VLA TECHNICAL REPORT #14

SYSTEMS TESTS OF JUNE 1975

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I. INTRODUCTION

This report describes tests of LO, IF, and digital-data transmission equipment for VLA Antenna #1 conducted in Charlottesville, Virginia during April 15 thru June 15, 1975. A summary of results of the test program is as follows:

1) Many minor problems were discovered and corrected during the test period; these are not described in this report.

2) Overall system design appears to be adequate; no problems requiring system re-design were found.

3) Optimum power levels within the system were determined.

4) A system temperature coefficient of 1.2°/°C was determined for 600 MHz phase reference transmission.

5) Modules L2 and L10 have temperature coefficients several times higher than above and need improvement.

6) Operation at simulated waveguide attenuation of 50 to 62 dB is possible with an IF signal-to-noise of 10 at 62 dB.

7) Adequate tolerance to waveguide reflections was demonstrated.

8) It was discovered that a small offset between control room and antenna carrier frequencies would allow more tolerance to spurious signal leakage.

9) Digital-data transmission as amplitude-modulation on an LO carrier appears to be acceptable; an FM link with module M6 is not necessary.

10) A gallery of photographs of waveforms and spectra showing normal system performance was produced and can be used as a benchmark for future system performance.

The following tests were not performed and are recommended for the next test program:

1) Measurements of temperature coefficients of individual racks.

2) Measurements of spurious signals within IF bands.

3) Measurement of correlator output noise.

4) Measurement of phase and amplitude response of IF bands.

5) Measurement of transmission-system decorrelation of perfectly correlated noise.

6) Tests of monitor points as read by the monitor and control system.
7) Measurement of power level stability as a function of temperature.
8) Measurement of radiated RFI.
9) Measurement of phase stability in the actual waveguide system.

II. SYSTEM TEST CONFIGURATION

The system under test consisted of Vertex Room (VR) Rack B1, Control Room (CR) Rack E1, Master Oscillator Rack M, Front-End Simulator, and a Dummy Waveguide Assembly. Block diagrams of these items are shown in Figures 2.1 thru 2.4, respectively. The module serial numbers installed as of June 13, 1975, are given in Tables I and II.

During the test period optimum levels were determined for power levels within the system and, prior to the final tests described in the next section, the levels were adjusted to the receive values shown in Figure 2.5. The transmit levels were within 2 dB of the values shown in Figure 2.5 but could not be adjusted to correct values because of difference in transmission loss at 1200 and 1800 MHz. Normally the transmitted levels should be adjusted since they are in the same location as the monitor point. A recommended level adjustment procedure is give in Table III. When an antenna is moved or waveguide attenuation is changed only the Receive Level controls on T2 modules need be adjusted.

Chart records of the following phases within the system were recorded during the test period (listed in left-to-right order on chart record):

a) 600 MHz Round Trip Phase - (600ϕ RT)

This signal is available from a rear connector on L14 and is an amplified phase comparison (~175 mV/°) between master and return 600 MHz signals. The phase detector can be adjusted to null by means of a panel-mounted mechanical phase shifter in the reference signal line. The reference signal can either be obtained from L10 (derived from 1200-1800 mixing) or from L2 in the master LO rack; a front-panel coax jumper near the phase-shifter makes this choice. The L10 reference was found to be temperature sensitive and was not used for final tests. The phase detector output has 1 ms spikes every 52 ms due to control room transmission period but these spikes are absorbed by pre-recorder time-constants.

b) 600 MHz One-Way Phase - (600ϕ 1W)

This phase comparison is performed by an HP8410B/8411 network analyzer comparing the VR Rack B 600 MHz rack output (normally connected to the front-end) and the phase shifted 600 MHz reference going into L14. Sensitivity is 10 mV/°.

c) <u>5 MHz Vertex-Room Phase</u> - (5ϕ VR)

This phase comparison is between 5 MHz received at the antenna and the local 5 MHz VCXO which is locked by the received 600 MHz; it is a measure of one-way transmission phase between 5 MHz and 600 MHz/120. The signal is available on position #2 of the VR L5 front-panel monitor jack and has a level of $\sim$175 mV/°.

d) <u>5 MHz Round Trip Phase</u> - (5ϕ RT)

This is the $\sim$175 mV/° output of the CR L9 5 MHz phase detector which compares master 5 MHz with 5 MHz returned from the antenna. A front panel control on the 600 MHz phase-shifter panel allows this phase detector to be set at null.

Unless otherwise noted all measurements are performed with the CR T1 carrier oscillator 30 kHz below the VR T1 carrier oscillator. This offset is introduced by supplying the CR carrier phase-locked-loop IF reference from a 10.03 MHz synthesizer in place of 10.00 MHz from the master LO; the carrier frequency then becomes 34,600 - 10.03 = 34,589.97 MHz. The purpose of this offset is discussed in Section IV.

TABLE I - RACK B1 MODULE COMPLEMENT

MODULE TYPE	SERIAL NO.	NAME-REMARKS
L6	A5	A Synthesizer, f_{LO} = 3240 MHz, Dial = 806
L7	A7	A Fringe Generator
L6	A9	B Synthesizer, f_{LO} = 3260 MHz, Dial = 811
L7	A8	B Fringe Generator
L6	A7	C Synthesizer, f_{LO} = 3310 MHz, Dial = 798
L7	A9	C Fringe Generator
L6	A4	D Synthesizer, f_{LO} = 3290 MHz, Dial = 818
L7	A2	D Fringe Generator
L1	A1	5/50 MHz VCXO
L2	A2	50/600 Multiplier
L3	A1	LO Transmitter
L4	A1	LO Receiver
L5	A1	LO Control
L8	A1	Digital Divider
P3	A3	+28V @ 1.43A, -28V @ .05A
F4	A5	A Frequency Converter, f_{IF} = 1325 MHz
F4	A9	B Frequency Converter, f_{IF} = 1425 MHz
F4	A7	C Frequency Converter, f_{IF} = 1575 MHz
F4	A8	D Frequency Converter, f_{IF} = 1675 MHz
T2	A4	IF Combiner
T1	A2	Modem (TRG) - Channel 4, 33.59 GHz LO
P1	A2	+5V @ 22A, -5V @ 2.95A
P2	A3	+15V @ 5.7A, -15V @ 1.07A

TABLE II - RACK E1 MODULE COMPLEMENT

MODULE TYPE	SERIAL NO.	NAME
T4A	A1	LO Offset
T4B	A3	LO Offset
T5	A6	A IF Receiver, f_{IF} = 1325 MHz
T5	A3	B IF Receiver, f_{IF} = 1425 MHz
T5	A2	C IF Receiver, f_{IF} = 1575 MHz
T5	A7	D IF Receiver, f_{IF} = 1675 MHz
T6	A1	IF Control
L5	(none)	LO Control
L9	A3	Central LO Receiver
L14	A2	Central LO Filter
L10	A2	Central LO Transmitter
T2	A1	IF Combiner
T1	A1	Modem (TRG) - Channel 4, 33.59 GHz LO
P4	A2	+5V @ 11A, -28V
P5	A3	+15V @ 3.5A, -15V @ 0.9A, +28V @ 1.0A
		RACK M MODULE COMPLEMENT
L1	A3	5/50 MHz VCXO
L2	A4	50/600 Multiplier
L13	A1	Central Multiplier
L8	A2	Digital Divider
L17	(none)	Synthesizer Offset
L18	(none)	LO Driver
P4	A3	+5V @ ∿0A, -28V @ ∿0A
P5	A4	+15V @ 1.2A, -15V @ 0.4A, +28V @ 1.47A

TABLE III - LEVEL ADJUSTMENTS

FUNCTION	ADJUST	MONITOR	CORRECT LEVEL
1200 CR XMIT Level	R4 in L10	CR T2-XMIT	-33 dBm @ 1200
5 MHz Sidebands	R8 in L10	CR T2-XMIT	-43 dBm @ 1195 or 1205
1800 CR XMIT Level	R7 in L10	CR T2-XMIT	-33 dBm @ 1800
Data Sidebands	R4 in L10	CR T2-XMIT	-48 dBm @ 1799.5 or 1800.5
VR Receive Level	RCV GAIN on VR T2	VR T2-RCV	-17 dBm @ 1200 or 1800
1200 VR XMIT Level	R5 in L3	VR T2-XMIT	-39 dBm @ 1200
5 MHz Sidebands	R4 in L3	VR T2-XMIT	-49 dBm @ 1195 or 1205
1800 VR XMIT Level	R7 in L3	VR T2-XMIT	-39 dBm @ 1800
Data Sidebands	R4 in L3	VR T2-XMIT	-54 dBm @ 1199.5 or 1200.5
CR Receive Level	RCV GAIN on CR T2	CR T2-RCV	-23 dBm @ 1200 or 1800

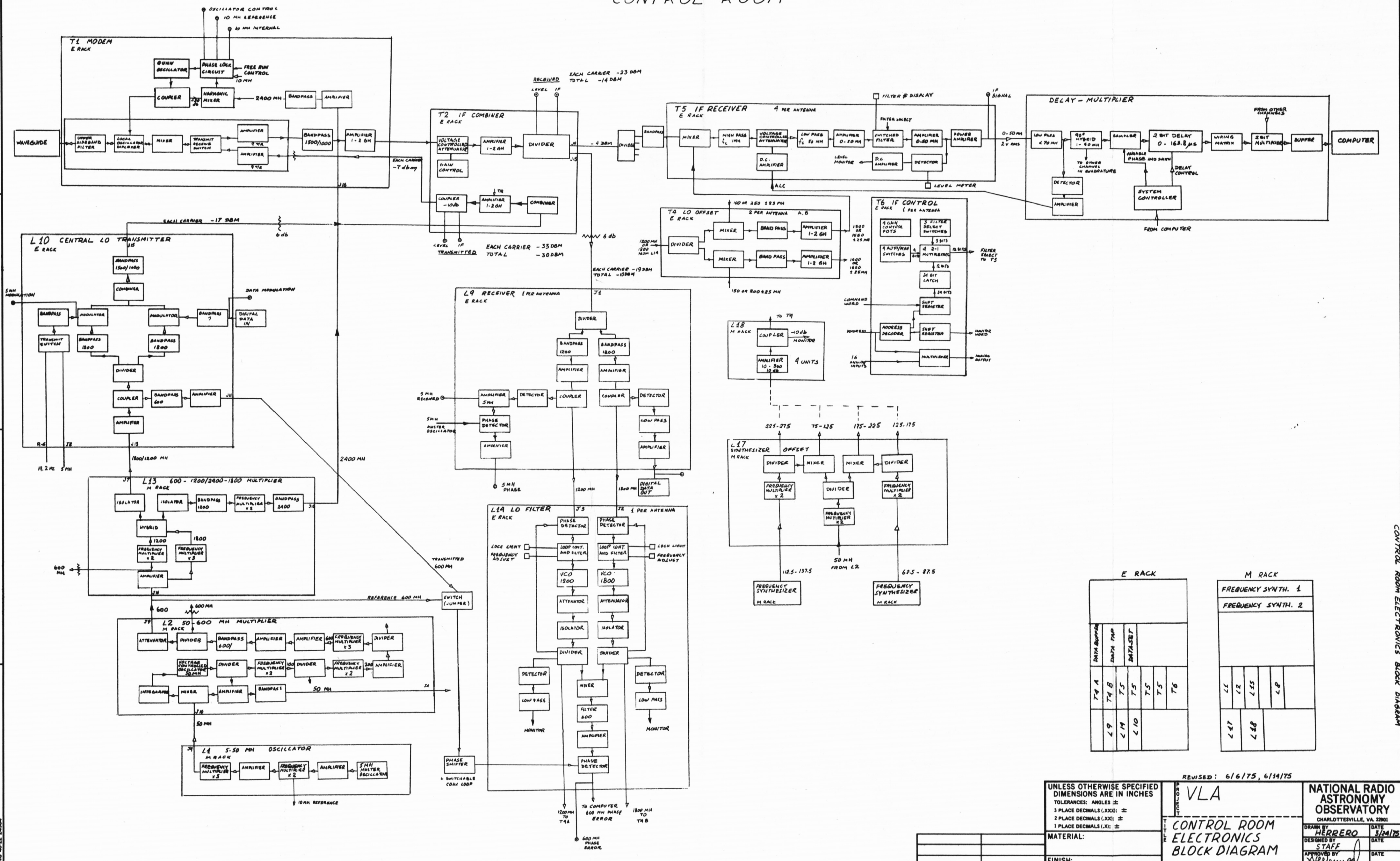
NOTES:

1) Lock CR T1 in XMIT, VR T1 in RCV for first five adjustements; reverse for last five adjustments.

2) Use module extender for L3 and L10 internal adjustments.

3) All measurements made with Spectrum Analyzer.

CONTROL ROOM



REVISED: 6/6/75, 6/19/75

NEXT ASSY	USED ON

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: ANGLES ±
3 PLACE DECIMALS (.XXX): ±
2 PLACE DECIMALS (.XX): ±
1 PLACE DECIMALS (.X): ±

MATERIAL:

FINISH:

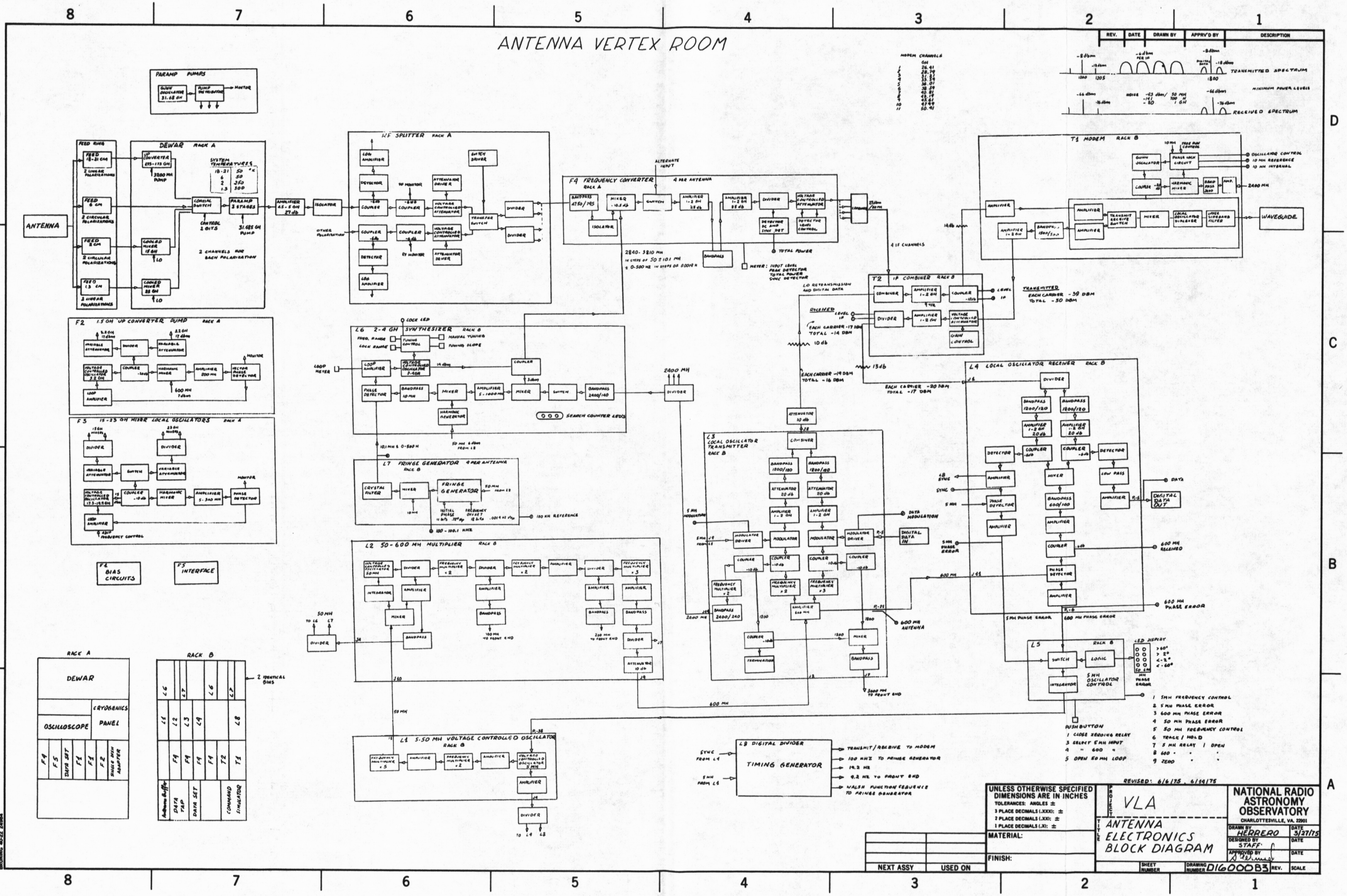
PROJECT: VLA

TITLE: CONTROL ROOM ELECTRONICS BLOCK DIAGRAM

NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, VA. 22901

DRAWN BY HERRERO — DATE 3/24/75
DESIGNED BY STAFF
APPROVED BY

SHEET NUMBER — DRAWING NUMBER D16000B2 — REV. — SCALE


ANTENNA VERTEX ROOM
PARAMP PUMPS
ANTENNA
FEED RING
DEWAR RACK A
SYSTEM TEMPERATURES
COAXIAL SWITCH
PARAMP 3 STAGES
AMPLIFIER 4.5 - 5 GH 27 db
ISOLATOR
RF SPLITTER RACK A
F4 FREQUENCY CONVERTER RACK A
4 PER ANTENNA
ALTERNATE INPUT
T1 MODEM RACK B
WAVEGUIDE
TRANSMITTED SPECTRUM
MINIMUM POWER LEVELS
RECEIVED SPECTRUM
MODEM CHANNELS
T2 IF COMBINER RACK B
F2 1.5 GH UP CONVERTER PUMP RACK A
F3 15-23 GH MIXER LOCAL OSCILLATORS RACK A
L6 2-4 GH SYNTHESIZER RACK B
L7 FRINGE GENERATOR 4 PER ANTENNA RACK B
L2 50-600 MH MULTIPLIER RACK B
L3 LOCAL OSCILLATOR TRANSMITTER RACK B
L4 LOCAL OSCILLATOR RECEIVER RACK B
L5
F6 BIAS CIRCUITS
F5 INTERFACE
RACK A
DEWAR
OSCILLOSCOPE
CRYOGENICS PANEL
RACK B
2 IDENTICAL BINS
L1 5-50 MH VOLTAGE CONTROLLED OSCILLATOR RACK B
L8 DIGITAL DIVIDER
TIMING GENERATOR
REVISED: 6/6/75, 6/14/75
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
MATERIAL:
FINISH:
NEXT ASSY
USED ON
VLA
ANTENNA ELECTRONICS BLOCK DIAGRAM
NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, VA. 22901
DRAWN BY HERRERO
DATE 3/27/75
DESIGNED BY STAFF
DRAWING NUMBER D16000B3

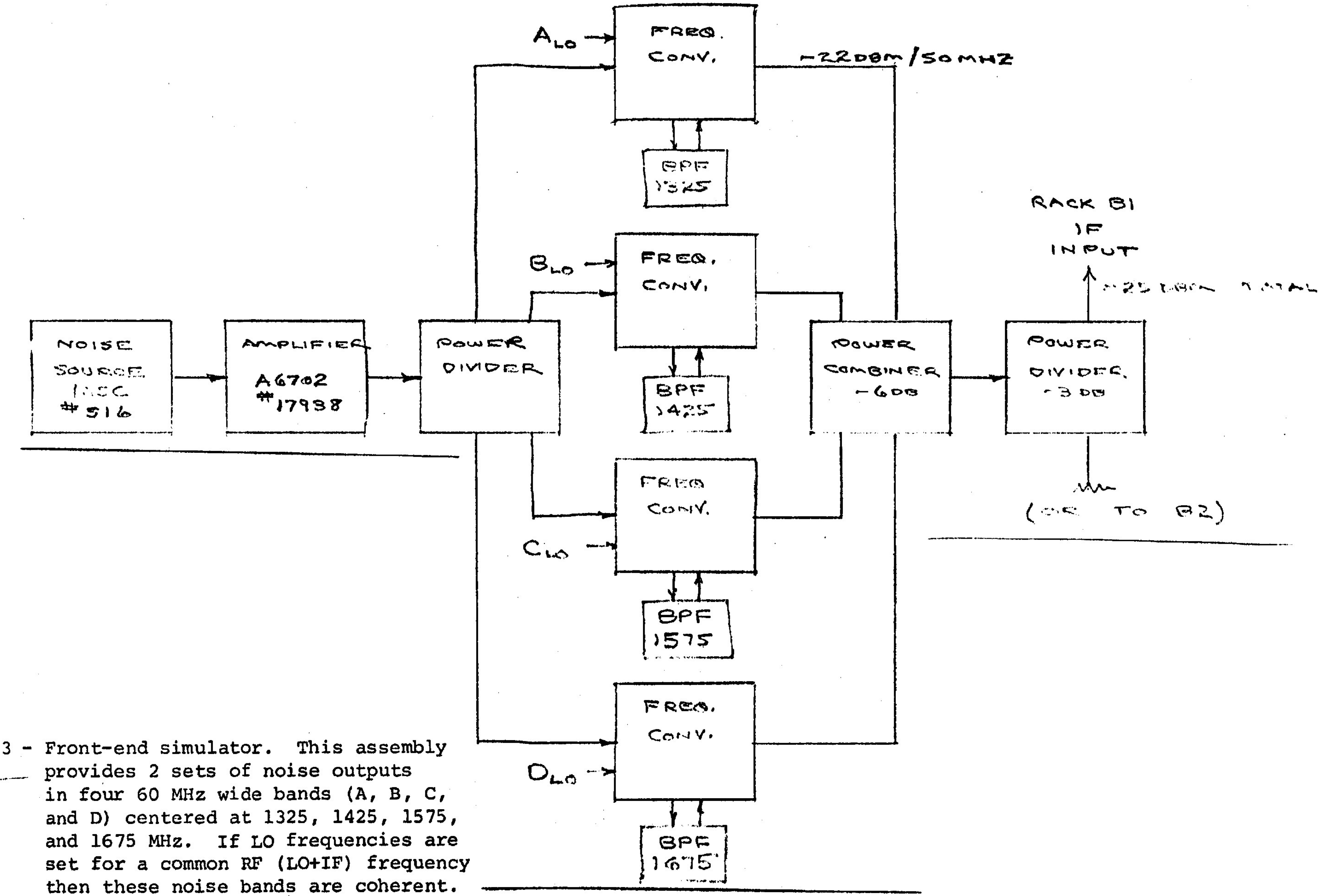


FIGURE 2.3 - Front-end simulator. This assembly provides 2 sets of noise outputs in four 60 MHz wide bands (A, B, C, and D) centered at 1325, 1425, 1575, and 1675 MHz. If LO frequencies are set for a common RF (LO+IF) frequency then these noise bands are coherent. LO frequencies were set for incoherent noise during most of the tests. The two outputs (i.e. Antenna 1 and Antenna 2) for a given band are always coherent.

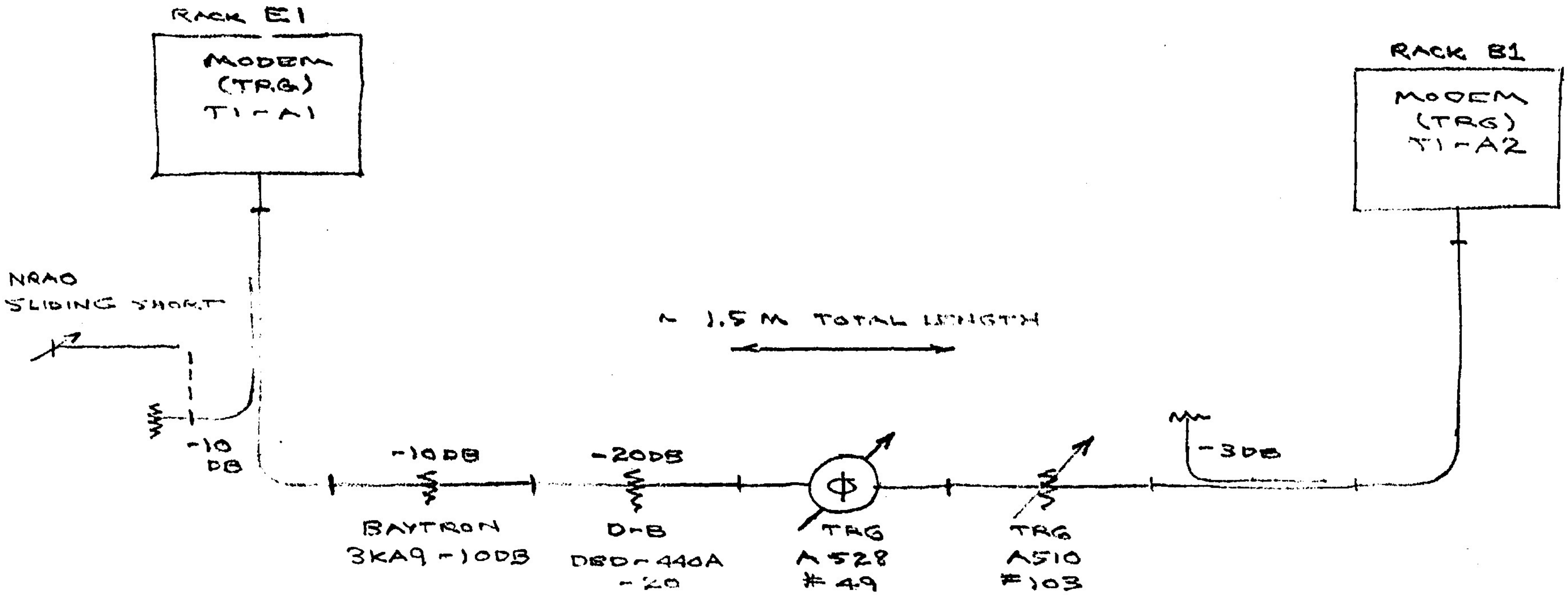


FIGURE 2.4 - Dummy waveguide assembly. The total attenuation consists of a fixed 35.5 dB (10 dB + 20 dB + 3 dB + 0.5 dB + 2 dB waveguide loss) plus the setting of the TRG precision attenuator - usually 20.5 dB for 56 dB total attenuation. A 20 dB return loss reflection was simulated by a sliding short on the 10 dB coupler next to Modem T1-A1. Modem LO frequency was 33.59 GHz (Channel 4).

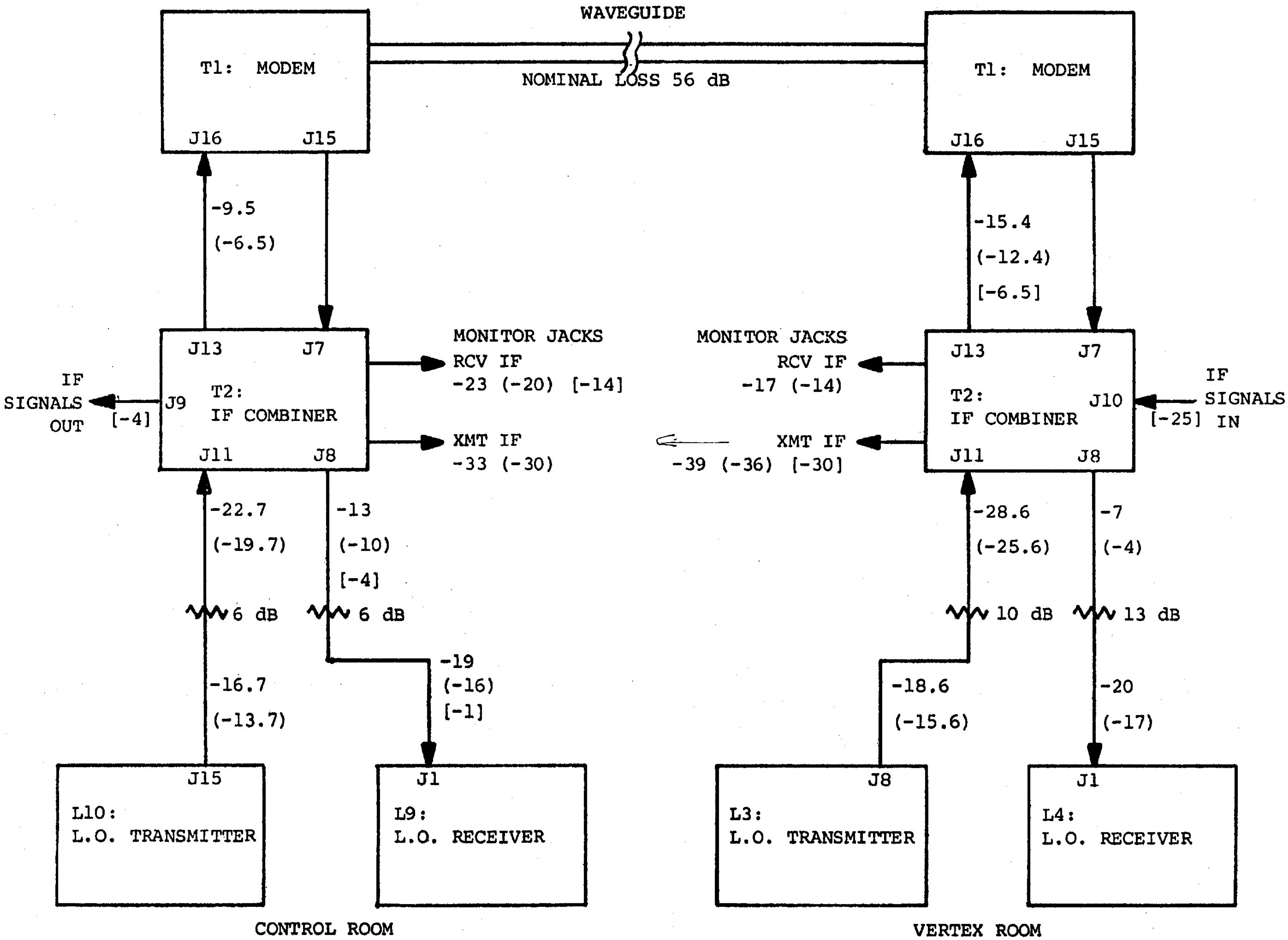


FIGURE 2.5 - System levels and pads. All power levels in dBm and apply to carrier if no parenthesis, total LO carriers if in parenthesis, and total IF and LO power if in brackets. All signal levels are when the signal is ON; they are not average levels.

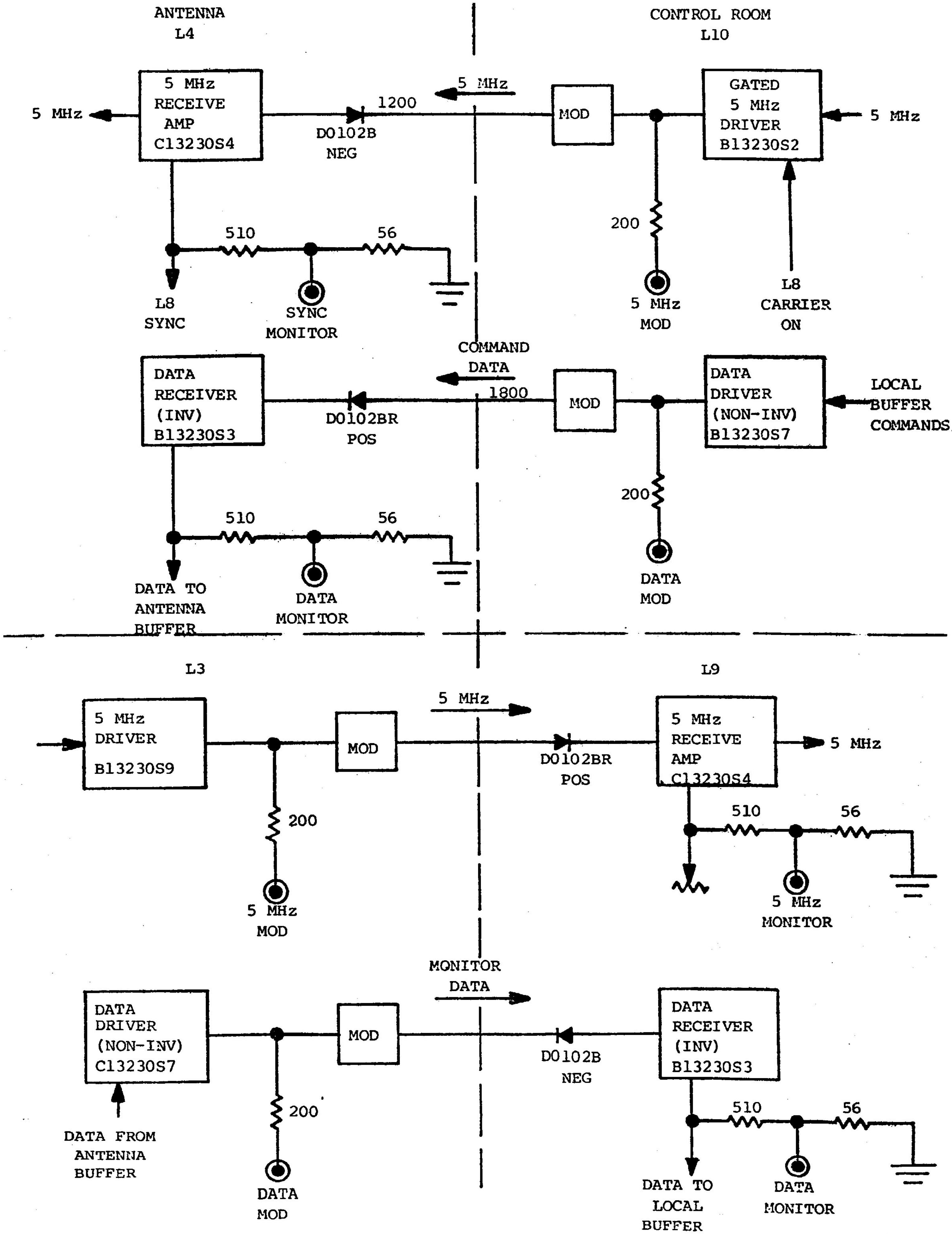


FIGURE 2.6 - Simplified block diagram of 5 MHz, SYNC, and DATA transmission. Refer to waveform photographs.

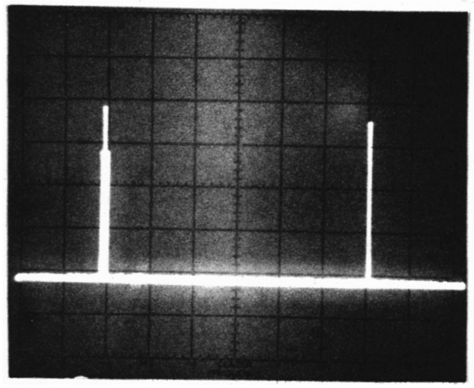
III. FINAL TEST DATA

Photographs of waveforms and spectra at system monitor points were taken on June 14 and 15, 1975, and are presented in this section.

The waveforms were measured with a Tektronix 7603/7A18N/7B53AN Oscilloscope which has 60 MHz vertical bandwidth and a delayed sweep. DC coupling was used in all cases and the zero-level is marked on the oscillograms. Triggering was from either CR L8, VR L8, or internal as indicated on the photograph captions.

Spectra were measured with a Hewlett-Packard 141T/8552B/8555A/8445B Spectrum Analyzer. The 8445B Tracking Pre-selector was bypassed for spectra below 2 GHz to avoid attenuation of the 1800 MHz carrier by the 1.8 GHz low-pass filter. A -1 dB correction was left on the Fine Log Ref Level control to approximately correct for 6' of RG-58 connecting cable.

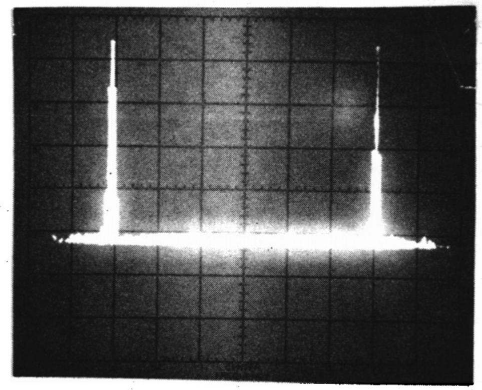
SPECTRA SA1-SA4B



1500 MHz

100 MHz/cm 300 kHz BW
10 kHz Video Filter

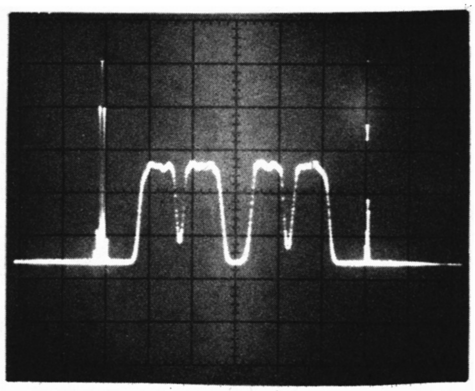
SA1 - Control Room T2-XMIT
(Lock in XMIT to Ant)



1500 MHz

100 MHz/cm 300 kHz BW
10 kHz Video Filter

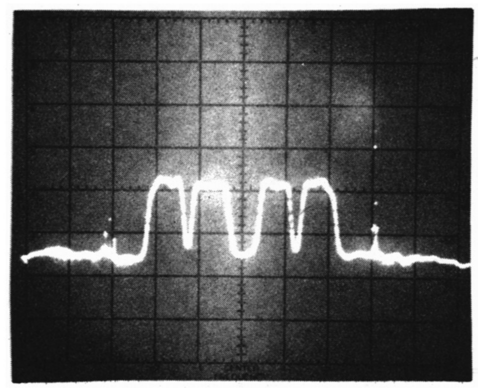
SA2 - Vertex Room T2 - Receive
(Lock in XMIT to Ant)



1500 MHz

100 MHz/cm 300 kHz BW
100 Hz Video Filter

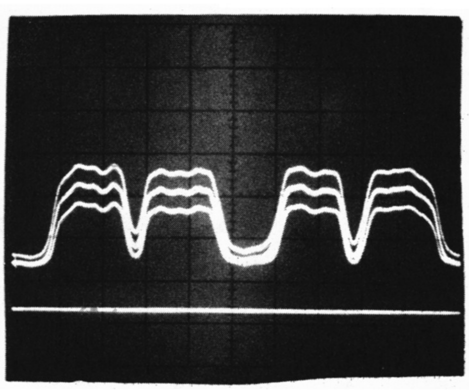
SA3 - Vertex Room T2-XMIT
(Normal)



1500 MHz

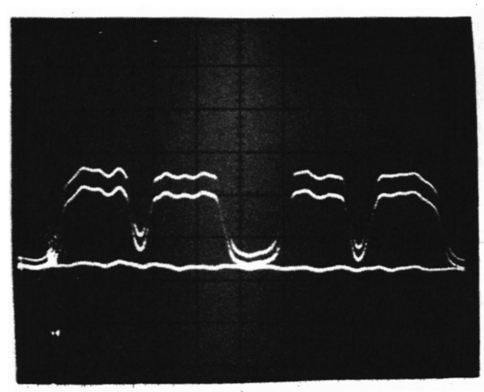
100 MHz/cm 300 kHz BW
100 Hz Video Filter

SA4 - Control Room T2-Receive



1500 MHz

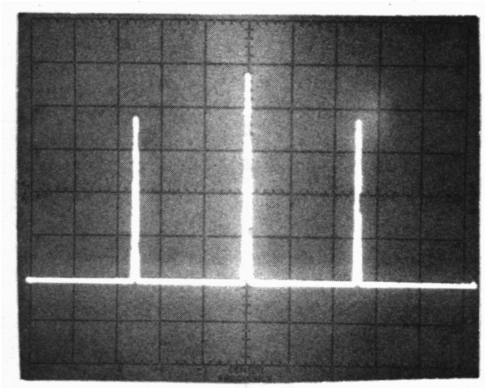
50 MHz/cm 300 kHz BW
100 Hz Video Filter
SA4A - Control Room T2-Receive
Top 51 dB WG Attenuation
Mid 56 dB WG Attenuation
Lower 61 dB WG Attenuation
Bottom - Analyzer Noise Level



1500 MHz

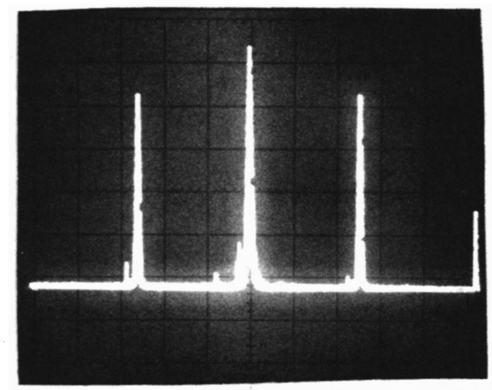
50 MHz/cm 300 kHz BW
100 Hz Video Filter
SA4B - Control Room T2-Receive
Top 51 dB WG Attenuation
Mid 56 dB WG Attenuation
Bottom 90 dB WG Attenuation

SPECTRA SA5-SA10



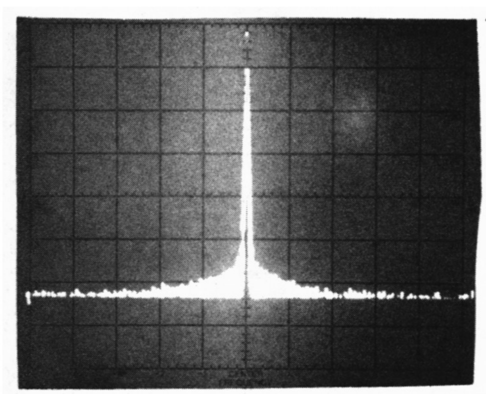
-20 dBm

1200 MHz
2 MHz/cm 30 kHz BW
100 Hz Video Filter
SA5 - Control Room T2-XMIT
(Lock in XMIT to Ant)



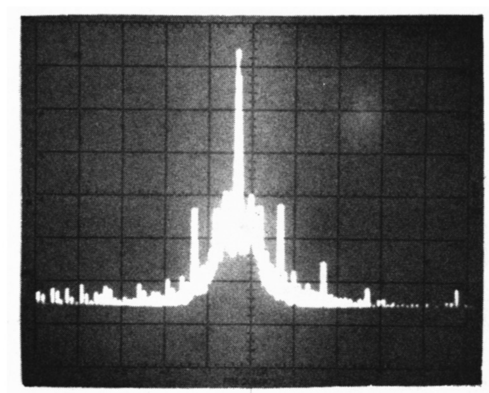
-10 dBm

1200 MHz
2 MHz/cm 30 kHz BW
100 Hz Video Filter
SA6 - Vertex Room T2-Receive
(Lock in XMIT to Ant)



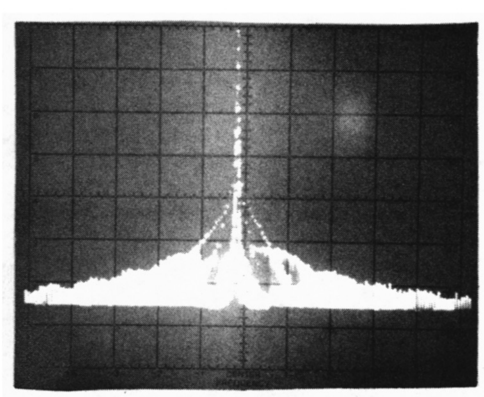
-30 dBm

1200 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA7 - Control Room T2-XMIT
(Lock in XMIT to Ant)



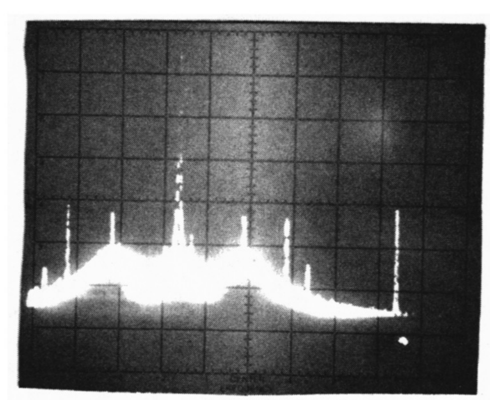
-10 dBm

1200 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA8 - Vertex Room T2-Receive
(Lock in XMIT to Ant)



-30 dBm

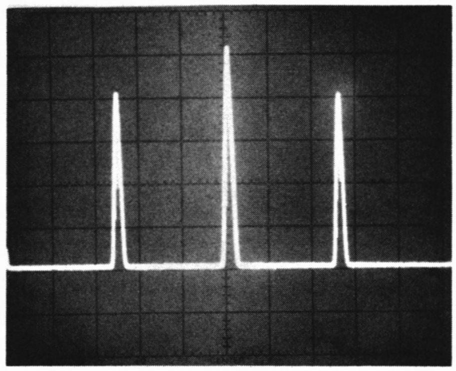
1200 MHz
.02 MHz/cm .3 kHz BW
10 Hz Video Filter
SA9 - Control Room T2-XMIT
(Lock in XMIT to Ant)



-10 dBm

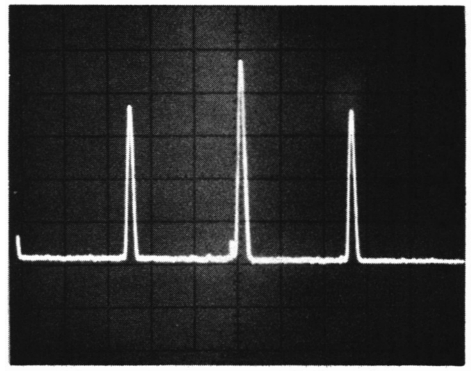
1200 MHz
.02 MHz/cm .3 kHz BW
10 Hz Video Filter
SA10 - Vertex Room T2-Receive
(Lock in XMIT to Ant)

SPECTRA SA11-SA16



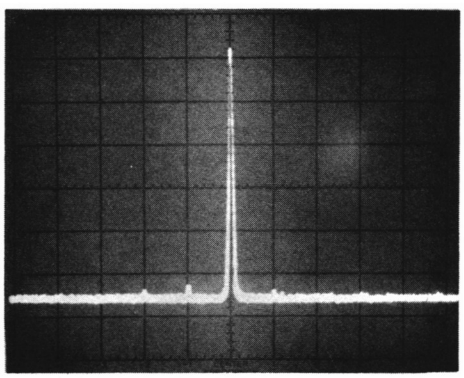
-30 dBm

1200 MHz
2 MHz/cm 100 kHz BW
100 Hz Video Filter
SA11 - Vertex Room T2-XMIT
(Normal Mode)



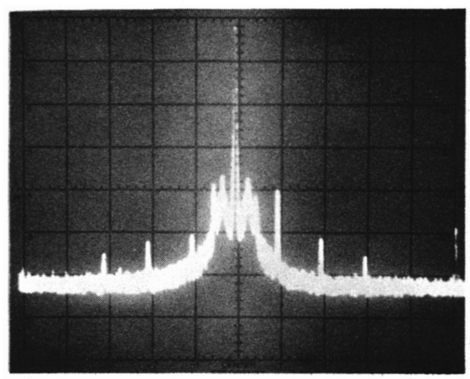
-10 dBm

1200 MHz
2 MHz/cm 100 kHz BW
100 Hz Video Filter
SA12 - Control Room T2-Receive
(Normal Mode)



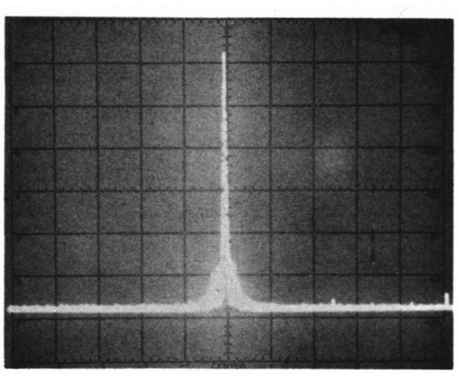
-30 dBm

1200 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA13 - Vertex Room T2-XMIT
(Normal mode)



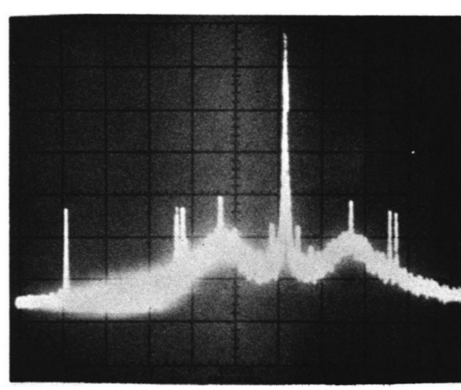
-20 dBm

1200 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA14 - Control Room T2-Receive
(Normal mode)



-30 dBm

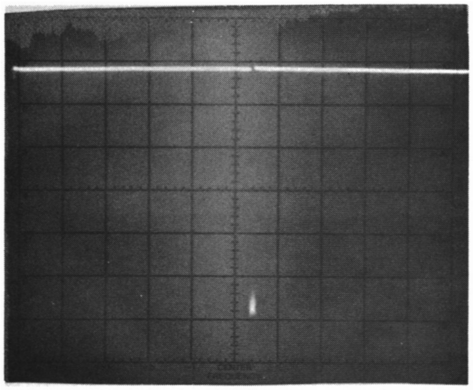
1200 MHz
.02 MHz/cm .3 kHz BW
100 Hz Video Filter
SA15 - Vertex Room T2-XMIT
(Normal mode)



-20 dBm

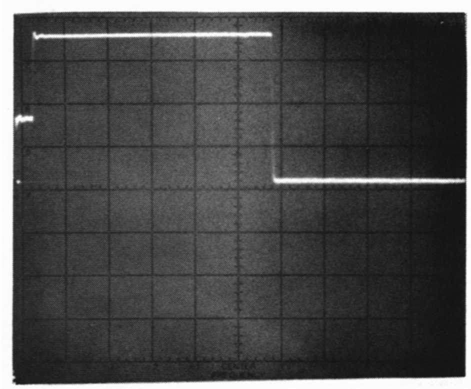
1200 MHz
.02 MHz/cm .3 kHz BW
10 Hz Video Filter
SA16 - Control Room T2-Receiver
(Normal mode)

SPECTRA SA17-SA22



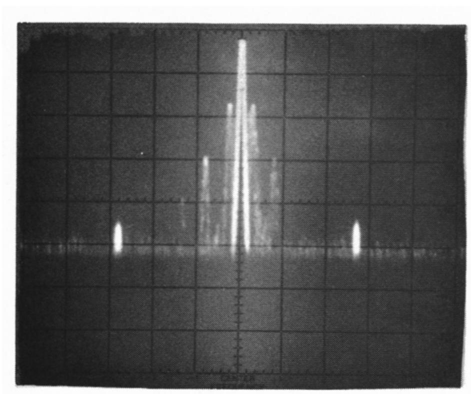
-10 dBm

1200 MHz
0 MHz/cm 300 kHz BW
Video Filter off
SA17 - Control Room T2-Receiver
(Video trigger, 10 ms/cm)



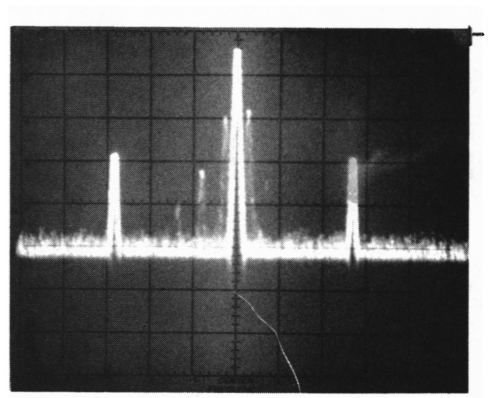
-10 dBm

1200 MHz
0 MHz/cm 300 kHz BW
Video Filter off
SA18 - Vertex Room T2-Receiver
(Video trigger, 200 μs/cm)



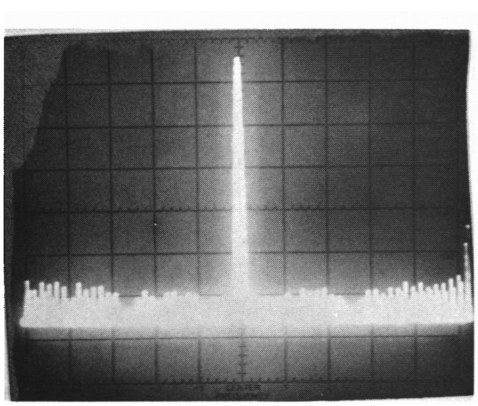
-30 dBm

1800 MHz
2 MHz/cm 100 kHz BW
Video Filter off
SA19 - Control Room T2-XMIT
(Lock in XMIT to Ant)



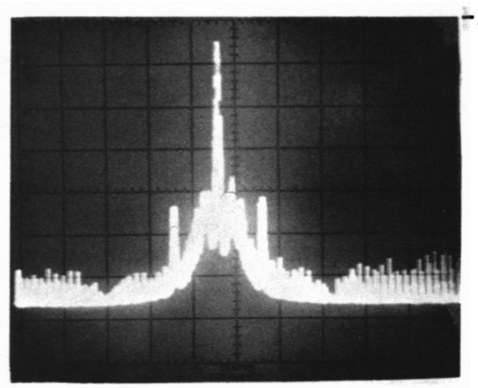
-10 dBm

1800 MHz
2 MHz/cm 100 kHz BW
Video Filter off
SA20 - Vertex Room Receive
(Lock in XMIT to Ant)



-30 dBm

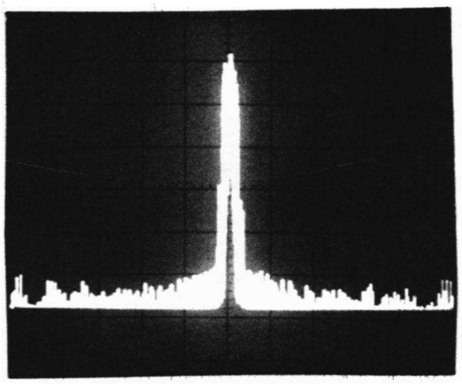
1800 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA21 - Control Room T2-XMIT
(Lock in XMIT to Ant)



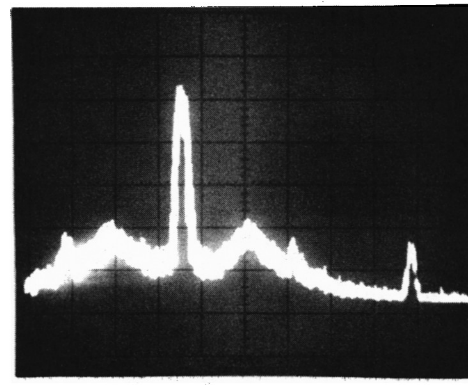
-10 dBm

1800 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA22 - Vertex Room T2-Receive
(Lock in XMIT to Ant)

SPECTRA SA23-SA28

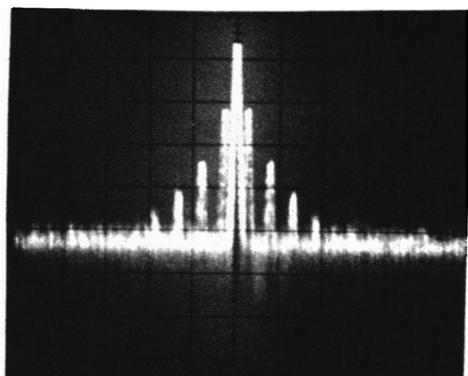

-30 dBm

1800 MHz
.02 MHz/cm .3 kHz BW
100 Hz Video Filter
SA23 - Control Room T2-XMIT
(Lock in XMIT to Ant)

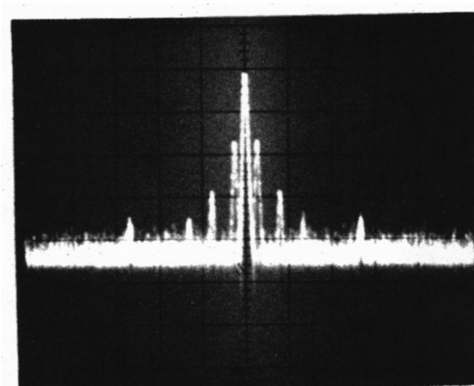

-10 dBm

1800 MHz
.02 MHz/cm .3 kHz BW
10 Hz Video Filter
SA24 - Vertex Room T2-Receive
(Lock in XMIT to Ant)

,36

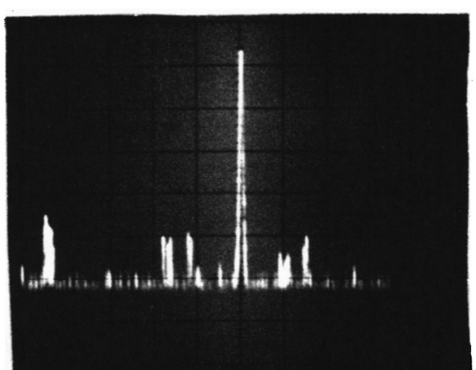

-30 dBm

1800 MHz
2 MHz/cm 100 kHz BW
Video Filter off
SA25 - Vertex Room T2-XMIT
(Normal mode)

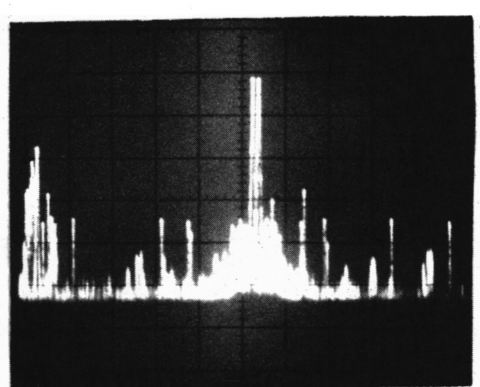

-10 dBm

1800 MHz
2 MHz/cm 100 kHz BW
Video Filter off
SA26 - Control Room T2-Receive
(Normal mode)

,36

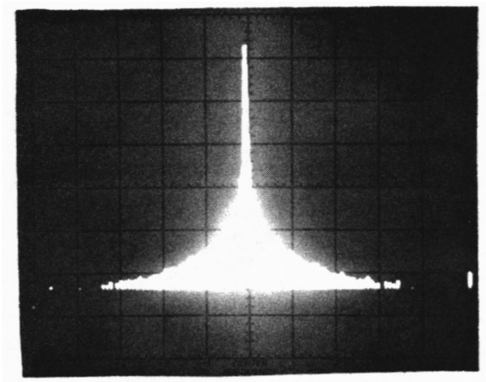

-30 dBm

1800 MHz
0.1 MHz/cm 3 kHz BW
Video Filter off
SA27 - Vertex Room T2-XMIT
(Normal mode 20 ms/cm)


-10 dBm

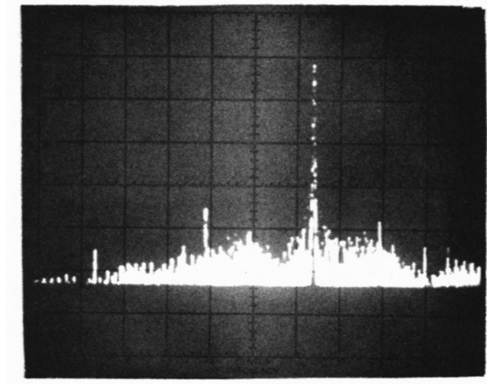
1800 MHz
0.1 MHz/cm 3 kHz BW
Video Filter off
SA28 - Control Room T2-Receive
(Normal mode 20 ms/cm)

SPECTRA SA29-SA34



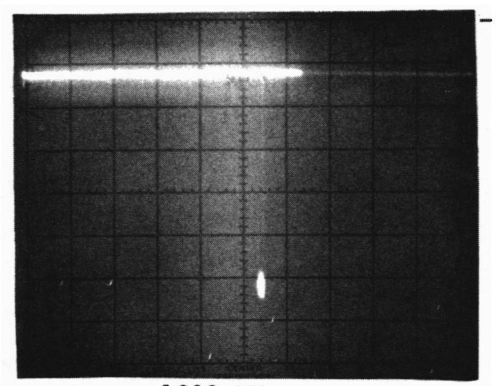
-30 dBm

1800 MHz
.02 MHz/cm .3 kHz BW
100 Hz Video Filter
SA29 - Vertex Room T2-XMIT
(Normal mode)



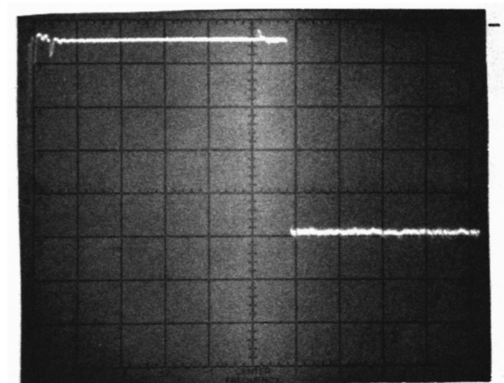
-10 dBm

1800 MHz
.02 MHz/cm .3 kHz BW
100 Hz Video Filter
SA30 - Control Room T2-Receive
(Normal mode)



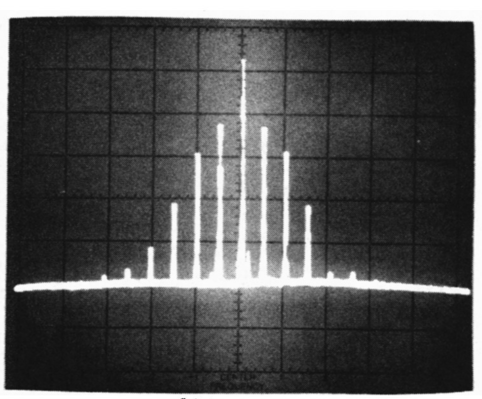
-10 dBm

1800 MHz
0 MHz/cm 100 kHz BW
Video Filter off
SA31 - Control Room T2-Receive
(Normal mode-video trigger
10 ms/cm)



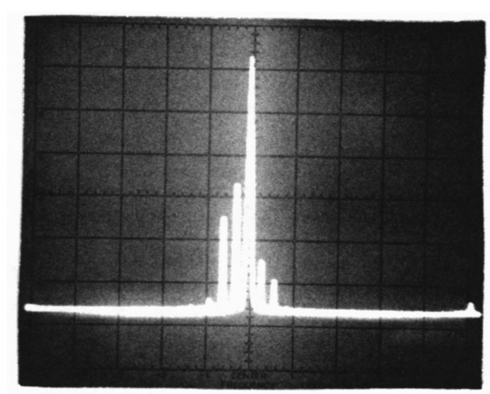
-10 dBm

1800 MHz
0 MHz/cm 100 kHz BW
Video Filter off
SA32 - Vertex Room-Receive
(Normal mode-video trigger
200 μs)



0 dBm

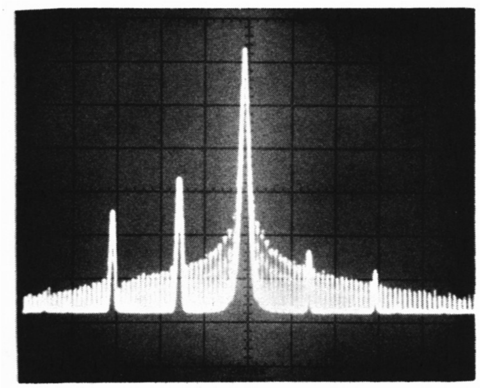
600 MHz
10 MHz/cm 100 kHz BW
100 Hz Video Filter
SA33 - Vertex Room L4-600 MHz
(Lock in XMIT to Ant)



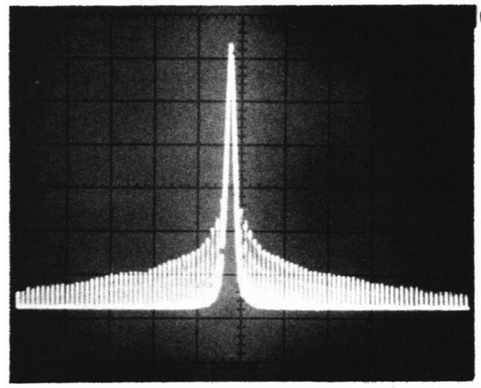
0 dBm

600 MHz
0.1 MHz/cm 3 kHz BW
10 Hz Video Filter
SA34 - Vertex Room L4-600 MHz
(Lock in XMIT to Ant)

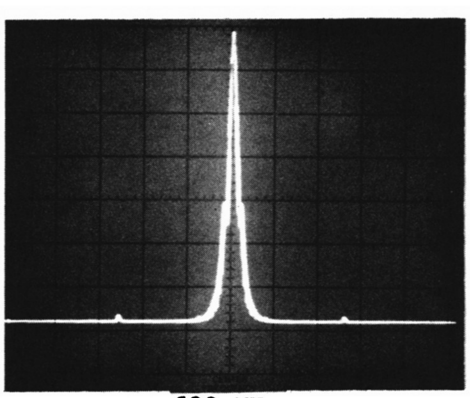
SPECTRA SA35-SA40



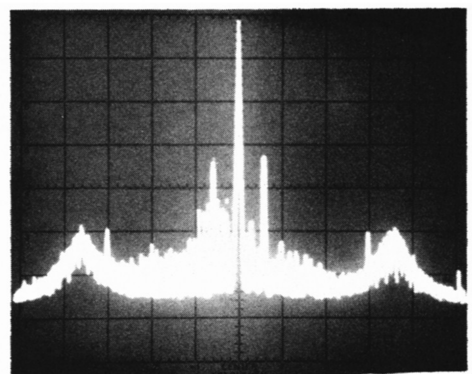
600 MHz
.02 MHz/cm 1 kHz BW
100 Hz Video Filter
SA35 - Vertex Room L4-600 MHz



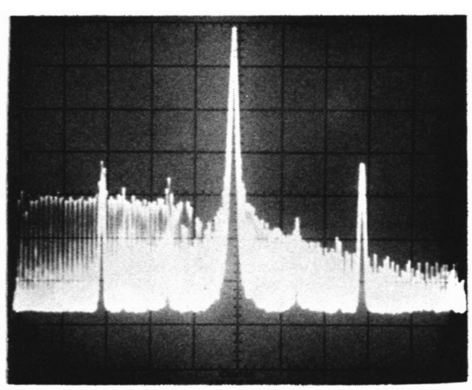
600 MHz
.02 MHz/cm 1 kHz BW
100 Hz Video Filter
SA36 - Vertex Room L4-600 MHz



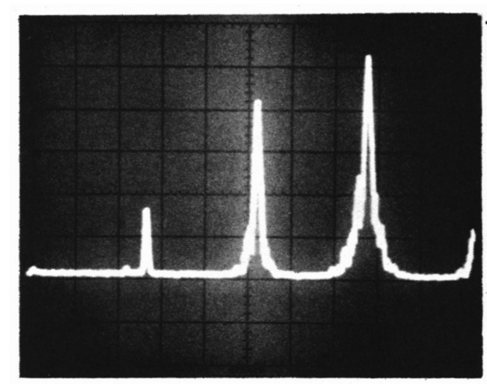
600 MHz
2 MHz/cm 100 kHz BW
100 Hz Video Filter
SA37 - Control Room L14-600 MHz
(Normal)



600 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA38 - Control Room L14-600 MHz
(Normal)

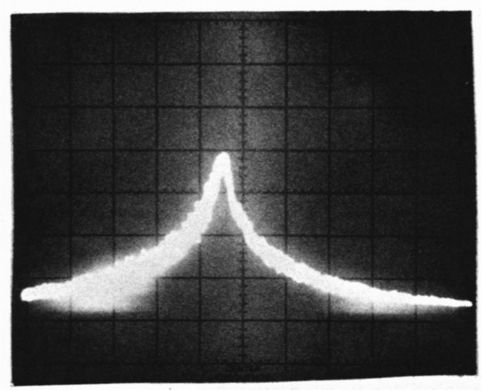


600 MHz
.02 MHz/cm 1 kHz BW
100 Hz Video Filter
SA39 - Control Room L14-600 MHz
(Normal)

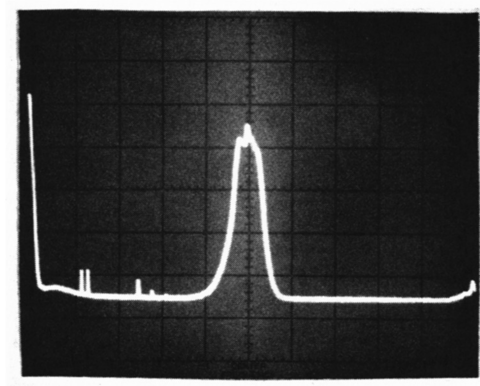


1200 MHz
2 MHz/ cm 100 kHz BW
100 Hz Video Filter
SA40 - Vertex Room T2-Receive
(Normal, unlock Vertex Room T1)

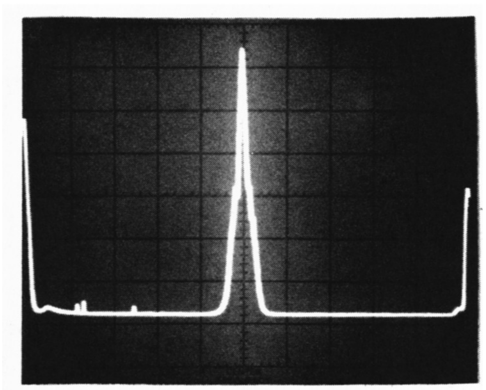
SPECTRA SA40a-SA44A


-10 dBm

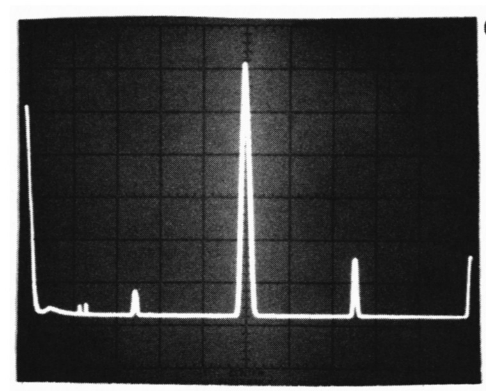
∿1200 MHz
.1 MHz/cm 3 kHz BW
10 Hz Video Filter
SA40a - Vertex Room T2-Receive
(Unlock Vertex Room T1)


-10 dBm

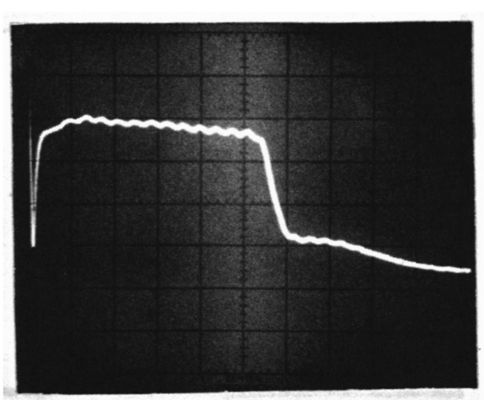
10 MHz
2 MHz/cm 100 kHz BW
100 Hz Video Filter
SA41 - Vertex Room T1-10 MHz IF
(Normal, unlock Vertex Room T1)


0 dBm

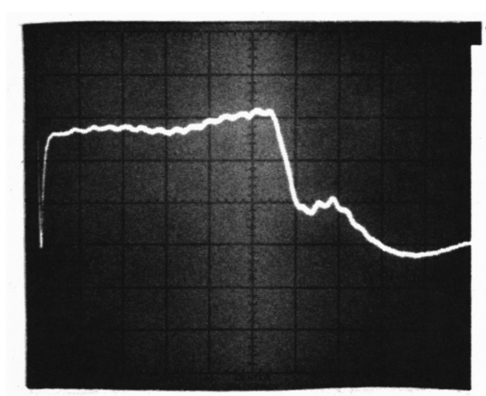
10 MHz
2 MHz/cm 100 kHz BW
100 Hz Video Filter
SA42 - Vertex Room T1-10 MHz IF
(Normal, locked)


0 dBm

10 MHz
2 MHz/cm 100 kHz BW
100 Hz Video Filter
SA43 - Vertex Room T1-10 MHz REF
(Normal)

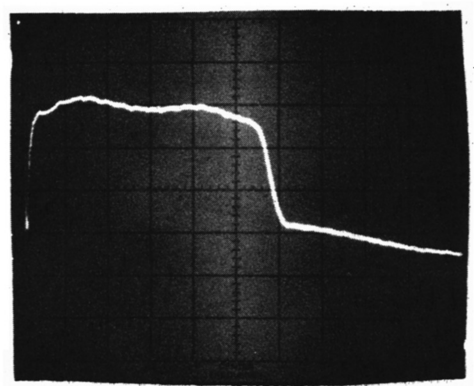

-10 dBm

50 MHz
10 MHz/cm 300 kHz BW
100 Hz Video Filter
SA44 - IF Receiver A-Monitor
(Open circuit 120' cable
on output)


-10 dBm

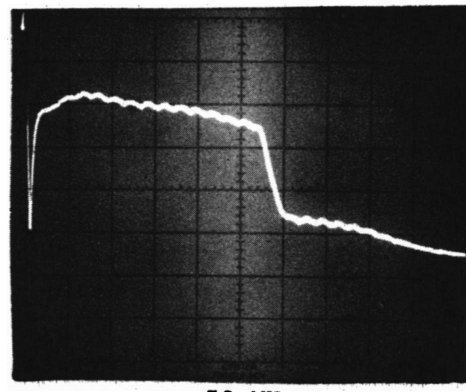
50 MHz
10 MHz/cm 300 kHz BW
100 Hz Video Filter
SA44A - IF Receiver B-Output
(Lock receiver-Control
Room 10 dB/cm)

SPECTRA SA44B-46A



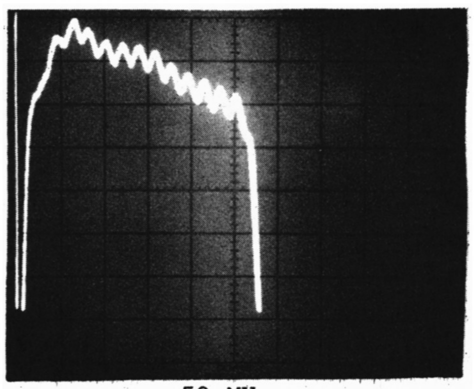
-10 dBm

50 MHz
10 MHz/cm 300 kHz BW
100 Hz Video Filter
SA44B - IF Receiver C-Output
(Lock receiver-Control Room 10 dB/cm)



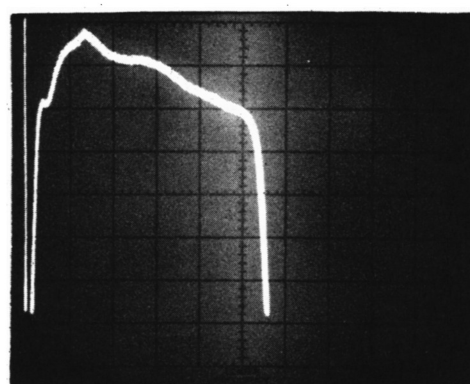
-10 dBm

50 MHz
10 MHz/cm 300 kHz BW
100 Hz Video Filter
SA44C - IF Receiver D-Output
(Lock receiver-Control Room 10 dB/cm)



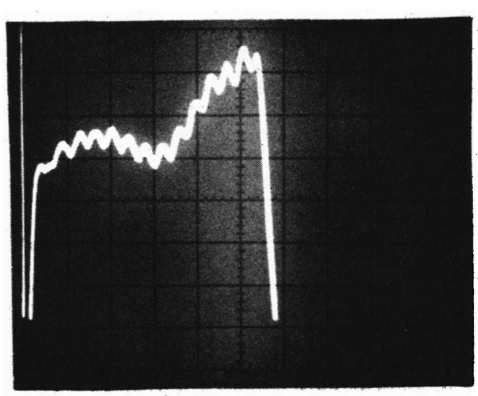
-38 dBm

50 MHz
10 MHz/cm 100 kHz BW
10 Hz Video Filter
SA45 - IF Receiver A-Monitor
(Open circuit 120' cable on output)



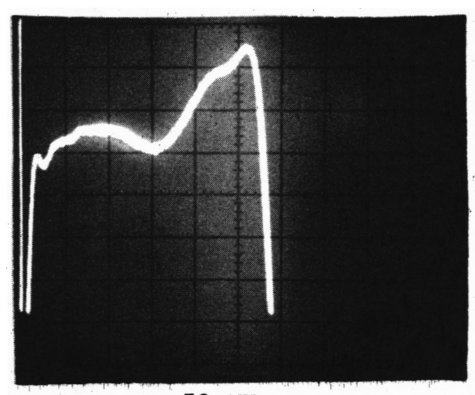
-38 dBm

50 MHz
10 MHz/cm 300 kHz BW
100 Hz Video Filter
SA45A - IF Receiver A-Output
(Termination on receiver output 2 dB/cm)



-36 dBm

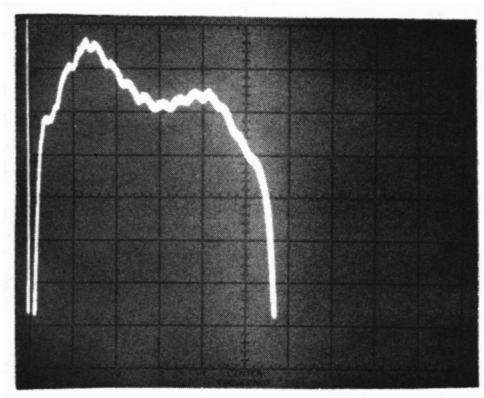
50 MHz
10 MHz/cm 100 kHz BW
10 Hz Video Filter
SA46 - IF Receiver B-Monitor
(Open circuit 120' cable on output 2 dB/cm)



-36 dBm

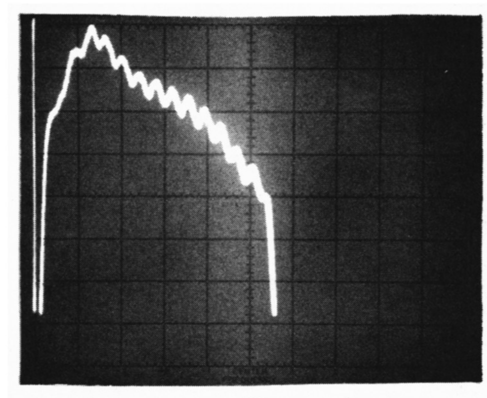
50 MHz
10 MHz/cm 300 kHz BW
100 Hz Video Filter
SA46A - IF Receiver B-Output
(Termination on receiver output 2 dB/cm)

SPECTRA SA47-SA51A



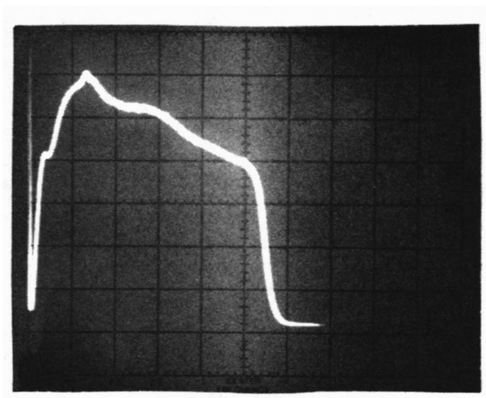
-36 dBm

50 MHz
10 MHz/cm 100 kHz BW
10 Hz Video Filter
SA47 - IF Receiver C-Monitor
(Open circuit 120' cable
on output 2 dB/cm)



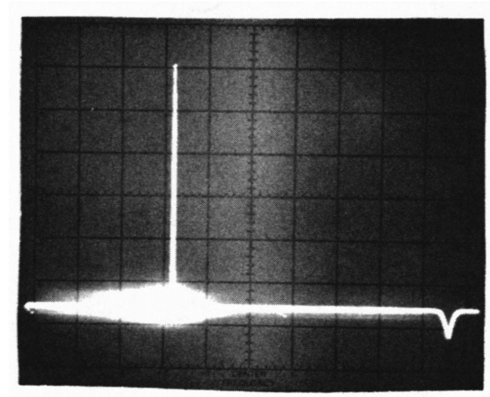
-36 dBm

50 MHz
10 MHz/cm 100 kHz BW
10 Hz Video Filter
SA48 - IF Receiver D-Monitor
(Open circuit 120' cable
on output 2 dB/cm)



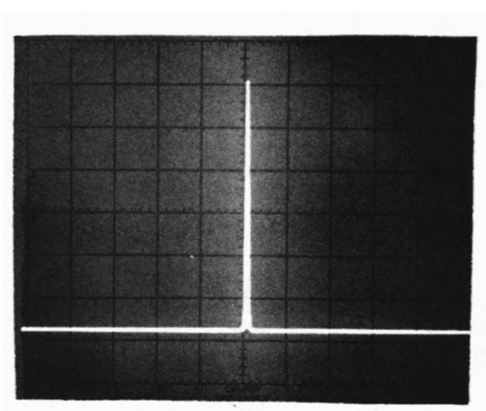
3.5 mV

50 MHz
10 MHz/cm 100 kHz BW
10 Hz Video Filter
SA49 - IF Receiver A-Monitor
(Output terminated
Linear voltage response)



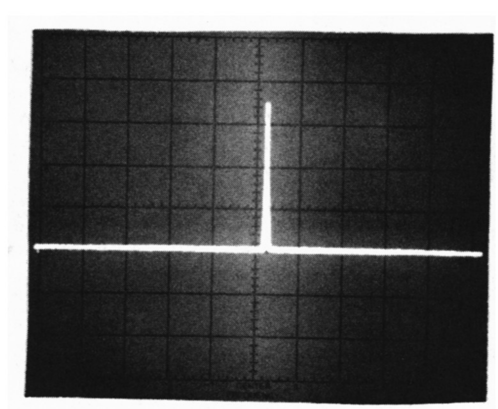
+20 dBm

3625 MHz
200 MHz/cm 300 kHz BW
100 Hz Video Filter
SA50 - Synth A-Output
(Tuned to 3240 MHz)



+20 dBm

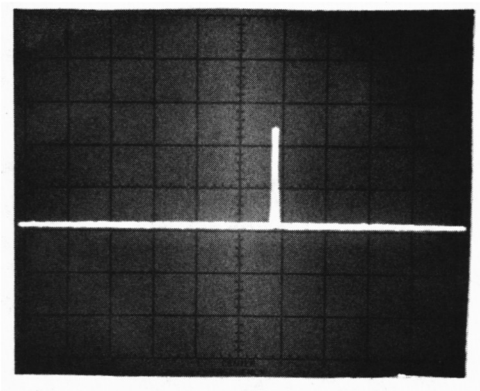
3240 MHz
10 MHz/cm 100 kHz BW
100 Hz Video Filter
SA51 - Synth A-Output



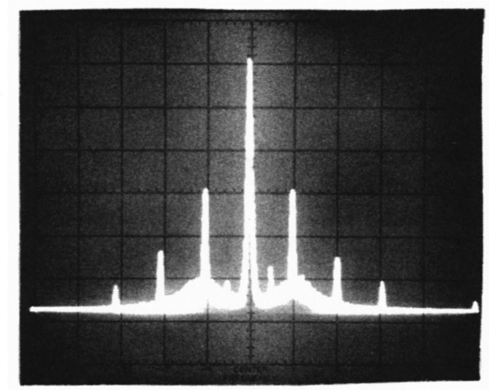
-20 dBm

6480 MHz
10 MHz/cm 300 kHz BW
100 Hz Video Filter
SA51A - Synth A-Output
(2nd harmonic)

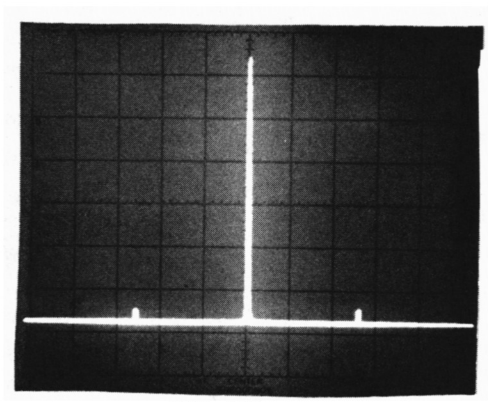
SPECTRA SA51B-SA55



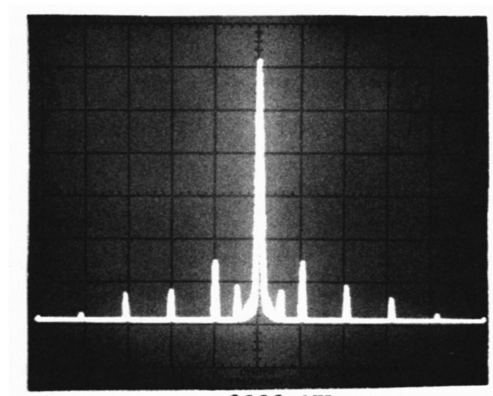
9720 MHz
10 MHz/cm 300 kHz BW
100 Hz Video Filter
SA51B - Synth A-Output
(3rd harmonic)



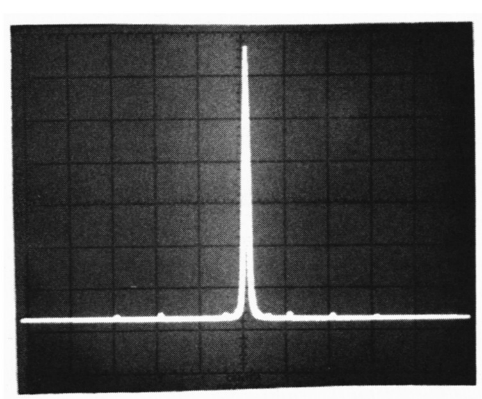
3240 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA52 - Synth A-Output



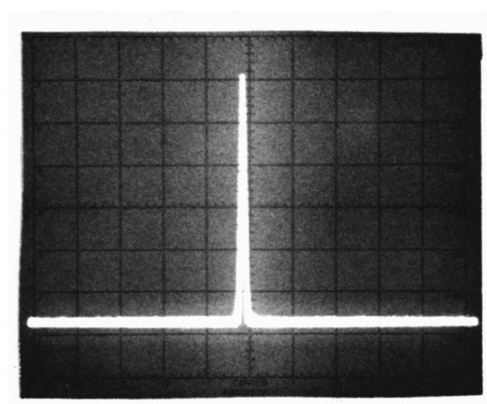
300 MHz
20 MHz/cm 30 kHz BW
100 Hz Video Filter
SA53 - 3 GHz Rack Output



3000 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA53A - 3 GHz Rack B Output

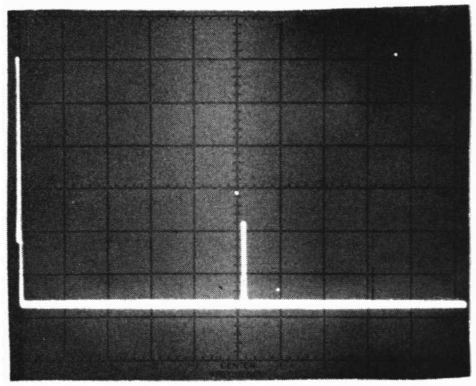


600 MHz
0.1 MHz/cm 3 kHz BW
100 Hz Video Filter
SA54 - 600 MHz Rack Output



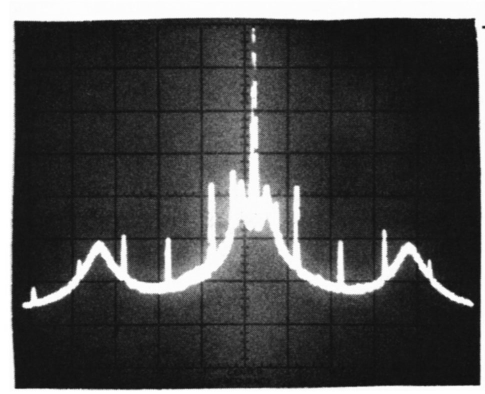
200 MHz
0.1 MHz/cm 3 kHz BW
10 kHz Video Filter
SA55 - 200 MHz Rack Output

SPECTRA SA56-SA60



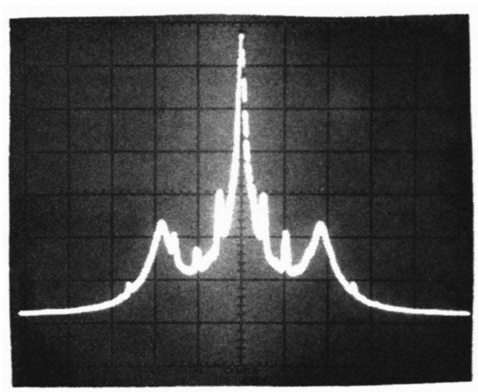
+30 dBm

200 MHz
20 MHz/cm 300 kHz BW
10 kHz Video Filter
SA56 - 100 MHz Rack Output



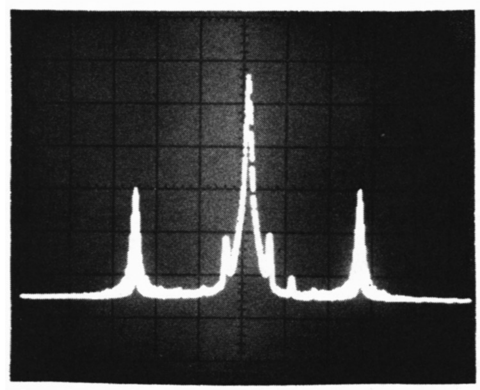
+10 dBm

1800 MHz
0.1 MHz/cm 3 kHz BW
10 Hz Video Filter
SA57 - T4B - P1 1800 MHz Input



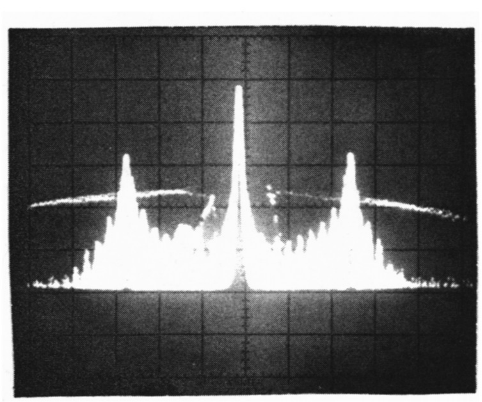
+10 dBm

1800 MHz
0.2 MHz/cm 10 kHz BW
10 kHz Video Filter
SA58 - T4B - P1 1800 MHz Input



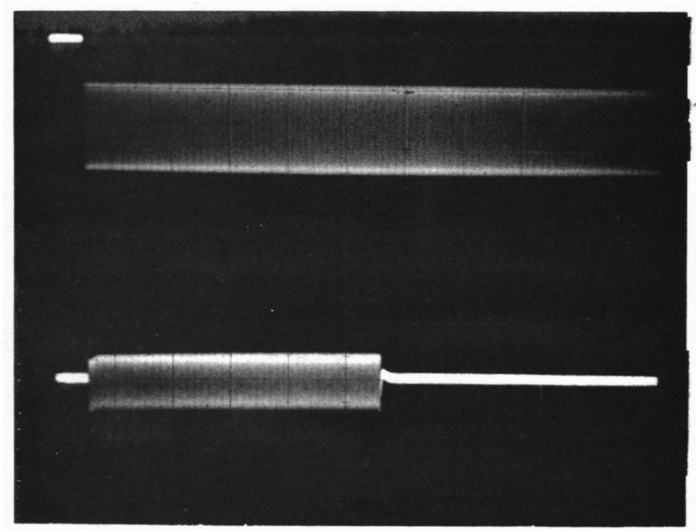
-10 dBm

1800 MHz
0.2 MHz/cm 10 kHz BW
10 kHz Video Filter
SA59 - T2 Control Room-Receive



-10 dBm

1800 MHz
0.2 MHz/cm 10 kHz BW
10 kHz Video Filter
SA60 - T2 Control Room-Receive



0

.5V/cm

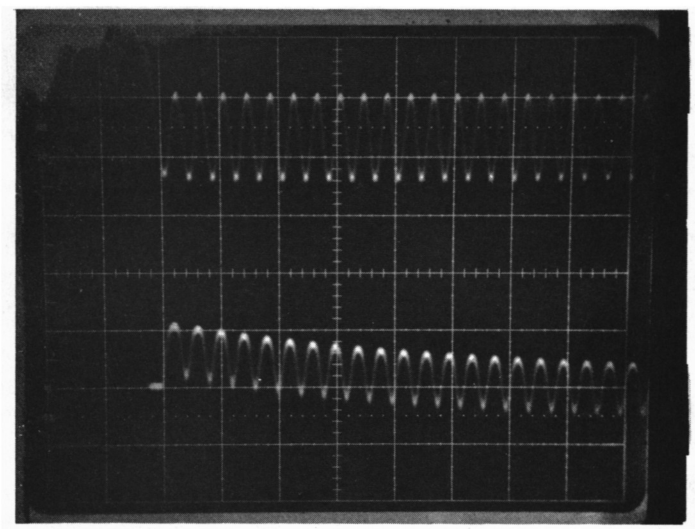
1A) L10 - 5 MHz Mod
Control Room

0

.1V/cm

1B) L4 - Sync Receive
Vertex Room

200 μs/cm, Trigger on C.R. T/R



0

.5V/cm

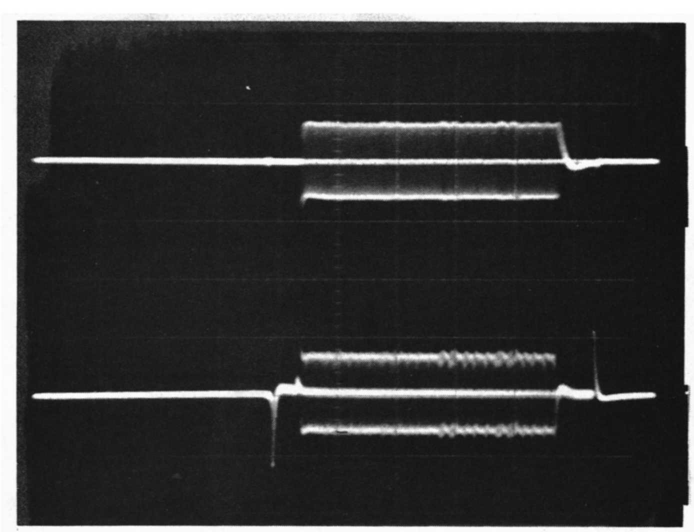
2A) L10 - 5 MHz Mod
Control Room
Delayed sweep-
leading edge

0

.1V/cm

2B) L4 - Sync Receive
Vertex Room
Delayed sweep-
leading edge

0.5 μs/cm, Trigger on C.R. T/R



0

.2V/cm

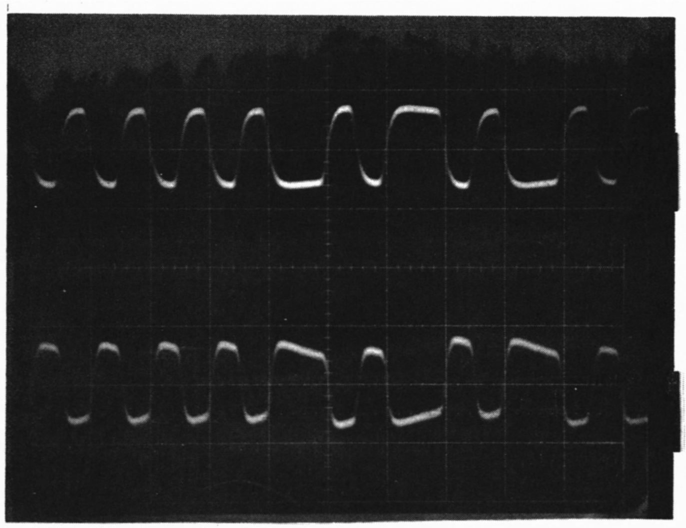
3A) L10 - Data Mod
Control Room

0

.2V/cm

3B) L4 - Data Receive
Vertex Room

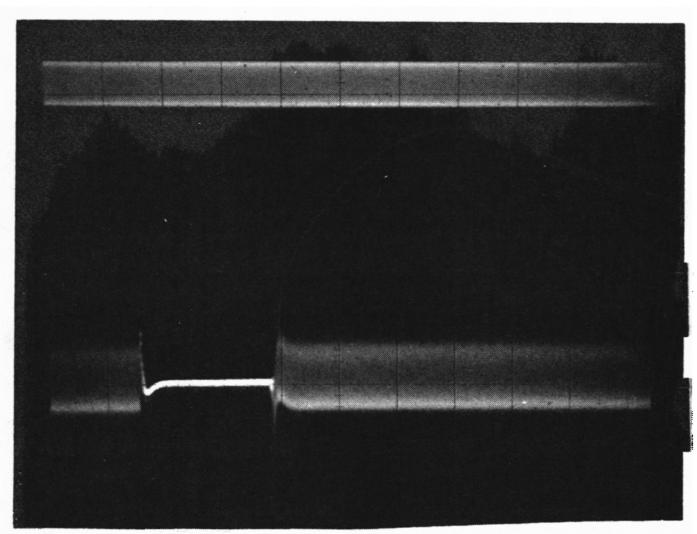
200 μs/cm, Trigger on carrier on C.R.



0
.2V/cm
4A) L10 - Data Mod
Control Room
Delayed sweep-
data bits

0
.2V/cm
4B) L4 - Data Receive
Vertex Room
Delayed sweep-
data bits

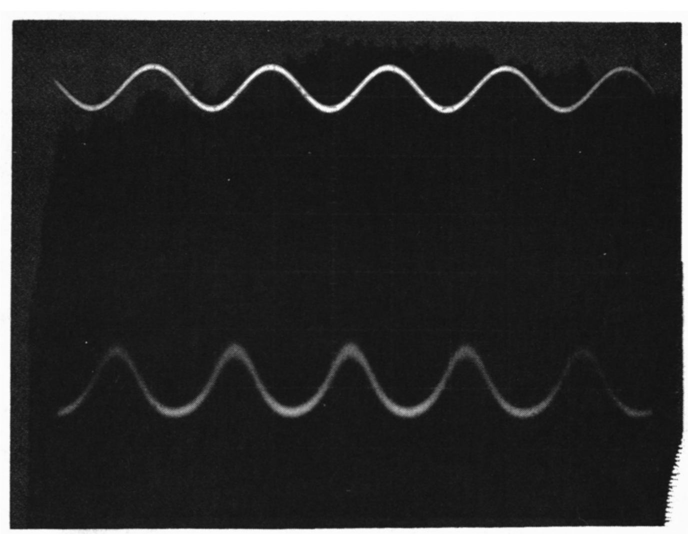
2 μs/cm, Trigger on carrier on C.R.



0
0.5V/cm
5A) L3 - 5 MHz Mod
Vertex Room

0
.1V/cm
5B) L9 - 5 MHz Receive
Control Room

500 μs/cm, Trigger on carrier on C.R.

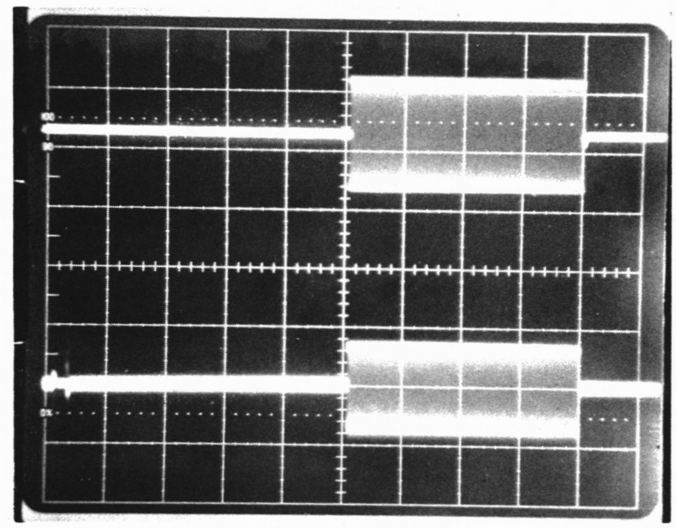


0
.05V/cm
6A) L3 - 5 MHz Mod
Vertex Room
Int. Trigger

0
.1V/cm
6B) L9 - 5 MHz Receive
Control Room
Int. Trigger

0.1 μs/cm, Trigger on carrier on C.R.

OSCILLOGRAMS 7-9



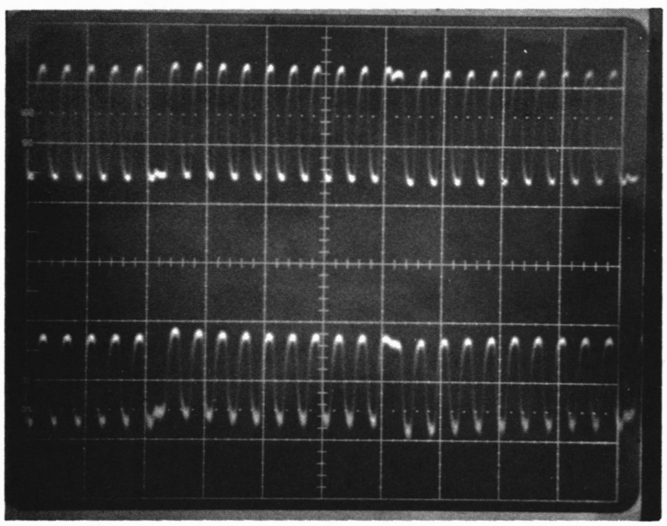
0

.2V/cm 7A) L3 - Data Mod
Vertex Room

0

.1V/cm 7B) L9 - Data Receive
Control Room

5000 μs/cm, Trigger on carrier on C.R.



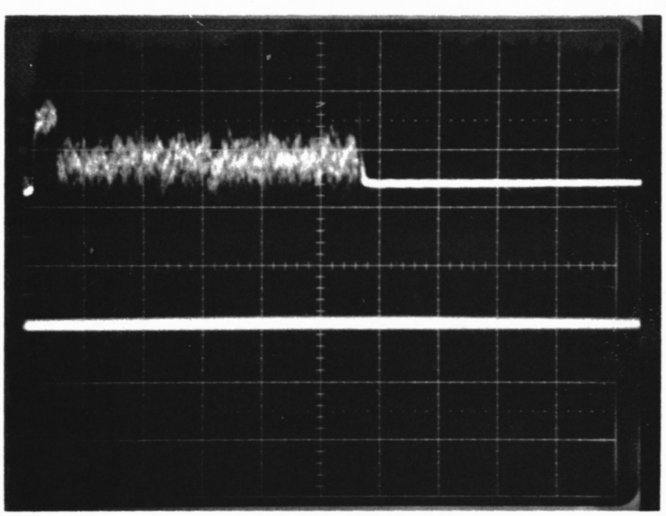
.2V/cm 8A) L3 - Data Mod
Vertex Room
Delayed sweep-
data bits

0

0

.1V/cm 8B) L9 - Data Receive
Control Room
Delayed sweep-
data bits

5 μs/cm, Trigger on carrier on C.R.



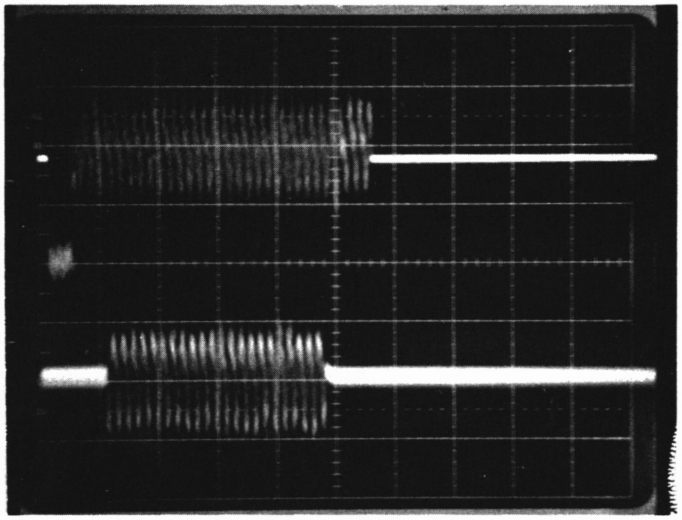
0

.1V/cm 9A) L4 - 5ϕ

.1V/cm 9B) L5 - #2 (Int. 5ϕ)

200 μs/cm, Trigger on Vertex Room T/R

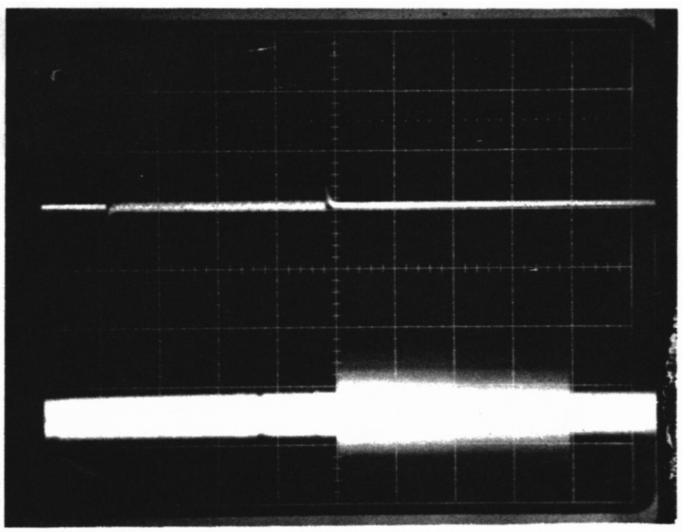
OSCILLOGRAMS 10-12



0
.5V/cm 10A) L4 - 600ϕ

0
.2V/cm 10B) L5 - #3 (Int. 600ϕ)

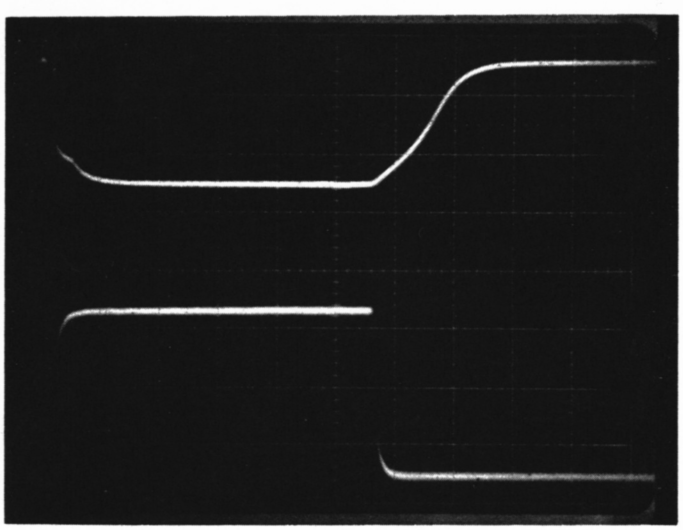
200 μs/cm, Trigger on Vertex Room T/R



0
.2V/cm 11A) L5 - #1 (5 FREQ)

0
.05V/cm 11B) L5 - #4 (50ϕ)

11A) 200 μs/cm, Trigger on Vertex Room T/R
11B) 5000 μs/cm, Trigger on Vertex Room T/R

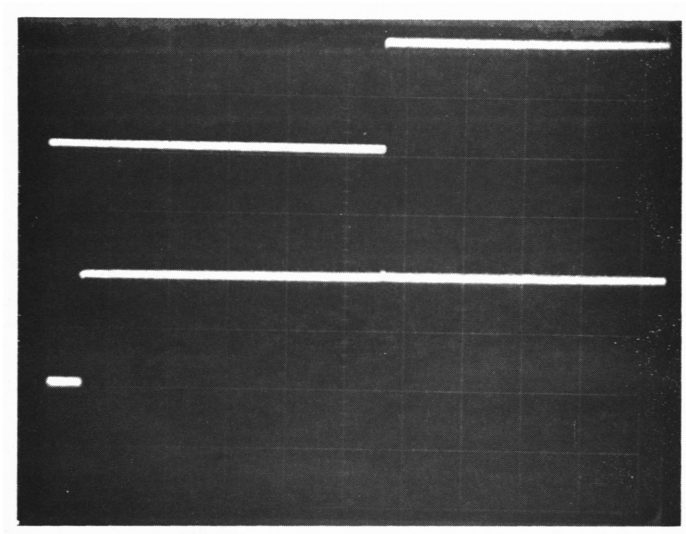


0
.2V/cm 12A) T2 - Receive Lev

0
.1V/cm 12B) T2 - XMIT Lev

12A) 200 μs/cm, Trigger on Vertex Room T/R
12B) 200 μs/cm, Trigger on Vertex Room T/R

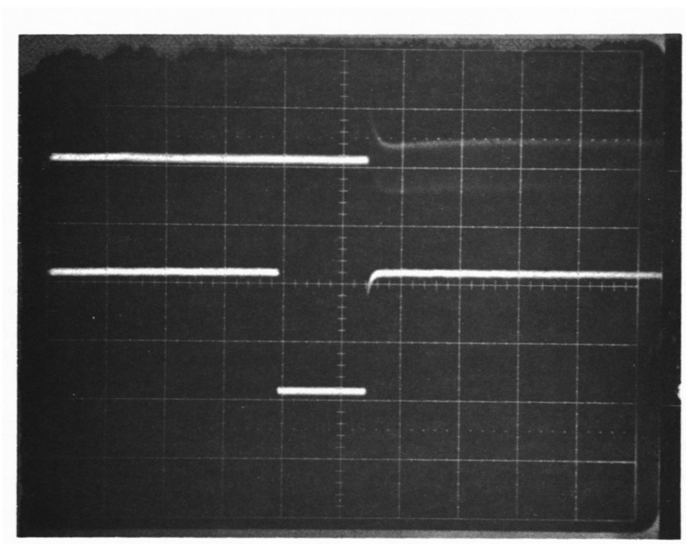
OSCILLOGRAMS 13-15



0
2V/cm 13A) L8 - T/R

0
2V/cm 13B) L8 - Carrier On

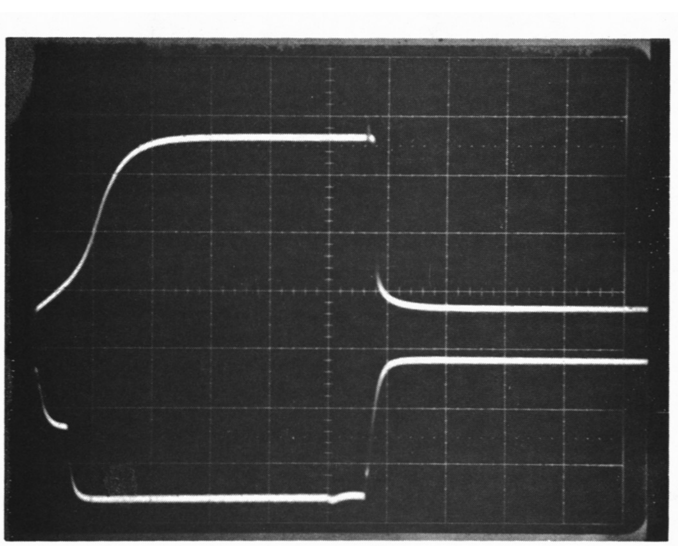
13A) 200 μs/cm, Trigger on internal
13B) same as 13A



0
.1V/cm 14A) L4 - Sync

0
2V/cm 14B) L8 - Sync

14A) 20 μs/cm, Trigger on Vertex Room T/R
14B) same as 14A

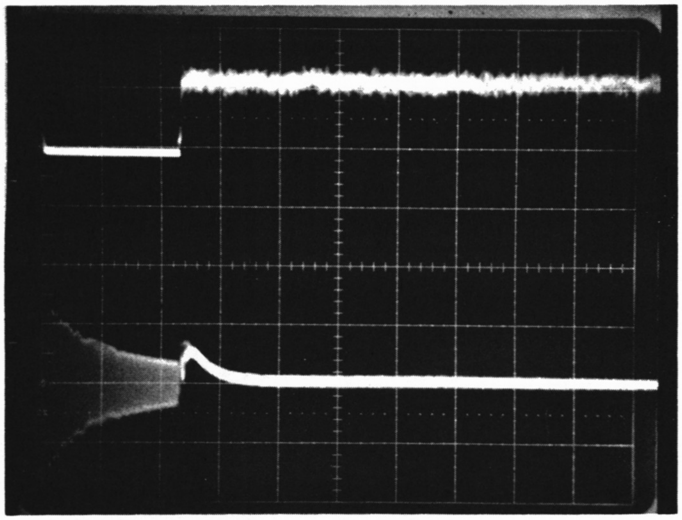


0
.2V/cm 15A) T2 - Control Room
Receive Lev

0
.2V/cm 15B) T2 - Control Room
XMIT Lev

15A) 200 μs/cm, Trigger on Control Room T/R
15B) same as 15A

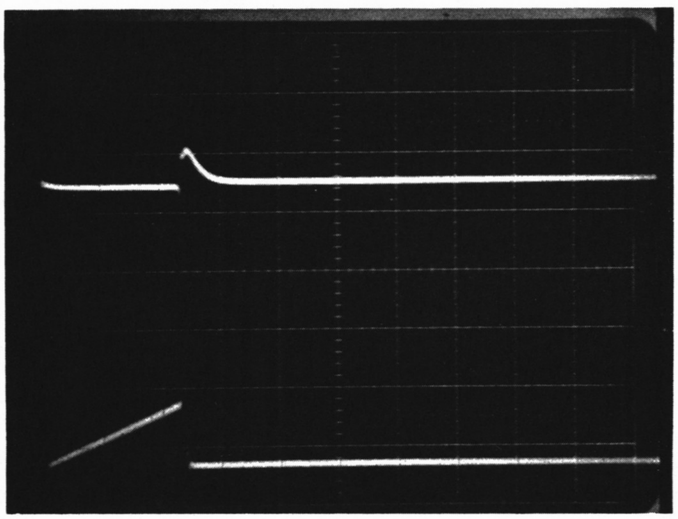
OSCILLOGRAMS 16-18



0
.5V/cm 16A) L9 - 5ϕ

0
.2V/cm 16B) (Back of L14) - 600ϕ

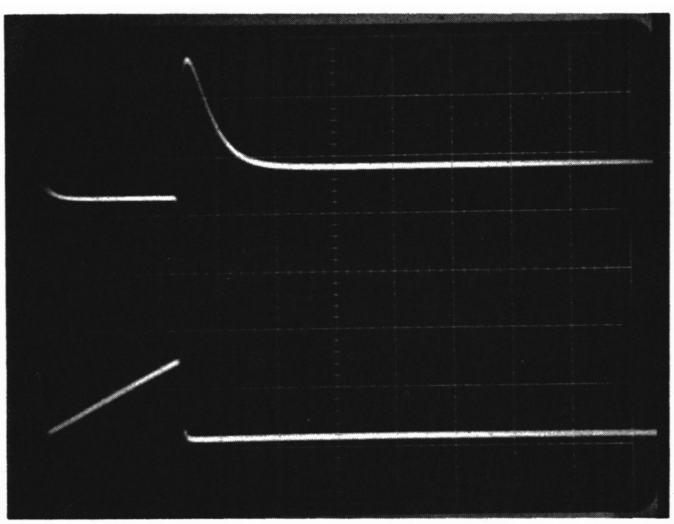
16A) 500 μs/cm, Trigger on Control Room T/R
16B) same as 16A



0
.5V/cm 17A) L9 - #1 1200ϕ

0
1V/cm 17B) L9 - #2 1200 VCO

17A) 500 μs/cm, Trigger on Control Room T/R
17B) same as 17A



0
.5V/cm 18A) L9 - #3 1800ϕ

0
1V/cm 18B) L9 - #4 1800 VCO

18A) 500 μs/cm, Trigger on Control Room T/R
18B) same as 18A

IV. SPURIOUS SIGNALS AND NOISE IN THE LO SYSTEM

A. Introduction

Spurious signals appearing at the receive port of the T1-T2 combination can degrade the performance of the LO system if they are at or near 1200 or 1800 MHz. Signals precisely at these frequencies are especially of concern because they alter the phase of the desired signals; such undesired signals must be <-55 dB with respect to the desired signal in order to insure <0.1° phase error. Undesired signals and noise which are near 1200 or 1800 MHz are also of concern, since - depending on their phase and frequency - they may degrade the noise performance of the phase-locked loops. It should be kept in mind that the phase-locked loop at the vertex room is sampled at 19.2 Hz, so spurious signals outside the loop bandwidth (∿1 Hz) may be aliased into the loop bandwidth by the sampling. Furthermore, undesired signals at frequencies far from 1200 and 1800 MHz (e.g. 2400 MHz) may result in 1200 or 1800 MHz intermodulation products at later points in the system.

Noise introduced in the transmission system is expected to consist primarily of phase noise from the modem LO's. But such noise should not appear on the recovered 600 MHz reference signals, since at each instant of time the phase error introduced by modem LO instability should be identical for the 1200 and 1800 MHz carriers. Other transmission noise, e.g. kT-noise from the modem mixers, is not expected to be significant within the LO system bandwidth (∿1 Hz, if phase measurements are required every ∿1 sec).

A fundamental source of noise is the short-term drift of the 5 MHz VCXO at each antenna (HP 10543A). Manufacturer's specifications imply rms phase fluctuations of .016° at 5 MHz (3.2° at 1 GHz) for samples separated by 1 sec (=loop bandwidth^{-1}); but the rms phase fluctuation which this introduces in the system is difficult to predict without detailed data on the spectrum of the phase fluctuations. System phase noise due to the oscillator instability has not been observable in our tests (see Section B below) implying that it is less than 0.1° rms at 1 GHz. If necessary it could be reduced by increasing the loop bandwidth, although the latter is strictly limited to half the 19.2 Hz sampling rate and in practice is limited to somewhat less. Resulting fluctuations in the round-trip phase measurement can be reduced by post-detection averaging of more than 1 sec, but this does not affect LO phase fluctuations at the antenna.

B. Test Results

1. Carrier Frequency Offset Experiments

A technique which we have found extremely useful in identifying spurious signals is to offset the carrier frequency of one of the modems as much as 300 kHz. This shifts the frequencies of the LO carriers (near 1200 and 1800 MHz) at the receiving modem's output, but leaves the recovered 600 and 5 MHz reference signals unaffected. Spurious signals of various kinds will then be shifted, as discussed below, by amounts different from the desired signals, enabling them to be identified on the sprectrum analyzer. The offset is inserted by supplying the modem's 10 MHz reference from a synthesizer set to 10 MHz + Δ, where Δ is the offset frequency; the 2400 MHz reference was still supplied by the system.

Unless otherwise noted, the measurements described in this section were made with the Westinghouse modems installed (Serial B3 in rack E1 and B4 in B1 unless otherwise noted), unlike the test data of Sections II-III, which used the TRG modems. Also, the received levels at the outputs of the T2 modules were about 3 dB higher in the present tests than the levels finally adopted for Section III.

Figure 4-1 shows the spectrum around 1800 MHz received at the vertex room with Δ=0, and Figure 4-2 is the same with Δ=100 kHz (control room modem). We see spurious lines which are, relative to the desired carrier:

-36 dB at $\pm\Delta$

-57 dB at -3Δ

-47 dB at -4Δ

-65 dB at -5Δ

Figure 4-3 shows that most of these remain even if the waveguide attenuation is increased to maximum (>90 dB, cf. 56 dB nominal). Similar results are seen at 1200 MHz.

On the theory that a spurious line at nΔ was due to the nth harmonic of the desired signal being propagated in the waveguide (and probably not much attenuated in our TE_{01} mode attenuators), we tried inserting a 45 GHz low-pass filter ("waffle-iron" waveguide low-pass filter; 3 dB loss at 35 GHz, $\geq$20 dB loss at 70 GHz, unknown loss at 105 GHz). The result is shown in Figure 4-4. All but the n=$\pm$1 lines are strongly suppressed, tending to confirm the theory.

The n=± 1 lines are thought to be caused differently from the others. One possibility is that 10 MHz sidebands exist on the 2400 MHz modem reference signal at a very low level (<-70 dB, not visible on spectrum analyzer). This would be enough to cause significant 10 MHz output from the modem's harmonic mixer (in addition to the desired 10 MHz $+\Delta$), and would result in f.m. of the modem LO at frequency Δ. Such f.m. is of little consequence in the system, since it cancels out in recovering the 600 MHz reference; but any accompanying a.m. will not cancel, resulting in a possible phase change at 600 MHz. This theory is supported by an experiment in which the 2400 MHz reference to the offset modem was provided by a free-running fundamental oscillator, carefully tuned to within a few kHz of 2400 MHz; the lines at $\pm\Delta$ were not seen. Also, the spurious lines are strongest when Δ equals the bandwidth of the modem's phase locked loop, suggesting interference on a loop reference signal or pickup within the loop.

Other experiments which were performed to investigate these effects further are illustrated in Figures 4-5 to 4-8. They are described below without extensive comment.

Figure 4-5 shows the effect of interchanging the two modems. The spurious lines are seen on the received 1800 MHz (VR) only when the offset is applied to modem B3, regardless of its location. Also, magnitudes of the unwanted signals are very nearly the same for either location of B3, even though the 2400 MHz reference is generated differently in each place (presummably it is cleaner in the control room).

Figure 4-6 shows the spectrum of the recovered 600 MHz reference at VR for various offset conditions, along with the received 1800 MHz (the 1200 MHz looks similar to the 1800 MHz). The fact that the spurious lines cancel out at 600 MHz when both modems are offset, but not when only one is offset, is difficult to explain but may be quite important. (These measurements used the TRG modems.)

Figures 4-7 and 4-8 are chart records of system phase errors as a function of offset frequency and waveguide phase shifter setting (the dummy waveguide run included a broadband, calibrated phase shifter: TRG Model A528). (See Table IV for the standard chart recorder channels and scales.) Note that with zero offset the 600 MHz phase is sensitive to the phase shifter setting, possibly indicating an interfering signal exactly on the frequency of a desired signal, but with phase affected differently by the phase shifter. Note also that with zero offset the noise on the return path depends on phase shifter setting, and is sometimes asymmetric.

TABLE IV: Standard Chart Recorder Setup for Phase Measurements (Applies to all chart recordings not otherwise labeled)

CHANNEL	QUANTITY	SCALE	NOTES
1	600 MHzϕ, round trip	$\pm 5°$ f.s.	reference may be
2	600 MHzϕ, one way VVM or Network Anal.	$\pm 5°$ f.s.	from M- or E-rack.
3	5 MHz $\Delta\phi$, VR(L4)	$\pm 0.5°$ f.s.	
4	5 MHz returned ϕ, CR (L11)	$\pm 0.5°$ f.s.	
5	Temperature of M-rack	1°C/small div.	Also internal temp. of modules.

From the one-way peak-to-peak error at 1 Hz offset (2.8°), it appears that the interfering signal at 600 MHz is -31 dB from the desired signal (spectrum SA35 shows a signal offset by Δ at just -30 dB).

Figure 4-9 shows the effects on the 600 MHz reference spectrum of varying the waveguide attenuation and of inserting the waveguide low-pass filter mentioned earlier.

2. Effect of Data Transmission

Figure 4-10 shows a recording of the 600 MHz phase (round trip and one way) with and without data transmission, using the finally adopted signal and modulation levels (see Section II). It shows that a phase shift of about 0.4° at 600 MHz occurs when data is transmitted outward (to VR), but there is no measurable effect from data transmitted back.

3. Miscellaneous Interfering Signals

(a) 100 kHz. Appears on received 1200, 1800 MHz at VR (see SA8, SA22), and on 600 MHz phase error at VR. Seems to cause no system problems because of the high frequency. Apparently originates in the fringe generators, since it disappears when they are unplugged.

(b) 5 kHz. Appears on received 1200 (SA10) and 1800 MHz, recovered 600 MHz reference, and 600 MHz phase error at VR. Apparently originates in Data Tap and gets around via the +5V supply bus. An LC filter has been installed in the Data Tap display to decouple it from the supply, and a careful check of the 600 MHz phase error should be made to determine whether the 5 kHz has been eliminated.

4. Noise and Short Term Stability

Figure 4-11 is a record of the 600 MHz and 5 MHz phases on a time scale of seconds for various recorder time constants. The 20 Hz (actually 19.2 Hz) pulses on the round-trip phases are due to the transmit-receive cycle and will be gated out of the final phase detectors. The 2.4 Hz periodicity apparent on both 600 MHz phase measurements for time constant τ=0.1 sec is probably due to 60 Hz on the VR 600 MHz phase detector output, being sampled at 19.2 Hz (60 - 3x19.2 = 2.4). On such time scales - .01 to 1.0 sec - these seem to be the dominant sources of phase error. The 2.4 Hz signal is about 0.3° peak-to-peak at 600 MHz. The effects of the basic oscillator instability are not seen in these records, implying very good oscillator performance.

On the return path there is considerable noise at much higher frequencies (>10 kHz), not seen on the chart recordings. At 600 MHz, this results from (a) phase noise in the 1200 and 1800 MHz cavity oscillators in L14 at or beyond their loop bandwidths; (b) imperfect cancellation of phase noise in the transmission system (modem LO's) at frequencies near the 1200 and 1800 MHz loop bandwidths; and (c) (possibly) intermodulation from the I.F. bands, although the latter has not been explicitly checked for. See spectrum SA38.

FIGURES 4-1 thru 4-3

-20 dBm

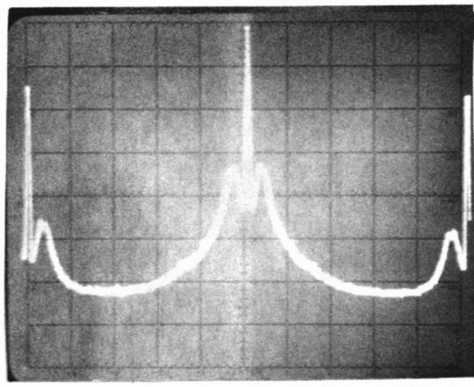


FIGURE 4-1. 1800 MHz carrier received at VR (T2 "RCV IF"). Data modulation on (500 kHz sidebands), offset Δ=0. Horiz: 100 kHz/div, 3 kHz BW; vertical: 10 dB/div, ref = 20 dBm. Westinghouse modems.

-30 dBm

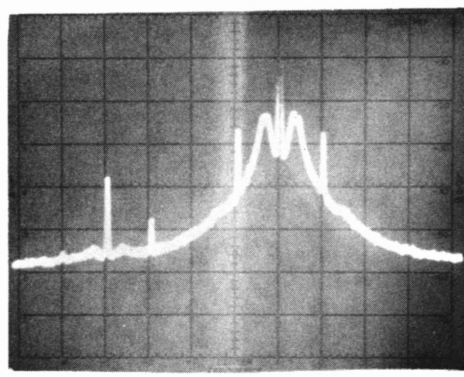


FIGURE 4-2. Same as 4-1 except CR modem offset Δ=100 kHz, data off, ref = -30 dBm.

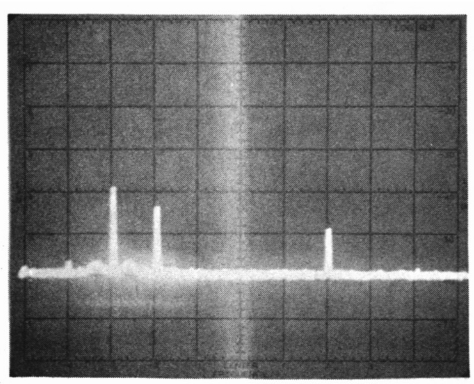


FIGURE 4-3. Same as 4-2 except waveguide attenuation increased increased to maximum (>90 dB; normal is 56 dB).

FIGURES 4-4 thru 4-5

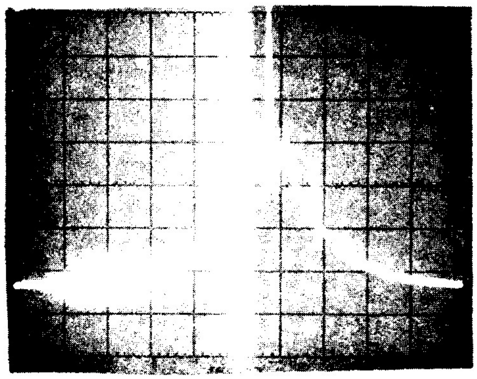


FIGURE 4-4. Same as 4-2 except 45 GHz LPF inserted in waveguide, and waveguide attenuator reduced 10 dB to compensate insertion loss. Ref = -20 dBm.

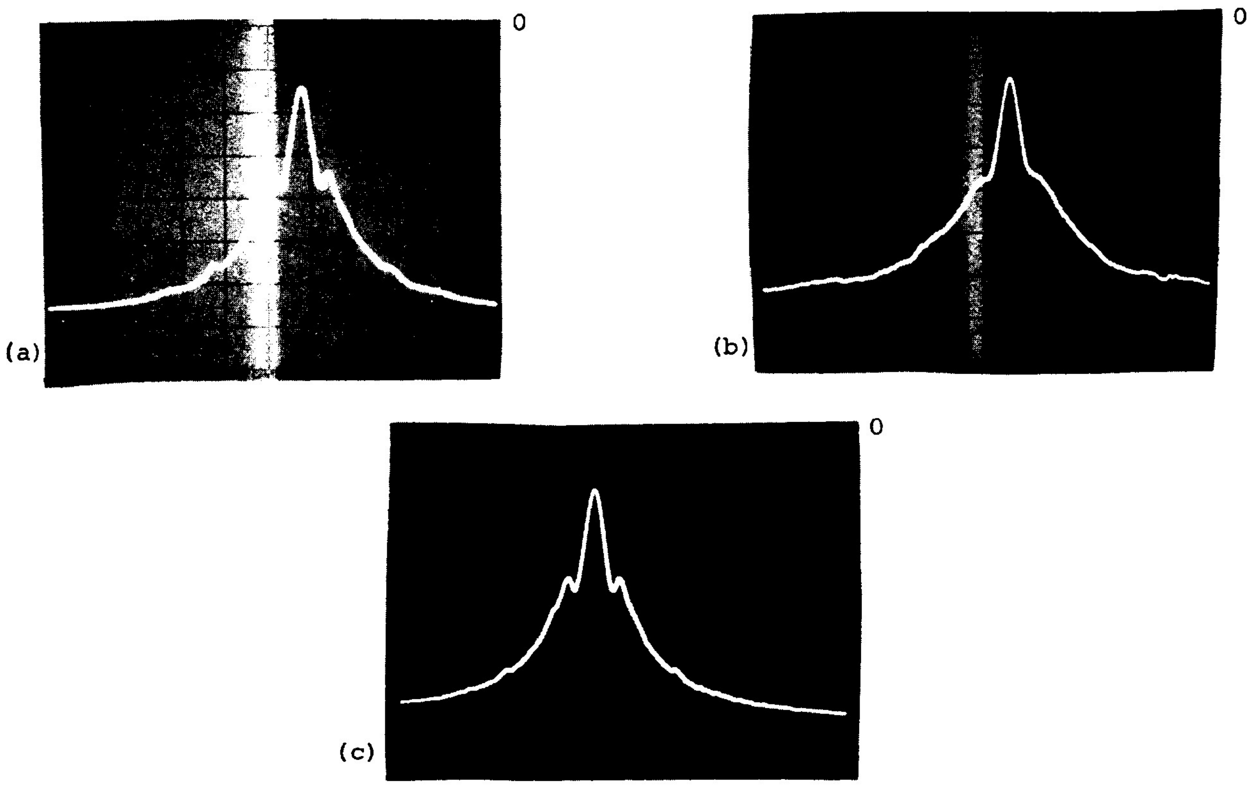


FIGURE 4-5. Effect of interchanging the Westinghouse modems. Received 1800 MHz (VR), 50 kHz/div, 100 kHz BW, 0 dBm ref, Δ=30 kHz. (a) CR modem offset, serial B3 in CR, B4 in VR; (b) CR offset, B3 in VR, B4 in CR; (c) VR offset, B3 in VR, B4 in CR.

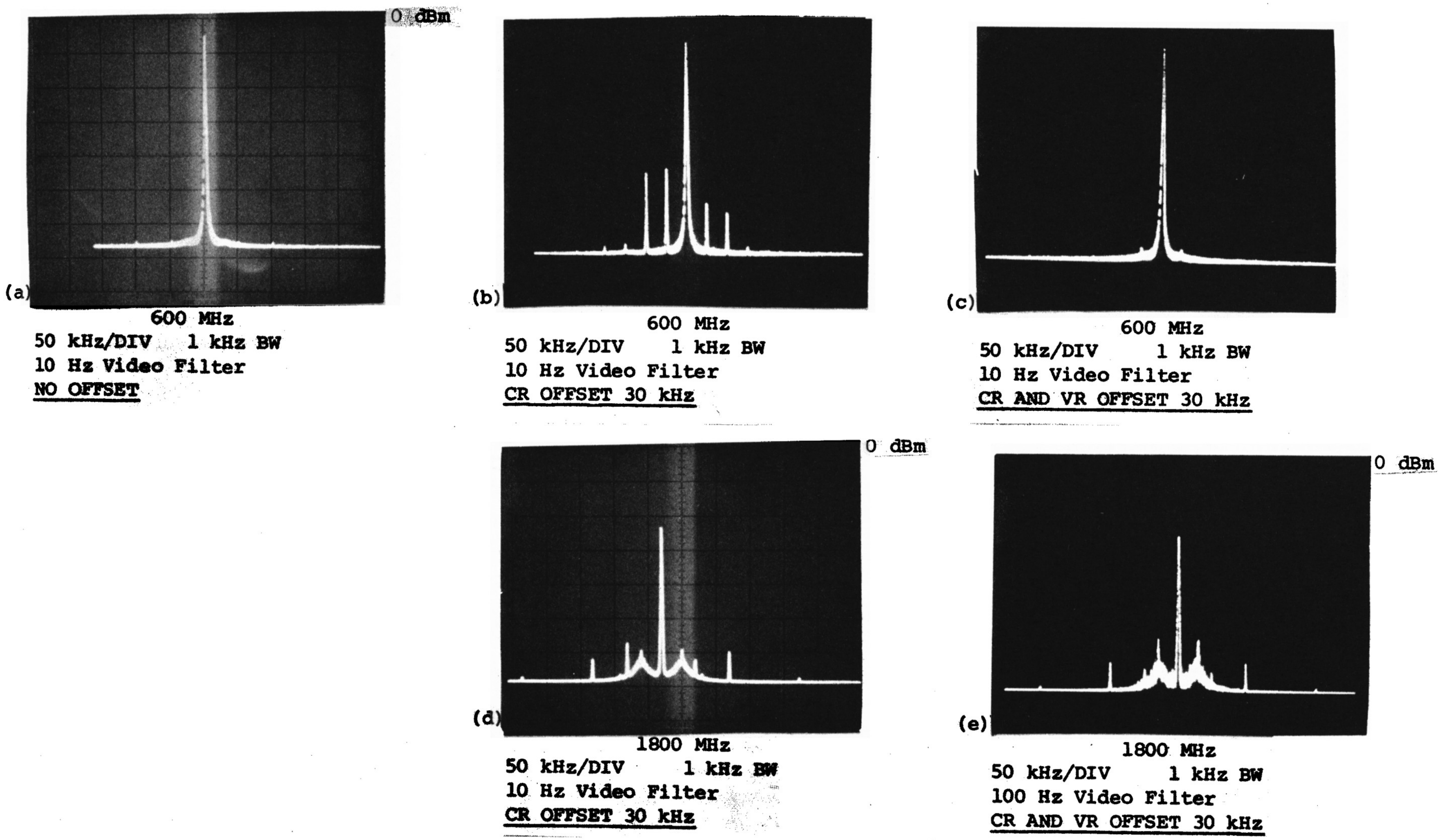


FIGURE 4-6. Effect of offsetting the LO frequency of both modems.
(a)-(c): Recovered 600 MHz reference (VR);
(d)-(e): Received 1800 MHz (VR). TRG modems.

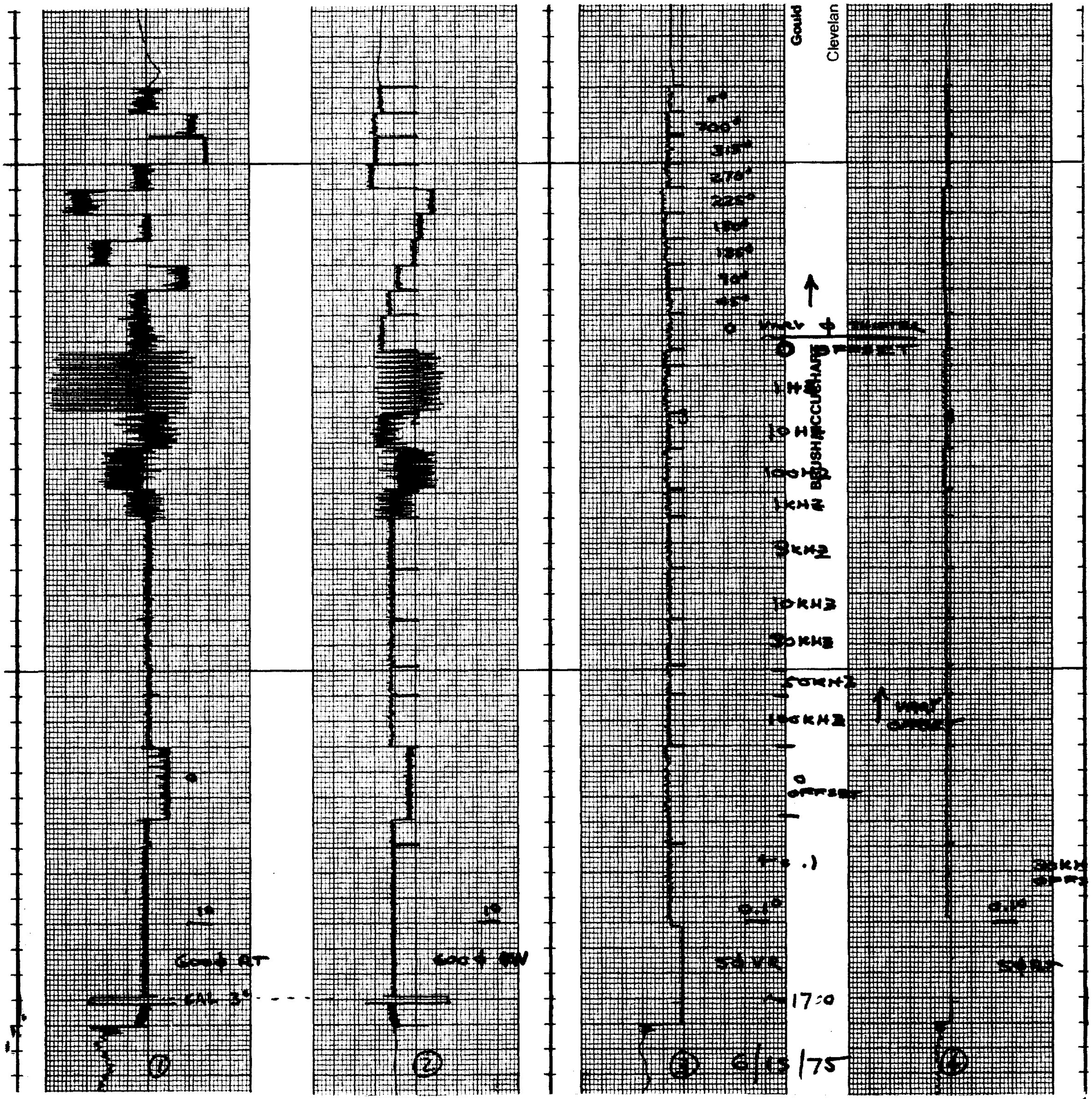


FIGURE 4-7. Phase errors vs. offset frequency Δ and phase shifter setting. See text and Table 4.1. Cf. Fig. 4-8. Westinghouse modems

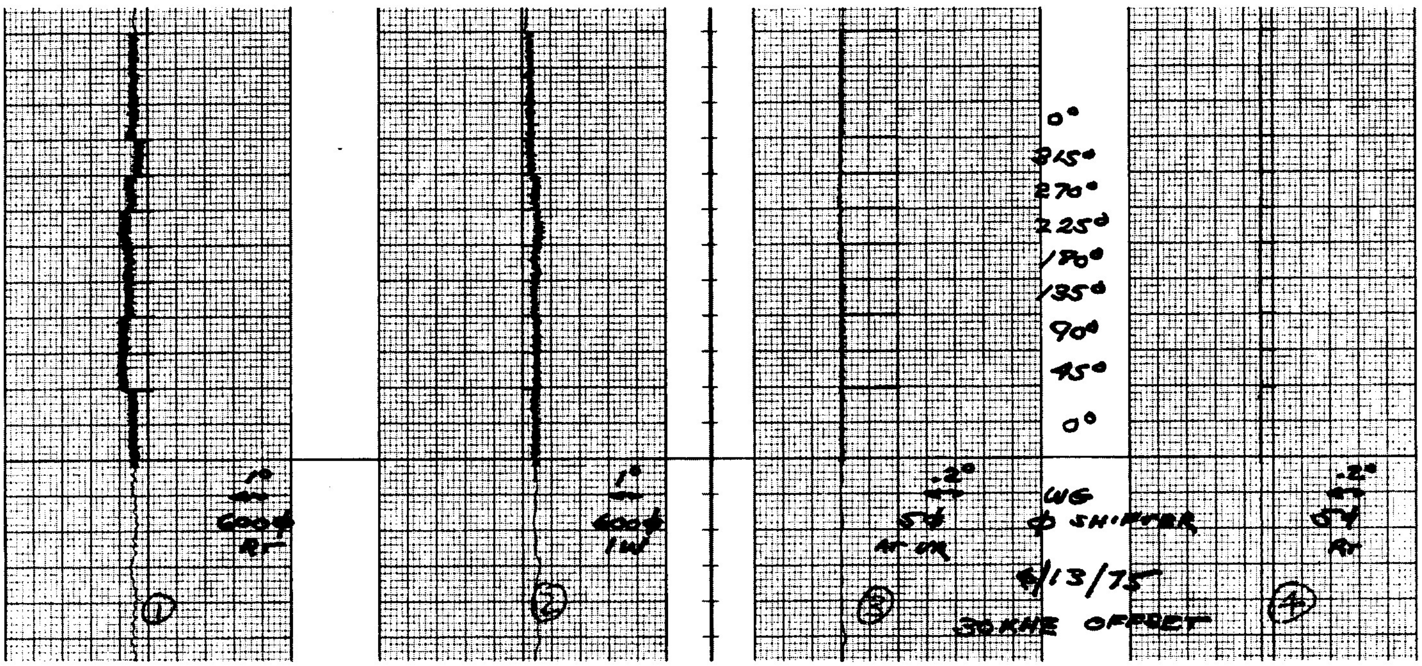


FIGURE 4-8. Phase errors vs. waveguide phase shifter setting at Δ=30 kHz. Westinghouse modems.

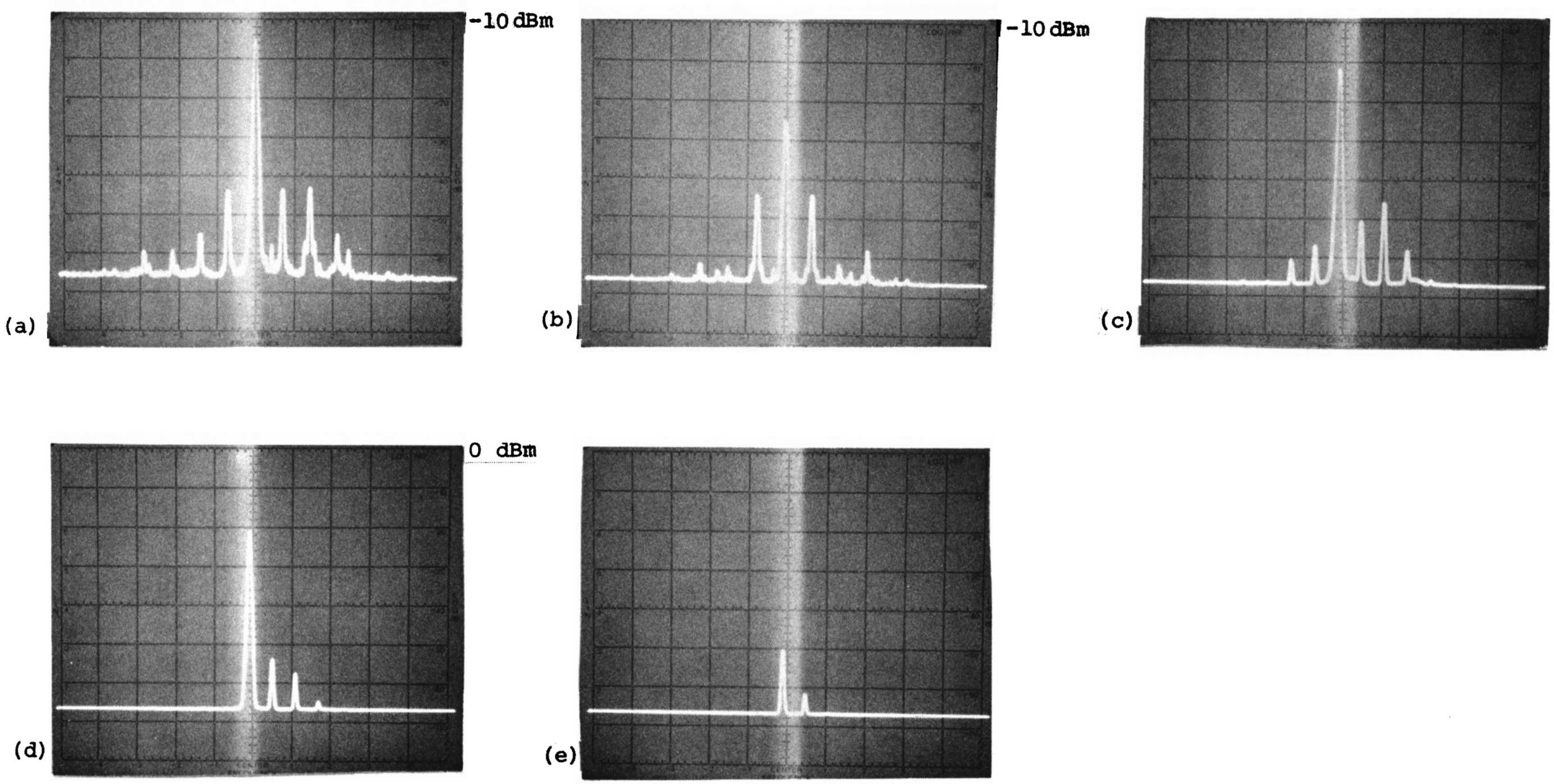


FIGURE 4-9. Recovered 600 MHz reference (VR), effects of waveguide attenuation and LP filter. 50 kHz/div; 3 kHz BW; ref = 10 dBm (a,b), 0 dBm (c,d,e). (a) Attenuation 56 dB, no filter; (b) 66 dB, no filter; (c) 46 dB plus filter; (d) 56 dB plus filter; (e) 66 dB plus filter.

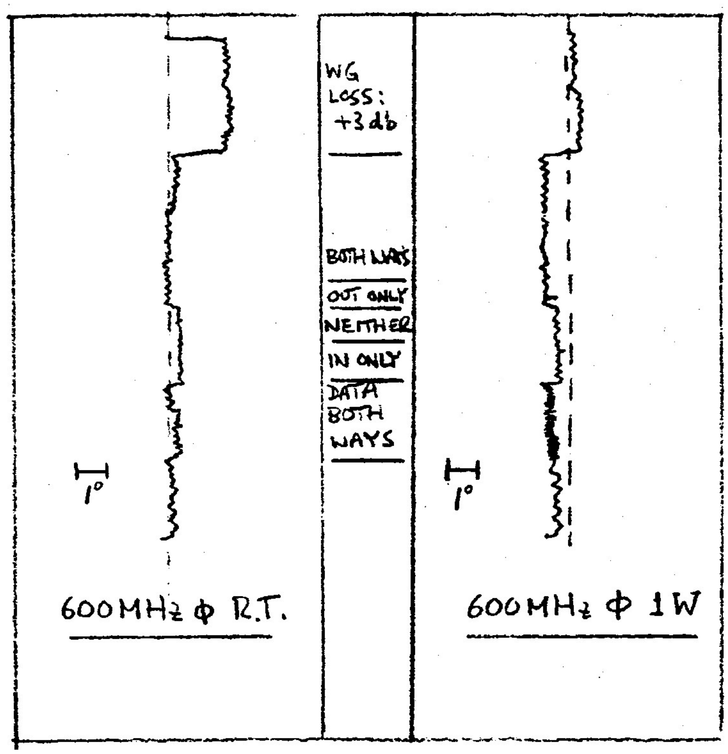


FIGURE 4.10 - Effect of data transmission on LO phase. TRG modems; levels same as Sections II-III. "Out" means CR to VR; "In" means VR to CR.

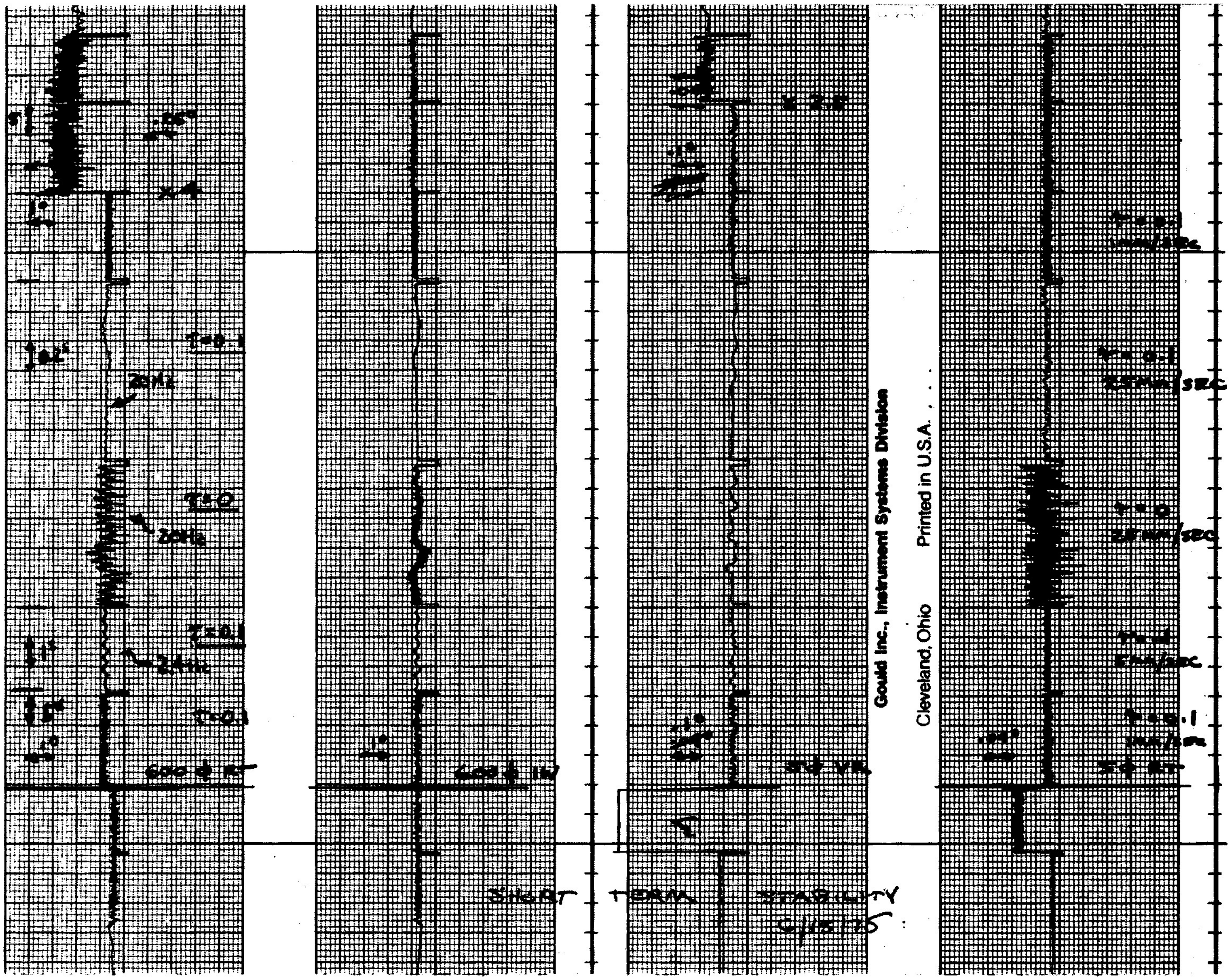


FIGURE 4-11. Phase errors on short time scales for various recorder time constants. See text for discussion

V. TEMPERATURE EFFECTS

A. Stability of 600 MHz Transmission

On numerous occasions during the system test period in Charlottesville the system was run overnight while monitoring the usual phase errors and room temperature on the chart recorder. The temperatures typically varied 2 to 5C, providing a measurement of the overall system temperature coefficient of phase. These tests also allowed a general assessment of the long term stability of the system, and occasionally showed up intermittent problems (glitches) which remain unexplained.

The last such recording made is reproduced in Figure 5.1. The system at this time was in as nearly final form as possible, with levels set as described in Section II, waveguide attenuation at 56 dB, and TRG modems installed. This particular run lasted nearly 22 hours. The 600 MHz reference for both phase recordings at that frequency was taken from L2 in rack M, rather than from L10. The random 1° jumps in the 600 MHz round trip phase (600 RTϕ, Channel 1) are not typical of these recordings, and so far the reason for them is not known. The temperature variation during the first 12 hours was only about 1°C, and the corresponding changes in 600 MHz phase were 1.6° one way and about 2° round trip. Near the end of the run the room was deliberately heated by 4.5°C, providing a more definitive measure of the system temperature coefficient of 0.9°/°C one way and 1.2°/°C round trip at 600 MHz. The 5 MHz vertex room phase showed no measurable temperature coefficient (<.005°/°C), but the returned 5 MHz coefficient was .01°/°C (in agreement with (1/120) times that of the RT 600 MHz).

B. Temperature Coefficient Measurements on Individual LO Modules

1. Early Tests Before Modifications to Modules

During the period 7-14 May 1975, certain local oscillator system modules were individually heated to measure their contributions to the system's temperature coefficient of phase error. The Westinghouse modems were installed and waveguide attenuation was 56 dB. Received levels for each LO carrier were set at -13.7 dBm at the vertex room and -19.6 dBm at the central station, measured at the T2 monitor port (old standard levels).

Heating was accomplished by dissipating 10W (DC) in a 10Ω/40W resistor mounted at suspected critical points within each module, while monitoring the temperature at one or two other points using thermistors. A temperature rise of 3 to 5C could be obtained in 10 to 20 minutes. Room temperature typically varied 0.5 to 1C over this time interval, due to air conditioner cycling.

System phase was monitored by comparing the master 600 MHz with the vertex room 600 MHz on a vector voltmeter, and with the round trip 600 MHz in L14 (Central LO Receiver). The two measurements generally showed approximately the same phase changes. Overnight runs showed a system temperature coefficient of 1.5-2 degrees of 600 MHz phase change per degree C temperature change.

<u>L1: Vertex Room 5/50 MHz Oscillator</u>

Heater was mounted on the top cover of the internal enclosure for the multiplier chain. Thermistor was mounted on the same cover, about 5 inches away. Heated from 37.5C to 41C in 10 minutes. As expected, 600 MHz phase showed no change (loop closed), but 5 MHz phase error at vertex room changed 0.34° (0.1°/°C).

<u>L2: Vertex Room 50/600 MHz Multiplier</u>

Heater on top cover of multiplier chain internal enclosure, thermistor about 5 inches away. Heated 41.5C to 45C in several cycles over two hours. No measurable effect on either 600 MHz or 5 MHz phase.

<u>L4: Vertex Room LO Receiver</u>

Heater mounted between the two amplifiers (1200 MHz and 1800 MHz); thermistor on the case of one amplifier. Heated 34.5 to 43.3 to 40C over one hour. 600 MHz phase changed monotonically by 1.6°, while room temperature increased about 1C. Temperature coefficient of L4 is therefore ≤1.6/(43.3-34.5) = .05°/°C.

<u>T2: Vertex Room IF Combiner</u>

Heated 33.5 to 36°C over 20 minutes. 600 MHz phase changed 0.2°: coefficient ≤.08°/°C.

<u>L10: Central LO Transmitter</u>

(a) Heater mounted on chassis, underneath 5 MHz modulator driver, thermistor alongside 5 MHz driver enclosure. Heated from 36 to 38.5C over 20 minutes. No significant change in 600 MHz phase, but 5 MHz phase error at vertex room changed 2.0° (0.5°/°C).

(b) Heater mounted next to Amplica amplifier at module input; thermistor on amplifier case, opposite side to heater, and another near 1200/1800 MHz modulators. Heated 44 to 47°C (measured at amplifier) over 5 minutes; corresponding temperature change at modulators was less than 1°C. Round trip 600 MHz phase changed by 6° (2°/°C). The 5 MHz phase error at the vertex room showed no significant change.

(c) An L10 module was removed from the rack, allowed to cool to room temperature, then replaced; system performance was observed as it warmed up. Round trip 600 MHz changed about 5° and 5 MHz changed about 10° in 17 minutes.

(d) It was discovered that in the above tests the input signal to L10 (from L13 in rack M) was +10 dBm (approx. +7 dBm each at 1200 and 1800 MHz), resulting in severe compression of the Amplica amplifier. The input level was reduced to -10 dBm, and the modulator drivers were readjusted to provide the same output levels (carriers and modulation) as before. Test (b) above was then repeated, resulting in no measurable temperature coefficient (<0.1°/°C).

NOTE: For all of the L10 tests, the reference for the 600 MHz phase comparisons was taken from the M-rack (L2), not from the 600 MHz recovered in L10.

2. Additional Tests, After Modifications

L10: Central LO Transmitter

Because of the large temperature coefficient observed in this module, minor modifications were made and its specified standard input level (1200 and 1800 MHz bus from M rack) was reduced to -4 dBm (-7 dBm per carrier). For other reasons, extensive modifications were also made to the modulator drivers for the 5 MHz and the digital data. The earlier tests were then repeated, observing the effect of module warmup on the 600 MHz phase (Fig. 5.2) and determining the new temperature coefficients of the Amplica amplifier. The coefficient for the 600 MHz one way phase was .16°/°C relative to master 600 MHz, and 1.2°/°C relative to the 600 MHz reference output from L10 (derived from intermodulation in the same amplifier). This indicates that the 1200 and 1800 MHz phase stability is much improved, but that the 600 MHz reference output stability still needs considerable improvement.

L2: 50-600 MHz Multiplier (VR)

This module is quite critical because it determines the phase of the 50 MHz signal from L1, which is multiplied by as much as 24 in the 2-4 GHz synthesizer; this multiplication puts stringent requirements on the 50 MHz phase stability. Therefore, an especially sensitive measurement of the temperature coefficient of L2 was attempted by observing the phase difference between two identically tuned 2-4 GHz synthesizers, one of which was locked to the VR 50 MHz as usual, and the other of which was locked to the master 50 MHz (from L1 in rack M).

A chart record of the test is reproduced in Fig. 5.3. The synthesizer were tuned to 3310 MHz, giving a multiplication factor of 18 for the 50 MHz signal (= (3310 - 10 - 2400)/50). A temperature coefficient of (4 $\pm$1)°/°C at 3310 MHz was observed, implying (0.22 $\pm$.06)°/°C at 50 MHz. This is much too large and will have to be improved. Note also that several hours of warmup were needed after plugging in L2 before the phase was stable enough to make this measurement; the 3310 MHz phase drifted 30-40° during this time.

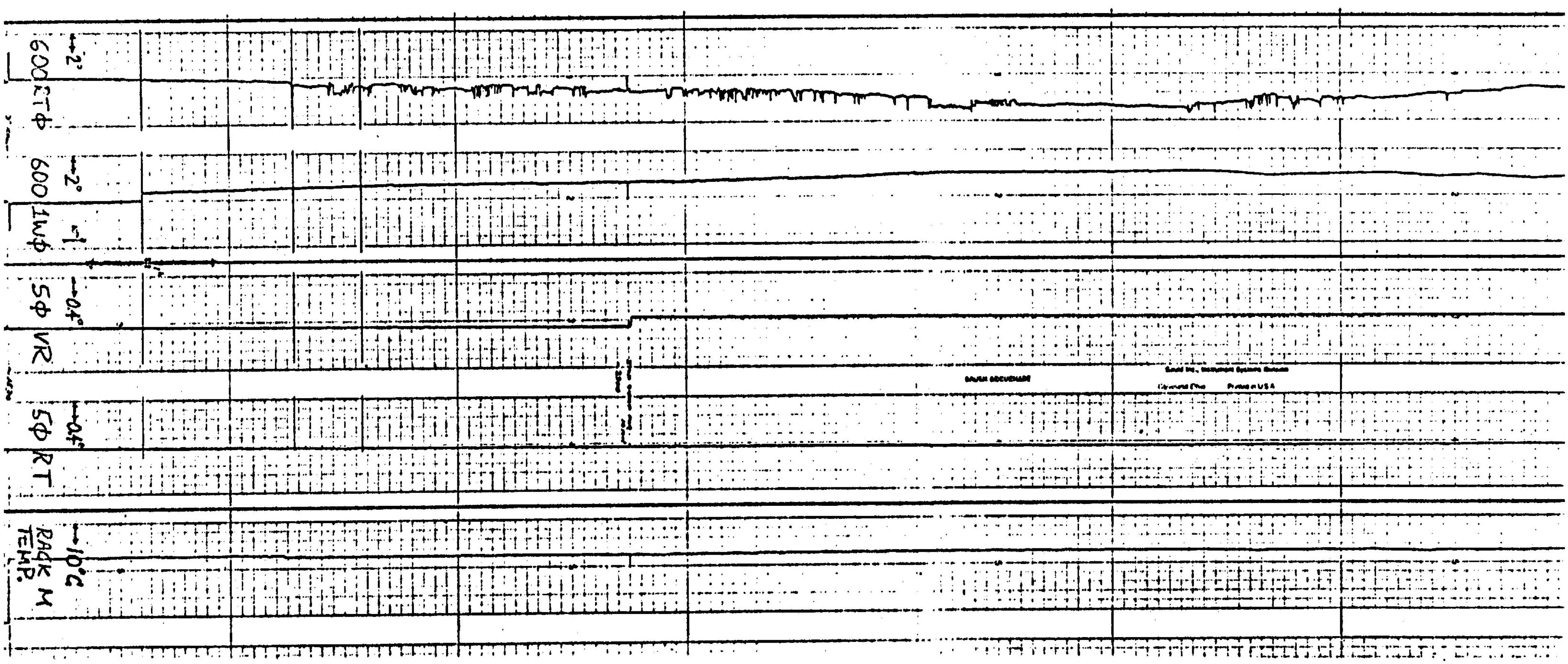


FIGURE 5.1 - Long term phase stability.

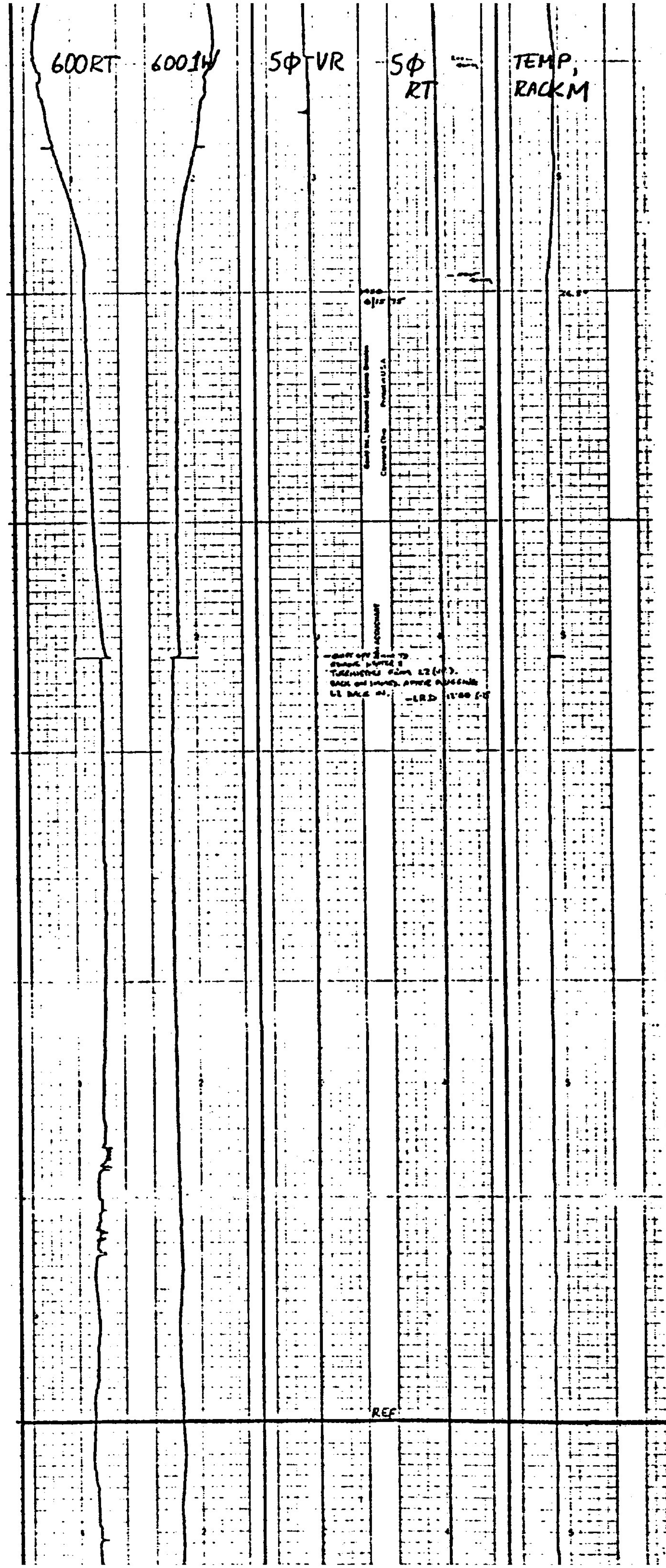


FIGURE 5.1 - continued

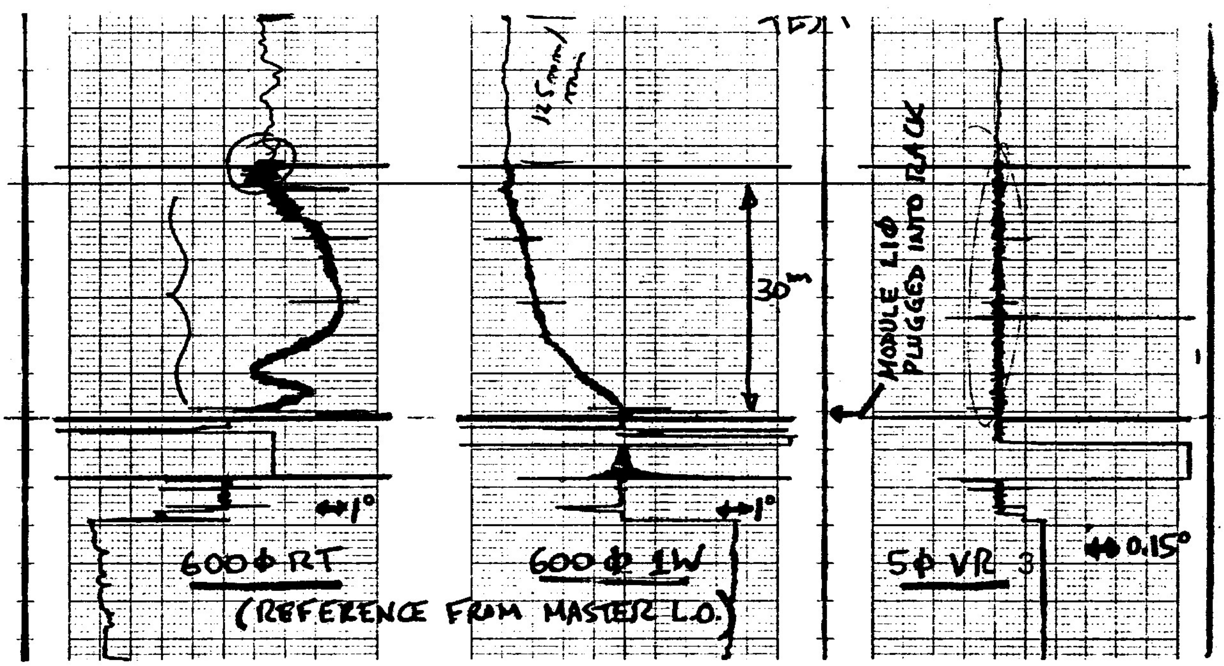


FIGURE 5.2(a) - Warmup of L10-A1, after modification (5 June 1975).

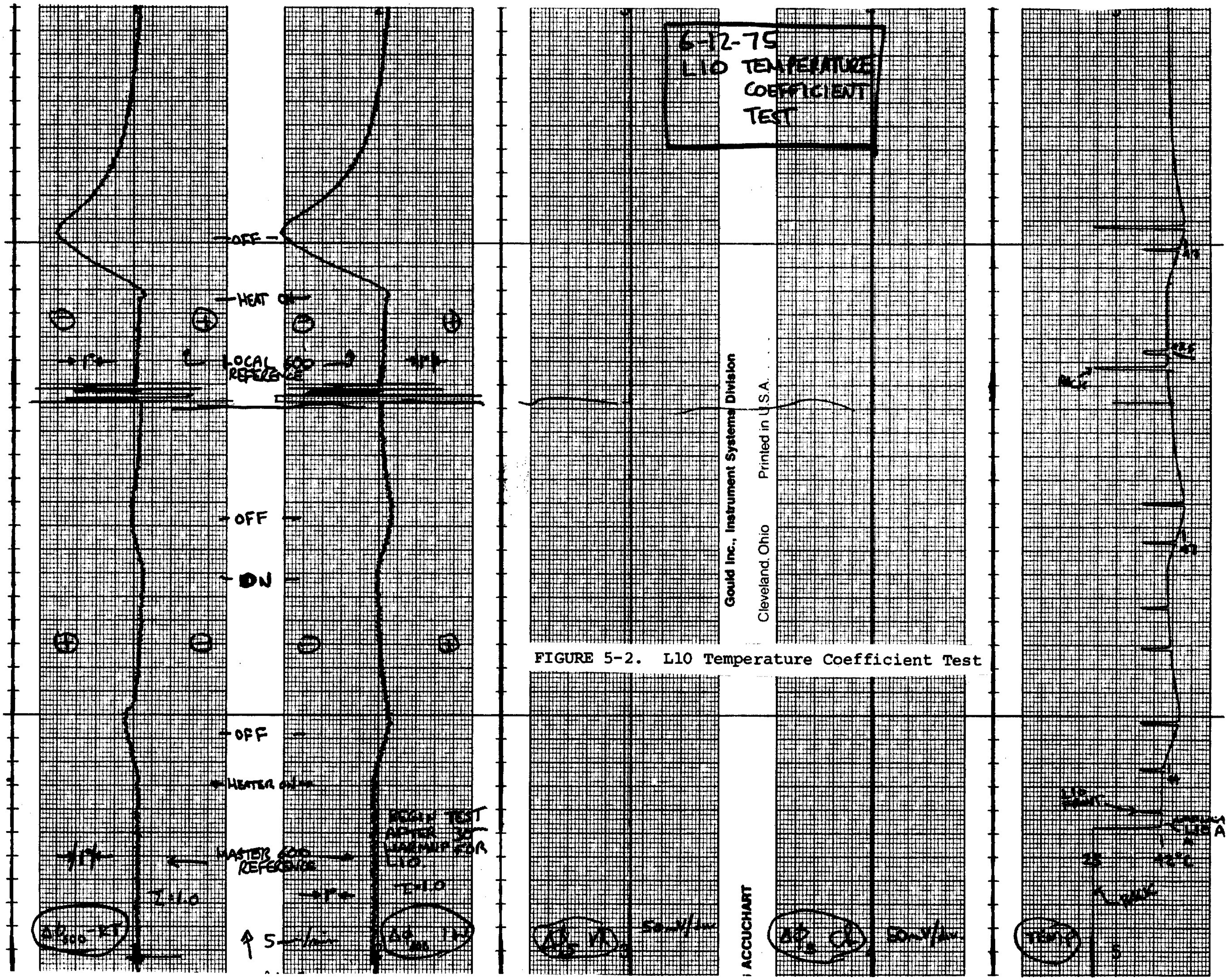


FIGURE 5-2. L10 Temperature Coefficient Test

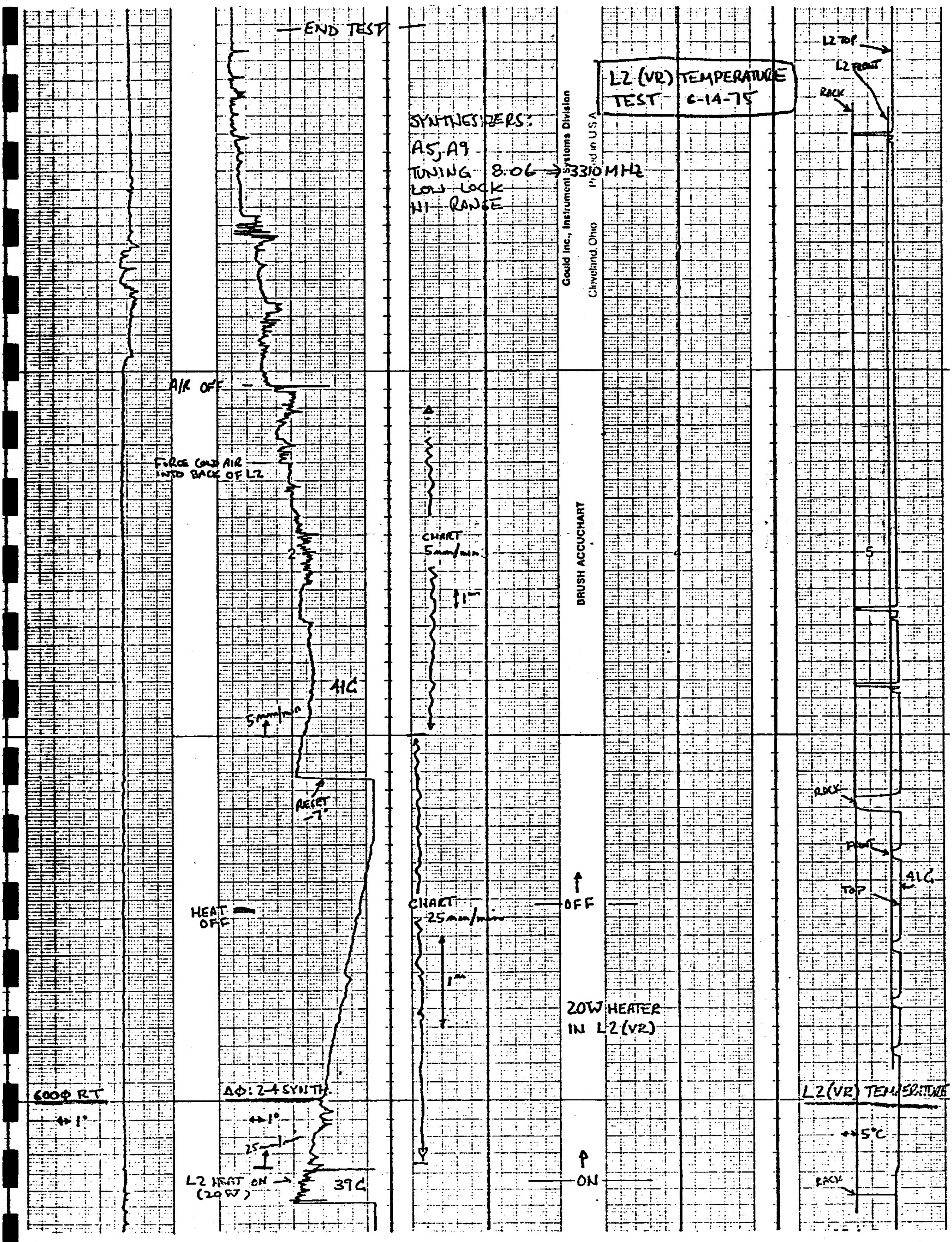


FIGURE 5.3 - L2 (VR) temperature coefficient measurement, using two 2-4 GHz synthesizers tuned to 3310 MHz.

VI. WAVEGUIDE ATTENUATION EFFECTS

It is important that the system be tolerant to level changes to insure reliable operation if levels change with time, if modules are changed, or if an antenna is moved to a station adjusted for slightly different loss. A specification of no failure other than small deterioration in IF S/N with a ± 6 dB waveguide attenuation change from a nominal value of 56 dB has been adopted.

It should be noted that the waveguide attenuation should be very stable. The resistive loss should vary with temperature approximately 0.1%/°C - as the square-root of copper wire conductivity. Loss due to bending should be stable unless there is unpredicted buckling (due to thermal compression) or earth movements. An ALC loop could also be used to correct for overall attenuation change but it is not known if the loop amplitude-to-phase change conversion would be low enough.

A. Attenuation Effect on LO Phase

A chart record showing the change of various LO phases as the variable attenuator was varied over a 16 dB range is shown in Figure 6.1. For a 1 dB variation of attenuation from 56 dB the curves show:

1) 1.5° variation in 600 MHz round-trip phase
2) 0.15° variation in 600 MHz one-way phase
3) 0.08° variation in 5 MHz vs 600 MHz VR phase
4) 0.02° variation in 5 MHz round-trip phase

All of the above coefficients are acceptable except 1). At 4 dB lower signal level coefficient 1) would drop to 0.3° per dB. This could be accomplished by increasing the attenuator between CR T2-J8 and L9-J1 from 6 dB to 10 dB and adjusting 5 MHz gain and DATA gain in L9 to compensate. However, the repeatability of the phase variation curves with different modules needs to be checked before this is done.

It was determined that adjustment of CR T2 gain to hold constant T2 output as attenuation was varied caused the round-trip 600 MHz phase to follow the one-way phase variation. This proves that the effect is a function of receive level and is not an attenuator characteristic. It is not know if the cause of these phase variations is amplifier non-linearity or phase-detector zero-shift.

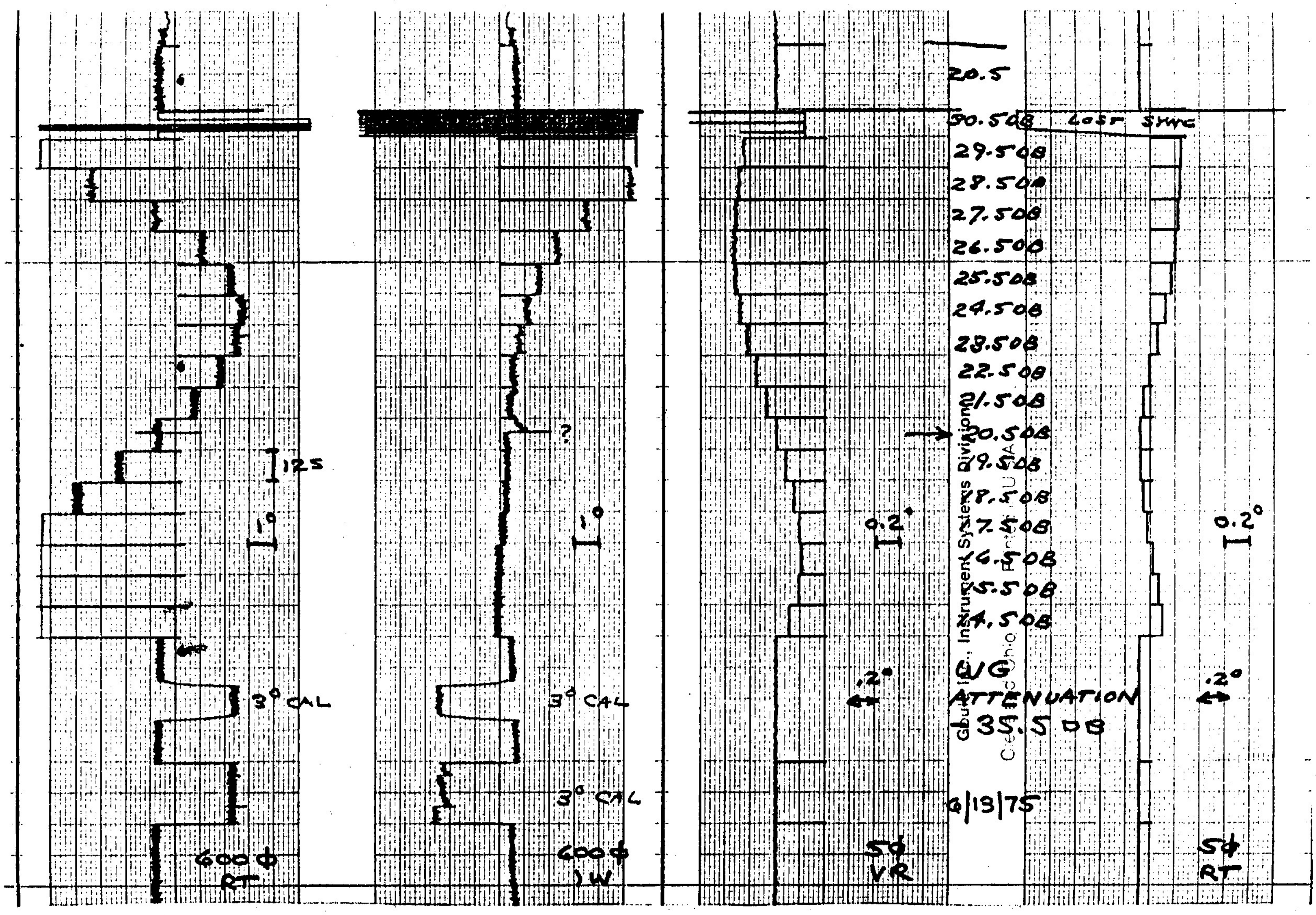


FIGURE 6.1 - Effect of waveguide attenuation change upon LO phase. The value marked "20.5 dB" corresponds to a total attenuation of 56 dB; thus signal level was changed +6 dB to -10 dB from the nominal value. The left-most column is 600 MHz round-trip phase; second column is CR to VR 600 MHz phase measured with an HP Network Analyzer; third column is 5 MHz received at VR compared to 5 MHz locked with received 600 MHz; and right-most column is 5 MHz round trip phase. All measurements are with 0.1 second time constant and a chart speed of 25 mm/minute.

Furthermore, if signal levels were adjusted so no amplifiers limited it is not known if overall system operation would be improved.

Measurements of phase-detector gain (volts per radian) vs attenuation were made and show that the phase detectors are saturated (desirable) at the nominal signal levels.

B Attenuation Effect on Sync

Transmit-receive synchronism between CR and VR is achieved by the turn-on of the 5 MHz-modulated 1200 MHz carrier every 52 ms. This turn-on edge is applied to L8 which times all changes in the VR. Normally the turn-on edge is 1.2 volts in amplitude (see Scope Photograph 2B) and L8 trigger level is set at 0.3 volts.

In final tests sync was lost at -10 dB from normal level and was not lost at +20 dB above normal level.

C. Attenuation Effect on Data

A quantitive measurement of error rate as a function of attenuation was not performed. However, with most signal levels 3 dB above the final values shown in Figure 2.5, attenuation variation of $\geq$9 dB was required to produce a large error rate.

D. Attenuation Effect on IF

Expected values for signal power and receiver noise-figure for IF transmission are as follows:

Transmitter Power per 60 MHz Bandwidth	-8 dBm
Attenuation	56 dB
Received Signal	-64 dBm
Receiver Noise for F=12 dB and B = 60 MHz	-84 dBm
Signal-to-Noise, S/N	20 dB

Even though the above values for transmitter power and receiver noise figure were measured at various times, the measured system S/N is approximately 3.5 dB less than the above value as can be observed in Spectra SA4 and SA4B. No explanation other than measurement error is evident.

It may be noted that transmitter intermodulation noise will limit the IF S/N. However, this is not the case at 56 dB attenuation as is evident in SA4B where it can be observed that the noise at 1500 MHz does not change by more than 1 dB as attenuation is changed from 90 dB to 56 dB, i.e. transmitter intermodulation noise is small compared to receiver noise.

As attenuation is decreased to 51 dB the 1500 MHz noise does increase indicating a limiting S/N of 19 dB due to intermodulation noise. In earlier tests (see Figure 2 of VLA Electronics Memo #130) it was noted that intermodulation noise is a function of IF drive to the transmit mixer. This drive should be adjusted for optimum received S/N at 56 dB attenuation.

Note in SA4B that the 1500 MHz noise is an accurate indicator of receiver noise level - it is equal to the noise level in the IF bands with no received signal (90 dB attenuation). The spectrum of the intermodulation noise is not known but to a first approximation can be assumed to be white.

VII. WAVEGUIDE REFLECTION EFFECTS

The antenna modem will be connected to a coupler located in an underground manhole by approximately 30 meters of 20 mm diameter circular waveguide. The reflection at the coupler is thus presented to the modem with a phase dependent upon the electrical length of the connecting waveguide. If a temperature coefficient of expansion of 20 x 10^{-16}/°C is assumed for this connecting waveguide the reflection phase, θ, will vary 72°/°C at a wavelength of 6 mm.

The effect of this unstable reflection upon LO phase stability has been analyzed by R. Predmore in his memo of September 24, 1973. The effect upon 600 MHz phase transmission depends on reflection coefficients of waveguide, modem in receive mode, and modem in transmit. Let the magnitudes of these reflection coefficients be Γ_{WG} Γ_R and Γ_T respectively, at carrier plus 1200 MHz and Γ'_{WG} Γ'_R and Γ'_T at carrier plus 1800 MHz. The effects upon LO phases are then summarized as follows:

1) One-way 600 MHz phase transmission is changed, in radians, by

$$\Gamma_{WG}\,\Gamma_R \cos\theta - \Gamma'_{WG}\,\Gamma'_R \cos\theta'$$

where θ_R and θ'_R are receive reflection phase angles for carrier + 1200 MHz and + 1800 MHz, respectively. As a worse case assume Γ'_{WG} or $\Gamma'_R = 0$ and a θ variation from -90° to +90° due to a 2.5°C temperature change. The peak-to-peak phase change, δ, is then 2 Γ_{WG} Γ_R as tabulated below:

Γ_{WG}	Γ_R	δ P. to P. 600 MHz
-25 dB	-20 dB	0.64°
-25 dB	-25 dB	0.36°
-20 dB	-15 dB	2.0°

2) Round trip 600 MHz phase error is changed by the above amount plus the return change,

$$\Gamma_{WG}\,\Gamma_T \cos\theta_T - \Gamma'_{WG}\,\Gamma'_T \cos\theta'_T$$

where θ_T and θ'_T are the transmit reflection phase angles. If $\Gamma_T = \Gamma_R$, $\Gamma'_T = \Gamma'_R$, $\theta_T = \theta$, and $\theta'_T = \theta_T$, the round trip phase error is twice the one-way phase error and will be corrected.

3) The one-way and round-trip 5 MHz phase errors can be described by the above equations if we refer the primed notation to 1205 MHz and unprimed to 1200 MHz (1200 and 1195 MHz could also be used with the same result). In this case the reflection coefficient magnitudes can be assumed equal for primed and unprimed frequencies and the peak-to-peak variation of $\cos\theta - \cos\theta'$ will be $2\pi\Delta f/f_B$ where f_B = propagation velocity divided by distance between mismatches and Δf = 5 MHz. The one way 5 MHz phase error is thus,

$$\Gamma_{WG}\,\Gamma_R \cdot \frac{2\pi\Delta f}{f_B}$$

and the round trip error is the above plus,

$$\Gamma_{WG}\,\Gamma_T \cdot \frac{2\pi\Delta f}{f_B}$$

For the 30 meter waveguide line, f_B = 5 MHz and the peak-to-peak 5 MHz phase error will be π times the 600 MHz values tabulated in the previous table.

To test sensitivity of the system to waveguide mismatch a sliding-short was installed on the -10 dB port of the coupler approximately 50 cm from TRG Modem T1-A1. Results are shown in Figure 7-1. The 600 MHz one way phase error shows a 2° peak-to-peak variation which can be explained by a 14 dB modem return loss at carrier frequency plus either 1200 or 1800 MHz and a much smaller reflection at the alternate frequency. The 600 MHz round trip error is almost exactly twice the one way error indicating that the modem transmit and receive reflections are nearly equal. For this modem a waveguide temperature change of 2.5° would cause a 1.2° 600 MHz one way phase error assuming a 25 dB waveguide return loss; however, this error would be corrected by the round trip system.

The test result shows a 0.16° peak-to-peak variation of 5 MHz one-way phase compared to antenna 600 MHz phase ÷ 120. The latter phase variation is 2°/120 = .016° and can be neglected. The 5 MHz one-way phase variation can be explained by assumptions of f_B = 300 MHz and Γ_R of -11 dB at 1200 MHz.

Round-trip 5 MHz phase error appears to be approximately equal to the one-way error and has identical variation with short position. This requires Γ_T to be much smaller than Γ_R which is consistent with the 600 MHz results. A more likely explanation is erroneous calibration of one of the 5 MHz phases.

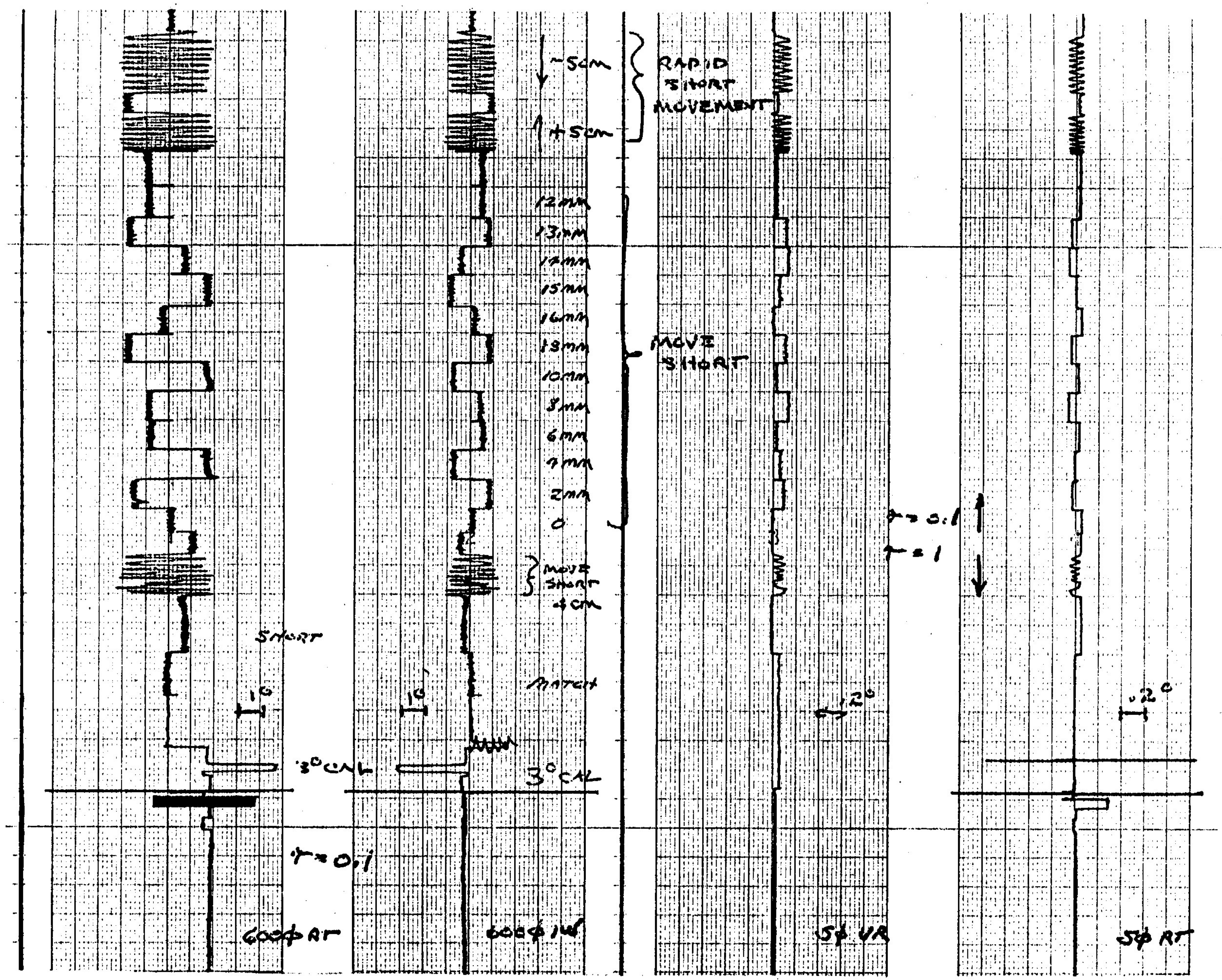


FIGURE 7.1 - Effect of moving short on -10 dB port of directional coupler approximately 50 cm from TRG Modem T1-A1.

VIII. MISCELLANEOUS PROBLEMS

A. 1200 and 1800 VCO Lock

The lock range of the 1800 MHz VCO in L14 must be limited to prevent lock-up on data sidebands which may be ±250 kHz from 1800 MHz; the loop must also not follow these sidebands since the VCO output is used in T4B to down-convert IF signals. The 1200 MHz VCO loop need not have this limitation but a similar loop design is used.

With this limited lock range it may be necessary to often adjust VCO frequency because of long term drift of the VCO's. The temperature coefficients of the present oscillators is specified by the manufacturer as "typically .001%/°C" which is 18 kHz/°C. The oscillators seem to stay in lock after 10 to 30 minutes of warmup but it has not been determined if the long term stability is adequate. A crystal VCXO-multiplier chain type of VCO may be needed at 1800 MHz.

The lost-lock problem is somewhat aggravated by the type of acquisition sweep circuitry which utilizes offsets to sweep the oscillator when out of lock. During the 1 ms transmit-time when no reference frequency is received the loop starts sweep in a positive direction as shown in oscillograms 17B and 18B. To avoid losing lock the frequency adjust control must be adjusted so the control voltage shown in these oscillograms is within ±3 volts of zero. The loop would be less prone to unlock if the sweep circuit was redesigned so it did not sweep during the 1 ms transmit time.

B. Power Supply Noise

The power supply system, especially in Rack B, seems to be susceptible to noise generation in the ten's of kHz range where lead inductance is not negligible and there is not sufficient bypass capacity within modules.

Initially 50 mV peak-to-peak of 5 kHz and 100 kHz waveforms could be observed on the +5 volt power line; this caused sidebands on 1200 and 1800 mHz spectra. Decoupling chokes and capacitors in the Data Tap, L8, and L7 reduced the noise to <5 mV peak-to-peak. However, weak 5 kHz sidebands were still observed on the 1800 MHz carriers; these disappeared when the Data Tap was removed. If this proves to be a problem some additional filtering may be needed in the module susceptible to the noise.

C. Lightning Storm

During a lightning storm the Sync Error indicator on L8 came on for a few seconds after each flash. It is not known if this was due to extraneous sync pulses or to upsetting of the counter in L8. If sync is frequently lost during power line transients, battery isolation may be required for a redesigned, low-power L8.

D. Data and Detector Polarity

The Bi-Phase code used for digital data transmission must have correct polarity to be correctly decoded. The command data digital modules are presently constructed so that an inversion is required in the communication path. This is accomplished by a positive output detector and an inverting receive amplifier in L4 as shown in Figure 2.6. On the other hand the monitor data path requires no inversion in the transmission system. This is accomplished by a negative output detector and an inverting receive amplifier.

In the future it may be advisable to modify the digital modules so no command inversion is required and use all negative output detectors in L4 and L9.