THE NATIONAL RADIO ASTRONOMY OBSERVATORY

SOCORRO, NEW MEXICO

VERY LARGE ARRAY PROGRAM

VLA ELECTRONICS MEMORANDUM NO. 197

MODEM T1 COMPRESSION, EARLY MEASUREMENTS, OPTIMIZATION OF CHANNEL SELECTION, AND RECOMMENDATIONS

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1.0 INTRODUCTION

Because of possible front end noise temperature variations across each 50-MHz IF passband it is desirable to measure the front end noise temperature after the narrow filters in the T4C baseband filter module. This puts an additional constraint on the IF communications system (modems and baseband modules) not originally envisoned in the design of these systems as to linearity. It is desired to have a maximum compression of 1% throughout the modem and baseband systems. The baseband system will be able to approach this through the design of a new power amplifier stage. The modems, however, operate at a disadvantage in that the same mixer is used for both transmit and receive functions. This results in a compromise between compression in transmit and noise figure in receive. System specifications were originally set using T1A1 and T1A2 (with the TRG prototype modem RF subassemblies) as examples. For a total modem output power from the vertex room of +1 dBm this resulted in a signal-to-noise ratio of 20 dB for each of the four IF signals for a maximum waveguide loss of -56 dB. It also resulted in some compression of the transmitted signal. Because of room limitations in the T1D series of modems it was decided to use fixed attenuator pads in 2-dB steps to set the modem total power transmit level (with a -6.5 dBm 1500-MHz transmit IF carrier) to about +1 dBm waveguide output power.

The compression for the "T1D" series modems on actual front end A, B, C, and D IF noise power became worse than that originally encountered on the prototype modems. This occurred for a number of reasons presented in Section 2.0. These problems have resulted in some modems compressing the A and C IF signals by more than 50%. The effect of this clipping on the array sensitivity is minimal, and since the front end noise temperature is currently measured at the F4 in the front end rack this measurement was also not affected in the previous continuum system.

However, the accuracy of front end noise temperature measurement at the T5B baseband driver output is severely degraded. Fortunately, the actual modem-to-modem waveguide loss is much less than the originally predicted -56 dB, and varies considerably from station to station. This report originally was an attempt to propose a modem channel selection versus antenna station selection based on predicted waveguide loss and measured modem performance that would provide less than 1% compression at $\geq$20 dB IF signal-to-noise ratio.

The paper also proposes alternative modem design changes to implement the lower transmit IF levels. Because of difficulties involved with measurement of 1% compression, it was not possible to gain adequate accuracy to permit a reliable channel selection. A proposal will be made for a better measurement scheme that might provide this in a future paper. However, time and funding may not permit the measurements to occur. A summary of measurement data with an example of an optimization program is, however, presented to demonstrate the methods that would be required to implement this in the future.

2.0 PRESENT MODEM COMPRESSION

Many problems have resulted in severe compression of the IF signals transmitted from the vertex room in the "T1D" series modems.

First, the peak-to-average ratio of a 1500-MHz transmit IF carrier is less than that of broadband noise power. Most of the power in the vertex room transmit IF passband is noise power.

Second, because of image enhancement effects in the modem mixer, the 1-dB compression point versus transmit IF frequency tends to peak at 1500 MHz and deteriorate in the rest of the passband. T1D19, for example, had a carrier -1 dB compression point of >+5 dBm at 1500 MHz, but only +0.5 dBm at 1000 MHz. Fortunately, the fact that the A, B, C, and D IF channels are near the center of the 1-2 GHz passband somewhat negates this effect. But LO cross-modulation effects have worsened.

Third, many modem mixers have -1 dB compression points with a 1500-MHz transmit IF carrier much worse than the +5 dBm specification on the mixer. This is in part due to diode availability problems and requirements of the modem installation schedule. An agreement with Spacekom to refit some modem mixers to meet specifications was obtained. However, the logistics required to do this have been prohibitive.

Fourth, the design of the Spacekom modem mixer is derived from an earlier design of a push-push frequency doubler. As such they emit a large amount of 2nd harmonic power of the LO signal. This is not effectively filtered by the SSB waveguide filter, as is the case with many waveguide filters. Thus the termination after the SSB filter may effect the compression performance of the mixer, when the reflected portion of the 2nd harmonic signal recombines in the mixer. The switched circulator is not controlled in this regard. However, measurements on T1D22 (channel 4) have indicated that most of this 2nd harmonic LO signal is either reflected or terminated at the circulator, and does not propagate out of the modem waveguide extension.

Fifth, -1 dB compression usually varies in step with local oscillator power in the modem mixer. Because the modem Gunn oscillators are specified at a power level of ±1 dB, the -1 dB compression point will also vary ±1 dB due to Gunn interchangeability. Also there is no data on long term Gunn output power variations, although Hughes has indicated that it has had problems with the diode mounts in these oscillators and, the poor reliability of these units is the greatest cause of modem failures.

Sixth, a number of problems limit the accuracy of compression measurements. Accurate calibration of millimetre wave power meter thermister mounts used in measuring Gunn power and modem -1 dB compression is poor at best. Hughes believes that their 33-50 GHz thermister mount absolute accuracy is on the order of ±0.5 dB, but this is not specified. Also harmonic power from the source can deteriorate this estimate. Because the slope of output power versus input power decreases near the -1 dB compression point, and since compression is measured with respect to output power, the slope degrades the accuracy of measurement of required input power. If the 1% compression point is desired the accuracy and repeatability are further degraded due to the low resolution of measurement on the lower power meter scales due to drift and noise. And it is cost prohibitive to amplify the modem millimetre wave output to improve this situation. Also VSWR presented to the transmit IF step attenuators and attenuator resettability may account for large errors in comparison measurement. Unless the step attenuators are calibrated at exactly the same meter readings for both XMT IF and modem waveguide output, change of meter scale and step attenuator range offset errors have prohibited accurate measurements. Because of the above factors the interpretation of data is highly subjective, particularly with 1% compression measurements.

Seventh, operator differences in interpretation of data and in test setups have caused modems to be level-set at different points. This has somewhat been alleviated with a more consistent procedure in the recent modem survey, but differences still exist.

Eighth, the resolution of 2-dB steps in level set pads along with availability of desired pad values at the time of calibration have also introduced variations in the -1 dB compression point of modems, relative to input power.

Ninth, the actual input level to the modem may change from antenna to antenna due to front end F4 variations and T2 transmit IF variations. Interchangeability of T2 modules may cause the T1 transmit IF input power to be greater than -6.5 dBm resulting in greater compression.

3.0 MODEM MEASUREMENTS

3.1 T1 Test Procedures

Many errors in modem compression and noise figure measurements have appeared in the past due to inconsistent operator test setups and interpretation of data. Therefore consistent test procedures and a consistent method of decoding of data were evolved to correct this problem. Both broadband noise compression and frequency swept sinewave compression and both broadband 1-2 GHz noise figure and spot noise figure measurements were taken for later comparison. Serial numbers of major modem RF components were recovered for each module for relation to manufacturer's data. When pertinent, correction factors were included on thermister mounts used in power measurement and the rated excess noise power of noise tubes were recorded with the data taken for later reference.

The test procedures and test setups used in all of the modem measurements are given in Figures 3-1 and 3-2. An example of a completed modem data sheet is given in Figure 3-3. Only channel 1-9 modems were measured since only they will be used in the operational array.

3.2 Calibration of Noise Tubes

Modem noise figure measurements are made with Maier Electronics noise tubes. The manufacturer does not calibrate these tubes across a millimetre wave waveguide band, but instead calculates a theoretical value of excess noise power for the gas tube in question and gives a peak-to-peak error specification in this value based on the maximum VSWR of the tube. Paul Crandall of Hughes had indicated to me that Signalite millimetre wave noise tubes can have actual excess noise power variations of ±3 dB across a waveguide band. Because this is a considerable error, a calibration of each noise tube for each modem waveguide channel was completed using the modems themselves as receivers. A hot and cold load (liquid nitrogen) and waveguide

MODEM TRANSMIT COMPRESSION MEASUREMENTS PROCEDURE

1. With the thermister power meter set levels such that -5 dB → -6.5 dBm from 1-2 GHz.

2. Calibrate the X-Y plotter from 1-2 GHz with the power meter at the end of the modem "transmit IF cable" in 1-dB steps.

3. Plot the modem output versus input level versus frequency from 1-2 GHz with the power meter at the waveguide output. Plot -1 dB compression point versus frequency.

4. Measure noise power level at modem "transmit IF cable" with 1-2 GHz noise source. Measure modem output power versus input power in 1-dB steps using digital voltmeter. Calculate -1% compression point.

Figure 3-1A

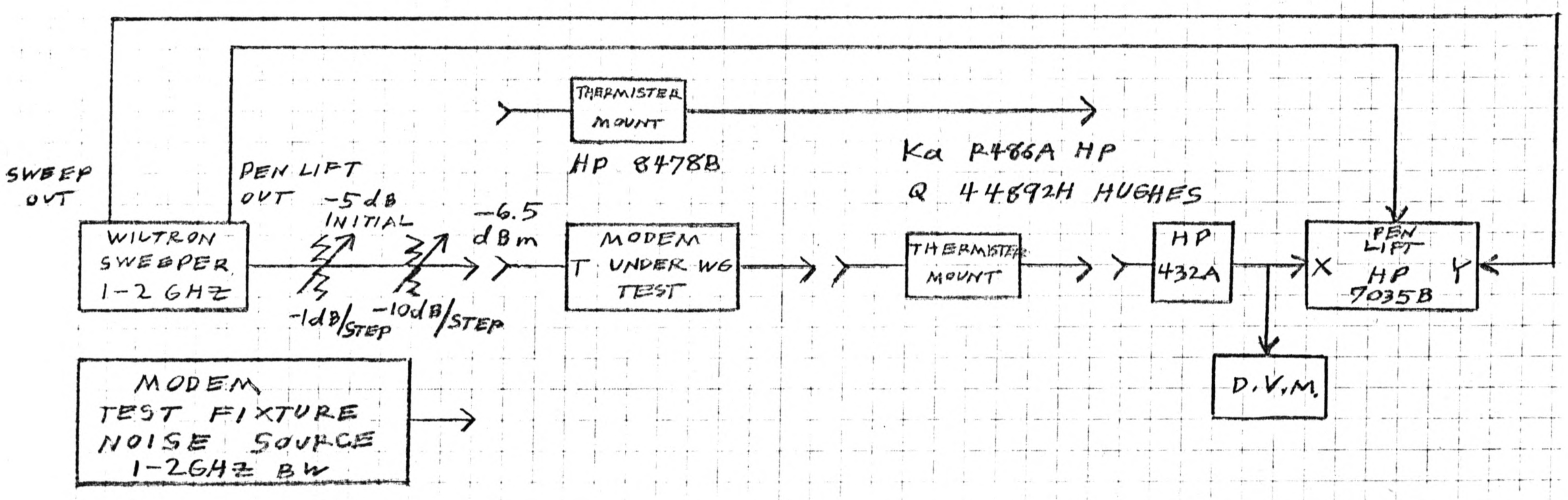


Figure 3-1B: MODEM TRANSMIT COMPRESSION MEASUREMENTS TEST SETUP

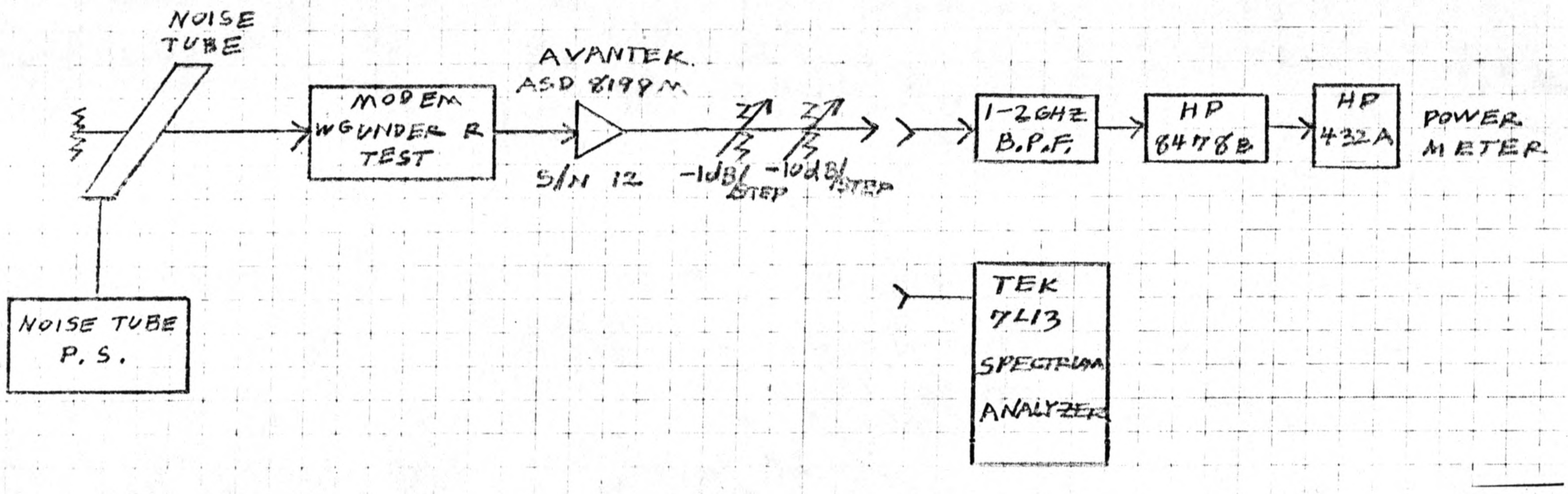
MODEM SPOT AND BROADBAND SSB NOISE FIGURE MEASUREMENT PROCEDURES

1. Measure broadband SSB noise Y-factor with power meter and 1-2 GHz filter as shown. Convert to noise figure and record.

2. Calibrate 7L13 spectrum analyzer on 2-dB/division scale with 1-dB step attenuator with noise source on.

3. Measure spot SSB noise Y-factor with spectrum analyzer in storage mode. Photograph results. Convert worst case (minimum Y-factor) to noise figure and record result.

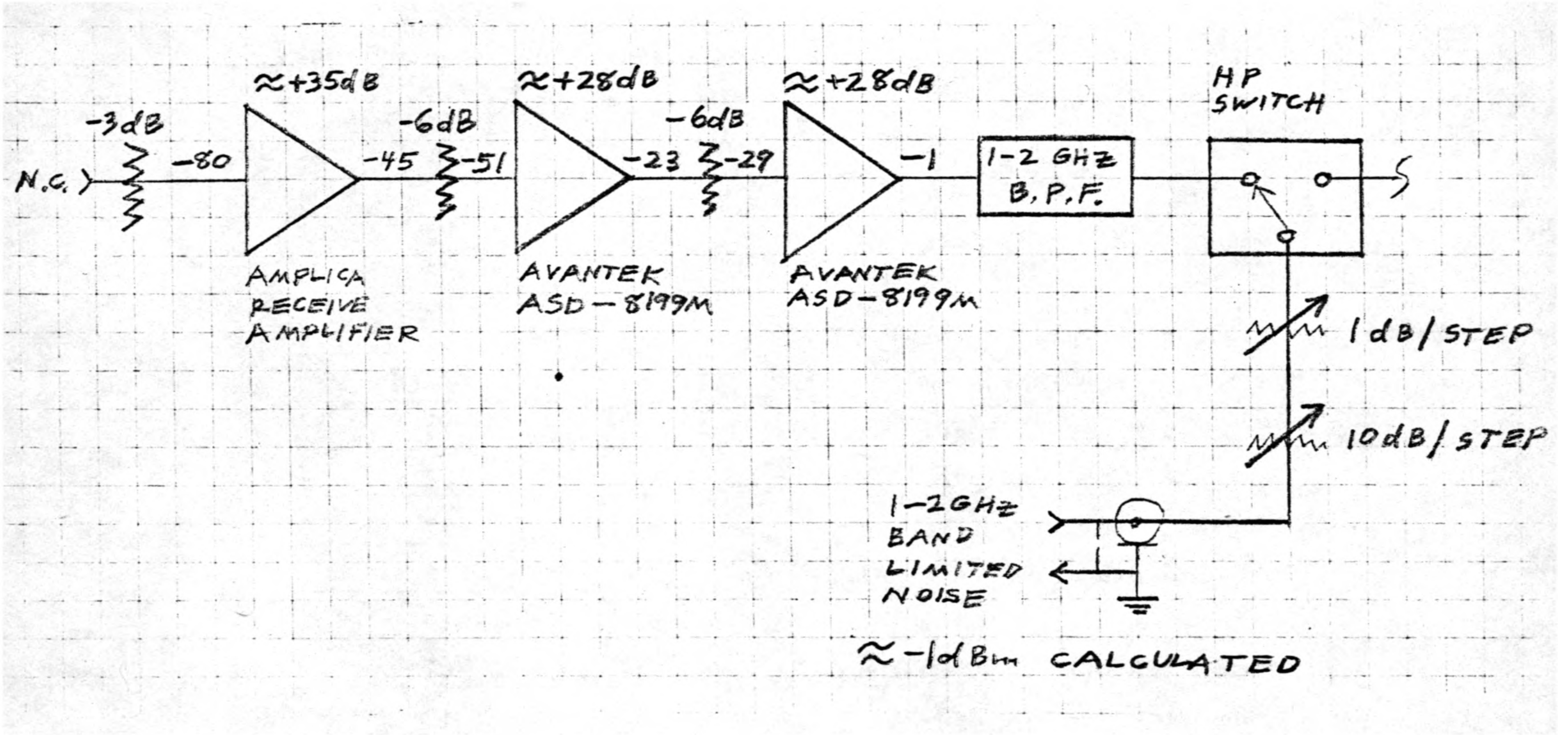
Figure 3-2A



N(dB) = excess noise (dB) -10 LOG (Y-1)
Y = Y-factor (power ratio)

2 dB/div
1-2 GHz
3-MHz BW
Slow sweep
Storage mode
10-dB RF attenuation

Figure 3-2B: MODEM SPOT AND BROADBAND SSB NOISE FIGURE MEASUREMENT SETUP



P_n = NKTB [@ 0 dB NF, noise factor = 1]
$P_n = (1)\ (1.38\times10^{-23})(290)(1\times10^{9})$
$P_n = 4 \times 10^{-12}$ watts @ 0-dB NF
$\therefore P_n = 4 \times 10^{-9}$ mW → -84 dBm
But N ≈ +4 dB for receive amplifier.
$\therefore P_{n(\text{input total})}$ = -84 dBm + 4 dB = -80 dBm
From above diagram Pn (output total ≈ -1 dBm)

ASD8199M -1 dB compression point ≥+7 dBm

Figure 3-2C: MODEM TEST FIXTURE NOISE SOURCE

WED 8/29/79
Modem SN T1D 15
Waveguide Channel 7
Location Rack B2 Antenna 2
Date 9-18-79
By

Component Serial Numbers

Latching Circulator (EMS)	3	
Up/down Mixer (Spacekom)	50C9	
Harmonic Mixer (Atlantic Microwave)	17	
Gunn Oscillator (Hughes)	087	
2400-MHz Amplifier (Avantek)	177	
SPDT Pin Diode Switch (Alpha)	18	
Receive Amplifier (Amplica)	110	
Transmit Amplifier (Locus)	01	
Transmit Level Set Pad Value	12	dB
SPST Pin Diode Switch (Alpha)	23	

Figure 3-3: EXAMPLE MODEM DATA SHEET
(Page 1 of 5)(Typed Version)

WED 8/31/79
Modem SN T1D 15
Waveguide Channel 7
Location Rack B2 Antenna 2
Date 9-18-79
By ________________

Sinewave Transmit Passband Measurements

(from attached XMT response plot)

WG PWR MTR CAL, 0-dBm Meter Reading = Actual	+.85	dBm
Power Output @ -6.5 dBm 1500-MHz input	+3.3	dBm
-1 dB Compression Point @ 1500 MHz (sinewave)	+3.7	dBm
Minimum Spot -1 dB Compression Point (sinewave)	+0.7	dBm
@	1900	MHz

1-2 GHz Noise Power Compression Measurement

Atten. Setting	IF PWR	WG PWR MTR Voltage	MTR Voltage should be:	% Compression	Actual WG PWR
0 dB	dBm	+.8093 V_{dc}	+3.8770 V_{dc}	-79.1%	dB
-1		+.7739	+3.0796	-74.9	
-2		+.7363	+2.4462	-69.9	
-3		+.6931	+1.9430	-64.3	
-4		+.6450	+1.5434	-58.2	
-5		+.5938	+1.2260	-51.6	
-6		+.5417	+ .9738	-44.4	
-7	-5.9	+.4848	+ .7735	-37.3	
-8	-6.9	+.4260	+ .6144	-30.7	+2.2
-9		+.3686	+ .4880	-24.6	
	-8.4<			(20%)<>	+1.4
-10		+.3242	+ .3877	-16.4	
-11		+.2728	+ .3079	-11.4	
-12		+.2282	+ .2446	- 6.7	
-13		+.1872	+ .1943	- 3.7	
-14		+.1517	+ .1543	- 1.7	
	>-13.4			(1%)<>	-1.8
Ref. -15		+.1226	+ .1226	0	
-∞		+.0004			

Figure 3-3 (Page 2 of 5)(Typed Version)

WED 8/29/79
T1D 15
By

1-2 GHz Noise Power Compression Summary

(From data on page 2)

-1% Change in Compression/dB Power Levels	IF PWR =	-13.4	dB
	WG PWR =	-1.8	dB
-20% (-1 dB) Compression	IF PWR =	-9.4	dB
	WG PWR =	+1.4	dB

Phase Lock Loop Measurements

Phase Detector Voltage (V5a, Pin 3)	2.60	V_{dc}
10-MHz IF Level	-7	dB
10-MHz IF Noise Floor/300-kHz BW	-53	dB

(measured @ 5 MHz with 300-Hz video filter)

SSB Noise Figure Measurements

Noise Source Type No.	B501C	
Serial No.	RW522	
Operating Current	35	mA
Excess Noise Power	18.1	dB @ CAL

Broadband (1-2 GHz IF) Noise Figure Measurement

Broadband SSB Noise Y-Factor	7.1	dB
Broadband SSB Noise Figure	12.2	dB @ CAL

Figure 3-3 (Page 3 of 5)(Typed Version)

W.G. OUTPUT (INCL. +.85db THERMISTOR CORR.) TI D15 (CH 7) XMT RESPONSE

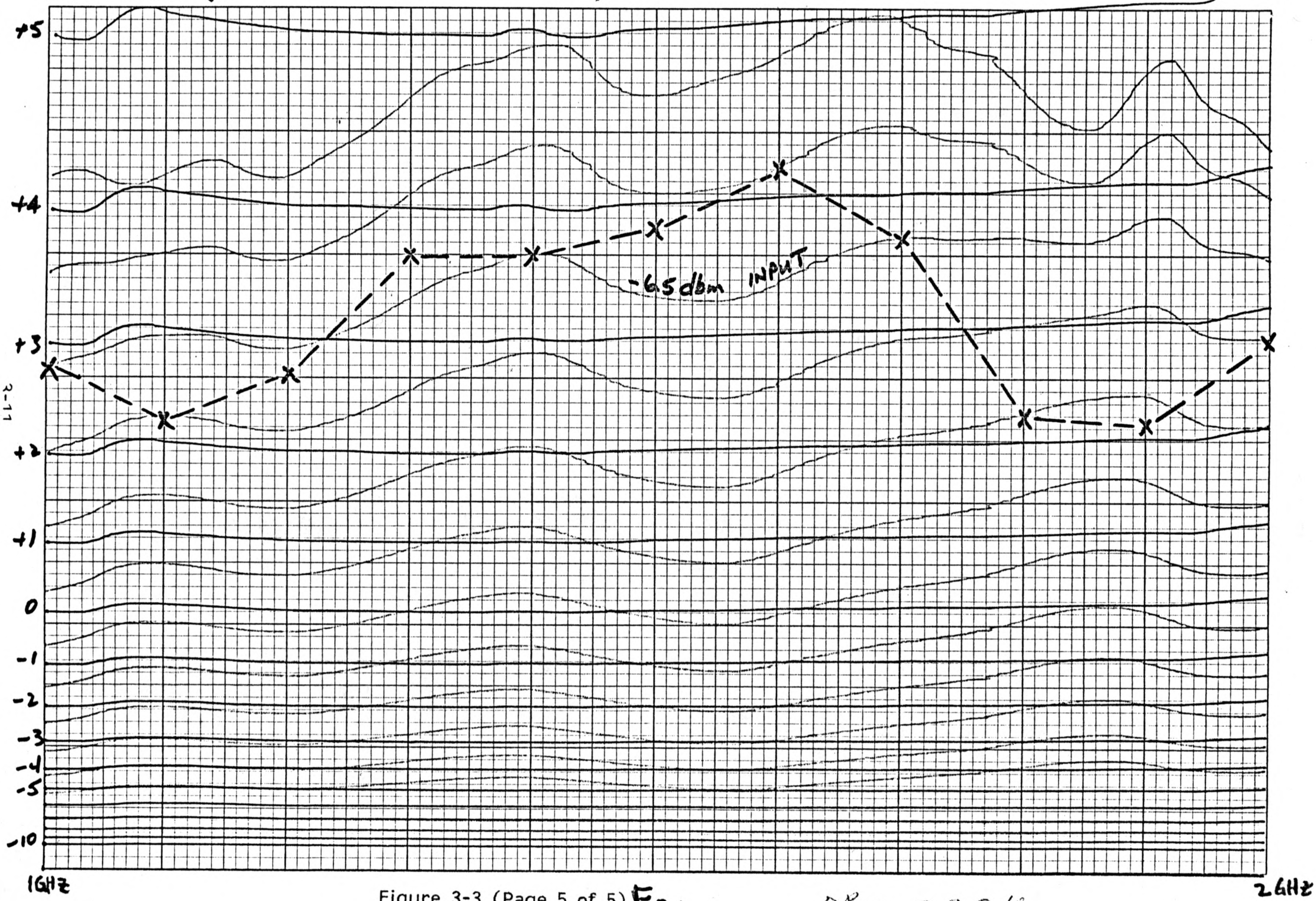
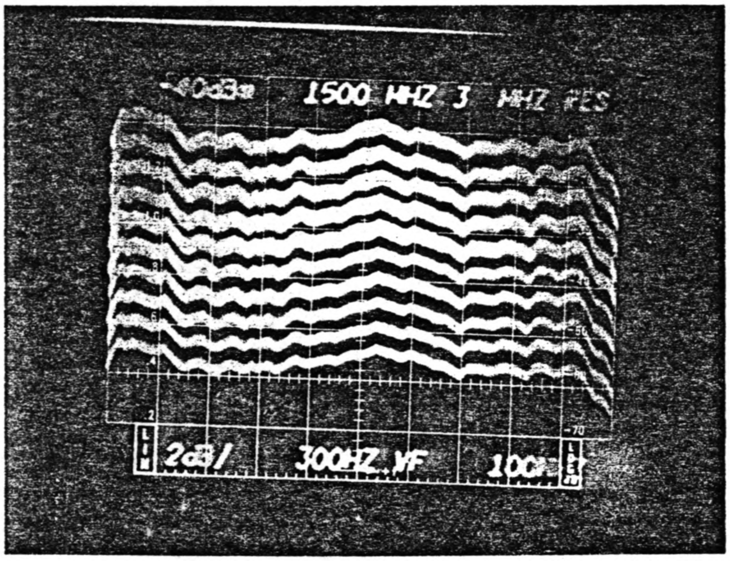


Figure 3-3 (Page 5 of 5) F_0

$\Delta P_{2090} = 2,0$ dB

WED 8/31/79
T1D 15
By

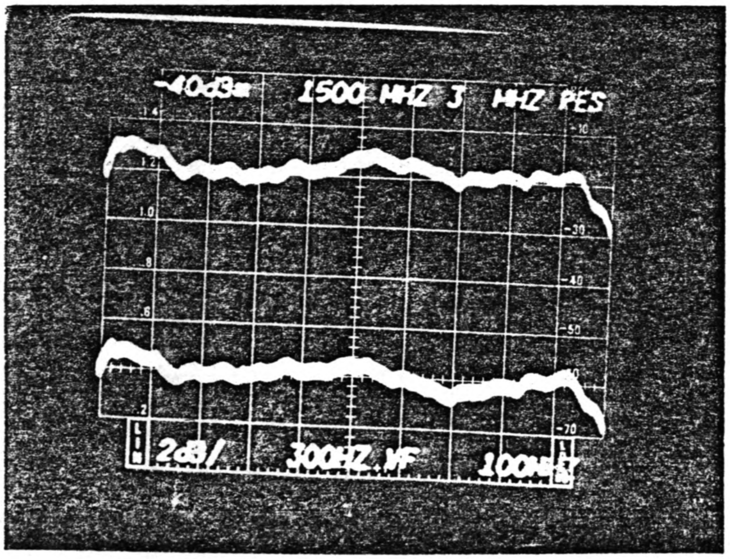
SSB Spot Noise Figure Measurements



SPECTRUM ANALYZER
CALIBRATION

1 dB/step

Retook w/FLANGE
11-13-79



SPOT Y-FACTOR
MEASUREMENT

2 dB/division
1-2 GHz

RETOOK w/FLANGE
11-13-79

Minimum SSB Spot Noise Y-Factor 7.8 dB
Maximum SSB Spot Noise Figure 11.1 dB @ CAL
@ 2000 MHz

Figure 3-3 (Page 4 of 5)

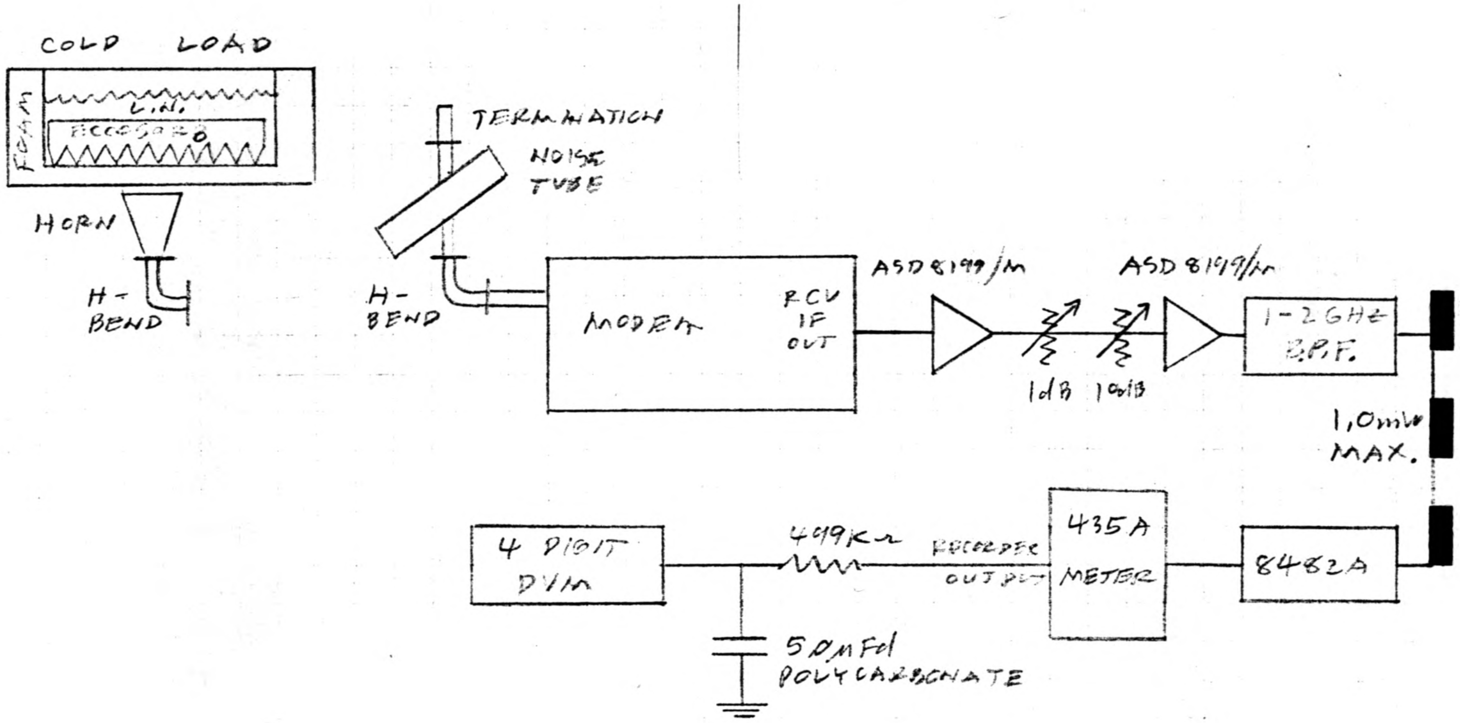
horn antenna was used as a standard of measurement. This is shown in Figure 3-5.

The antenna system was chosen over the waveguide switch system because of lower losses which are significant with a hot and cold load Y-factor of about 0.4 dB or so for the high modem noise figures of about 10 dB. An RC time constant of 2.5 seconds was used with a 4-digit DVM to insure best accuracy of measurement of the low Y-factor.

The results of these measurements are given in Figures 3-6 and 3-7. From measurements of different modems of the same channel at different times, it appears that a measurement error ≥ 0.4 dB in excess noise power, and therefore noise figure, exists with this system. Note that an increase in noise figure was obtained when the H-bend elbow was removed from the modem waveguide. This may have been due to horn antenna VSWR, or possibly modem variations with time, or possibly reading errors.

One other problem concerns modem and noise tube variations with warmup time. Data taken on WED-10/5/79 (not shown) indicates a 0.7-dB degradation in modem noise figure after modem warmup. Cooling the Hughes Gunn oscillator and the Spacekom mixer did not improve this situation. Changes such as these have been seen on other modems as well. A similar warm-up drift of 0.3-dB degradation in excess noise power of the noise tube was indicated in WED 10/5/79 data. Because of the long time required to stabilize these readings, all modem noise figure measurements are taken with both the modem and noise tube at a cold start for convenience. The cause of warmup drift is not understood.

Another problem exists with apparent variations in cold load temperature versus horn placement under the cold load. This was especially evident with the K_a-band measurements when a rather coarse Eccosorb material was used. The Q-band measurements were made with AN-72 Eccosorb material. In both cases the horn position was adjusted for lowest cold load noise power.



1. Set step attenuators for $\leq$1.0 mW at PWR meter at maximum input conditions.
2. Using cold load measure P_{HOT} and P_{COLD}.
3. Calculate noise figure of modem using the following equations:

$$T_E = \frac{290 - (P_H/P_C)(77)}{(P_H/P_C) - 1}$$

$$F = 100 \text{ dB } \text{LOG}_{10} \left(1 + \frac{TE}{290}\right)$$

4. Using noise tube measure P_{ON} and P_{OFF}.
5. Calculate excess noise power (dB) using following equation

$$\text{Excess (dB)} = F + 10 \text{ dB } \text{LOG}_{10} \left[(P_{ON}/P_{OFF})-1\right]$$

Figure 3-5: NOISE TUBE CALIBRATION TEST SETUP
(Refer to Appendix A for derivations)

NOISE TUBE CALIBRATION
Tube Type A501C
Serial No. 152001

Based on EWS 11/30/79
EWS 12/3/79
EWS 12/4/79
EWS 12/5/79

Excess Noise 18.3 dB ±0.2 dB Specification
Current 40 mA

MODEM		HOT/COLD LOAD					NOISE TUBE			Excess Noise	Notes
T1D	CH	P_{HOT}	P_{COLD}	P_{HOT}/P_{COLD}	T_e (K)	F (dB)	P_{ON}	P_{OFF}	P_{ON}/P_{OFF}	(dB)	
38	1	.8270	.7484	1.1050	1952	8.9	.9942	.1057	9.406	18.1	
73	2	.8700	.8034	1.0829	2492	9.8	.8555	.1079	7.929	18.2	
13	3	.8752	.8145	1.0745	2782	10.6	.7250	.1110	6.532	18.0	
65	3	.7926	.7188	1.1027	1997	9.0	.9302	.1060	8.775	17.9	
—	3	AVG. →								18.0	
37	4	.9450	.8726	1.0830	2489	9.8	.8812	.1244	7.084	17.6	
56	4	.7377	.6673	1.1055	1942	8.9	.9941	.1200	8.284	17.5	
56	4	.9121	.8278	1.1018	2015	9.0	.8030	.0964	8.330	17.7	
56	4	.8177	.8978	1.0980	2096	9.2	"	"	"	17.9	W/O Elbow @ Horn
—	4	AVG. →								17.7	
30	5	.9818	.9105	1.0783	2643	10.0	.8728	.1265	6.900	17.7	
72	5	.9955	.9039	1.1013	2026	9.0	.8722	.1032	8.452	17.7	
—	5	AVG. →								17.7	
8	6	.9530	.9044	1.0537	3889	11.6	.6507	.1231	5.286	17.9	
58	6	.8496	.7862	1.0806	2566	9.9	.8109	.1120	7.240	17.9	
58	6	.8485	.7858	1.0797	2596	10.0	.8104	.1128	7.184	17.9	T + 180 min
—	6	AVG. →								17.9	

$\therefore$ Measurement error $\geq \pm 0.4$ dB in excess noise power and therefore noise figure.

Figure 3-6: NOISE TUBE CALIBRATION DATA FOR "Ka" BAND

NOISE TUBE CALIBRATION Based on EWS 12/12/79

Tube Type B501C

Serial No. RW522

Excess Noise 18.0 dB ±0.5 dB Specification

Current 35 mA

MODEM		HOT/COLD LOAD					NOISE TUBE			Excess Noise (dB)	Notes
TID	CH	P_{HOT}	P_{COLD}	P_{HOT}/P_{COLD}	T_e (°K)	F (dB)	P_{ON}	P_{OFF}	P_{ON}/P_{OFF}		
54	7	.8338	.7778	1.0720	2881	10.4	.9135	.1360	6.717	18.0	
77	7	.9136	.8525	1.0717	2894	10.4	.8046	.1182	6.807	18.0	
77	7	.9105	.8515	1.0693	2997	10.5	"	"	"	18.1	
77	7	.9105	.8502	1.0709	2927	10.5	"	"	"	18.1	
77	7	.9105	.8505	1.0705	2944	10.5	"	"	"	18.1	
—	7	AVG. →								18.1	
61	8	.8698	.8352	1.0414	5068	12.7	.8031	.1841	4.362	18.0	
81	8	.8150	.7845	1.0389	5399	12.9	.8495	.2145	3.960	17.6	
80	8	.8764	.8405	1.0427	4911	12.5	.9851	.2290	4.302	17.7	
—	8	AVG. →								17.8	
19	9	.9995	.9683	1.0322	6538	13.7	.9536	.2625	3.633	17.9	
75	9	.8832	.8398	1.0517	4043	11.7	.8841	.1794	4.928	17.6	
—	9	AVG. →								17.8	
46	10	.8348	.7981	1.0460	4553	12.2	.8069	.1710	4.719	17.9	

∴Measurement error ≥±0.4 dB in excess noise power and therefore noise figure.

Figure 3-7: NOISE TUBE CALIBRATION DATA FOR "B" BAND

3.3 Summary of Results

Because of the large volume of data gathered, a summary rather than detailed data sheets is given in Figure 3-8.

3.4 Measurement Error Analysis

3.4.1 Instrument errors

(a) Hughes Thermister Head:
(#44892H-1000) (33-50 GHz)
There is no specification on absolute accuracy given with these units. However, Dick Larsen of Hughes believes the absolute accuracy error is in the neighborhood of ±10% ≈ ±0.4 dB, based on their comparison tests with other standards.

(b) HP Thermister Head:
(#R486A)(26.5-40 GHz)
Again absolute accuracy is not given. Therefore, assume ±0.4 dB as with Hughes head.

(c) Maier Noise Tube
(#A501C)(WR-28)26.5-40 GHz)
From hot and cold load calibration data given in Section 3.2. Absolute accuracy error is $\geq$±0.4 dB in excess noise power or noise figure.

(d) Maier Noise Tube
(#B501C)(WR-19)(40-60 GHz)
From hot and cold load calibration data given in Section 3.2. Absolute accuracy error is $\geq$±0.4 dB in excess noise power or noise figure.

(e) HP #435A Power Meter Broadband Y-Factor Measurement
The linearity specification = ±1% error of full scale reading. The Y-factor measurements were always done near full scale with the noise tube on. The largest broadband Y-factor measured was 9.25 dB with T1D27. -9.25 dB = 12%. Therefore a 1%

WAVEGUIDE CHANNEL	MODEM SERIAL NO.	SPACEKOM MIXER SERIAL NO.	WG POWER @ 1500-MHz IF @ -6.5 dBm INPUT	LEVEL SET ATTENUATOR VALUE	WG POWER @ -1 dB COMPRESSION @ 1500-MHz INPUT	WG POWER @ MINIMUM SPOT -1 dB COMPRESSION	IF FREQ @ MINIMUM SPOT -1 dB COMPRESSION	PEAK-TO-PEAK CHANGE IN -1 dB COMPRESSION ACROSS 1-2 GHz IF	WG POWER @ -1 dB COMPRESSION WITH 1-2 GHz NOISE
			TRANSMIT CARRIER						
#	#	#	(P_{OUT}) dBm	dB	dBm	dBm	GHz	dB	dBm
1	D27	9E25	+0.8	-16	+3.4	+2.0	1.8	2.5	+0.6
2	D23	20A6	+1.5	-14	+6.1	+4.4	2.0	2.0	+2.7
2	D49	8D12	+0.4	-16	>+5.0	+3.5	2.0	2.0	+1.8
2	D73	8L10	+0.1	-16	+4.5	+3.0	2.0	1.6	+1.4
3	D65	8D21	-1.0	-18	+3.3	+0.8	2.0	3.1	+2.4
3	D34	7B21	+2.2	-12	+4.6	+4.6	1.5	1.0	+2.5
4	D37	7B26	-0.4	-16	+1.5	+1.5	1.5	3.2	-1.0
4	D56	8D26	-0.5	?	+4.4	+3.4	1.0	>1.6	+1.9
5	D30	51E6	+0.6	-14	+5.0	+3.9	2.0	1.0	+1.7
5	D29	52E6	-0.7	-12	+4.5	+2.5	1.0	1.8	+0.8
5	D72	8L15	+0.9	-14	+2.6	+2.0	1.3	1.1	+0.6
6	D58	8E10	-0.8	-16	+4.4	+3.6	1.9	0.8	+0.8
6	D8	40L5?	+1.2	-12	>+5.0	+1.9	1.0	>4.0	+2.4
7	D15	50C9	+3.3	-12	+3.7	+0.7	1.9	2.0	+1.4
7	D52	8H20	+1.3	-12	+3.7	+2.7	2.0	1.4	+2.0
7	D54	8H21	+1.6	-12	+2.5	+0.5	1.0	2.3	-1.0
7	D77	8L29	+0.9	-14	+2.4	+0.3	2.0	2.7	-0.7
8	D61	8H24	+0.1	-14	+2.2	-0.1	2.0	2.2	-1.4
8	D79	8M07	-0.7	-14	+2.5	-0.2	1.1	2.8	-1.4
8	D80	8M09	-0.7	-14	+4.3	+2.6	2.0	1.8	-0.2
8#	D81	8M08							
9	D19	71F6	+0.7	-14	>+5.0	+1.0	1.0	>5.0	+1.5
9	D21	8M11	-3.0	-10	-0.4	-1.8	1.8	1.5	-7.4
9	D75	7C17	-0.9	-14	+1.4	-0.8	1.0	2.1	-2.3

*NOTE: Broadband SSB noise figure measurements rejected after discovery c offset error in HP8478B thermister head.

#NOTE: Transmit data rejected due to positive $\frac{\Delta P_{OUT}}{\Delta P_{IN}}$ region.

Figure 3-8: MODEM MEASUREMENTS SUMMAF

error corresponds to 1%/12% × 100% =±8.3% error in the Y-factor measurement. 9.25 dB Y-factor = 8.4. Therefore, the error in noise figure measurement = -10 dB LOG_{10}[(8.4±8%)-1] = ±0.4 dB.

(f) HP 8494 Attenuator Accuracy = ±0.5 dB @ -11 dB setting from 1-2 GHz. Attenuation repeatability = ±0.03 dB which corresponds to ±0.7%.

(g) Tektronix 7L13 Spot Y-Factor Measurement Error The interpretation of reading error of the Y-factor measurement on the 2-dB/division scale after calibration with the step attenuators is probably on the order of ±0.4 dB or ±10% in Y-factor (one graticule division). Attenuation accuracy [from (f)] = ±0.5 dB or ±11% for Y = 8.4 dB minimum (T1D72).

The total error in Y-factor measurement = -10 dB LOG_{10} [(6.9±21%)-1] = -1.0+1.2 dB.

3.4.2 Total measurement errors

(a) Broadband noise compression measurement error

An attempt was made to determine experimentally the total error in 1% broadband noise compression measurement with and without correcting for step attenuator linearity. Step attenuator linearity was not simultaneously measured with modem linearity. Thus errors due to VSWR changes and attenuator resetability are not compensated. This is shown in Figures 3-9, 10 and 11 using T1D27 as a subject.

A measurement of attenuator linearity is shown in Figure 3-10. Note that a worst case % error from linear of +2.3, -2.4% from 0 dB to -15 dB is indicated. The attenuation repeatability is specified by HP at ±0.03 dB which corresponds to ±0.7%. Since 1% compression (or deviation from

WED 8/31/79

Modem SN T1D 27

Waveguide Channel 2

Location Rack Spares Antenna __

Date 9-28-79

By ________________

Sinewave Transmit Passband Measurements

(from attached XMT response plot)

WG PWR MTR CAL, 0-dBm Meter Reading = Actual 0 dB (96% cal fac) dBm

Power Output @ -6.5 dBm 1500-MHz input +0.8 dBm

-1 dB Compression Point @ 1500 MHz (sinewave) +3.4 dBm

Minimum Spot -1 dB Compression Point (sinewave) +2.0 dBm

@ 1800 MHz

1-2 GHz Noise Power Compression Measurement

	Atten. Setting	IF PWR	WG PWR MTR Voltage	MTR Voltage should be:	% Compression	Actual WG PWR	Corrected Error WED 10/4/79
	0 dB	dBm	1.0040 V_{dc}	2.4887 V_{dc}	-59.7%		-62.0 %
	-1		.9115	1.9769	-53.9		-55.4
	-2		.8216	1.5702	-47.7		-49.5
	-3		.7273	1.2473	-41.7		-43.0
	-4		.6331	.9908	-36.1		-36.4
	-5		.5445	.7870	-30.8		-28.4
	-6		.4657	.6251	-25.5		-25.6
	-7	-6.2<	.3906	.4966	-21.3		-20.8
					<20%>	+0.6 dBm	
	-8	-6.8	.3234	.3944	-18.0		-16.6
	-9		.2662	.3133	-15.0		-12.8
	-10		.2239	.2489	-10.0		-11.8
	-11		.1838	.1977	- 7.0		- 8.0
	-12		.1505	.1570	- 4.1		- 5.7
	-13		.1218	.1247	- 2.3		- 3.8
	-14	-12.8	.0979	.0990	- 1.1 (1%)	-5.3	- 1.7
Ref.	-15		.0787	.0787	0		

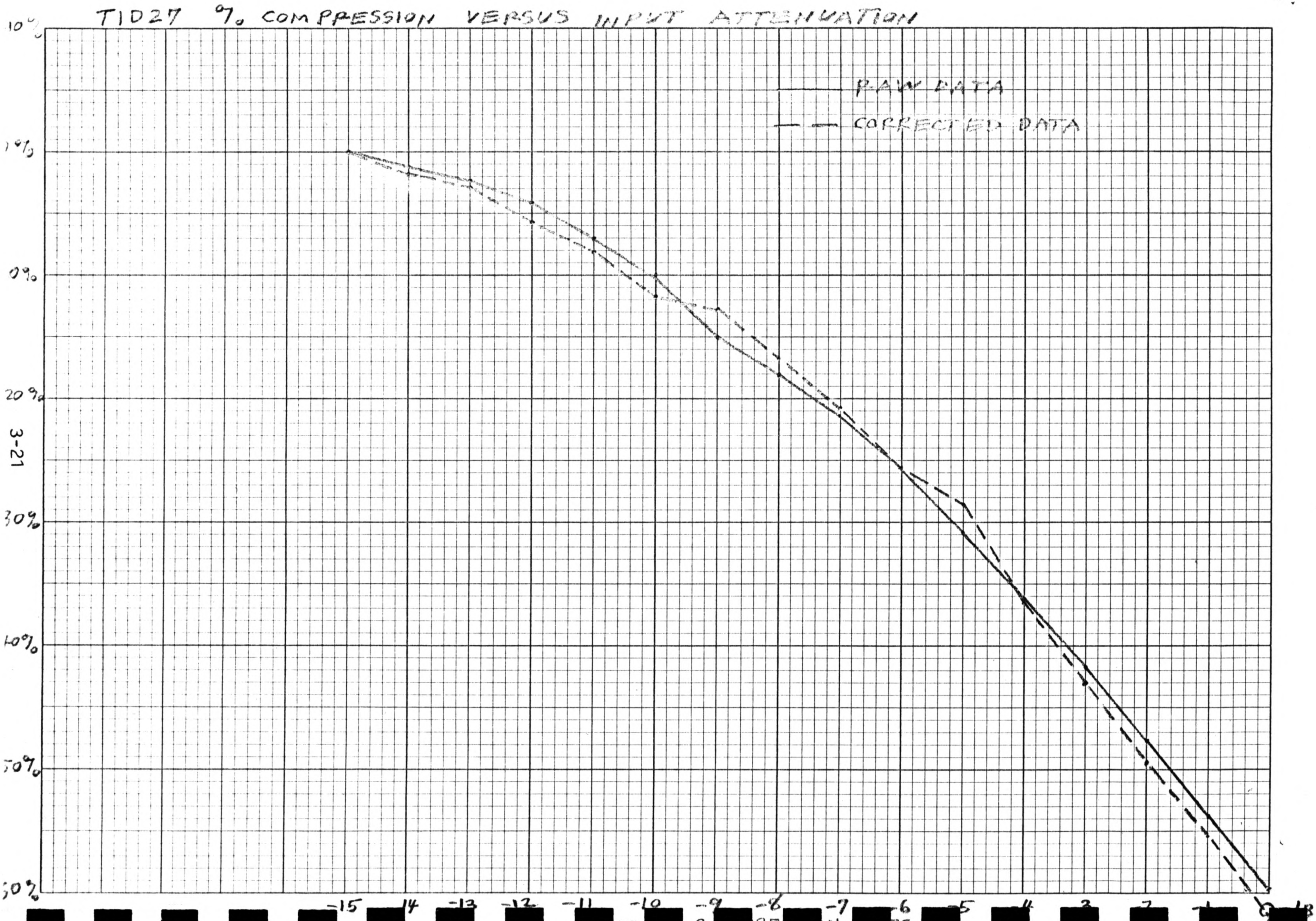
Figure 3-9: TID 27 Compression Results

WED 10/4/79-1

Atten. Setting		Error Spec		Meter Out	(-) Offset	Should Be	% Error
0 dB	0 dB	0 dB	0 dB	+.4042	.4044	.3953	+2.3
0	-1		±0.2	+.3184	.3186	.3140	+1.5
0	-2		±0.2	+.2538	.2540	.2494	+1.8
0	-3		±0.3	+.2005	.2007	.1981	+1.3
0	-4		±0.3	+.1577	.1579	.1574	+0.3
0	-5		±0.3	+.1245	.1247	.1250	-2.4
0	-6		±0.3	+.0992	.0994	.0993	+0.1
0	-7		±0.4	+.0783	.0785	.0789	-0.5
0	-8		±0.4	+.0615	.0617	.0626	-1.4
0	-9		±0.4	+.0485	.0487	.0498	-2.2
0	-10		±0.4	+.0386	.0388	.0395	-1.8
-10	0	0 dB	0 dB	+.0400	.0402	.0395	+1.8
-10	-1	±0.2	±0.2	+.0315	.0317	.0314	+1.0
-10	-2	±0.2	±0.2	+.0251	.0253	.0249	+1.6
-10	-3	±0.2	±0.3	+.0199	.0201	.0198	+1.5
-10	-4	±0.2	±0.3	+.0156	.0158	.0157	+0.6
-10	-5	±0.2	±0.3	+.0123	.0125	.0125	0.0
00	00		OFFSET =	-.0002	.0000	.0000	0.0

Combined HP8494A, HP8495A Step Attenuators, HP8482A Power Sensor, and HP435A Power Meter Errors, for 1-2 GHz Noise Power.

Figure 3-10: TID 27 NOISE POWER COMPRESSION WITH CORRECTIONS



TID27 % COMPRESSION VERSUS INPUT ATTENUATION

[redacted]

Figure 3-11 TID27 COMPRESSION PLOTS

linearity) is negligible as related to absolute power input and output level measurement, it can be assumed that input error = output error for 1% compression. Also, since the compression change per dB in the region of 1% compression is usually on the order of 1%/dB, the error of power measurement can be calculated as below. Note that after compensating for attenuator nonlinearity as in Figure 3-11, the curve is less smooth, indicating other errors (such as changes in linearity versus VSWR during attenuation calibration as opposed to modem measurement) are comparable to twice the attenuator nonlinearity as measured.

Waveguide output power level error at 1% compression without compensating for attenuator nonlinearity.

Power meter linearity (1-2 GHz) = ±1% × $\frac{1\text{dB}}{1\%}$
= ±1 dB

Attenuator resettability = ±0.03 dB

Attenuator linearity error $\geq$(+2.3%-2.4%)x $\frac{1\text{dB}}{1\%}$
$\geq$+2.3-2.4 dB

Power meter accuracy (WG) = ±0.4 dB

Other errors $\geq$2(+2.3%-2.4%) × $\frac{1\text{dB}}{1\%}$ $\geq$+4.6-4.8 dB

Least significant bit error in interpretation of level at 1% compression = ±1.0 dB

Total $\geq$+9.3-9.6 dB.

Waveguide output power level error at 1% compression after compensating for attenuator nonlinearity.

Power meter linearity (1-26 Hz) = ±1% × $\frac{1\text{dB}}{1\%}$
= ±1 dB

Attenuator resettability = ±0.03 dB

Power meter accuracy (WG) = ±0.4 dB
Other errors = $2\ (+2.3\%-2.4\%) \times \frac{1\text{dB}}{1\%} \geq +4.6-4.8$ dB
Least significant bit error in interprestation of level at 1% compression = ±1.0 dB
Total ≥7.0-7.2 dB.

Since the "other error" appeared to be at least twice as great as the attenuator linearity error it was decided to not compensate for it to save time in measurement. Therefore the total error in measurement of 1% compression is considered to be ≥+9.3-9.6 dB.

b) Broadband noise figure measurement error
Power meter linearity error = ±0.4 dB
Excess noise power error ≥±0.4 dB after calibration
∴ Total ≥±0.8 dB.

c) Spot noise figure measurement error
Y-factor error = -1.0+1.2 dB
Excess noise power error ≥±0.4 dB
∴ Total ≥-1.4+1.6 dB.

d) Total error in calculation of "M" (maximum acceptable waveguide loss for -1% compression and +20 dB S/N in each IF passband).

Because of an unfortunate defective power meter thermister mount for 1-2 GHz which was discovered after all measurements were completed, the spot SSB noise figure measurement had to be used for the calculation of "M" filter though the measurement error was worse than the broadband noise figure measurement.

Also since most of the modem transmit power at the vertex room is noise rather than carrier, broadband noise rather than carrier compression was used for the modem transmit level.

Note that transmit power level variations are already included in the calcuation of "M".

Spot SSB noise figure error ≥-1.4+1.6 dB

1% noise power compression error in waveguide transmit power ≥+9.3-9.6 dB

∴Total possible error in "M" ≥+10.9-11.0 dB.

e) Rejection of data

Because the total possible error in "M" is greater than the variation in "M" it has been decided to reject this data until better measurement methods are developed and new data taken. See Appendix C for an improved method of 1% compression measurement. Because of the greater complexity required in such a measurement (½ man-day is required just to calculate the resultant compression curve) it was not possible to remeasure the modems using this method.

Because of the variations in modems for a given channel, it is unlikely that sampling only one out of three of 75 modems would be adequate. If it is decided to retake the data using the improved measurement scheme, it would therefore be desirable to measure all modems. One significant advantage to this would be that modems with better performance in 1% compression could be allocated to antennas only, thus gaining a significant improvement in performance.

WHILE THE DATA PRESENTED IN SECTION 4.0 IS CONSIDERED QUESTIONABLE IT IS PRESENTED ANYWAY IN ORDER TO DEMONSTRATE THE METHODOLOGY IN OPTIMIZATION.

4.0 MODEM SUMMARY DEFINITIONS

$P_{1\%}$ = Measured modem transmit power at -1% compression with 1-2 GHz broadband noise power input. (dBm)

$P_{1\%MIN}$ = Worst case value of measured modems for a given channel. (dBm)

F = Measured worst case spot SSB noise figure from 1-2 GHz (dB) for a particular modem. Excess noise power of source based on hot/cold calibration.

F_{MAX} = Worst case value of measured modems for a given channel. (dB)

M = Calculated allowable modem-to-modem waveguide loss for a given waveguide channel for -1% compression and 20-dB signal-to-noise ratio in the IF powers. (dB)

W = Actual modem-to-modem waveguide loss for a given channel and antenna station. (dB)

Δ = M-W = Difference between allowable and actual waveguide loss for a given channel and station.

4.1 Calculation of Allowable Modem-to-Modem Waveguide Loss (M) for a Given Waveguide Channel

Let M = $-P_{1\%MIN}$ [transmit power @ -1% compression]

+7 dB/50 MHz [ratio of individual IF power to total power for 4 -IF system]

$+F_{MAX}$ [noise figure]

-97 dBm/50 MHz [noise power for 0-dB noise figure]

+20 dB [signal-to-noise ratio]

+2 dB [Gunn oscillator power variation due to Gunn interchangeability, worst case]

+0.5 dB [max peak FE IF variation for new system]

+2.3 dB [max peak T1 transmit passband variation]

+2.7 dB [max peak T2 transmit passband variation]

$\therefore M = -P_{1\%MIN} + F_{MAX} - 62.5$ dB

4.2 Assumptions in the Calculation of M

1. Ignores small number of samples (24 out of 75).
2. Assumes T2 nominal gain has been determined and that -6.5 dBm T1 transmit IF input power corresponds to that gain.
3. Ignores -1% noise power compression passband variations, since compression is usually best near A, B, C, and D IF channel frequencies.
4. Ignores measurement errors, although uses calibrated noise figures.
5. Accounts for Gunn oscillator power variation due to interchangeability. (Assumes Gunn power was at lowest permissible level during measurement, that compression point is proportional to Gunn power, and that noise figure is unaffected by Gunn power.)
6. Accounts for worst case linear passband variations due to front end, T2 transmit components and T1 transmit components.
7. Assumes LO/IF power transmit ratios have been correctly set.
8. Ignores warmup drift of modem noise figure and compression points.
9. Ignores linear passband variations due to VSWR effects.

ALLOWABLE MODEM-TO-MODEM WAVEGUIDE LOSS PREDICTIONS (Based on Figure 3-4)

	Per Modem			Worst Case Per WG Channel		
WG CH	Modem No.	$P_{1\%}$ (dBm)	F (dB)	$P_{1\%MIN}$ (dBm)	F_{MAX} (dB)	M (dB)
1	D27	-5.3	9.9	-5.13	9.9	-47.3
	D23	-2.2	10.9			
2	D49	-3.8	11.6		11.6	-45.8
	D73	-5.1	10.8	-5.1		
	D65	-3.7	9.8	-3.7		
3						-45.3
	D34	-0.6	13.5		13.5	
	D37	-6.2	12.7	-6.2	12.7	
4						-43.6
	D56	-5.2	10.8			
	D30	-4.4	10.6			
5	D29	-4.4	11.2		11.2	-46.1
	D72	-5.2	9.7	-5.2		
	D58	-4.4	10.5	-4.4		
6						-45.7
	D8	-3.1	12.4		12.4	

NOTE: Data questionable - For Example Only.

Figure 4-1A

ALLOWABLE MODEM-TO-MODEM WAVEGUIDE LOSS PREDICTIONS (Based on Figure 3-4)

	Per Modem			Worst Case Per WG Channel		
WG CH	Modem No.	$P_{1\%}$ (dBm)	F (dB)	$P_{1\%MIN}$ (dBm)	F_{MAX} (dB)	M (dB)
7	D15	-1.8	11.1			-44.4
	D52	-3.5	11.7			
	D54	-5.3	12.8	-5.3	12.8	
	D77	-5.2	12.1			
8	D61	-6.0	12.5	-6.0		-43.5
	D79	-5.6	12.8			
	D80	-5.1	13.0		13.0	
	D81	#	12.5			
9	D19	-5.5	14.0			-40.1
	D21	-8.2	14.2	-8.2	14.2	
	D75	-6.4	13.0			

NOTE: Data questionable - For Example Only.

#Note: Transmit data rejected due to positive

$$\frac{\Delta P_{OUT}}{\Delta P_{IN}}$$

region in mixer compression curve.

Figure 4-1B

5.0 PREDICTED MODEM-TO-MODEM WAVEGUIDE LOSS PER STATION AND PER MODEM CHANNEL

The modem-to-modem loss per station and waveguide channel is shown in Figure 5-1. This data is based on calculations for west arm performance (the worst case condition) computed by Rey Serna. -24 dB couplers are assumed at stations 1 through 19, -15 dB couplers are assumed at stations 20, 21 and 22, and a -6 dB coupler is assumed at station 23. No coupler is required at station 24 since it is at the end of the array. An insertion loss of -0.25 dB is assumed for each -24 and -15 dB coupler. An insertion loss of -2.0 dB is assumed for the -6 dB coupler. A list of the maximum tolerable waveguide loss (M) for -1% compression and -20 dB signal-to-noise ratio is provided in the right-hand column.

NOTE: The data is questionable and is presented only to demonstrate an example of the methodology used.

MODEM-TO-MODEM WAVEGUIDE LOSS, W(dB), VS STATION AND CHANNEL

WG CH #	Waveguide Stations																								M(dB)
	1 DW1	2 CW1 DW2	3 DW3	4 BW1 CW2 DW4	5 DW5	6 CW3 DW6	7 DW7	8 AW1 BW2 CW4 DW8	9 DW9	10 CW5	11 BW3 CW6	12 CW7	13 AW2 BW4 CW8	14 CW9	15 BW5	16 AW3 BW6	17 BW7	18 AW4 BW8	19 BW9	20 AW5	21 AW6	22 AW7	23 AW8	24 AW9	
1	-35.3	-35.8	-36.2	-36.6	-37.1	-37.6	-38.1	-38.6	-39.2	-39.8	-40.8	-41.9	-43.2	-44.5	-44.6	-47.0	-49.6	-52.0	-54.5	-48.3	-54.1	-61.3	-60.3	-59.2	-47.3
2	-35.2	-35.7	-36.1	-36.5	-36.9	-37.4	-37.9	-38.4	-39.0	-39.6	-40.5	-41.6	-42.7	-44.0	-44.0	-46.2	-48.7	-50.8	-53.2	-46.7	-51.9	-58.5	-56.8	-54.8	-45.8
3	-35.1	-35.6	-36.0	-36.4	-36.8	-37.3	-37.7	-38.2	-38.8	-39.3	-40.2	-41.3	-42.3	-43.4	-43.5	-45.5	-47.3	-49.7	-51.8	-45.1	-49.7	-55.7	-53.3	-50.8	-45.3
4	-35.1	-35.5	-35.9	-36.3	-36.7	-37.2	-37.6	-38.1	-38.7	-39.2	-40.1	-41.1	-42.1	-43.2	-43.2	-45.1	-47.3	-49.1	-51.1	-44.3	-48.6	-54.3	-51.5	-48.5	-43.6
5	-35.0	-35.5	-35.4	-36.3	-36.7	-37.1	-37.6	-38.0	-38.5	-39.1	-39.9	-40.9	-41.9	-42.9	-43.0	-44.7	-46.8	-48.5	-50.4	-43.4	-47.5	-52.9	-49.7	-46.3	-46.1
6	-34.6	-35.5	-35.7	-35.9	-36.3	-36.6	-37.1	-37.5	-37.9	-38.4	-38.9	-39.7	-40.4	-41.3	-41.8	-43.3	-44.9	-46.7	-48.4	-41.5	-45.1	-49.3	-45.0	-40.6	-45.7
7	-34.6	-35.5	-35.8	-35.9	-36.2	-36.6	-37.0	-37.5	-37.9	-38.4	-38.9	-39.6	-40.4	-41.2	-41.6	-43.1	-44.6	-46.4	-48.0	-41.0	-44.6	-48.4	-43.8	-39.1	-44.4
8	-34.6	-35.5	-35.7	-35.8	-36.2	-36.6	-37.0	-37.4	-37.8	-38.3	-38.8	-39.5	-40.3	-41.1	-41.5	-43.0	-44.4	-46.1	-47.6	-40.5	-44.0	-47.6	-42.8	-37.8	-43.5
9	-34.5	-35.4	-35.6	-35.8	-36.2	-36.6	-37.0	-37.4	-37.8	-38.3	-38.8	-39.5	-40.3	-41.1	-41.5	-43.0	-44.3	-46.0	-47.4	-40.4	-43.7	-47.1	-42.1	-37.0	-40.1
	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-15	-15	-15	- 6	0	Coupler (dB)
	-0.0	-0.25	-0.5	-0.75	-1.0	-1.25	-1.5	-1.75	-2.0	-2.25	-2.5	-2.75	-3.0	-3.25	-3.5	-3.75	-4.0	-4.25	-4.5	-4.75	-5.0	-5.25	-5.5	- 7.5	Total Coupler IL(dB)

(NOTE: M(dB) Data is Questionable.)

Figure 5-1

6.0 WAVEGUIDE VERSUS ANTENNA STATION SELECTION

The chart of Figure 5-1 was modified to show the difference Δ(dB) between tolerable waveguide loss and actual waveguide loss by subtracting the two numbers for each channel and station [Δ(dB) = M(dB) - W(dB)]. This is plotted in Figure 6-1, and provides a figure of merit or quality factor which can be used to select modem channels for each station.

Two other requirements which must be met before any selection procedure can be utilized are the development of a list of priorities for selection and an algorithm for channel selection based on the former. These are given in Figures 6-2 and 6-3.

A basis for the priority list was suggested by Barry Clark.

Priority 1 is a result of the A array having the worst case waveguide losses, because of the longer distances involved. Priorities 2 and 3 are based on desired convenience. And priority 4 is based on lower losses for smaller arrays.

Many algorithms were tried and many failed due to traps that were found to exist with different Δ value arrangements. The algorithm given in Figure 6-3 was determined by trial and error with different examples. It insures that all Δ values selected for an array are less than or equal to the worst case condition that would have to be selected anyway. A possible improvement that was not considered in detail might involve some sort of averaging technique on all possible combinations after an initial selection. This was disregarded however, because of the added complexity.

The actual array channel selection based on the previous priorities and optimization algorithm is shown in Figure 6-4. (Note: The data is questionable.)

A summary of modem performance as a result of the optimization procedure is given in Figure 6-5. An example of a typical modem compression curve is given to permit insight into what compression performance is likely to result from the selection procedure. The % compression figure should only be considered crude approximations, however, since modem compression curves differ widely from unit to unit. Again note that the data is questionable, and that it is only presented as an example of the nethodology used.

Results in terms of antenna moves from any array to any other array are given in Figure 6-5. And results in terms of waveguide extension coupler channel number for given stations are given in Figures 6-6 and 6-7. Again note that the data is questionable. The following results are shown as an example of procedure only.

BLE AND ACTUAL WAVEGUIDE LOSS [Δ(dB) = M(dB) - W(dB)]
B) vs Waveguide Station

11	12	13	14	15	16	17	18	19	20	21	22	23	24	
		AW2			AW3		AW4		AW5	AW6	AW7	AW8	AW9	
BW3		BW4		BW5	BW6	BW7	BW8	BW9						
CW6	CW7	CW8	CW9											TL* M(dB)
-6.5	-5.4	-4.1	-2.8	-2.7	-0.3	+2.3	+4.7	+7.2	+1.0	+6.8	+14.0	+13.0	+11.9	-47.3
-5.3	-4.2	-3.1	-1.8	-1.8	+0.4	+2.9	+5.0	+7.4	+0.9	+6.1	+12.7	+11.0	+ 9.0	-45.8
-5.1	-4.0	-3.0	-1.9	-1.8	+0.2	+2.0	+4.4	+6.5	-0.2	+4.4	+10.4	+ 8.0	+ 5.5	-45.3
-3.5	-2.5	-1.5	-0.4	-0.4	+1.5	+3.7	+5.5	+7.5	+0.7	+5.0	+10.7	+ 7.9	+ 4.9	-43.6
-6.2	-5.2	-4.2	-3.2	-3.1	-1.4	+0.7	+2.4	+4.3	-2.7	+1.4	+ 6.8	+ 3.6	+ 0.2	-46.1
-6.8	-6.0	-5.3	-4.4	-3.9	-2.4	-0.8	+1.0	+2.7	-4.2	-0.6	+ 3.6	- 0.7	- 5.1	-45.7
-5.5	-4.8	-4.0	-3.2	-2.8	-1.3	+0.2	+2.0	+3.6	-3.4	+0.2	+ 4.0	- 0.6	- 5.3	-44.4
-4.7	-4.0	-3.2	-2.4	-2.0	-0.5	+0.9	+2.6	+4.1	-3.0	+0.5	+ 4.1	- 0.7	- 5.7	-43.5
-1.3	-0.6	+0.2	+1.0	+1.4	+2.9	+4.2	+5.9	+7.3	+0.3	+3.6	+ 7.0	+ 2.0	- 3.1	-40.1
-24	-24	-24	-24	-24	-24	-24	-24	-24	-15	-15	-15	- 6	0	Coupler (dB)
-2.5	-2.75	-3.0	-3.25	-3.5	-3.75	-4.0	-4.25	-4.5	-4.75	-5.0	-5.25	-5.5	- 7.5	Total Coupler IL(dB)

stionable

Figure 6-1

PRIORITIES IN CHANNEL SELECTION VERSUS WAVEGUIDE STATION

1. "A" array channel selection optimized first, since it has the worst case waveguide losses.

2. No antenna shall be moved from a station when changing arrays if that station is used for both arrays.

3. No modem shall be transferred between antennas.

4. The B, C and D arrays shall be optimized as possible after the above conditions are met.

Figure 6-2

ALGORITHM FOR CHANNEL SELECTION VERSUS WAVEGUIDE STATION IN A GIVEN ARRAY

(Refer to Array Channel Selection Chart)

1. For a given array, choose the maximum Δ that allows an adequate number of channels to be available for any arbitrary number of stations. Box in Δ values that are equal to or less than this value for each station in the array, after having eliminated channels that were repeated for stations also used in a previous array channel selection.

2. Find station(s) with least number of choices as to channel selections. Choose station channel if it does not recur for other stations in this subset.

3. For remaining stations in the above subset, select the station that provides the worst case best Δ. Choose the best Δ for that station.

4. Repeat (2) and (3) for remaining stations having eliminated previously selected stations and channels.

5. Having completed (4) move to the next array, with an array priority of A first, B second, C third, and D fourth.

Figure 6-3

DIFFERENCE [Δ(dB)] BETWEEN TOLERABLE AND ACTUAL WAVEGUIDE LOSS [Δ(dB) = M(dB) - W(dB)]
Δ(dB) vs Waveguide Station

WG CH #	1 DW1	2 CW1 DW2	3 DW3	4 BW1 CW2 DW4	5 DW5	6 CW3 DW6	7 DW7	8 AW1 BW2 CW4 DW8	9 DW9	10 CW5	11 BW3 CW6	12 CW7	13 AW2 BW4 CW8	14 CW9	15 BW5	16 AW3 BW6	17 BW7	18 AW4 BW8	19 BW9	20 AW5	21 AW6	22 AW7	23 AW8	24 AW9	TL* M(dB)
1	-12.0	-11.5	-11.1	-10.7	-10.2	-9.7	-9.2	-8.7	$\boxed{-8.1}$	-7.5	-6.5	$\boxed{-5.4}$	-4.1	-2.8	-2.7	$\boxed{-0.3}$	+2.3	+4.7	+7.2	+1.0	+6.8	+14.0	+13.0	+11.9	-47.3
2	-10.6	-10.1	$\boxed{-9.7}$	- 9.3	- 8.9	-8.4	-7.9	-7.4	-6.8	-6.2	-5.3	-4.2	$\boxed{-3.1}$	-1.8	-1.8	+0.4	+2.9	+5.0	+7.4	+0.9	+6.1	+12.7	+11.0	+ 9.0	-45.8
3	$\boxed{-10.2}$	- 9.7	- 9.3	- 8.9	- 8.5	-8.0	-7.6	-7.1	-6.5	-6.0	$\boxed{-5.1}$	-4.0	-3.0	-1.9	-1.8	+0.2	+2.0	+4.4	+6.5	$\boxed{-0.2}$	+4.4	+10.4	+ 8.0	+ 5.5	-45.3
4	- 8.5	- 8.1	- 7.7	- 7.3	- 6.9	-6.4	-6.0	$\boxed{-5.5}$	-4.9	-4.4	-3.5	-2.5	-1.5	-0.4	-0.4	+1.5	+3.7	+5.5	+7.5	+0.7	+5.0	+10.7	+ 7.9	+ 4.9	-43.6
5	-11.1	-10.6	-10.7	- 9.8	$\boxed{-9.4}$	-9.0	-8.5	-8.1	-7.6	$\boxed{-7.0}$	-6.2	-5.2	-4.2	-3.2	-3.1	-1.4	$\boxed{+0.7}$	+2.4	+4.3	-2.7	+1.4	+ 6.8	+ 3.6	$\boxed{+0.2}$	-46.1
6	-11.1	-10.2	-10.0	- 9.8	- 9.4	-9.1	$\boxed{-8.6}$	-8.2	-7.8	-7.3	-6.8	-6.0	-5.3	$\boxed{-4.4}$	-3.9	-2.4	-0.8	+1.0	$\boxed{+2.7}$	-4.2	-0.6	$\boxed{+3.6}$	- 0.7	- 5.1	-45.7
7	- 9.8	- 8.9	- 8.6	- 8.5	- 8.2	$\boxed{-7.8}$	-7.4	-6.9	-6.5	-6.0	-5.5	-4.8	-4.0	-3.2	-2.8	-1.3	+0.2	$\boxed{+2.0}$	+3.6	-3.4	+0.2	+ 4.0	- 0.6	- 5.3	-44.4
8	- 8.9	$\boxed{-8.0}$	- 7.8	- 7.7	- 7.3	-6.9	-6.5	-6.1	-5.7	-5.2	-4.7	-4.0	-3.2	-2.4	$\boxed{-2.0}$	-0.5	+0.9	+2.6	+4.1	-3.0	$\boxed{+0.5}$	+ 4.1	- 0.7	- 5.7	-43.5
9	- 5.6	- 4.7	- 4.5	$\boxed{-4.3}$	- 3.9	-3.5	-3.1	-2.7	-2.3	-1.8	-1.3	-0.6	+0.2	+1.0	+1.4	+2.9	+4.2	+5.9	+7.3	+0.3	+3.6	+ 7.0	$\boxed{+2.0}$	- 3.1	-40.1
	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-15	-15	-15	- 6	0	Coupler (dB)
	-0.0	-0.25	-0.5	-0.75	-1.0	-1.25	-1.5	-1.75	-2.0	-2.25	-2.5	-2.75	-3.0	-3.25	-3.5	-3.75	-4.0	-4.25	-4.5	-4.75	-5.0	-5.25	-5.5	- 7.5	Total Coupler IL(dB)

NOTE: Data is Questionable
(Optimization Detail Not Shown for Clarity)

*TL is Tolerable Loss

$\boxed{}$ = Selected channel

Figure 6-4: ARRAY CHANNEL SELECTION

SUMMARY OF OPTIMUM CHANNEL SELECTION FOR EACH ARRAY
NOTE: Data is Questionable.

	Array											
	A			B			C			D		
Station	CH No.	Δ (dB)	% Com (%)	CH No.	Δ (dB)	% Com (%)	CH No.	Δ (dB)	% Com (%)	CH No.	Δ (dB)	% Com (%)
1	4	-5.5	0	9	-4.3	0	8	-8.0	0	3	-10.2	0
2	2	-3.1	0	4	-5.5	0	9	-4.3	0	8	- 8.0	0
3	1	-0.3	-1.0	3	-5.1	0	7	-7.8	0	2	- 9.7	0
4	7	+2.0	-6.3	2	-3.1	0	4	-5.5	0	9	- 4.3	0
5	3	-0.2	-1.0	8	-2.0	-0.4	5	-7.0	0	5	- 9.4	0
6	8	+0.5	-2.3	1	-0.3	-1.0	3	-5.1	0	7	- 7.8	0
7	6	+3.6	-13.2	5	+0.7	-3.3	1	-5.4	0	6	- 8.6	0
8	9	+2.0	- 6.3	7	+2.0	-6.3	2	-3.1	0	4	- 5.5	0
9	5	+0.2	- 1.3	6	+2.7	-10.4	6	-4.4	0	1	- 8.1	0

Station = stations for given array in consecutive order

Δ(dB) = M(dB) - W(dB) difference between tolerable and actual waveguide loss for 1% compression and 20-dB S/N in IF powers

% Com = % compression at given value of Δ (based on compression curve given below) only approximate

T1D23 CH 2
Compression
Curve Versus Δ

Δ	% Compression
+11 dB	-54.7%
+10	-47.7
+ 9	-40.8
+ 8	-34.1
+ 7	-27.8
+ 6	-21.6
+ 5	-16.8
+ 4	-13.2
+ 3	-10.4
+ 2	- 6.3
+ 1	- 3.3
0	- 1.3
- 1	- 0.5
- 2	- 0.4
- 3	0

Figure 6-5

A ARRAY ANTENNA MOVES

	Station	B1	B2	B3	B4	B5	B6	B7	B8	B9
	A1		<4>							
	A2				<2>					
	A3						<1>			
	A4								<7>	
A↔B	A5			3						
	A6					8				
	A7									6
	A8	9								
	A9							5		

	Station	C1	C2	C3	C4	C5	C6	C7	C8	C9
	A1				<4>					
	A2								<2>	
	A3							1		
	A4			7						
A↔C	A5						3			
	A6	8								
	A7									6
	A8		9							
	A9					5				

	Station	D1	D2	D3	D4	D5	D6	D7	D8	D9
	A1								<4>	
	A2			2						
	A3									1
	A4						7			
A↔D	A5	3								
	A6		8							
	A7							6		
	A8				9					
	A9					5				

1-9 = modem channel of antenna to be moved
<1-9> = modem channel of antenna at station used in both arrays (not moved)

NOTE: Data is Questionable.

Figure 6-6A

B ARRAY ANTENNA MOVES

Station	C1	C2	C3	C4	C5	C6	C7	C8	C9
B1		<9>							
B2				<4>					
B3						<3>			
B4								<2>	
B5	8								
B6							1		
B7					5				
B8			7						
B9									6

Station	D1	D2	D3	D4	D5	D6	D7	D8	D9
B1				<9>					
B2								<4>	
B3	3								
B4			2						
B5		8							
B6									1
B7					5				
B8						7			
B9							6		

NOTE: Data is Questionable

Figure 6-6B

C ARRAY ANTENNA MOVES

Station	D1	D2	D3	D4	D5	D6	D7	D8	D9
C1		<8>							
C2				<9>					
C3						<7>			
C4								<4>	
C5					5				
C6	3								
C7									1
C8			2						
C9							6		

NOTE: Data is Questionable

Figure 6-6C

WAVEGUIDE EXTENSION/COUPLER CHANNEL NO.
VERSUS WAVEGUIDE STATION
NOTE: Data is Questionable

Station	ARRAY NO. A	B	C	D	CH No.	WG Band
1				1	3	K_a
2			1	2	8	B
3				3	2	K_a
4		1	2	4	9	B
5				5	5	K_a
6			3	6	7	B
7				7	6	K_a
8	1	2	4	8	4	K_a
9				9	1	K_a
10			5		5	K_a
11		3	6		3	K_a
12			7		1	K_a
13	2	4	8		2	K_a
14			9		6	K_a
15		5			8	B
16	3	6			1	K_a
17		7			5	K_a
18	4	8			7	B
19		9			6	K_a
20	5				3	K_a
21	6				8	B
22	7				6	K_a
23	8				9	B
24	9				5	K_a

Therefore need 17 K_a-band extensions and need 7 B-band extensions

(K_a-band → 26.5 - 40.0 GHz)
(B-band → 33.0 - 50.0 GHz)

Figure 6-7

7.0 MODEM AND WAVEGUIDE LEVEL SETTING HISTORY

In 1975 Weinreb, D'Addario and Herrero set a specification for modem-to-modem total waveguide loss of 56 dB±6 dB with no failure other than small deterioration in IF S/N ratio.[1] With the modem power output and noise figure specifications at that time, this resulted in a signal-to-noise ratio for each IF channel of 20 dB.[2] Waveguide couplers were to be designed with coupling values to compensate for main waveguide loss variations. Dynamic range of the modem receive system was not a problem in this instance. Later the waveguide losses were found to be much less than expected. Also waveguide coupler fabrication difficulties led to the adoption of only several standard coupling values.

Both of these factors decreased the minimum waveguide loss encountered at the closer waveguide stations. A worst case calculation was made on April 20, 1977[3] to determine the minimum waveguide loss that could be tolerated by the T1 module's receive amplifier based on the amplifier's output power being held to a maximum of -10 dBm. The amplifier's specified output -1 dB compression point was at 0-dBm total power.[4] Thus the receive amp compression (and corresponding third order distortion) would be well below limiting case of modem mixer transmit compression, which was operated at approximately -4 dB below the specified -1 dB compression point.

This resulted in a worst case modem waveguide receive level of -43.1 dBm which would correspond to a worst case minimum modem-to-modem waveguide loss of -44.1 dB, assuming a maximum modem output power of +1 dBm. Shortly afterward D. S. Bagri in a system signal level chart showed the modem-to-modem waveguide loss limits to be between -46 to -56 dB.[5] Since waveguide losses can be well below

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[1] S. Weinreb, L. R. D'Addario and V. Herrero, VLA Technical Report No. 14, "Systems Tests of June 1975", p. 6-1.
[2] Ibid, p. 6-3.
[3] W. E. Dumke, lab book number 3, pp. 152-153, April 20, 1977.
[4] NRAO Specification A13440N7A, October 7, 1976.
[5] D. S. Bagri, VLA Technical Report No. 37, "System Performance in December, 1977", March 1978, Figure 2.5.

this minimum figure for certain channels and stations, (see Figure 5-1), a waveguide attenuator was placed in the distributor box to D-Rack line, and set to provide a minimum modem-to-modem loss for all possible stations for that channel. This resulted in a somewhat degraded signal-to-noise ratio at the furthermost stations, but was satisfactory, since the total worst case waveguide loss of -56 dB could be met in any event. However, in order to meet 1% compression with 20-dB signal-to-noise, for all stations, it is necessary to minimize the attenuation to the furthermost stations.

Unfortunately, the maximum modem-to-modem waveguide loss that can be tolerated by the channel 8 and 9 modems based on Figure 4-1B is -43.5 dB for channel 8 and -40.1 dB for channel 9.

Also operating at -44.1 dB minimum waveguide loss will not guarantee that less than 1% compression will occur in the T1 receive amplifier, since the maximum operating point of -10 dB below the -1 dB compression point was chosen only to insure that the modem mixer would be the limiting factor in compression at the previous modem output power operating point of +1 dBm. Thus the receive amplifier may contribute more to compression than the T1 mixer in transmit if a 20-dB signal-to-noise ratio is desired for a channel 9 modem that by chance has a very low mixer conversion loss. Originally the modem total transmit power was to be the same in both directions even though no "IF" power was transmitted to the antennas. This approach resulted in a problem concerning excessive cross-modulation of the 5-MHz sidebands onto the 1800-MHz carrier and DCS data sidebands onto the 1200-MHz carrier. Thus the total transmit IF input power at the D-Rack modem was reduced by -6 dB to correct this situation, which was primarily due to severe compression in out-of-spec modem mixers at the +1.0 dBm level. The lowest modem-to-modem waveguide loss in Figure 5-1 for any channel along the west arm is -34.5 dB. This would be approximately -1 dB lower for the east and north arms.

Assuming no compression in the transmit modem mixer and the level select pad selected for +1.0 dBm output power for -6.5 dBm input the resultant modem waveguide output power for the LO carriers from the D-Rack would be -5.0 dBm. With -33.5 dB waveguide loss (worst case north and east arm, data from Rey Serna) this results in a total modem receive power at the B-Rack of -38.5 dBm, or -5.6 dB above the -44.1 dBm calculated receive level for operation -10 dB below the -1 dB compression point in the T1 receive amplifier. The worst case resultant operating point for the T1 receive amplifier would be -4.3 dB below the minimum specified -1 dB compression point.

This would only be an approximation and could not be guaranteed. In the past operation at -4 dB below the -1 dB compression point of modem transmit mixers has in some instances caused considerable cross talk between the 1200- and 1800-MHz modulation sidebands, although no known specification relating to this problem has ever been generated.

Because of possible modem receive amplifier compression at waveguide losses lower than -44.1 dB waveguide attenuators (TRG Part No. A522 and B522) were purchased to provide a minimum loss of -44 dB for each waveguide channel for any antenna station in any array configuration. The attenuators were to be installed in the distributor box to D-Rack rectangular waveguide line under the central electronics room floor. The value of this attenuator would be set once for -44 dB minimum loss and then left at that value. Because these attenuators would never be changed for different arrays, the worst case loss for the A array would be somewhat worse than it could be, because of the attenuator value, but would still be under -56 dB (the original modem-to-modem waveguide loss specification).

For the new specified 1% compression and 20-dB signal-to-noise ratio per IF channel, this method is not satisfactory.

Alternative methods for level setting and the advantages and disadvantages of each are given in the next chapter.

8.0 DESIGN ALTERNATIVES

Many methods may be utilized to reduce modem transmit mixer compression to 1% while maintaining a 20-dB signal-to-noise ratio for each IF channel, as well as preventing possible receive amplifier compression and local oscillator cross talk. Several of these are presented here along with problems associated with each approach.

8.1 Waveguide Attenuator

These units are currently utilized to increase the minimum waveguide loss for prevention of modem receive amplifier IF channel compression and LO carrier cross-modulation.

As explained in Section 7 the waveguide attenuator cannot be set and left at one value for all array configurations without also degrading performance. The present mounting technique prohibits easy adjustment because of inaccessability. A sketch of the current distribution box to modem waveguide interface is shown in Figure 8-1.

Note that to move the waveguide attenuator to an accessible location in the D-Rack would require two extra WR-22 to WR-19 transitions if WR-22 (lower loss) waveguide was to still be used for the majority of the rectangular waveguide run. Also the current waveguide sections would have to be modified to accommodate the attenuator with two transitions. The cost of these modifications would be over $300 based on 1979 prices. The introduction of extra flanges (always difficult to install correctly) could degrade the waveguide phase stability due to high return loss. Also the waveguide attenuator would not prevent possible LO cross-modulation due to the modem transmit mixer at the D-Rack. Therefore it is proposed to eliminate the waveguide attenuator from consideration except as a possible temporary measure.

8.2 Modem Fixed Level Set Pads

The fixed level set pads could be changed or added to in each modem to reduce compression in the transmit mixer. This

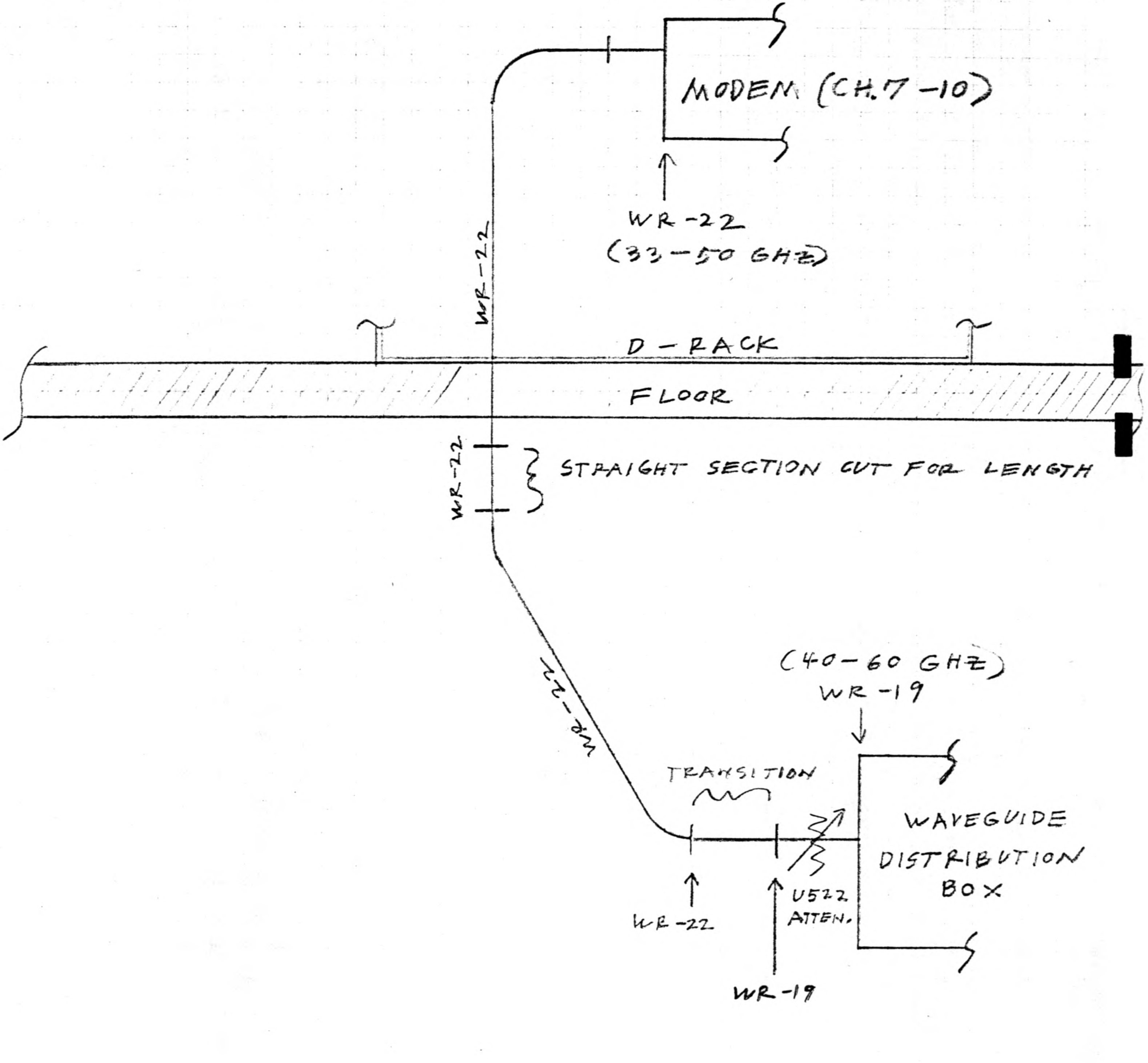


Figure 8-1: MODEM TO DISTRIBUTION BOX WAVEGUIDE (Channels 7-11)

would be one of the less expensive alternatives, easier to implement as a once only change, and would not degrade passband flatness to any serious extent, but would harbor several serious disadvantages.

In order to implement a fixed pad system it is necessary to accurately know the required value. As was shown in the previous measurement error analysis, this would be difficult even if the errors could be reduced through better techniques. Also parts interchangeability would require a repeated measurement and change of value each time a Gunn oscillator or mixer, etc. would be replaced in order not to degrade optimum performance.

A fixed pad system with incremental values (e.g., 1 dB/station) can not be set to an exact value anyway. And input level variations and modem performance drift with age and temperature could not be readily compensated thereby resulting in greater degradation in performance.

Versatility and adaptability to change would be inhibited. Take the current situation as an example. The antenna-to-CER and CER-to-antenna signals could not be set independently, and addition of other signals or future level changes could not be readily adopted.

Also because of the large quantity of values required (many unknown and subject to change) waste would occur since many more pads would have to be stocked than are actually required.

Because of the above problems with a fixed level set procedure in which tolerances, measurement figures, system variations, and versatility degrade optimum system performance below the minimum acceptance, a variable level set scheme is deemed necessary for both vertex room and central electronics room modems. Variable level setting would also compensate for modem input level changes, thus improving performance.

Three techniques are examined in the following sections.

8.3 Modem Pin Diode Switch as Variable Attenuator

A portion of the modem R. F. block diagram (C13440B1) is shown in Figure 8-2. Current level setting is accomplished through the use of a fixed attenuator pad between the SPST pin diode switch and the transmit amplifier. An inexpensive method to accomplish variable level setting is to use the single pole single thru (SPST) 1 - 2 GHz pin diode switch as a variable pin diode attenuator. The proposed system is shown in Figure 8-3. Note that two different manufacturers units are utilized. Alpha used a series-shunt diode arrangement whereas Frequency Sources used a simple shunt diode. Thus the driver circuits to obtain the variable current to control attenuation are different for both units. In either case the driver circuits are required to provide a variable bias in transmit and a fixed bias to provide maximum attenuation during receive. A pot positioned in place of the front panel "Int Out" jack connector provided variable control of bias during transmit. Attneuator pads were placed at both the input and output of the switch for three reasons.

First, phase and amplitude instability with temperature along with passband ripple will increase with switch attenuation value even if the input and output are perfectly matched. Thus the pin switch should be operated at as low an attenuation value as possible. From the data of Figure 8-3 it appeared that a minimum combined pad/pin switch attenuation of 14 dB would be required to achieve 1% compression. Therefore the total pad value was set at 12 dB to allow for insertion loss and tolerance.

Second, since the pin switch is a reactive attenuator the input and output load would have to be isolated. Placing an attenuator at the input to the switch isolated its reflection coefficient from the T2/T1 transmission line. The transmit amplifier input match could have provided a good output match.

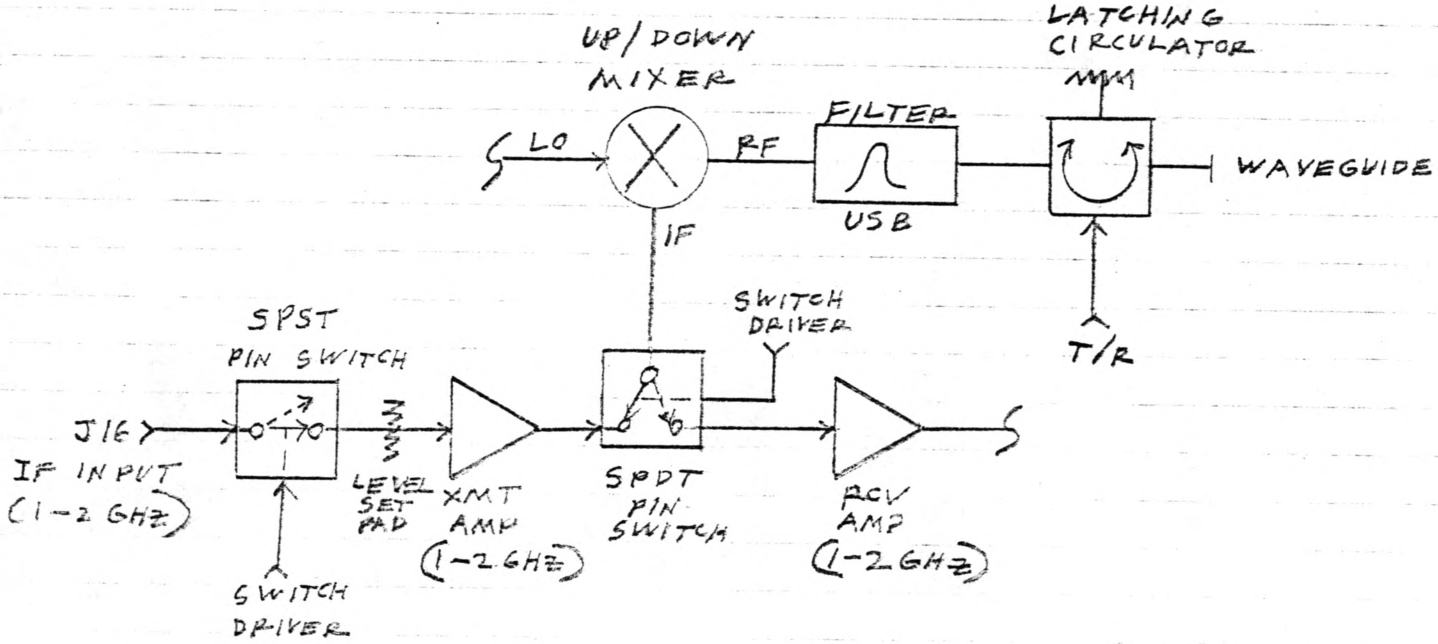
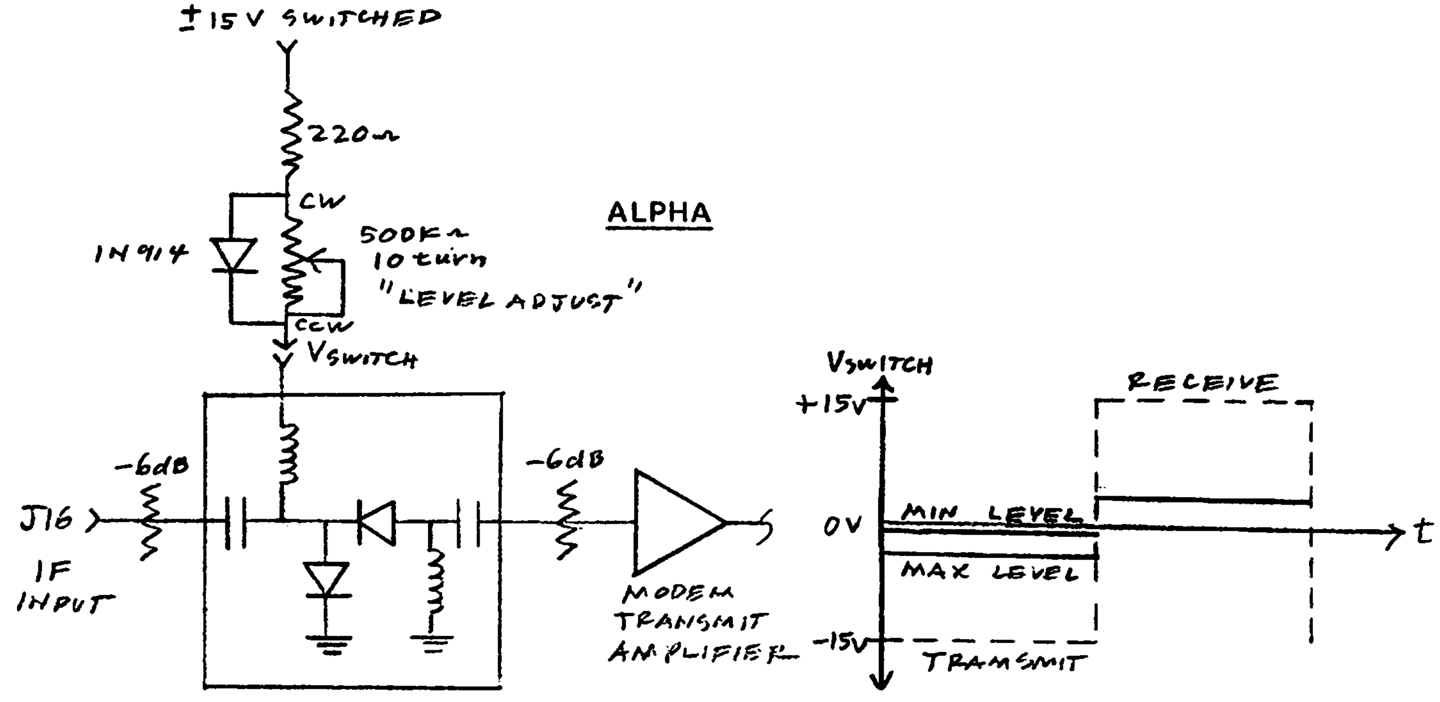


Figure 8-2: MODEM TRANSMIT LINE BLOCK DIAGRAM

ALPHA



FREQUENCY SOURCES

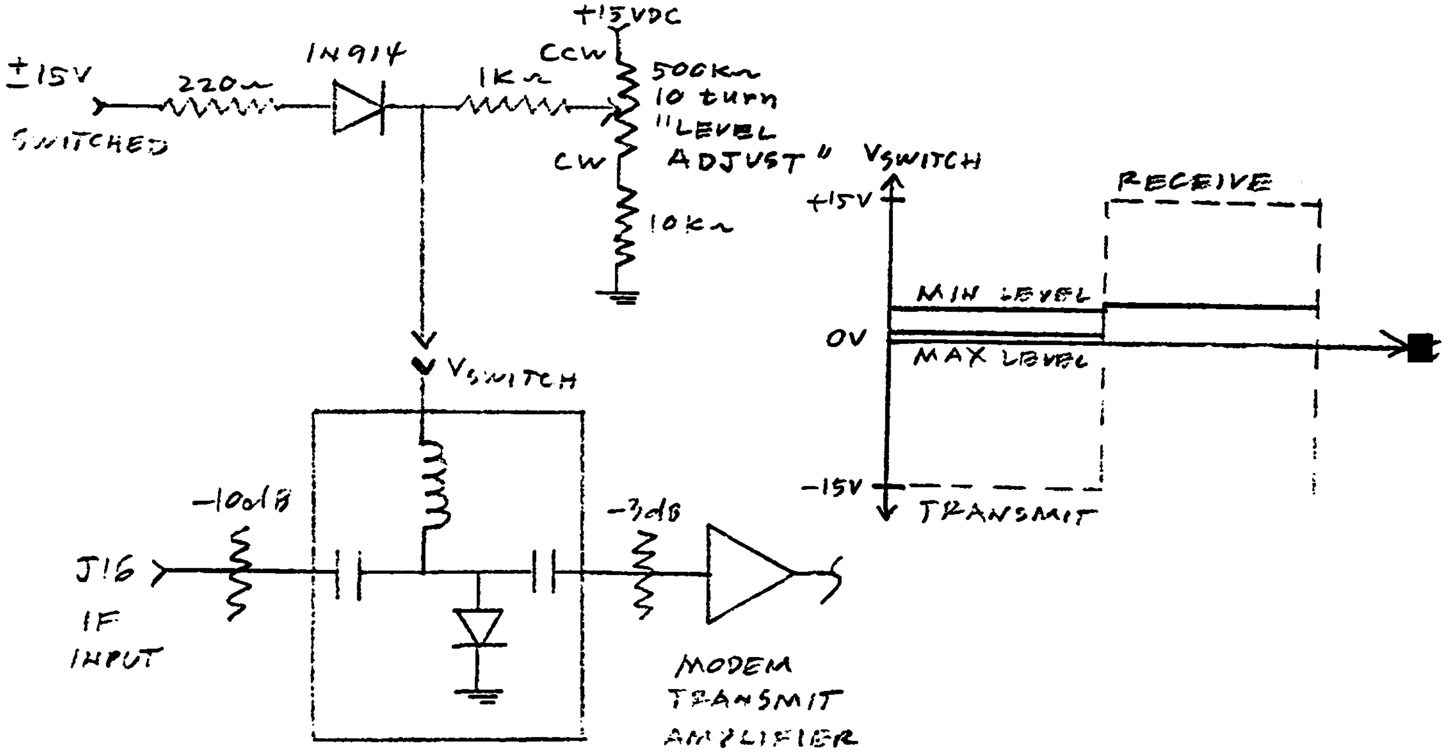
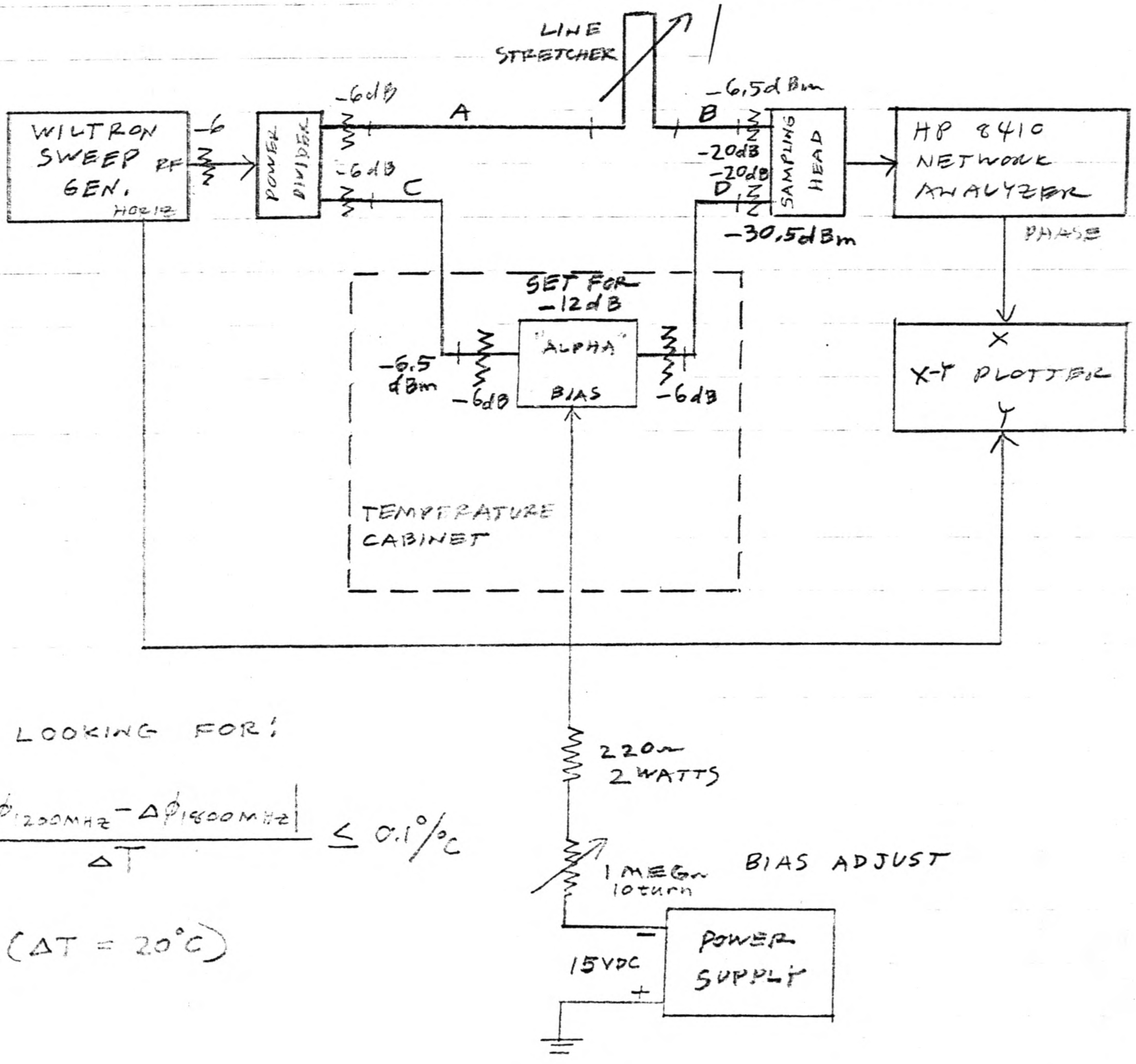


Figure 8-3: SPST PIN DIODE SWITCHES USED AS VARIABLE ATTENUATORS

Third, oscillation problems have occured during receive with the transmit amplifier when both the input and output are mismatched. Since the SPDT switch is reactive during receive the input to the transmit amplifier must be kept at a reasonable match. Thus the total fixed pad value must be divided between the input and output of the switch. In the first modification done with an Alpha switch -6 dB were allocated to the input and -6 dB were allocated to the output.

A test set-up was fabricated with an Alpha switch. A 6 dB pad was allocated to the input and another -6 dB pad was allocated to the output. Figure 8-4 shows this test set-up. Measurement results are shown in Figures 8-5, 8-6, 8-7, and 8-8. Measurement system test results are summarized and compared to worst case calculated values in Figure 8-9. Calculations of phase and amplitude ripple due to worst case system reflection coefficients are presented in Figure 8-10. Note that they agree with actual results in Figure 8-9. The derivation of the calculation procedure is given in Appendix D.

TEST SET-UP FOR PIN-DIODE SWITCH
ATTENUATOR PHASE STABILITY vs. TEMPERATURE



LOOKING FOR:

$$\frac{\left|\Delta\phi_{200MHz} - \Delta\phi_{1800MHz}\right|}{\Delta T} \le 0.1°/_{C}$$

@ ($\Delta T = 20°C$)

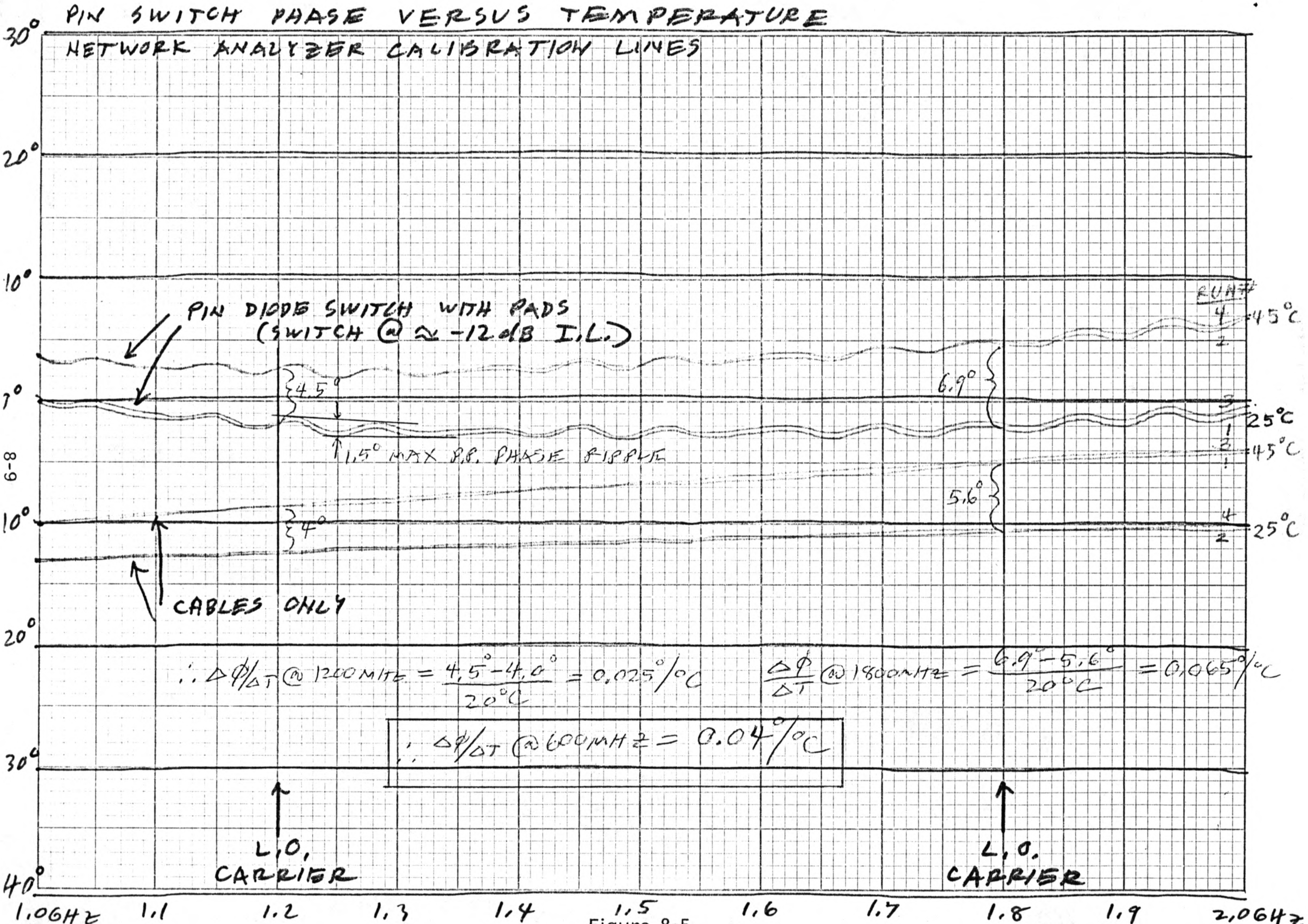
Figure 8-4

[redacted] [redacted]/8[redacted]!

HEWLETT-PACKARD 9270-1006

PIN SWITCH PHASE VERSUS TEMPERATURE

NETWORK ANALYZER CALIBRATION LINES



$\therefore \Delta\phi/\Delta T$ @ 1200MHz $= \frac{4.5° - 4.0°}{20°C} = 0.025°/°C$

$\frac{\Delta\phi}{\Delta T}$ @ 1800MHz $= \frac{6.9° - 5.6°}{20°C} = 0.065°/°C$

$\boxed{\therefore \Delta\phi/\Delta T \text{ @ } 600\text{MHz} = 0.04°/°C}$

Figure 8-5

WED 1/9/80-2

46 0780

PIN SWITCH AMPLITUDE VERSUS TEMPERATURE

∴ ≈ 0.02 dB/°C AMPLITUDE CHANGE VERSUS TEMP

46 0780

V[redacted]D /1[redacted]0

PIN SWITCH VSWR RIPPLE VERSUS INSERTION LOSS

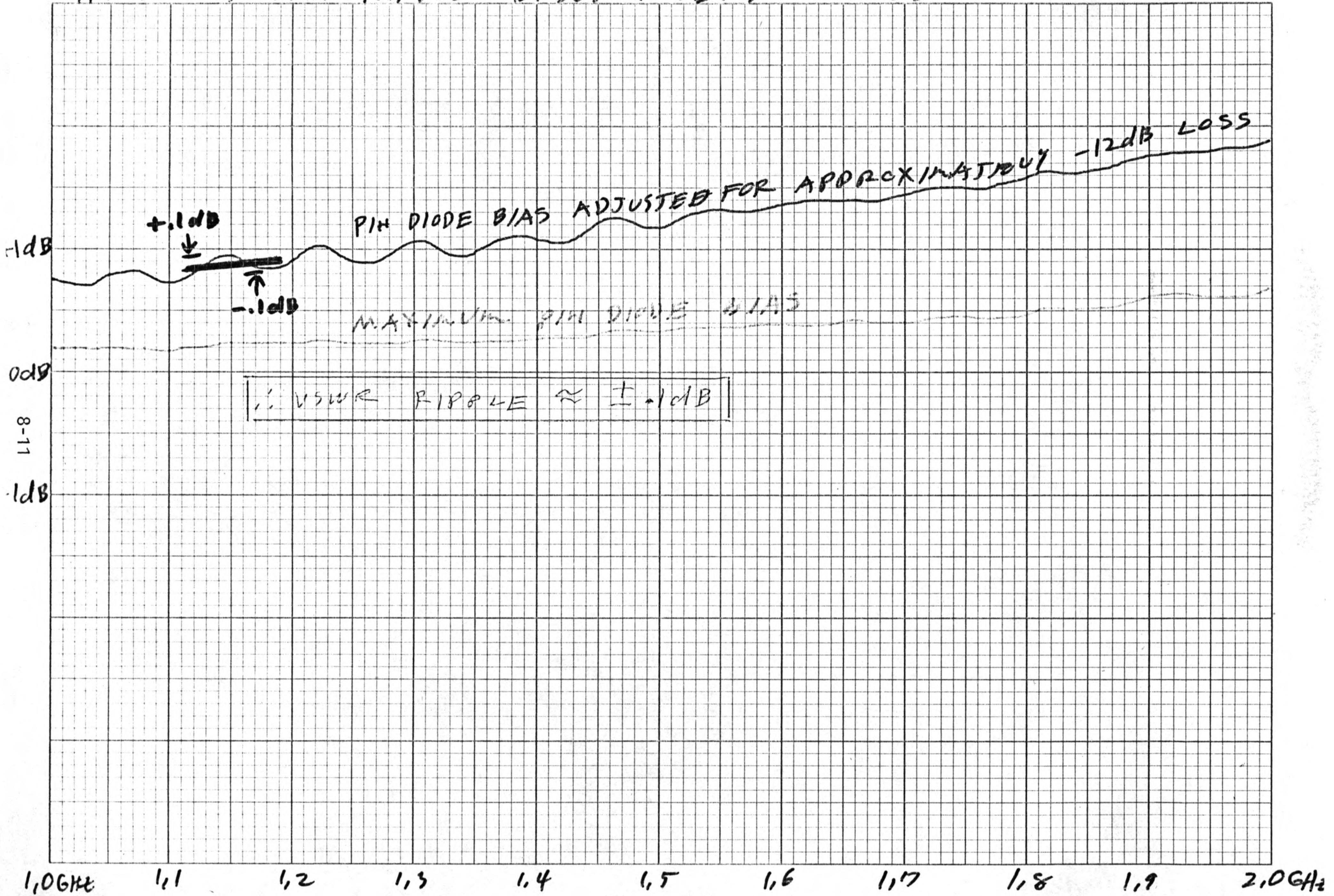
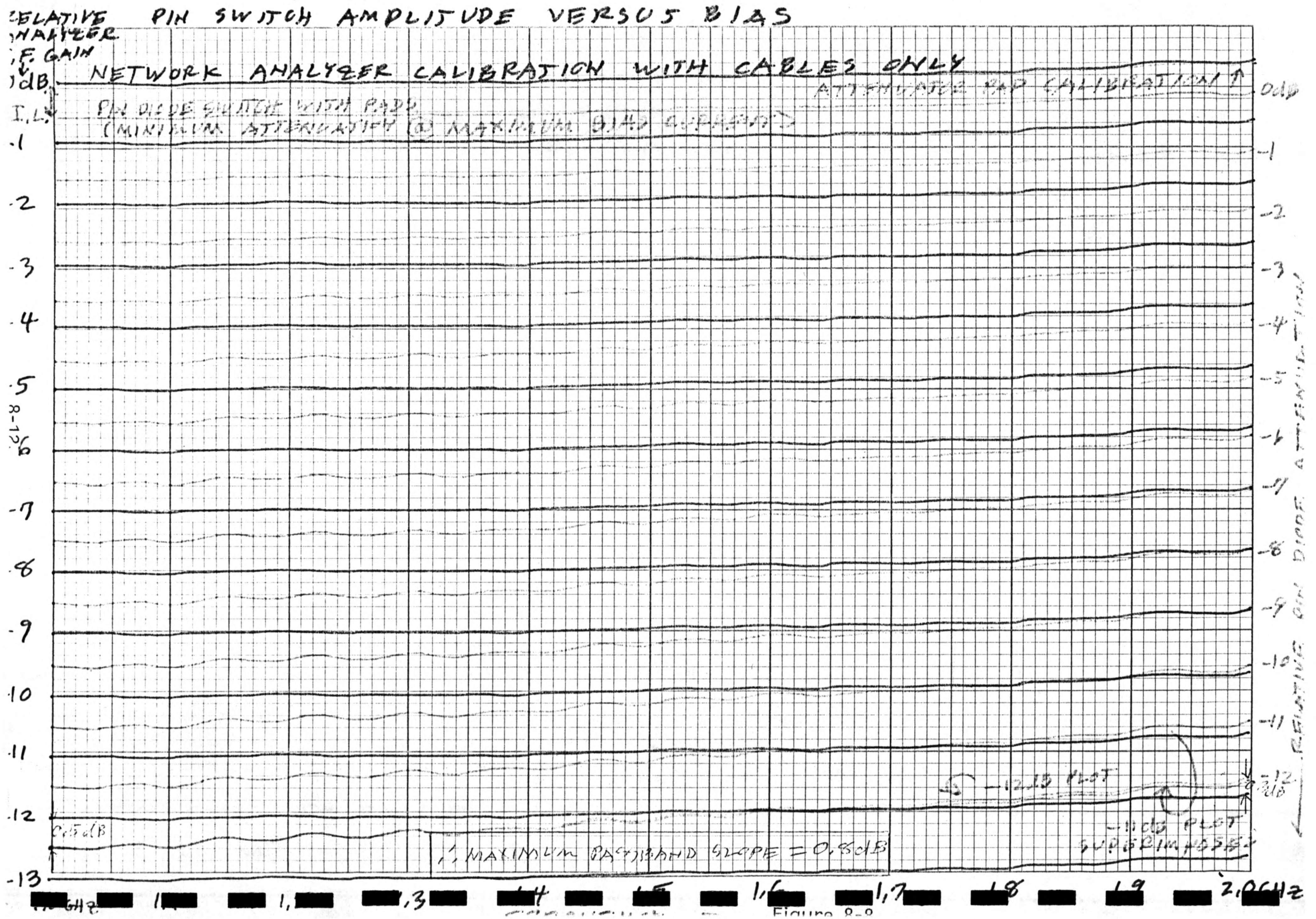


Figure 8-7

WED 1/14/80 -1



[redacted]

8-12

Figure 8-8

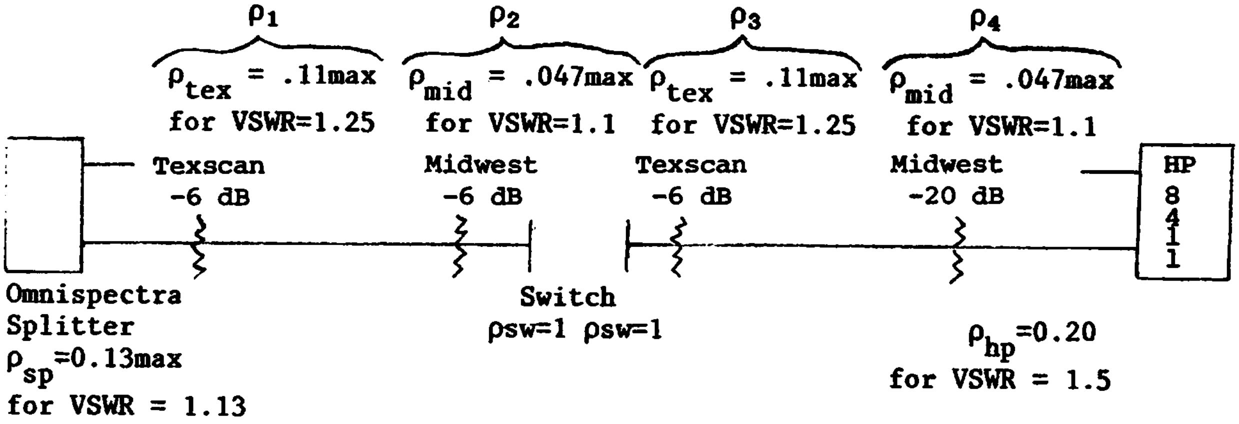
Parameter	Measurement	Calculated Worst Case For System
Phase Stability versus Temperature at 600 MHz	0.04°/°c	---------------
Amplitude stability versus Temperature	0.02 dB/°c	---------------
Amplitude Slope From 1-2 GHz	+0.8 dB	---------------
Amplitude Ripple Due to VSWR Effects	0.2 dB pp	1.2 dB pp
Phase Ripple Due to VSWR Effects	1.5° pp	7.7° pp

NOTE: All measurement results taken at pin switch attenuation equal -12 dB, the worst case condition.

Figure 8-9: ALPHA SWITCH USED AS VARIABLE ATTENUATOR SUMMARY

The T2/T1 transmit coax line is one of the most serious contributors to fine grain passband ripple in the modem system. Expected worst case amplitude and phase ripple die to the T2/T1 transmit coax line for the pin switch used as an attenuator is given in Figure 8-11. Worst case ripple for the present T2/T1 transmit coax line is given in Figure 8-12. Note that amplitude and phase ripple magnitudes are only slightly degraded.

WED 1/14/80-3



$\rho_{-12} = 0.25$ $\qquad$ $\rho_{-12} = 0.25$ $\quad$ $\rho_{-12} = 0.25$ $\qquad$ $\rho_{-20} = 0.10$

$\rho_1 = .11 + (.13)(.25)$ $\quad$ $\rho_2 = .047 + (0.25)(1)$ $\quad$ $\rho_3 = .11 + (0.25)(1)$ $\quad$ $\rho_4 = .047 + (0.10)(0.2)$

$\rho_1 = .143$ $\quad$ $\rho_2 = .297$ $\quad$ $\rho_3 = .36$ $\quad$ $\rho_4 = .067$

$$\text{Error(dB)pp} = 20\text{dB}\,\text{LOG}_{10}\left(\frac{1+(.143)(.297)}{1-(.143)(.297)}\right) \qquad \text{Error(dB)pp} = 20\text{dB}\,\text{LOG}_{10}\left(\frac{1+(.36)(.067)}{1-(.36)(.067)}\right)$$

$$= 20\text{dB LOG}_{10}(1.0887) \qquad\qquad = 20\text{dB LOG}_{10}(1.0494)$$

$$\text{Error(dB)pp} = .74\ \text{dB max} \qquad \text{Error(dB)pp} = .42\ \text{dB max}$$

$$\therefore \text{Total Error} = .74 + .42 = \boxed{1.16\ \text{dB peak to peak maximum}}$$

$$\text{Error}(^\circ)\text{pp} = 2\tan^{-1}(.143)(.297) \qquad \text{Error}(^\circ)\text{pp} = 2\tan^{-1}(.36)(.067)$$

$$= 4.9^\circ\ \text{max} \qquad\qquad = 2.8^\circ\ \text{max}$$

$$\therefore \text{Total Error} = 4.9 + 2.8 = \boxed{7.7^\circ\ \text{peak to peak}}$$

CHECK:

Measured 0.2 dB max pp amplitude error and 1.5° max pp phase error

$$0.2 = 20\ \text{LOG}_{10}\left(\frac{1+\rho^2}{1-\rho^2}\right) \qquad \therefore \rho^2 = .011$$

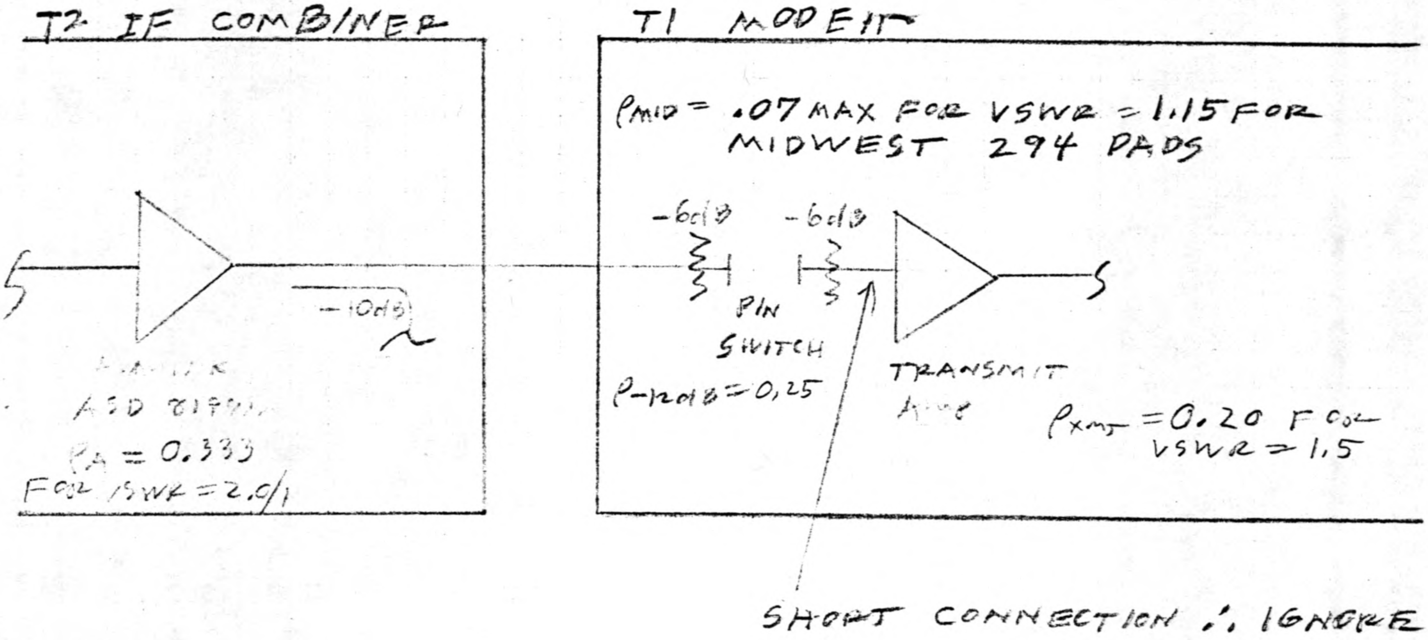
$$\text{Error}(^\circ)\text{pp} = 2\tan^{-1}(.011) = 1.3^\circ \approx 1.5^\circ$$

$\therefore$ Theory works

MEASUREMENT SYSTEM PHASE AND AMPLITUDE RIPPLE CALCULATIONS

Figure 8-10

PREDICTED PHASE AND AMPLITUDE RIPPLE FOR ACTUAL MODEM SYSTEM USING PIN SWITCH AS A VARIABLE ATTENUATOR



$$\text{ERROR}(dB)_{PP} = 20\,dB\ \text{LOG}_{10}\left(\frac{1+\rho_A(\rho_{MID}+\rho_{-12})}{1-\rho_A(\rho_{MID}+\rho_{-12})}\right)$$

$$\text{ERROR}(dB)_{PP} = 20\,dB\ \text{LOG}_{10}\left(\frac{1+(0{,}333)(0{,}07+0{,}25)}{1-(0{,}333)(0{,}07+0{,}25)}\right)$$

$$= 20\,dB\ \text{LOG}_{10}\left(\frac{1+.1066}{1-.1066}\right) = 20\,dB\ \text{LOG}_{10}(1.239)$$

$$\boxed{\therefore \text{MAX ERROR}(dB)_{PP} = 1.86\,dB}$$

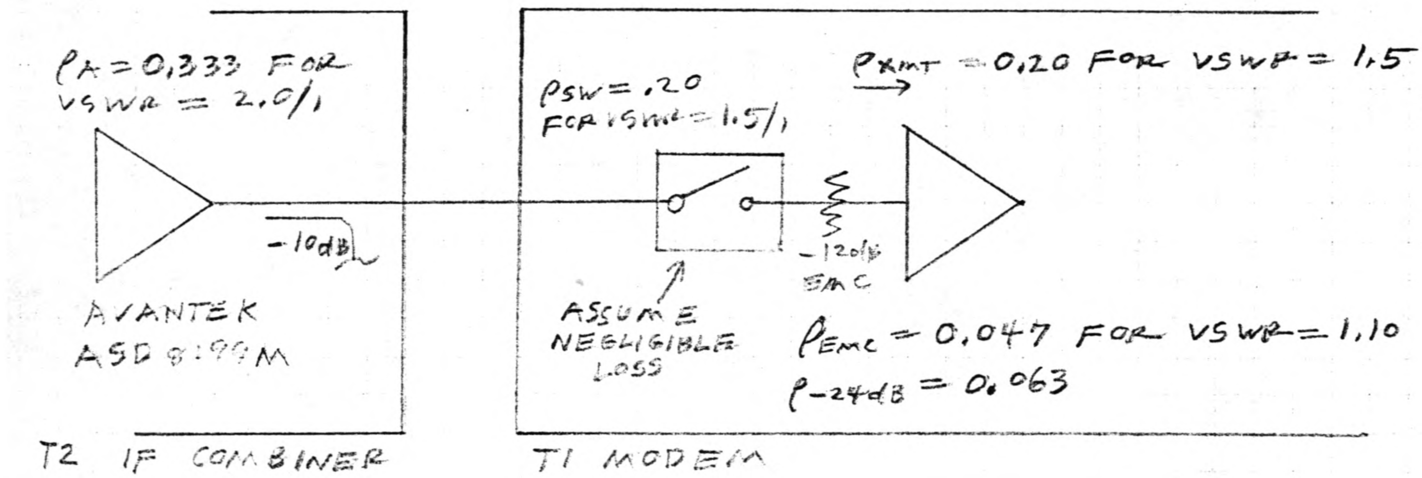
$$\text{ERROR}(^\circ)_{PP} = 2\tan^{-1}\left[\rho_A(\rho_{MID}+\rho_{-12})\right]$$

$$= 2\tan^{-1}\left[0.333(0{,}07+0{,}25)\right]$$

$$\boxed{\therefore \text{MAX ERROR}(^\circ)_{PP} = 12.2^\circ}$$

Figure 8-11

PHASE AND AMPLITUDE RIPPLE FOR PRESENT MODEM XMT INPUT LINE



$$\rho_{MODEM} = \rho_{SW} + \rho_{EMC} + \rho_{-24dB}\,\rho_{XMT}$$

$$= 0.20 + 0.047 + (0.063)(0.20)$$

$\therefore \rho_{IF\,COMBINER} = 0.333 \qquad \therefore \rho_{MODEM} = 0.26$

$$ERROR(dB)_{PP} = 20dB\,LOG_{10}\left(\frac{1+(.333)(.26)}{1-(.333)(.26)}\right)$$

$$= 20dB\,LOG_{10}\left(\frac{1+.08658}{1-.08658}\right)$$

$$\boxed{ERROR(dB)_{PP} = 20dB\,LOG_{10}\left(\frac{1.08658}{.91342}\right) = 1.51dB\ MAX.}$$

$$ERROR(^\circ)_{PP} = 2\tan^{-1}[(.333)(.26)]$$

$$\boxed{ERROR(^\circ)_{PP} = 9.9^\circ\ MAX.}$$

Figure 8-12

The total length of the .141 coax line is approximately 45" for the "B" rack and 46" for the "D" rack. The ripple frequency of a length of transimission line is given by:

$$\Delta f = \frac{c}{2 \cdot l \cdot \frac{1}{v}}$$

Where Δf = Ripple frequency (Hz)

$c = 3 \times 10^8$ m/s

l = physical length (m)

v = velocity factor

$v = 0.69$ for .141 semi rigid coax

$$\therefore \Delta f_B = \frac{3 \times 10^8 \text{ m/sec}}{2(45'')\,(.0254\text{m}/'')\,(\frac{1}{0.69})} = 91 \text{ MHz}$$

$$\Delta f_D = \frac{3 \times 10^8\text{m/sec}}{2(46'')\,(.0254\text{m}/'')\,(\frac{1}{0.69})} = 89 \text{ MHz}$$

This result can be seen in the passband response of various modems in the system.

Data was also taken of compression at the system levels. The data is not presented because lack of simultaneous input/output power measurement prohibited an accurate measurement to be taken. However, a tendency for the switch conversion loss to decrease with increasing input power was noticed with input power levels slightly above the nominal -6.5 dBm. This non-linearity could have similar derogatory effects on system performance as normal compression.

This effect is probably due to the pin diode turning on with input R.F. power. This effect would be more noticeable at low D.C. bias currents through the pin diodes.

The SPST Frequency Sources pin diode switch in TID58 was then modified for variable level setting, as in Figure 8-3. Because of the VSWR ripple problem with the T2/T1 transmit line a -10 dB pad was used as the input attenuator rather than the previous -6 dB pad. As a result a -3 dB pad was used between the switch and transmit amplifier instead of the previous -6 dB pad to obtain the desired operating point and still present the transmit amplifier with a worst case VSWR of 3:1. The amplifier remained stable at all settings of the gain control. The resulting measured passband response is shown in Figure 8-13. The -2.3 dB rolloff from 1-2 GHz was considered unsatisfactory from an IF transmission system point of view. A compression measurement with simultaneous input and output power measurement for greater accuracy showed some additional compression switch in the vicinity of the modem 1% compression operating point. This was probably due to the shunt pin diode turning on with R.F. power thus increasing its conversion loss with increasing power. Because of these problems and many other uncertainties it was decided to abandon this method of level setting.

4-21-80 Ewr

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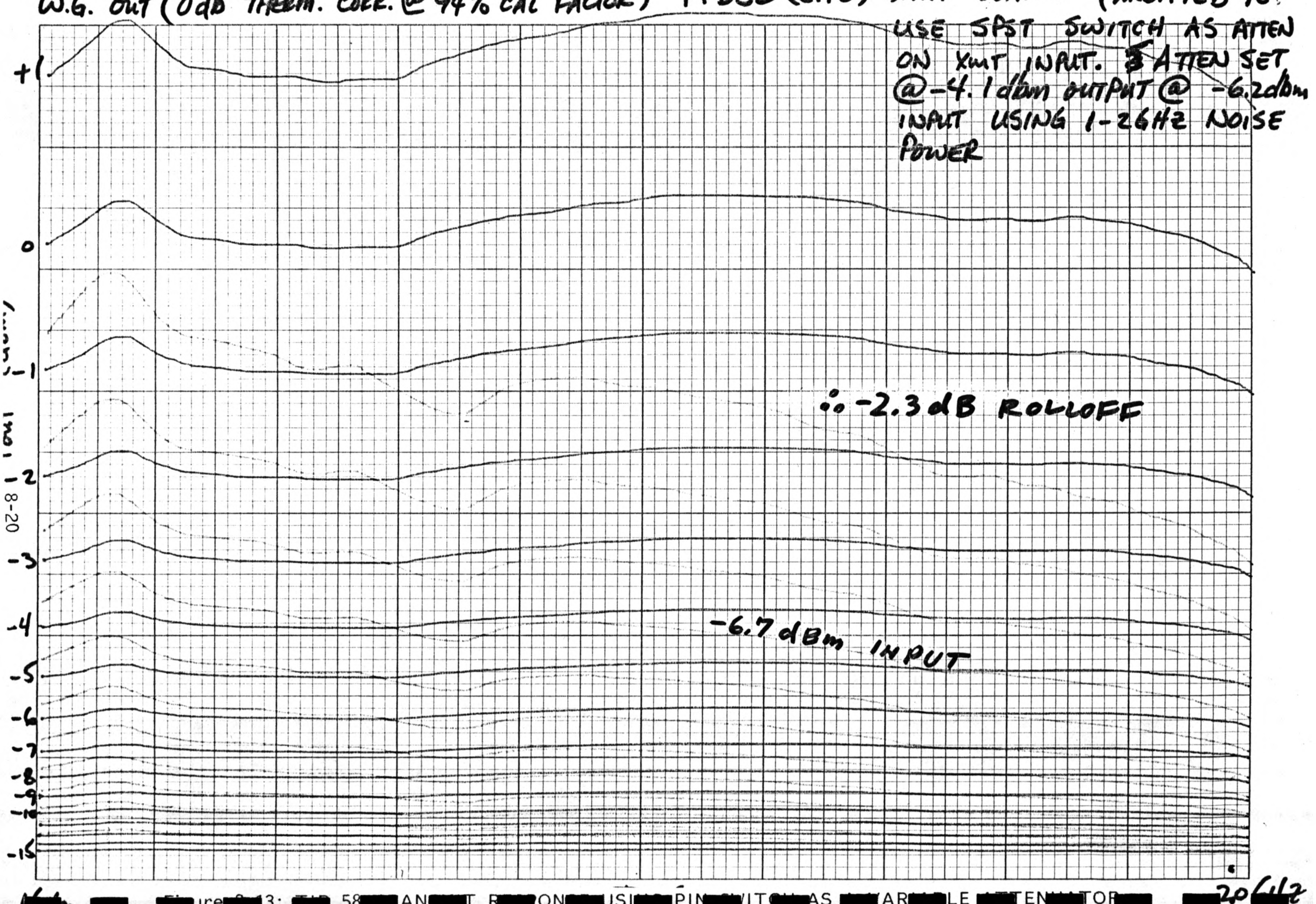
W.G. OUT (0db THERM. CORR. @ 94% CAL FACTOR) TID58 (CH6) SINEWAVE XMT OUTPUT (MODIFIED TO USE SPST SWITCH AS ATTEN ON XMT INPUT. ATTEN SET @ -4.1 dBm OUTPUT @ -6.2 dBm INPUT USING 1-2GHz NOISE POWER



∴ -2.3 dB ROLLOFF

-6.7 dBm INPUT

[redacted] [redacted] ure [redacted] 13: [redacted] 58 [redacted] AN [redacted] T R [redacted] ON [redacted] USI [redacted] PIN [redacted] WITC [redacted] AS [redacted] VAR [redacted] LE [redacted] TTEN [redacted] TOR [redacted] [redacted]

8.4 ADDITIONAL VARIABLE ATTENUATOR

Another alternative to level setting would be to place a variable pin diode or mechanical attenuator external to the modem. This could be mounted at the back of the rack or in an adjacent module. The present modem level setting would continue to be used.

Mounting the attenuator in the back of the rack would have a number of disadvantages. First it is not as convenient nor as standard as a front panel adjustment. Second, mechanical exposure may incur damage, and third, temperature instability could result since it is no longer in the controlled rack air-flow.

Mounting an external attenuator in a seperate module is presently under evaluation in the actual system.

8.5 REPLACEMENT OF MODEM PIN DIODE SWITCH WITH VARIABLE PIN ATTENUATOR

Because of the high return loss of the T2 transmit IF output and modem transmit IF input in conjunction with the long line length it would be desirable for any modification to reduce this problem. One method of accomplishing this would be to replace the SPST switch with a non-reflective pin attenuator to provide a good VSWR to the transmit amplifier. Thus the present level set pad could be moved to the T2 output or T1 input to lower the product of the two voltage reflection coefficients.

Besides improving the passband ripple this would also have other advantages. Module hardware required for the external attenuator would no longer be necessary. Thus a cost savings would be realized. Also the number of connectors in the transmission line would be reduced by two (in the case of directly mounting the attenuator at the back of the rack) or by four (in the case of the external module). Thus phase stability, mechanical reliability, and amplitude response would be optimized, and the length of the coax line would be minimized.

9.0 PROPOSED LEVEL-SETTING PROCEDURE

Set FE to CC band, L6(A):3860
L6(C):3860
unless otherwise noted.

9.1 Central Electronics Room T1 Transmit Level Adjust

1. With spectrum analyzer set to 1500-MHz center, 100 MHz/div, 3-MHz resolution, 300-Hz video filter, 10 dB/div, -10 dBm reference level @ 20-dB RF attenuation, and 0.5 sec/div, connect to the T2 "RCV IF" monitor jack at the vertex room. Check to be sure the analyzer noise floor is at least 10 dB below the T2 "RCV IF" noise floor. This may require additional gain ahead of the analyzer.

2. Set CER T1 modem to full XMT and vertex room T1 to full RCV.

3. Adjust CER "XMT Level" pot for 43.5-dB signal-to-noise ratio (analyzer reading will be 46-dB S/N with 2.5-dB analyzer error factor) minimum for each 1200-MHz and 1800-MHz carrier. The 1200-MHz LO will usually be the worst case.

9.2 Vertex Room T2 RCV Gain Adjust

4. Connect power meter to T2 "RCV IF" monitor jack at the vertex room.

5. Adjust vertex room T2 "RCV gain pot" for -14 dBm total LO power.

6. Reconnect analyzer to the vertex T2 "RCV IF" jack and photograph result.

9.3 Vertex Room T1 Transmit Level Adjust

1. With spectrum analyzer set to 1500-MHz center, 100 MHz/div, 3-MHz resolution, 300-Hz video filter, 10 dB/div, and -20 dBm reference level @ 10-dB RF attenuation, connect to the T2 "RCV IF" monitor jack at the central electronics room.

   Check to be sure the analyzer noise floor is at least 10 dB below the T2 "RCV IF" noise floor. This may require additional gain on the analyzer.

2. Set CER T1 modem to full RCV and vertex room T1 to full XMT.

3. Adjust vertex room "XMT level" pot for 20-dB signal-to-noise ratio minimum for all IF channels (analyzer reading will also be 20 dB). Channel A will usually be the worst case.

9.4 Central Electronics Room T2 RCV Gain Adjust

4. Connect power meter to T2 "RCV IF" monitor jack at central electronics room.

5. Set L6 to CH A 0, CH C 0 at C-band to kill front end noise power.

6. Set CER T2 RCV gain for -20 dBm T2 "RCV IF" power level (total LO power).

7. Reconnect analyzer to the CER T2 "RCV IF" jack and photograph result.

8. Record T_{SYS}/T_{CAL} ratio from front end overlay for each IF channel and calculate T_{SYS}/T_{CALFE} as follows:

$$T_{SYS}/T_{CALFE} = (T_{SYS}/T_{CALDMT}) \times \frac{15}{40}$$

9. Record "cal off" and "syn" voltages from baseband overlay and calculate T_{SYS}/T_{CAL} for each channel as follows:

$$T_{SYS}/T_{CALBB} = \frac{V_{CAL\ OFF} \times 10}{V_{SYN}}$$

10. Calculate $\varepsilon\%$ for each channel as follows:

$$\varepsilon\% = \frac{T_{SYS}/T_{CALBB} - T_{SYS}/T_{CALFE}}{T_{SYS}/T_{CALFE}} \times 100\%$$

$\varepsilon\% \leq -1\%$ as a design goal. (Assumes no deterioration in $\frac{\text{signal + noise}}{\text{noise}}$ ratio due to T1 modem or T3 IF to baseband converter.)

APPENDIX A

CHANNEL	LOCAL OSCILLATOR FREQUENCY f_o, GHz	SIGNAL BAND LOW	HIGH
1	26.41	27.41	28.41
2	28.79	29.79	30.79
3	31.21	32.21	33.21
4	33.59	34.59	35.59
5	36.01	37.01	38.01
6	38.39	39.39	40.39
7	40.81	41.81	42.81
8	43.19	44.19	45.19
9	45.61	46.61	47.61
10	47.99	48.99	49.99
11	50.41	51.41	52.41

Figure A-1: MODEM WAVEGUIDE CHANNEL ALLOCATIONS

APPENDIX B

NOISE FIGURE/EFFECTIVE TEMPERATURE DERIVATIONS USING HOT AND COLD LOAD AS WELL AS NOISE TUBE MEASUREMENT TECHNIQUES

B.1.0 Definitions of Terms

P_n = available noise power in watts

K = Boltzmann's constant = 1.38×10^{-23} J/K

T = absolute temperature in K

B = bandwidth in hertz

T_E = effective input noise temperature of system

N = noise ratio

F = noise figure in dB = 10 dB $\mathrm{LOG}_{10}N$

G = gain of device

B.2.0 Definition of Noise Figure

P_n = KTB for a linear, passive network

Let N_i =

Noise input to device from terminated load at temperature 290 K

$\therefore N_i = K(290)B$

Let N_o =

Noise output of device from terminated load at 290 K and effective input noise temperature

$\therefore N_o = GKB(290+T_E)$

$$N = \frac{N_o}{GN_i} \qquad \text{From IRE definition of noise factor}$$

$$\therefore N = \frac{GKB(290+T_E)}{GKB(290)}$$

$$\therefore N = 1 + \frac{T_E}{290}$$

$$\therefore \boxed{F = 10\ \mathrm{dB}\ \mathrm{LOG}_{10}(1+\frac{T_E}{290})}$$

B.3.0 Noise Figure Measurement with Hot and Cold Load

Let Y_{HC} =

Y-factor (output noise power ratio) for hot and cold load measurement.

$$\therefore Y_{HC} = \frac{G(T_E+290)}{G(T_E+77)}$$

$$\therefore \boxed{T_E = \frac{290 - (Y_{HC})(77)}{Y_{HC} - 1}}$$

$$\boxed{\text{with } F = 10\ \mathrm{dB}\ \mathrm{LOG}_{10}(1+\frac{T_E}{290})}$$

B.4.0 Noise Figure Measurement Using Noise Tube

Let Y_T =

Y-factor (output noise power ratio) for noise tube measurement.

Let X =

ratio of excess noise power available from noise tube.

Let T_X =

excess noise temperature of tube.

$$X = \frac{T_X - 290}{290} \qquad \text{by definition}$$

$$\therefore\ T_X = 290(1+X)$$

$$Y_T = \frac{G(T_X+T_E)}{G(290+T_E)} = \frac{290(1+X)+T_E}{290+T_E}$$

$$\therefore\ \boxed{T_E = \frac{290 - (1+X-Y_T)}{Y_T - 1}}$$

From definition of noise figure,

$$F = 10 \text{ dB } \mathrm{LOG}_{10}(1+\frac{T_E}{290})$$

$$F = 10 \text{ dB } \mathrm{LOG}_{10}[1+\frac{290}{290}\ (\frac{1+X-Y_T}{Y_T-1})]$$

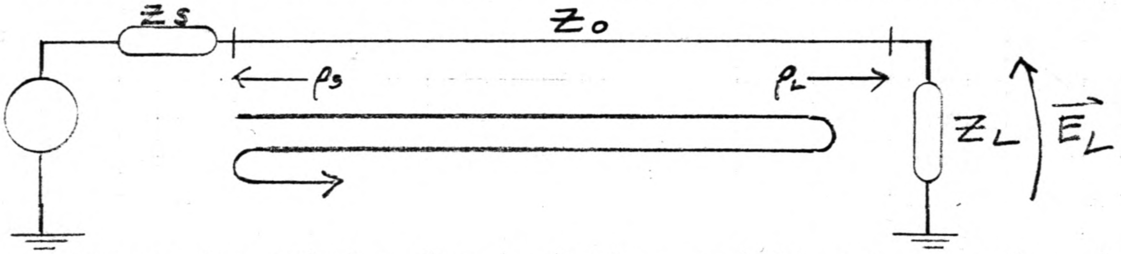
$$F = 10 \text{ dB } \mathrm{LOG}_{10}[\frac{X}{Y_T-1}]$$

$$\therefore\ \boxed{F = 10 \text{ dB } \mathrm{LOG}_{10}X - 10 \text{ dB } \mathrm{LOG}_{10}[Y_T-1]}$$

Reference: W. W. Mumford and E. H. Scheibe, Noise Performance Factors in Communications Systems, 1968, Horizon House-Microwave, Inc.

APPENDIX C

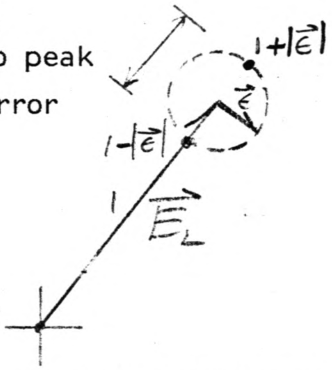
DERIVATION OF MISMATCH ERRORS DUE TO REFLECTION COEFFICIENT AT SOURCE AND LOAD ENDS OF A LENGTH OF TRANSMISSION LINE.



Assume transmission line is lossless and let average value of $|\vec{E}_L| = 1$ and E_L = voltage error at load.

Phasor Diagrams

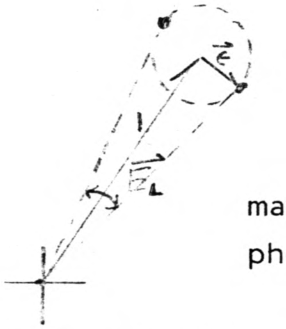
Max peak to peak amplitude error



$$|\vec{\epsilon}| = \frac{|\rho_s||\rho_L|}{1}$$

.·. maximum peak to peak amplitude error

$$= 20 \text{ dB } \mathrm{LOG}_{10} \frac{1+|\rho s||\rho l|}{1-|\rho s||\rho l|}$$



$$|\vec{\epsilon}| = \frac{|\rho_s||\rho_L|}{1}$$

max peak to peak phase error

.·. Maximum peak to peak phase error

$$= 2 \tan^{-1} \frac{|\rho s||\rho l|}{1} = 2 \tan^{-1} |\rho s||\rho l|$$

Figure C-1