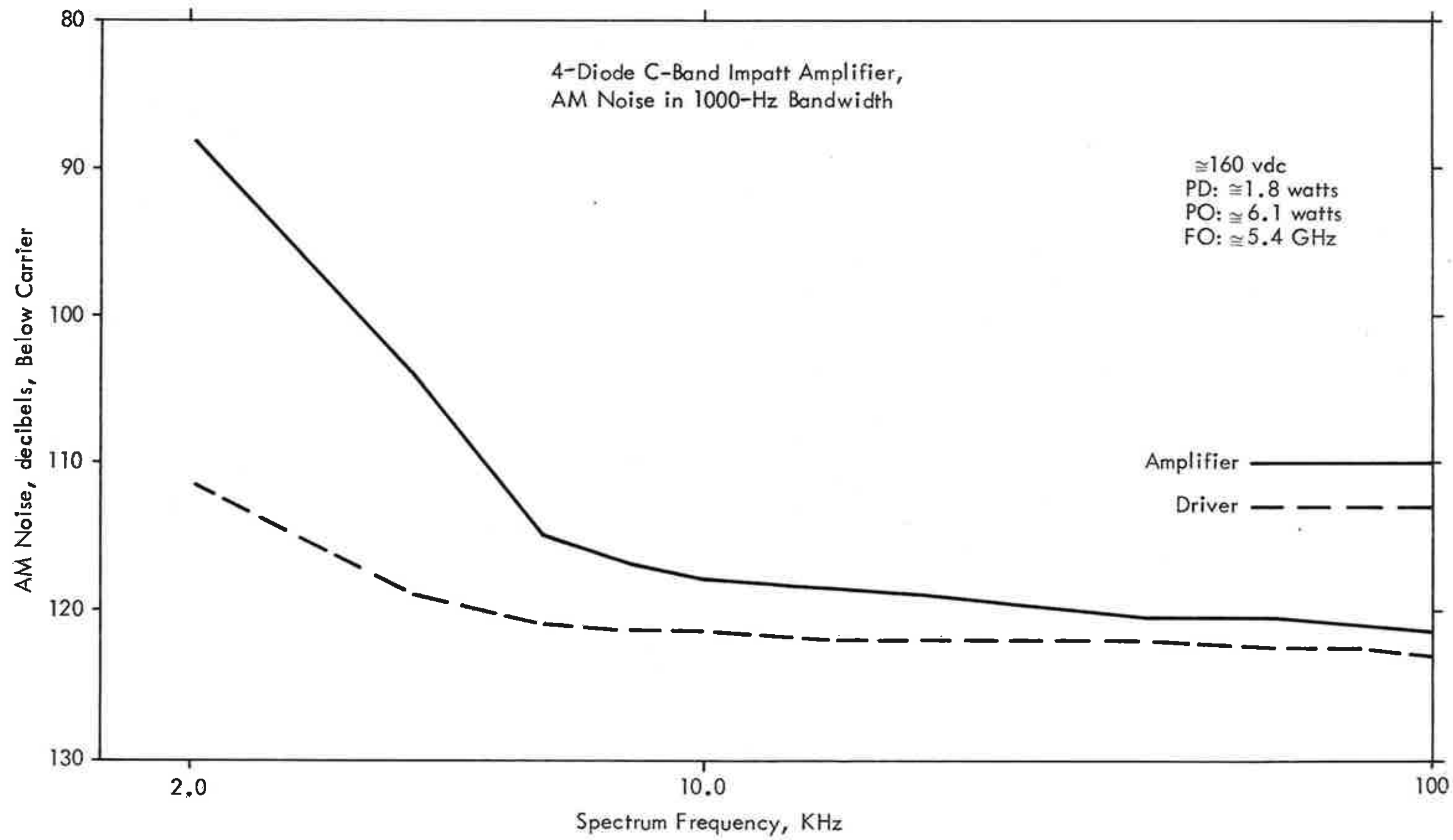


Figure B.46 4-Diode C-Band Impatt Amplifier AM Noise in 1000 Hz Bandwidth

APPENDIX C

ELEVATION COMPONENT SPECIFICATION

Two types of components purchased for the Elevation Antenna Subsystem are the power dividers and the digitally controlled 4-bit diode phase shifters. The specifications of the power divider are, except for somewhat tighter mechanical requirements, similar to those given in Table B.6. The specifications for the phase shifters have been modified from the earlier procurement to provide the best possible unit within the exigencies of a reasonable system time schedule and the limitations imposed by the current state-of-the-art. The contract for these fifty two phase shifters has been awarded to Microwave Associates, Burlington, Mass. Forty eight of the units will be incorporated into the Elevation Antenna Subsystem. The phase shifter specifications are presented in Table C.1.

TABLE C.1

Specification: C-Band Digitally Controlled, 4-bit Phase Shifter

1. Scope: This document contains the performance and data requirements for a C-band digitally controlled, 4-bit diode phase shifter to be used for fine phasing in a phased array antenna.

2. Applicable Documents:

MIL-I-6181D	Interference Control Requirements, Aircraft Equipment
MIL-217A	Reliability Handbook
FAA-G-2100	Electronic Equipment, General Requirements; Basic Requirements for all Equipments

3. Requirements:

3.1 Summary: This section defines the requirements for the diode digital phase shifter. The device shall be reciprocal in order to be used in either a transmit or receive mode.

3.2 Drawings:

1. The vendor shall supply general schematic diagrams, and parts lists suitable for engineering use and analysis.

2. The vendor shall supply an outline drawing of the phase shifter within thirty (30) days ARO. Mounting holes, dimensions, and connector locations shall be clearly indicated. The TSC Technical Monitor shall approve or reject these within seven (7) days of submission.

3.3 Electrical Requirements:

1. Frequency Range: 5.0 to 5.25 GHz; 4.9 to 5.35 GHz goal

2. VSWR: 1.80 maximum at input or output (relative to 50 ohms)

3. Insertion Loss: 1.30 ± 0.40 dB maximum, from -30°C to +40°C at all frequencies; 1.5 ± 0.4 dB from +40°C to +70°C at all frequencies.

4. Power Handling Capability: Shall be 700mW minimum, with one watt desired. All units shall meet all the technical requirements of this Exhibit at any power level up to the maximum stated herein.

5. Phase Shift: 0 to 337.5 deg in steps of 22.5 deg. Each unit at any given frequency: rms phase error over all bias states shall be 5 deg or less. From -30°C to +40°C; not more than two points to exceed ±7 deg phase deviation from the nominal; maximum phase deviation from the nominal at any bias state shall be plus or minus 10 deg; the total of the maximum positive and the maximum negative deviations from the nominal shall not exceed 17 deg. From +40°C to +70°C; maximum phase deviation from the nominal not to exceed ±8 deg.

6. Insertion Phase: Unit-to-unit at zero phase shift setting: For 48 out of 52 units, the maximum insertion phase difference between any two units shall not exceed 15 deg at any frequency; for all 52 units, the maximum difference shall not exceed 20 deg.

7. Switching Time: Total switching time shall not exceed 700 nanoseconds under all operating conditions required by this specification and under a single set of power supply voltage levels to be specified by the vendor. Total switching time to be measured from 90% of final level of pulse logic voltage applied at driver in phase shifter to 90% of the RF bias state change, including ringing. This measurement shall be performed on the 45 deg bit.

8. Control: Phase shifter driver shall be designed to interface over the entire temperature range, with TTL logic, wherein a 0 to 0.8 volts represents a logic "zero" and 2.5 to 5.0 volts represents a logic "one". In no case shall the logic source be required to sink more than 16 mA per bit in the logic "zero" condition or to source more than 400 microamps per bit in the logic "one" condition. The steady state current through the microwave switching diodes shall not be dependent on the current gain (beta) of any of the transistors in the phase shifter driver circuit.

   With all four bits in logic "zero" state, the phase shifter shall be in its electrically shortest state.

9. Switching Rate: Up to 40 kHz maximum

10. RF Isolation: C-band energy on the phase shifter control leads shall be down by at least 30 dB below the RF input signal under any test condition.

11. Number of Drivers: Four (one for each bit), integral with phase shifter. Each unit shall contain, integral with the phase shifter, suitable capacitors shunting

the forward and reverse bias input lines, for the purpose of smoothing out bias line voltage fluctuations.

12. Phase Shifter Status Monitor: One sensing resistor shall be incorporated in the drive circuit for each diode in the 180 deg and 90 deg bits and one sensing resistor in the drive circuit for each pair of diodes in the 45 and 22.5 deg bits, to permit remote monitoring of the phase shifter status.

13. Switching Transients ("dribble"): The generation of energy on the RF input and output ports commonly caused by the phase shifter control signals shall be minimized. Maximum advantage is to be taken of the relatively slow switching time in order to achieve this end.

    With no RF signal applied and the input and output ports terminated in 50-ohms (1.1 max, VSWR), the phase shifter shall meet the following requirements:

    a. Above 2.0 GHz, power density to be less than -85 dBm/MHz.

    b. Video switching transient signals present on the RF ports as observed with a suitable broadband oscilloscope shall not exceed an amplitude of 1.0 volts peak maximum.

14. Third Order Intermodulation Products: When the phase shifter is driven by two test signals of equal amplitude within the specified operating bandwidth, it shall meet the following performance characteristics:

    1. With two test signal levels less than +27 dBm, third order products shall be equal to or greater than 20 dB below test signal levels.

    2. With two test signal levels less than +20 dBm, third order products shall be equal to or greater than 30 dB below test signal levels.

    3. With two test signal levels below 0 dBm, third order products shall be equal to or greater than 40 dB below test signal levels.

NOTE: The above specification shall be met with the test signals injected at either RF port and with the phase shifter set at any value within its specified operating range. Test signal frequency separation shall be such that third order intermodulation products fall "in-band".

15. Spurious Signals: When the phase shifter is driven by one test signal of 700 mW, nominal, in the design band, spurious signals in the 4.0 to 12.0 GHz band shall be equal to or greater than 40 dB below the test signal level.

16. RFI: The generation of RFI and the vulnerability of the component described herein to RFI shall meet the limits of Specification MIL-I-6181D.

3.4 Mechanical Requirements:

1. Connectors:

RF input:	SMA Female, end launch; model number to be approved by TSC.
RF output:	SMA male, end launch; model number to be approved by TSC.
Control:	Shielded ribbon cable, 24" minimum length. Phase shifter status monitor leads may be included in the control cable.

2. Weight: Less than 1 lb.

3. Size: Maximum Length, 7.00 in: unit-to-unit length variation between mating RF surfaces shall be ±.020 in. maximum. Height and width should be small enough, including driver, to allow connectors to feed into 2 inch by 2 inch grid (maximum unit size to be 1.50 by 1.00 inches, small size preferable).

4. Mounting: Shall mount to a flat surface with 4-40 hardware.

5. Finish: Corrosion resistant. The assembly shall be suitably finished to prevent deterioration of the housing material over the operating and environmental conditions in the specification.

6. Cooling: The phase shifter shall be designed to be cooled solely by natural convection.

7. Marking: All units shall have a label (stenciling to be avoided) that contains at least the following information:

   1. Manufacturer's Name
   2. Model Number
   3. Serial Number
   4. Device Nomenclature
   5. TSC Contract Number

3.5 Reliability:

1. Devices to be designed to have an MTBF of at least 20,000 hours.

2. As a minimum, the phase shifter and driver shall be designed for continuous operation for a period of one year with no more than minor maintenance.

3.6 Environmental Requirements:

1. Temperature: -30°C to +70°C.

2. Humidity: 0 to 100%

3. Salt Atmosphere: As encountered in coastal service

4. Altitude:

   Non-operating: Sea Level to 30,000 ft.
   Operating: Sea Level to 10,000 ft.

5. Shock (non-operating): 10g any direction

6. Vibration (non-operating): 10 to 55 cps with a 0.03 inch total excursion

7. General: Since condensation and salt-laden atmospheres are expected within the stated temperature range, the phase shifter shall be capable of operating under these conditions.

3.7 Design Requirements:

1. The design approach shall be amenable to large quantity production.

2. The phase shifter shall be so shielded that its performance is not degraded by the proximity of adjacent phase shifters spaced on 2 inch centers.

4. Quality Assurance Provision:

4.1 Temperature Cycling: Prior to final evaluations for obtaining test data required by this specification, each unit shall be temperature cycled by the manufacturer over the temperature extremes a minimum of two times with the units soaked for a minimum of one (1) hour at each temperature extreme. The Government reserves the right to temperature cycle all units, between the temperature extremes for the soak times specified, at least 100 times in the course of a year after final delivery. The manufacturer guarantees that all units will operate in conformance with the technical requirements of this Exhibit at the end of each or any cycling segment, or at any temperature within the extremes.

4.2 First Article Tests: The following first article tests will be performed on the first two production units by the manufacturer at his facility in the presence of a TSC representative. (Written notice must be received by the TSC Technical Monitor at least seven (7) days prior to the date of the test. TSC reserves the right to not witness the tests.) These tests will be performed over the specified temperature and RF power ranges and over a frequency range from 4.9 to 5.35 GHz at intervals of 50 MHz, and at 5.125 GHz if swept frequency techniques are not used.

a. Phase shift accuracy at all settings
b. Insertion phase tracking
c. Insertion loss
d. VSWR of both RF ports
e. Switching speed at band center for 45 degree bit
f. Switching transients
g. Spurious outputs: to be measured on a Hewlett Packard 851B Spectrum Analyzer, or equivalent.

Test data sheets shall be supplied with all units per data sheet formats approved by TSC.

4.3 Production Tests (all units): The following production tests shall be performed by the supplier at his facility on all production units. These tests shall be performed at room ambient temperature over a frequency range of 5.0 to 5.25 GHz at intervals of 50 MHz and at 5.125 GHz if swept frequency techniques are not used.

a. Phase shift accuracy at all settings
b. Insertion phase tracking
c. Insertion loss, and
d. VSWR

Test data shall be supplied with all units per data sheet formats approved by TSC.

4.4 Acceptance: The supplier shall guarantee all performance requirements of this specification. TSC will also perform tests to verify that the units meet the requirements of this specification. Final acceptance or rejection shall be made only after the satisfactory completion of these tests, which shall be made within thirty (30) days after receipt by the TSC Technical Monitor.