VLA-VLBA Interference Memo No. 14

Radiated RFI Emissions from the ALMA Test Correlator and 1.6 GHz Digitizers and Comparison to Harmful Levels to VLA Observations

National Radio Astronomy Observatory, Very Large Array, Array Operations Center
Raul Armendariz, November 15, 2000

Abstract:

ALMA prototyping at the VLA and the EVLA both propose to digitize at the antennas, and locate more electronics within vertex and pedestal rooms. This raises a concern as to whether the radiated RFI levels will be tolerable. On August 29-31, 2000 radiated electric field emissions measurements of the ALMA test correlator were conducted at NRAO in Charlottesville, Virginia. The test device included the 64 chip correlator, two 1.6 GHz samplers (2-bit 3-level digitizers), and a VME mounted MV2700 processor board. The hardware was rack mounted in a 6.6-foot AMCO FRF freestanding RFI shielded enclosure, and in addition each sampler in an individual shielded module enclosure. These tests were performed in the correlator design lab, which is neither shielded nor anechoic.

Measurements were made from 20 MHz to 13 GHz. The strongest emissions were from the digitizers with a maximum effective isotropic radiated power (EIRP) of -91 dBW/Hz at 1.6 GHz. The harmful threshold for D-array VLA continuum observations per the International Telecommunications Union Handbook on Radio Astronomy, Radiocommunications Bureau, is approximately -237 dBW/m^{2}Hz spectral power flux density. Additional attenuation of 146 dB is required to meet this limit. Most of the power at 1.6 GHz is within a bandwidth less than 1 kHz; sideband power extends at least 600 kHz with an EIRP of -168 dBW/Hz. Above 2.7 GHz the only emissions detected were the 2nd and 3rd harmonics of the Samplers at 3.2 GHz and 4.8 GHz; higher order harmonics are expected but were below the noise floor of the test equipment. The equipment under test emits white and broadband noise over multiple frequencies. Over 1350-1450 MHz and 1550-1650 MHz the white emissions EIRP is -178 dBW/Hz, and over 305-355 MHz is -155 dBW/Hz.

There was no significant difference in radiated emissions with the Samplers digitizing an input signal versus no input signal. During correlator start-up there is a ~ 10 second initialization sequence of the Xilinx logic during which the equipment under test radiates strong white noise over 200-450 MHz and 1350-1650 MHz. After initialization the radiation power drops 15 dB but is still present. It is assumed most white noise originates from the correlator and not from the digitizers. If the correlator is housed in the VLA control building, which is approximately 166m away from the nearest VLA pad (DW8), the distance would provide ~ 55 dB in path loss.

Table of Contents   Page

I) Description of Equipment Under Test

The Equipment Under Test (EUT) is referred to as the ALMA test correlator, and is comprised of a 64 chip correlator, two 1.6 GHz (2-bit 3-level) free-running digitizers, and a VME mounted MV2700 processor board (see appendix 3 for detailed description). All units are mounted in a 6.6 foot FRF AMCO RFI shielded enclosure (see pictures 1 and 2 in appendix 2). External to the EUT was a 100 MHz system clock phase-locked to the digitizers; also external to the EUT was a −120 dBW/Hz, 800-1000 MHz analog white noise source (figure 11 in appendix 1 is a plot of the noise source output). The digitized output from the samplers is connected to the correlator via unshielded non-fiber flat cables. Digitizer ECL data output at 100 MHz was recorded (pictures 3, 4, and 5 in appendix 2 show digitizer, output cables, and ECL output). For the purposes of this report the system clock and noise source are not considered part of the EUT. The enclosure doors were closed, the noise source was on, and the system clock was running during all testing unless otherwise stated.

Logic rates and equipment specifications

Test Digitizers:

- Two 1.6 GHz 2-bit 3-level free-running digitizers PLL locked to 100 MHz system clock
- Some logic at 400 MHz
- ~ 1m unshielded flat cables for digitized output

Test Correlator: 64 chips each with 1024 lags distributed among 4 correlator cards (65,536 hardware correlators)

- Logic mostly runs at 100 MHz
- Some logic at 50 MHz (100 MHz/2)
- Some logic at 33.3 MHz (100 MHz/3)
- Some logic at 25 MHz (100 MHz/4)
- 4 microprocessors each with a free running 16 MHz crystal oscillator

VME mounted control computer:

- MV2700 power PC processor board

EUT Power Supply:

- 208 volts, 3 phase, < 1 kW power, filters on power lines

External system clock:

- 100 MHz sinusoidal crystal oscillator

External noise source:

- 800–1000 MHz, −120 dBW/Hz analog white noise source

Operating configurations of EUT

Measurements were made of the ambient RFI background with the EUT off, referred to here as configuration 1, and then compared to measurements made with the EUT on, configuration 2. Configuration 2 was chosen to maximize emissions. Results are determined by subtracting the ambient RFI background from the radiated spectra with EUT on. In the text and plots below "EUT off" means configuration 1, and "EUT on" means configuration 2. Any other configurations used are specifically described.

Configuration 1: power supply off, VME off, correlator and digitizers off, no data flow, analog noise source on, external system clock on.

Configuration 2: power supply on, VME on, correlator and digitizers on, data flow from correlator to VME on, analog noise source on, external system clock on. Correlator was programmed to process an 800 MHz bandwidth, with products 0R x 1R (2 antenna inputs in right polarization), 512 leads x 512 lags, 8-samples delay resolution, and integration time = 10 sub integrations with each sub int. = 76 x 1.31072 ms (correlator tick time).

II) Test Setup

The test setup was as per figure 1 below and pictures 6-14 in appendix 2. The swept spectrum analyzer was used in RMS peak detection mode, with auto-calibration; no time-varying emissions were detected from the EUT. Radiated signals were significantly stronger than the detection equipment internal system noise and thus this system noise was ignored. Because of possible constructive interference of ground reflected waves and destructively interfering wall reflections the antenna was moved through various heights to maximize reception. For 1.85-13 GHz measurements the linearly polarized horn was oriented 45 degrees from the vertical. No line impedance stabilization network (LISN), ground plane, balun, or matching network was used.

DC-200 MHz:

A 20-200 MHz linearly polarized biconical receive antenna was situated in position 1 at a height of 1.3 m above the floor, and a distance of 1.5 m from the EUT (see pictures 6-8 in appendix 2). The biconical antenna was used in both horizontal and vertical orientation to determine the maximum emissions (figure 12 in appendix 1 is the antenna correction factor). A 10-1000 MHz LNA, providing 15 dB gain, was used at the antenna output (figure 13 in appendix 1 shows LNA gain). The test distance of 1.5 m is near field over this range and therefore the near field antenna correction factor was applied.

200-1000 MHz:

A 200-1000 MHz circularly polarized conical log-spiral receive antenna was situated in position 1 at a height of 1.3 m above the floor and a distance of 1.5 m from the EUT. See pictures 9 and 10 in appendix 2 for test setup. Figure 14 in appendix 1 is the antenna correction factor. A 10-1000 MHz LNA providing 15 dB gain was used at the antenna output (figure 13 in appendix 1 shows LNA gain). The test distance of 1.5 m is 1 wavelength at 200 MHz and several wavelengths at higher frequencies; 3-5 lambda is typically considered far field. The antenna correction factor used applies to both near and far field over this range.

1-1.85 GHz:

A 1-10 GHz circularly polarized conical log-spiral receive antenna was used (see pictures 11 and 12 in appendix 2 for test setup; figure 15 in appendix 1 is antenna correction factor). Positions 1, 2, and 3 were checked at 1.6 GHz and position 1 was found to be noisiest. The receive antenna was placed at different heights from 0.5-2 m, and a height of 1.3 m found to be the noisiest. The antenna was situated in position 1 and at a height of 1.3 m above the floor, and a distance of 1 m from the EUT for all further tests (plots 19-48 in section VI). A 1-2 GHz LNA providing 17 dB gain was used at antenna output (figure 16 in appendix 1 shows LNA gain). The test distance of 1 m is several wavelengths over this range. The antenna correction factor available was applied, and is assumed to be far-field.

1.85-13 GHz:

A 2-18 GHz vertically polarized horn receive antenna was used, and tripod mounted at 45 degrees relative to the vertical (see pictures 13 and 14 in appendix 2 for test setup; figure 17 in appendix 1 is antenna gain pattern). In position 1 the antenna was placed at different heights from 0.5-2 m, and a height of 1.3 m was found to be the noisiest. For all further tests the horn was situated in position 1 at a height of 1.3 m above the floor, at a distance of 1 m from the EUT. A 1-5 GHz LNA providing 34 dB gain was used at antenna output for the range 1.85-5 GHz (figure 18a and 18b in appendix 1 shows LNA gain). Above 5 GHz no LNA was used. The test distance of 1 m is several wavelengths over this range; the antenna gain pattern available was applied, and is assumed to be far-field.

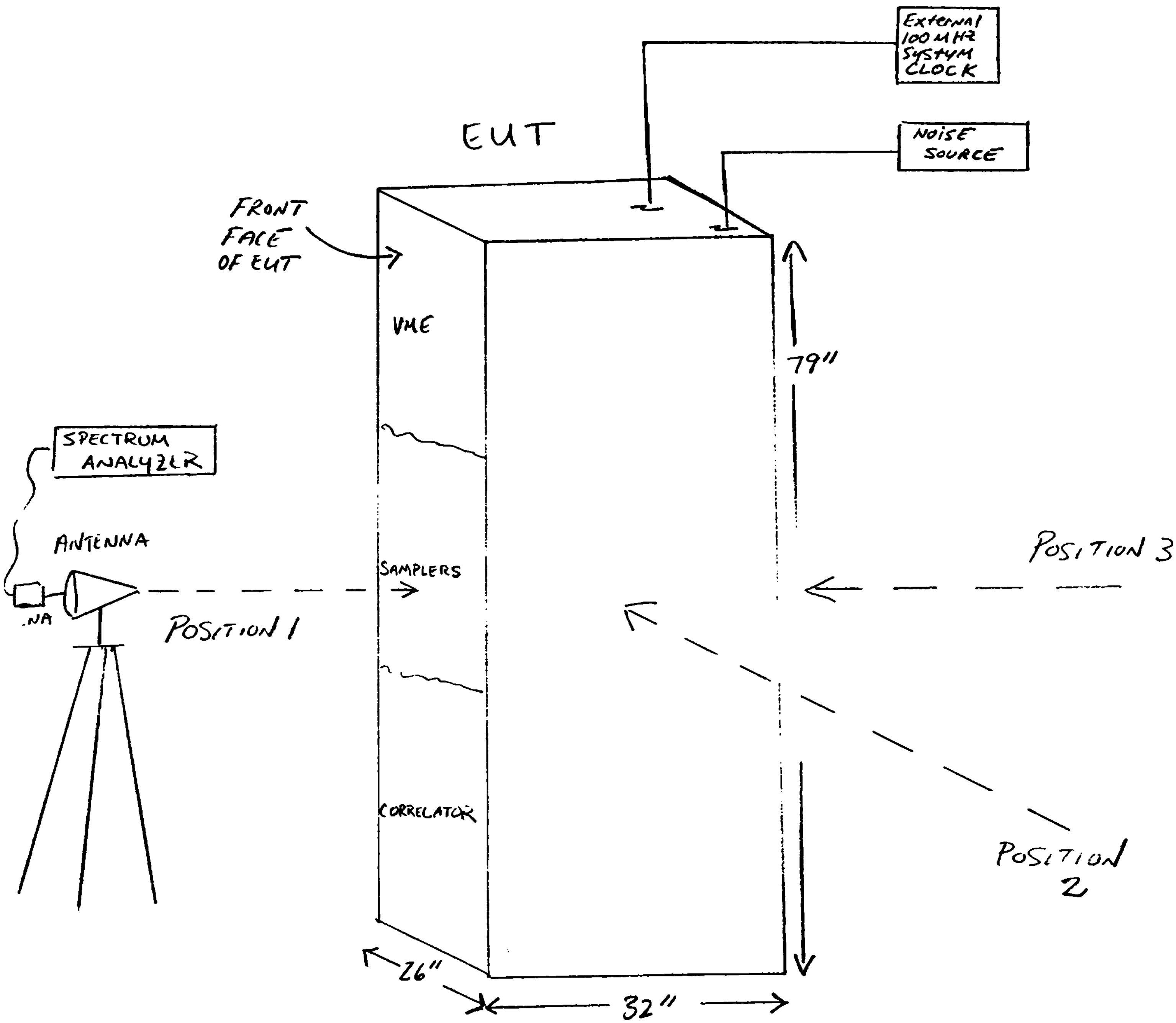


FIGURE 1 : TEST SETUP RADIATED EMISSIONS

III) Comparison of detection equipment sensitivity to VLA harmful levels

Figure 2 below is an excerpt from chapter 4 of the International Telecommunications Union (ITU) Handbook on Radio Astronomy, Radiocommunications Bureau, Geneva, 1995, and gives harmful interference thresholds for VLA continuum observations The Handbook levels are based on levels published in ITU-R RA-769. Figure 3 compares the sensitivity of the detection equipment used to VLA harmful levels. The sensitivity is given per a 1 Hz RBW, however the narrowest RBW used for these tests was 1 kHz.

The detection equipment system noise power was dominated by spectrum analyzer internal noise and levels are inferred by reviewing plots in section VI. The line loss was measured to be ~ 0.5-1.5 dB over the frequency range. Amplifier performance plots, antenna gain patterns, and antenna correction factors are in appendix 1. Equipment sensitivity is given in terms of spectral power flux density (SPFD) at a test distance of 1m, and compared against harmful RFI SPFD levels.

Derivation of detection system sensitivity

EIRP = effective isotropic radiated power
PFD = power flux density per given bandwidth
SPFD = spectral power flux density (per 1 Hz bandwidth)
SP.antenna = spectral power after receive antenna
SP.amplifier = spectral power after low noise amplifier
P.signal = power recorded by spectrum analyzer per given resolution bandwidth
SP.signal = power recorded by spectrum analyzer and converted to a 1 Hz bandwidth
P.noise = detection equipment internal noise power per bandwidth, in absence of signal
SP.noise = detection equipment internal noise power per 1 Hz bandwidth
BW = bandwidth BB = broad band NB = narrow band
CW= continuous wave S = signal N = noise
RBW = resolution bandwidth
EUT = equipment under test (ALMA correlator)
LNA = low noise amplifier
G.is = gain over isotropic of receive antenna
ACF = antenna correction factor
Ae = antenna effective area

1) P.noise (dBW/RBW) - 10Log(RBW/1Hz) = SP.noise (dBW/Hz)
2) SP.noise + line loss – amplifier gain = detectable SP.antenna in dBW/Hz
3) SP.antenna (W/Hz) / Ae (m^2) = detectable SPFD (W/m^2Hz) at receive antenna
   where G.is = 10Log {(4 pi Ae) / $lambda^2$)}
or
3a) SP.antenna (dBW/Hz) + ACF (dB) –8.76 dB (conversion) = detectable SPFD (dBW/m^2Hz)
   where ACF = - G.is – 10Log($lambda^2$) + 19.75 dB
4) detectable EIRP (dBW/Hz) = SPFD + |path loss (dB)|
   where path loss = 10Log {1 / (4 pi d^2)}, d = test distance of 1m or 1.5 m
5) detectable SPFD at test distance of 1m from EUT = EIRP – |path loss|
   where path loss = 10Log{1/(4 pi 1^2)}

Table 1: Detection System Sensitivity (SPFD)

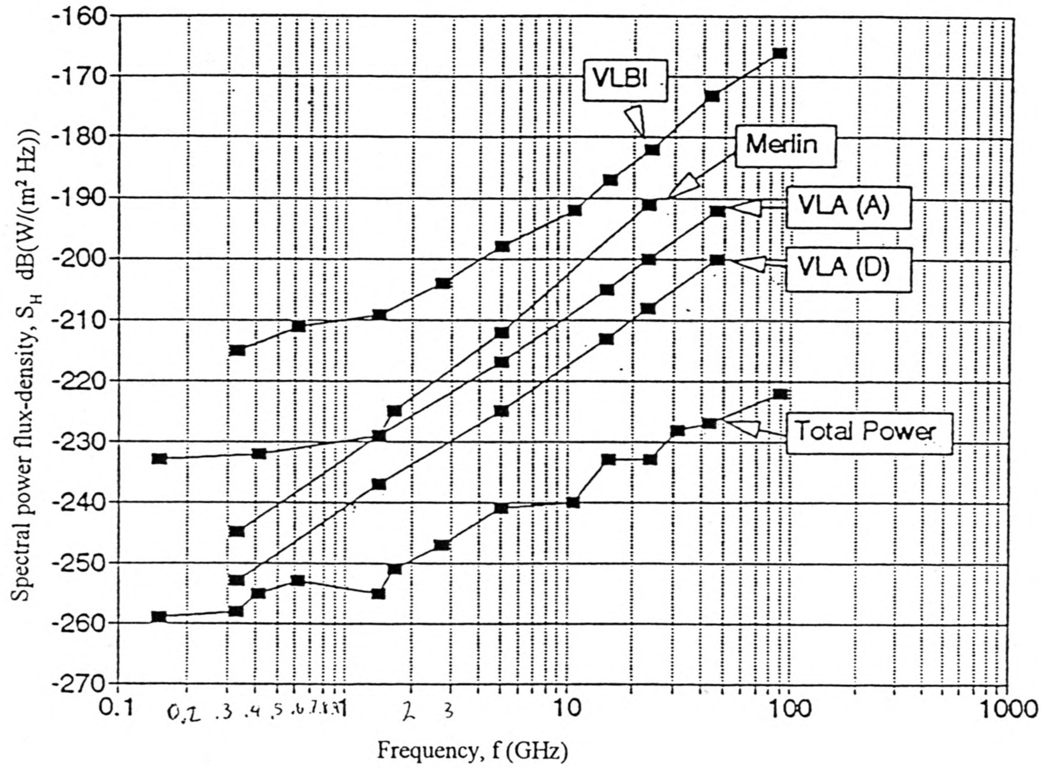
Freq. MHz	SP.noise dB/W/Hz	LNA dB gain	SP.antenna dBW/Hz	ACF dB	SPFD dBW/m^2Hz at test distance	EIRP dBW/Hz	SPFD at 1m dBW/m^2Hz
20	-162	15	-176	12	-173	-158	-169
100	-162	15	-176	12.5	-172	-157	-168
200	-165	15	-179	21	-167	-152	-163
300	-165	15	-179	17	-171	-156	-167
600	-165	15	-179	21.5	-166	-151	-162
1050	-165	17	-181	27	-162	-151	-162
1400	-165	17	-181	29.5	-160	-149	-160
1600	-165	17	-181	31	-159	-148	-159
2000	-165	34	-198	30.25	-177	-166	-177
4000	-165	34	-198	31.25	-176	-165	-176
6000	-170	0	-169	31.25	-147	-136	-147
8000	-170	0	-169	31.25	-147	-136	-147
10000	-170	0	-169	32.25	-146	-135	-146
13000	-170	0	-169	33.75	-144	-133	-146

Excerpt FROM ITU HANDBOOK ON RADIO ASTRONOMY -1995

FIGURE 2:

Harmful thresholds of interference for continuum observations with several types of radio telescope systems

(The ordinate is spectral power flux-density)



Threshold interference levels for VLBI observations

Centre Frequency (MHz)	Harmful Level dB(W/(m^2 Hz))
325.3	-215
611	-211
1 413.5	-209
2 695	-204
4 995	-198
8 400	-194
10 650	-192
15 375	-187
23 800	-182
43 000	-173
86 000	-166

As a guide to the vulnerability of VLBI systems to interference, it should be noted that Figure 4 indicates that the hurmful thresholds for VLBI are approximately 40 dB greater than for continuum total power systems at the same frequency. The area between the VLBI curve and the total power curve covers the range of thresholds for all types of radio telescopes. It must be emphasized that the use of interferometers and arrays is generally confined to studies of discrete high brightness sources with angular dimensions no more than a few minutes of arc for arrays like the VLA or a few tenths of a second of arc for VLBI. The total power results in Tables 4 and 5 thus remain valid for the general protection of radio astronomy.

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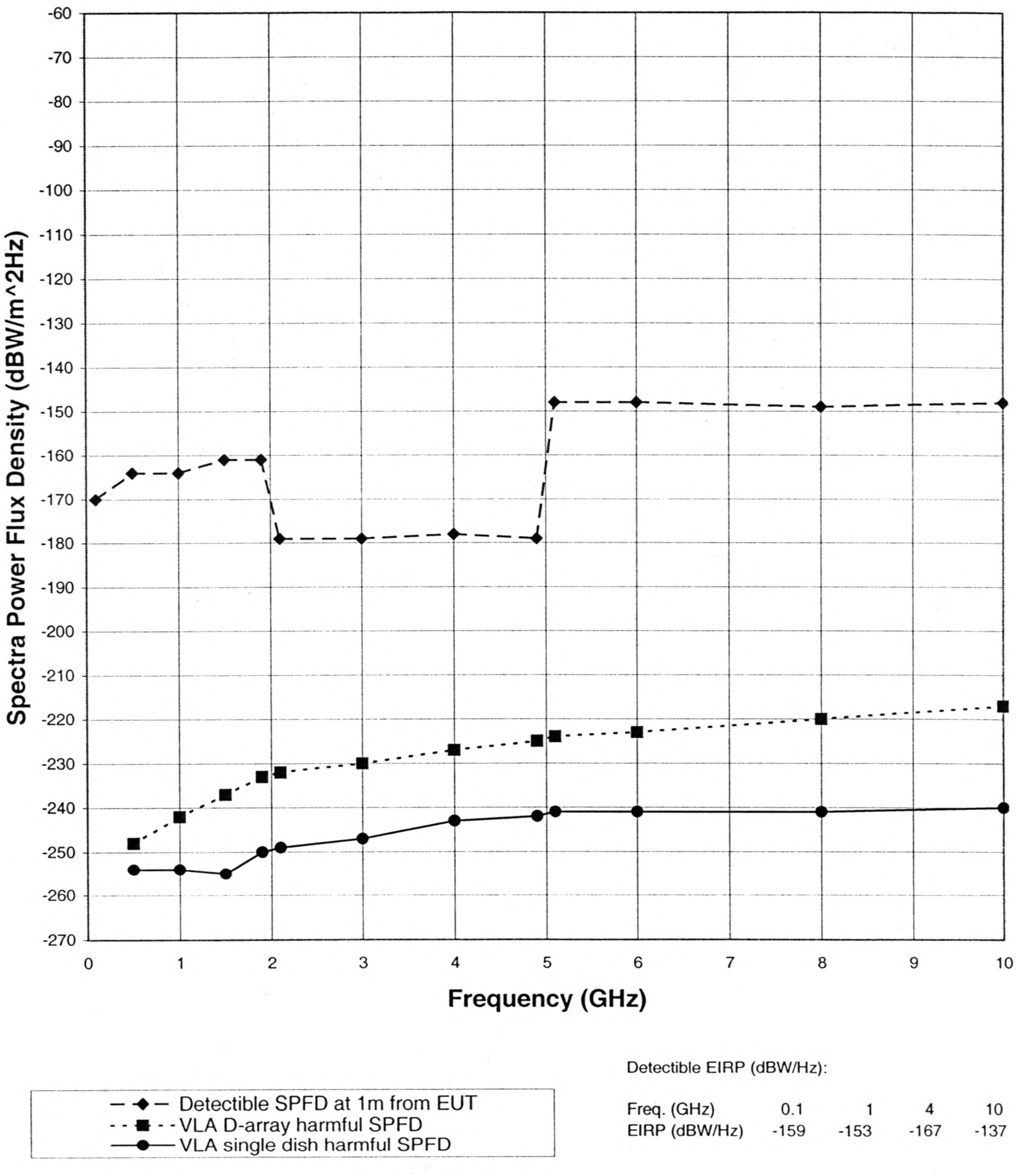
Figure 3: Detection Equipment Sensitivity Compared to VLA Harmful RFI Levels



Detectible EIRP (dBW/Hz):

Freq. (GHz)	0.1	1	4	10
EIRP (dBW/Hz)	-159	-153	-167	-137

IV) Results

Over 20 MHz-13 GHz the strongest narrow band emission is at 1.6 GHz from the digitizer. With the AMCO doors closed, an 800-1000 MHz, -120 dBW/Hz white noise analog signal tee'd into the samplers, and digitized data sent to the correlator on unshielded non-fiber flat cables, the maximum EIRP at 1.6 GHz is -91 dBW/Hz (with AMCO doors closed). Emissions at 3.2 GHz and 4.8 GHz, which are the 2nd and 3rd harmonics of the digitizer, were detected. The EUT emits several other CW's. The EUT emits white and broadband power over various frequency ranges including 200-450 MHz, 1350-1450 MHz, and 1550-1650 MHz. The AMCO enclosure was found to provide at least 30 dB of attenuation at 1.6 GHz. Attaching the VME cover plate attenuated broadband emissions at least 10 dB. The power in signals detected while using a 1 kHz RBW are given 30 dB down with reference to a 1 Hz bandwidth for white noise, and reported as detected for CW signals regardless of bandwidth.

IVa) Derivation of effective isotropic radiated power and spectral power flux density.

EIRP = effective isotropic radiated power
PFD = power flux density per given bandwidth
SPFD = spectral power flux density (per 1 Hz bandwidth)
SP.antenna = spectral power after receive antenna
SP.amplifier = spectral power after low noise amplifier
P.signal = power recorded by spectrum analyzer per given resolution bandwidth
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EUT = equipment under test (ALMA correlator)
LNA = low noise amplifier
G.is = gain over isotropic of receive antenna
ACF = antenna correction factor
Ae = antenna effective area

1) P.signal (dBW/RBW) – 10Log(RBW/1 Hz) = Sp.signal (dBW/Hz)
2) SP.signal + line loss – LNA gain = SP.antenna (dBW/Hz)
3) SP.antenna (W/Hz) = 10E {SP.antenna (dBW/Hz) / 10}
4) SPFD (W/m^{2}Hz) = SP.antenna (W/Hz) / Ae (m^2)
   where G.is = 10Log {(4 pi Ae / lambda^2)}

or

4a) SPFD (dBW/m^{2}Hz) = SP.antenna (dBW/Hz) + ACF (dB) – 8.76 dB
   where ACF = -G.is –10Log(lambda^2) + 19.75 dB
5) EIRP (dBW/Hz) = SPFD + |path loss|
   where path loss = 10Log {1 / (4 pi d^2)}, d = test distance of 1-1.5 m
6) SPFD (10m) = EIRP - |10Log {1 / (4 pi 10^2)}|
7) Enclosure with doors closed provides 30 dB shielding at 1.6 GHz

Derivation of EIRP and SPFD (at 10m) for CW and white noise

1600 MHz CW

P.signal = -48 dBm/kHz (AMCO doors open)
Assume most power contained in 1Hz bandwidth, therefore P.signal = SP.signal
SP.signal = -48 dBm/Hz
SP.signal = -78 dBW/Hz
SP.antenna = -78 dBW/Hz + 1dB (line loss) –17 dB (LNA gain) = -94 dBW/Hz
SPFD (1m) = -94 dBW/Hz + 31dB (ACF) – 8.76dB (conversion) = -72 dBW/m^2Hz
EIRP = -72 dBW/m^2Hz + 11dB/m^2 (1m path loss) = -61 dBW/Hz
SPFD (10m) = -61 dBW/Hz – 31 dB/m^2 (10m path loss) = -92 dBW/m^2Hz
SPFD (10m) with doors closed = -92 dBW/m^2Hz – 30 dB = -122 dBW/m^2Hz

1550-1650 MHz White Noise

P.signal = -105 dBm/kHz (AMCO doors open)
Assume emitted noise power is white over 1550-1650 MHz range, therefore:
SP.signal = -105 dBm/kHz – 10Log(1kHz/1Hz) = -135 dBm/Hz
SP.signal = -165 dBW/Hz
SP.antenna = -165 dBW/Hz + 1dB (line loss) –17 dB (LNA gain) = -181 dBW/Hz
SPFD (1m) = -181 dBW/Hz + 31dB (ACF) – 8.76dB (conversion) = -159 dBW/m^2Hz
EIRP = -159 dBW/m^2Hz + 11dB /m^2 (1m path loss) = -148 dBW/Hz
SPFD (10m) = -148 dBW/Hz – 31dB/m^2 (10m path loss) = -179 dBW/m^2Hz
SPFD (10m) with doors closed = -179 dBW/m^2Hz – 30dB = -209 dBW/m^2Hz

IVb) Emissions from ALMA Test Correlator and 1.6 GHz Digitizers

20 MHz- 200 MHz:

Frequency	BW	EIRP	SPFD at 10m	AMCO doors	Plots
a) 20-200 MHz	BB	------	------------	closed	none
b) 100 MHz	CW	-80 dBW/Hz	-111 dBW/m^{2}Hz	closed	5, 6
c) 200 MHz	CW	-67 dBW/Hz	-98 dBW/m^{2}Hz	closed	1, 2

Note: No CW emissions were detected over the VLA 4-band of 73-75 MHz.

200-1000 MHz:

Frequency	BW	EIRP	SPFD at 10m	AMCO doors	Plots
a) 200-450 MHz	BB	--------	----------	closed	7, 8
b) 200 MHz	CW	-67 dBW/Hz	-98 dBW/m^{2}Hz	closed	1, 2
c) ~300 MHz	NB	--------	----------	closed	7, 8
d) 305-355 MHz	white	-155 dBW/Hz	-186 dBW/m^{2}Hz	closed	9, 10
e) ~320 MHz	CW	--------	----------	closed	9, 10
f) 332-334 MHz	4 CW	--------	----------	closed	11, 12
g) 333.5 MHz	CW	-96 dBW/Hz	-127 dBW/m^{2}Hz	closed	11, 12
h) 400 MHz	CW	---------	----------	closed	7, 8
i) 700 MHz	CW	---------	----------	closed	7, 8

Note: The EUT radiates 4 CW signals over 332-334 MHz, and 1 at 320 MHz (VLA standard P-band is 325-335 MHz). No emissions detected at 610 MHz (VLA 50 cm band).

1050 MHz- 1850 MHz

Frequency	BW	EIRP	SPFD at 10m	AMCO doors	Plots
a) 1350-1450 MHz	white	-149 dBW/Hz	-180 dBW/m^{2}Hz	open	28,30,31
		-179 dBW/Hz	-210 dBW/m^{2}Hz	closed	assumed
b) ~1358,1375,1392 MHz	NB	--------	----------	closed	28,30,31
c) 1400 MHz	CW	-80 dBW/Hz	-111 dBW/m^{2}Hz	open	32, 33
		-110 dBW/Hz	-141 dBW/m^{2}Hz	closed	assumed
sidebands > 60 kHz					33
d) 1550-1650 MHz	white	-148 dBW/Hz	-179 dBW/m^{2}Hz	open	39,41,42
		-178 dBW/Hz	-209 dBW/m^{2}Hz	closed	assumed
e) ~1575,1583,1592 MHz	BB	--------	----------	closed	41, 42
f) 1600 MHz	CW	-61 dBW/Hz	-92 dBW/m^{2}Hz	open	39, 42
		-91 dBW/Hz	-122 dBW/m^{2}Hz	closed	39, 41
sidebands > 600 kHz		-138 dBW/Hz	-169 dBW/m^{2}Hz	open	44
		-168 dBW/Hz	-199 dBW/m^{2}Hz	closed	43, assumed
g) ~1625, 1633 MHz	BB	--------	----------	closed	41, 42
h) ~1640, 1642 MHz	BB	--------	----------	closed	41, 42
i) 1700	CW	--------	----------	closed	45, 46
j) 1800 MHz	CW	-106 dBW/Hz	-137 dBW/m^{2}Hz	closed	47, 48

Note: EUT radiates broad band noise over the 1350-1450 MHz (VLA standard L-band is 1360-1489 MHz).

1.850-13.000 GHz

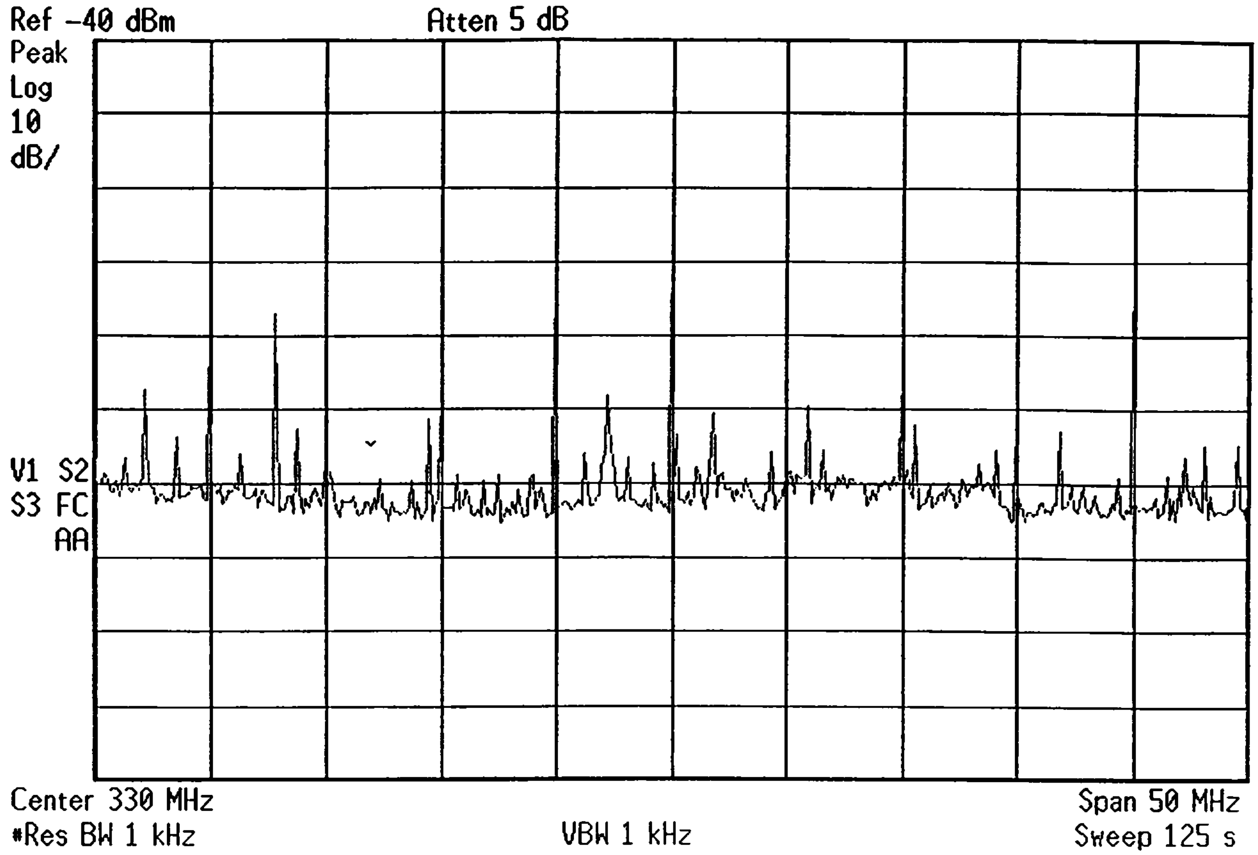
Frequency	BW	EIRP	SPFD at 10m	AMCO doors	Plots
a) 2.2, 2.3, 2.4 GHz	CW	-----	---------	closed	54,55,58-61
b) 2.5, 2.7 GHz	CW	-----	---------	closed	54, 55
c) 3.2 GHz	CW	-93 dBW/Hz	-124 dBW/m^{2}Hz	closed	62,63,65
		-63 dBW/Hz	-94 dBW/m^{2}Hz	open	assumed
sidebands > 1.2 MHz				closed	64, 65
d) 4.8 GHz	CW	-113 dBW/Hz	-144 dBW/m^{2}Hz	closed	68,69,70
		-83 dBW/Hz	-114 dBW/m^{2}Hz	open	assumed
sidebands > 2.4 MHz					assumed

Note: No emissions detected over 4.81-4.91 GHz (VLA C-band) or 8.41-8.51 GHz (VLA X-band).

IVc) Plots of Strongest Emissions

hp 02:34:05 Aug 31, 2000

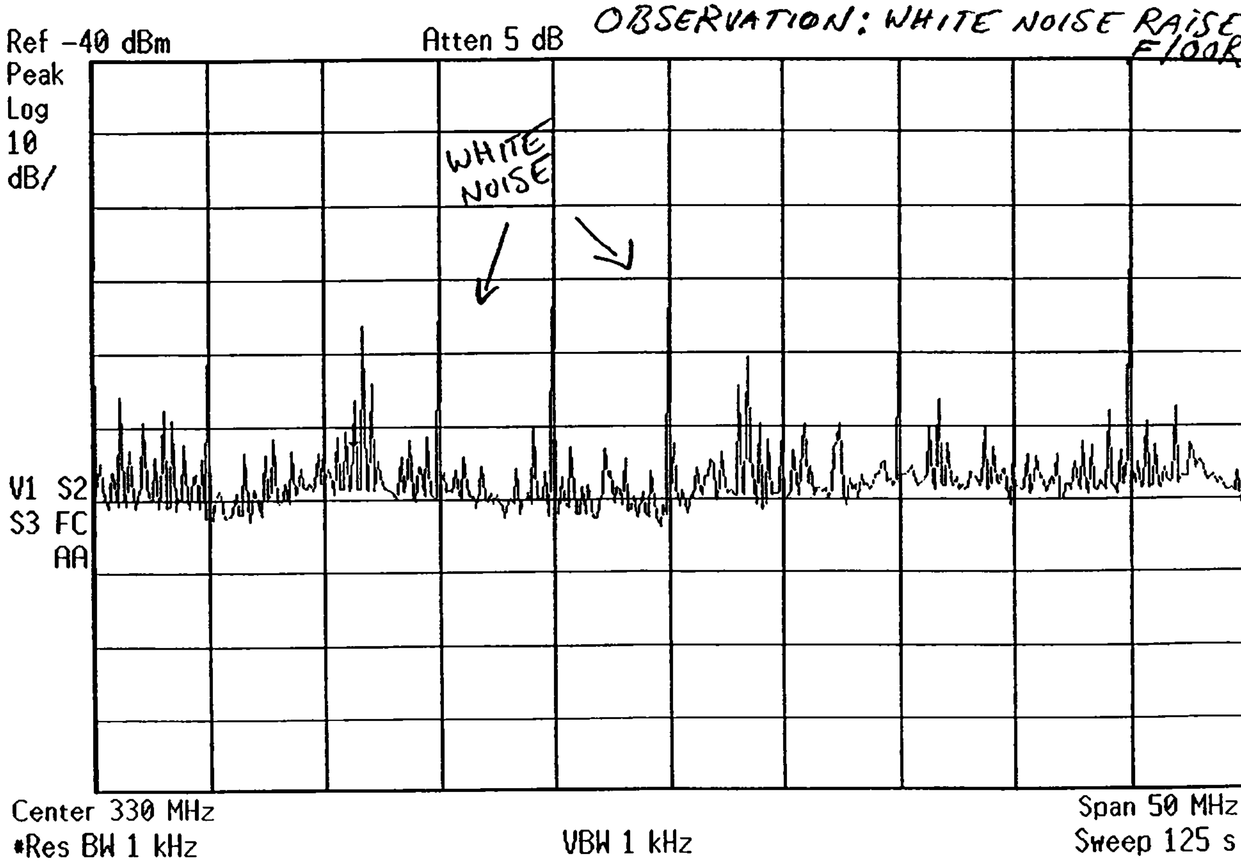
Plot 1-9 : EUT OFF



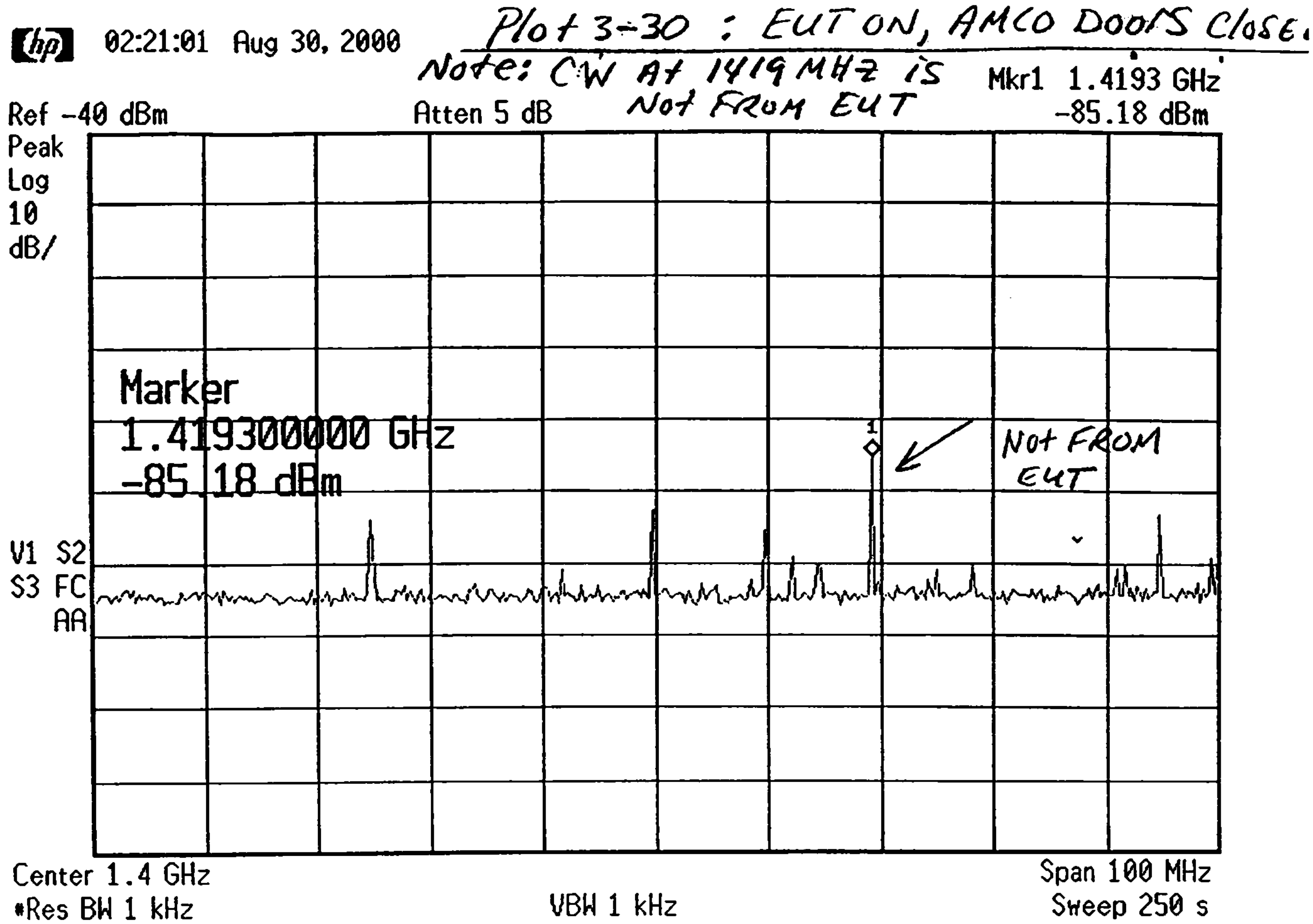
hp 01:52:53 Aug 31, 2000

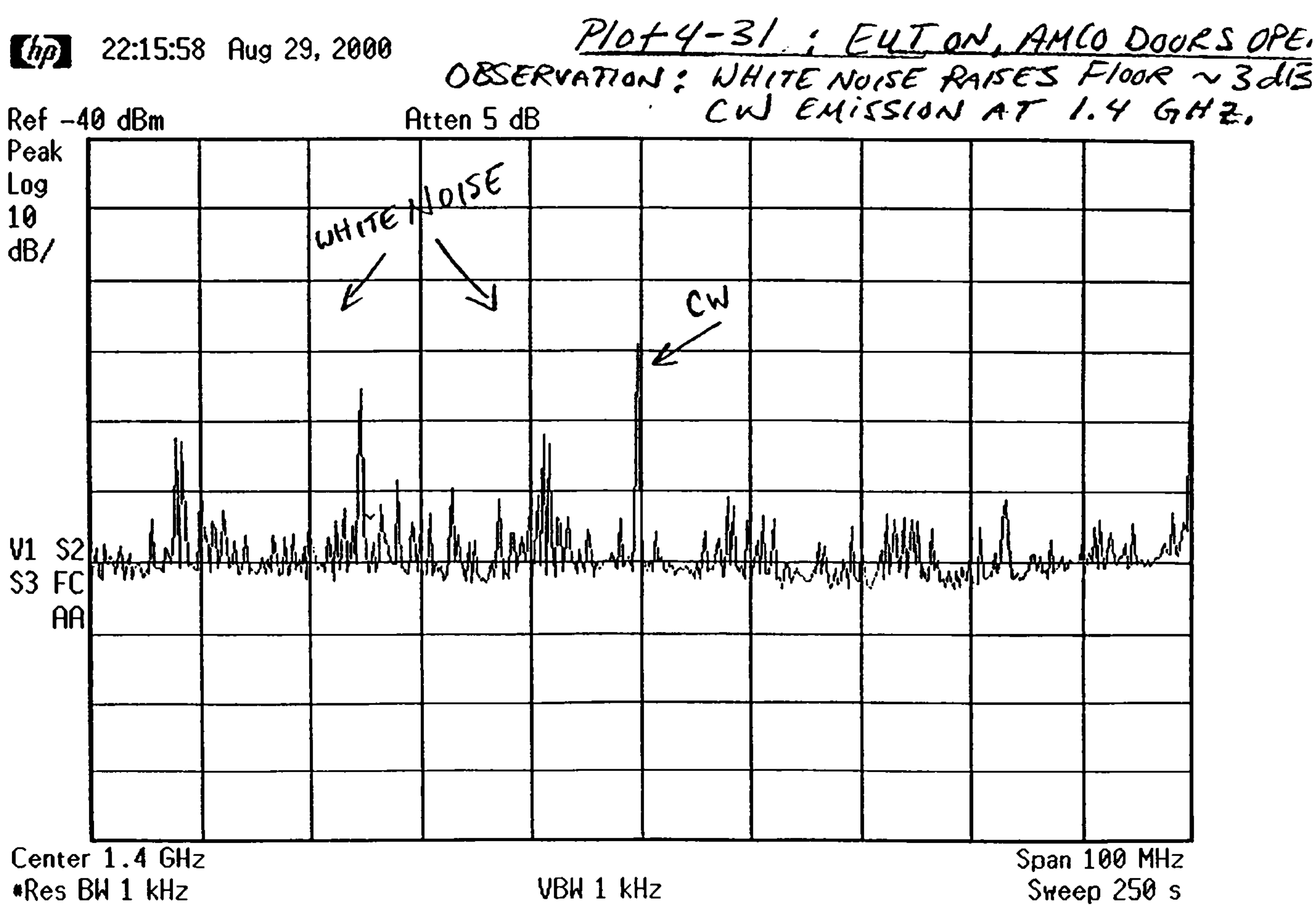
PlOT 2-10 : EUT ON

OBSERVATION: WHITE NOISE RAISES FLOOR 3d

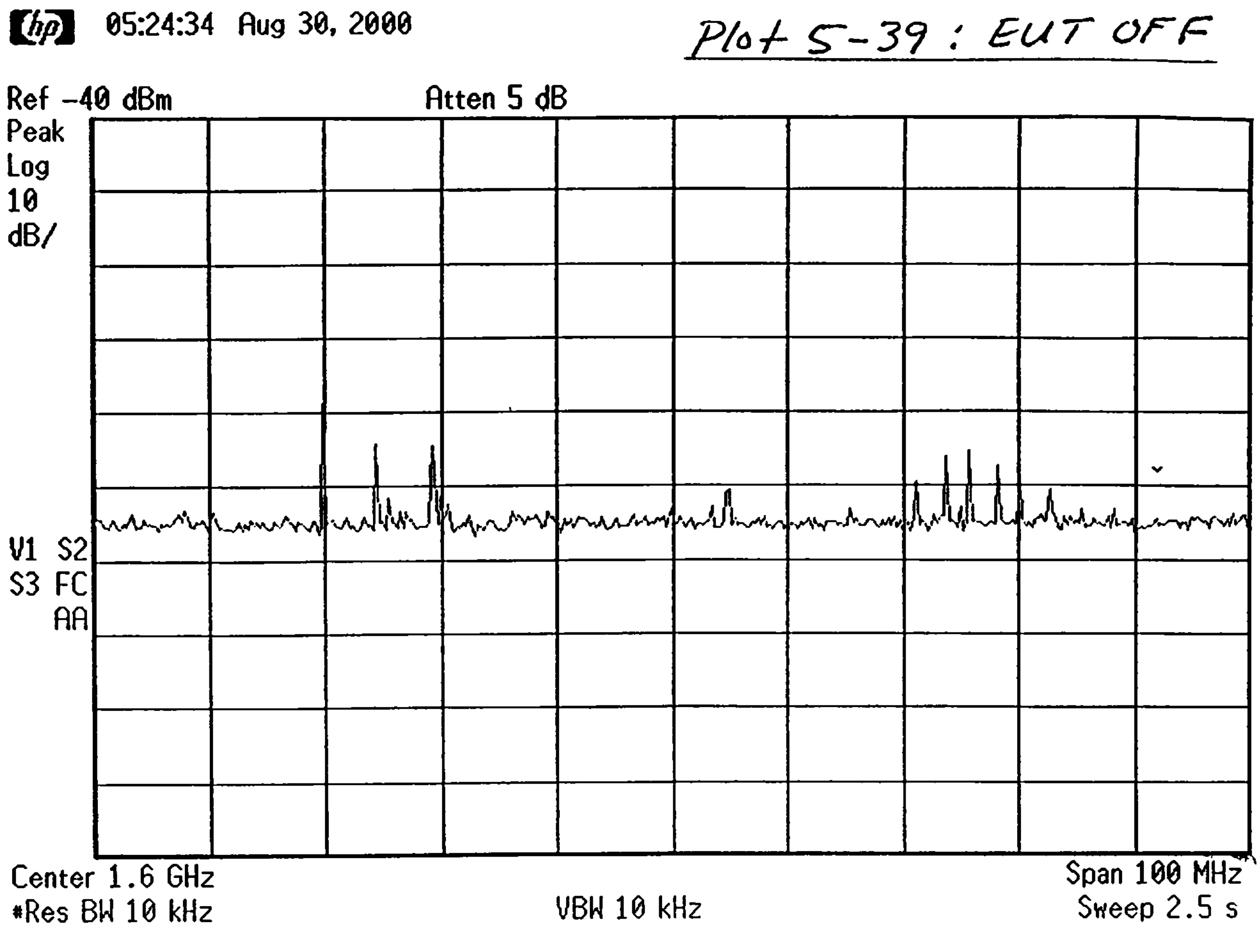


— AMCO DOORS CLOSED

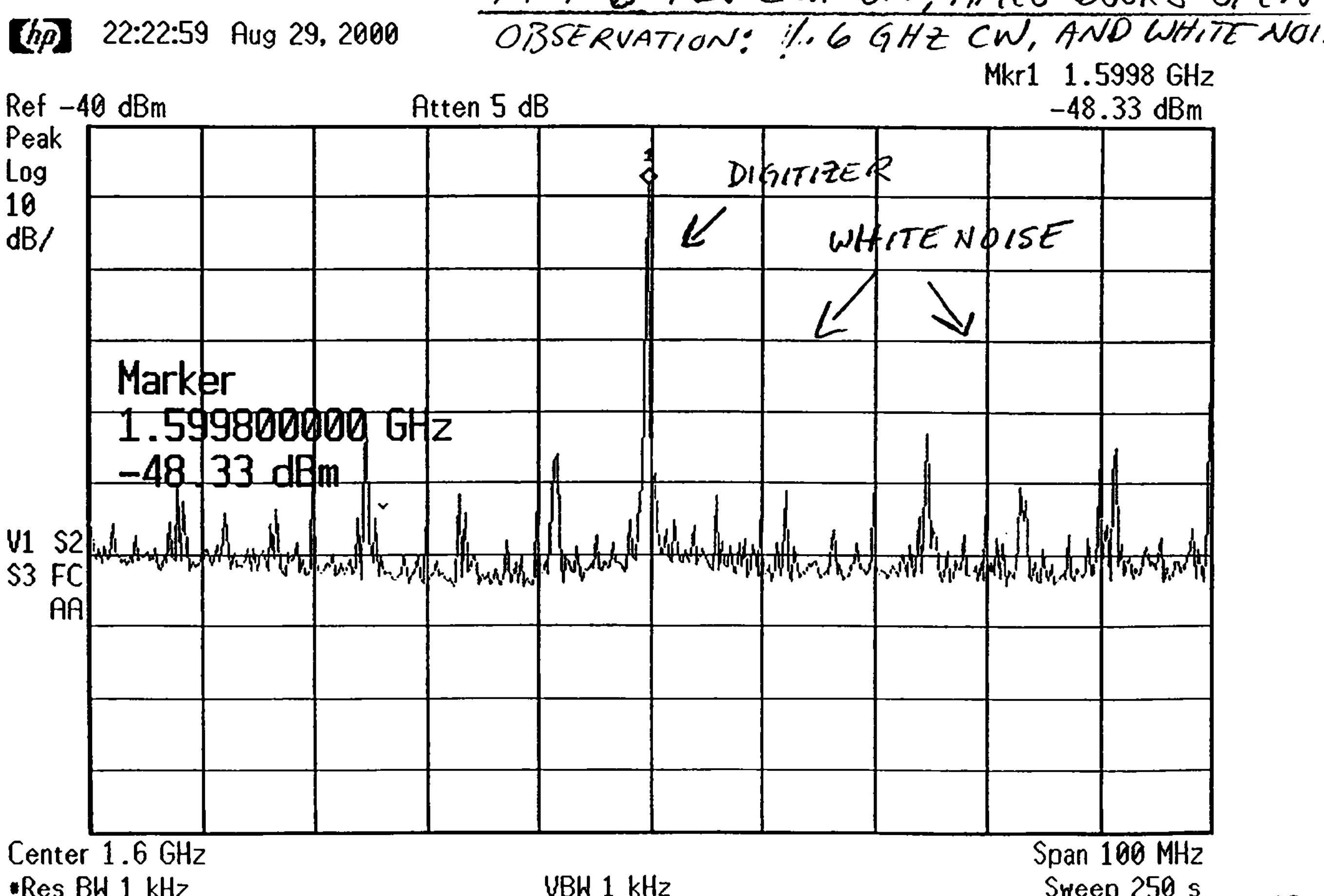

02:21:01 Aug 30, 2000
Plot 3-30 : EUT ON, AMCO DOORS CLOSE.
Note: CW At 1419 MHz is Not FROM EUT
Mkr1 1.4193 GHz
-85.18 dBm
Ref -40 dBm
Atten 5 dB
Peak
Log
10
dB/
Marker
1.419300000 GHz
-85.18 dBm
Not FROM EUT
V1 S2
S3 FC
AA
Center 1.4 GHz
#Res BW 1 kHz
VBW 1 kHz
Span 100 MHz
Sweep 250 s


22:15:58 Aug 29, 2000
Plot 4-31 : EUT ON, AMCO DOORS OPE.
OBSERVATION: WHITE NOISE RAISES FLOOR ~3dB
CW EMISSION AT 1.4 GHz.
Ref -40 dBm
Atten 5 dB
Peak
Log
10
dB/
WHITE NOISE
CW
V1 S2
S3 FC
AA
Center 1.4 GHz
#Res BW 1 kHz
VBW 1 kHz
Span 100 MHz
Sweep 250 s

Plot 5-39 : EUT OFF

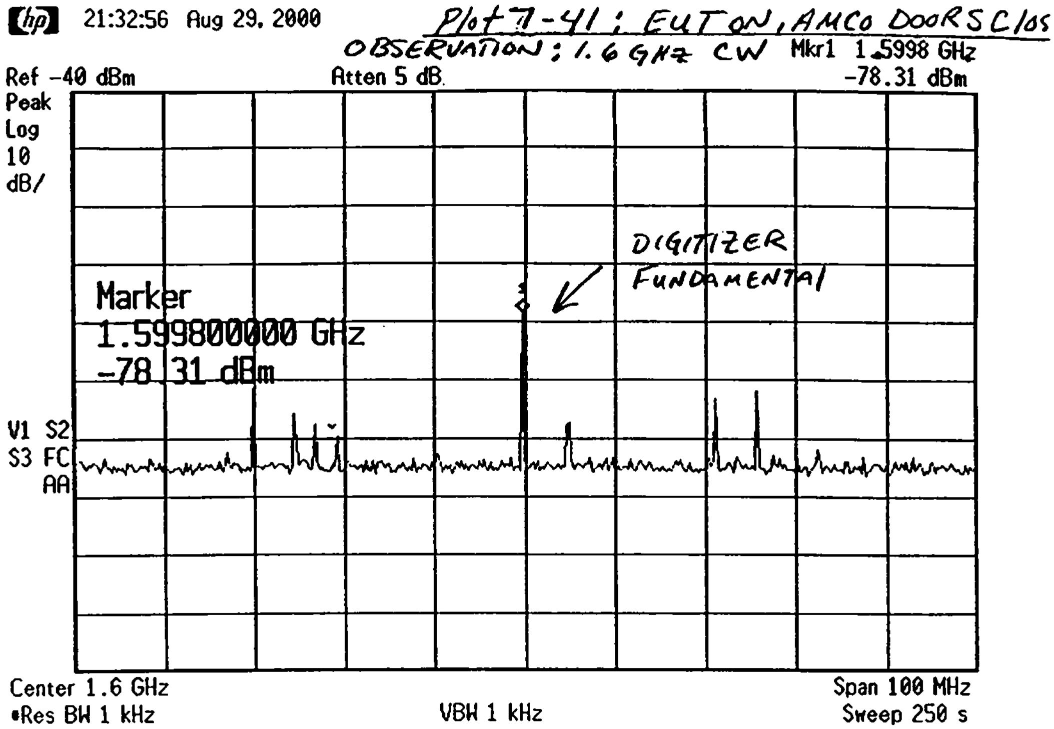


Plot 6-42: EUT ON, AMCO DOORS OPEN
OBSERVATION: 1.6 GHz CW, AND WHITE NOIS



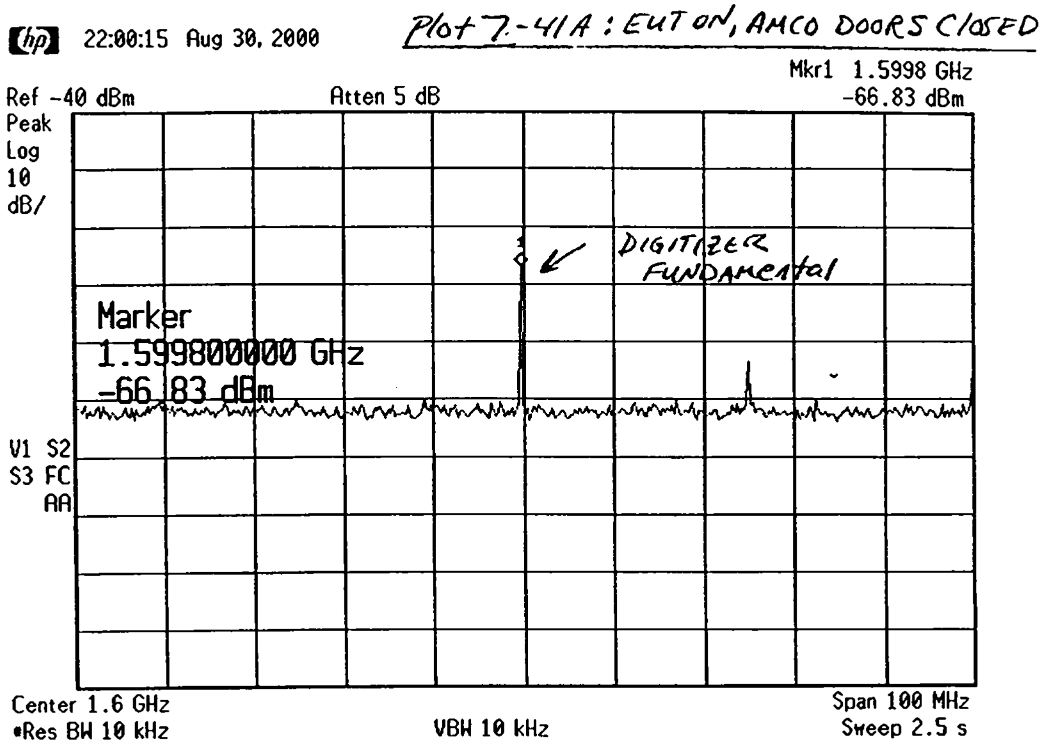
Plot 7-41: EUT ON, AMCO DOORS Clos

OBSERVATION: 1.6 GHz CW



SETUP: USED 3 dB GAIN LS LOG SPIRAL WITH 17 dB GAIN LI

Plot 7-41A: EUT ON, AMCO DOORS CLOSED

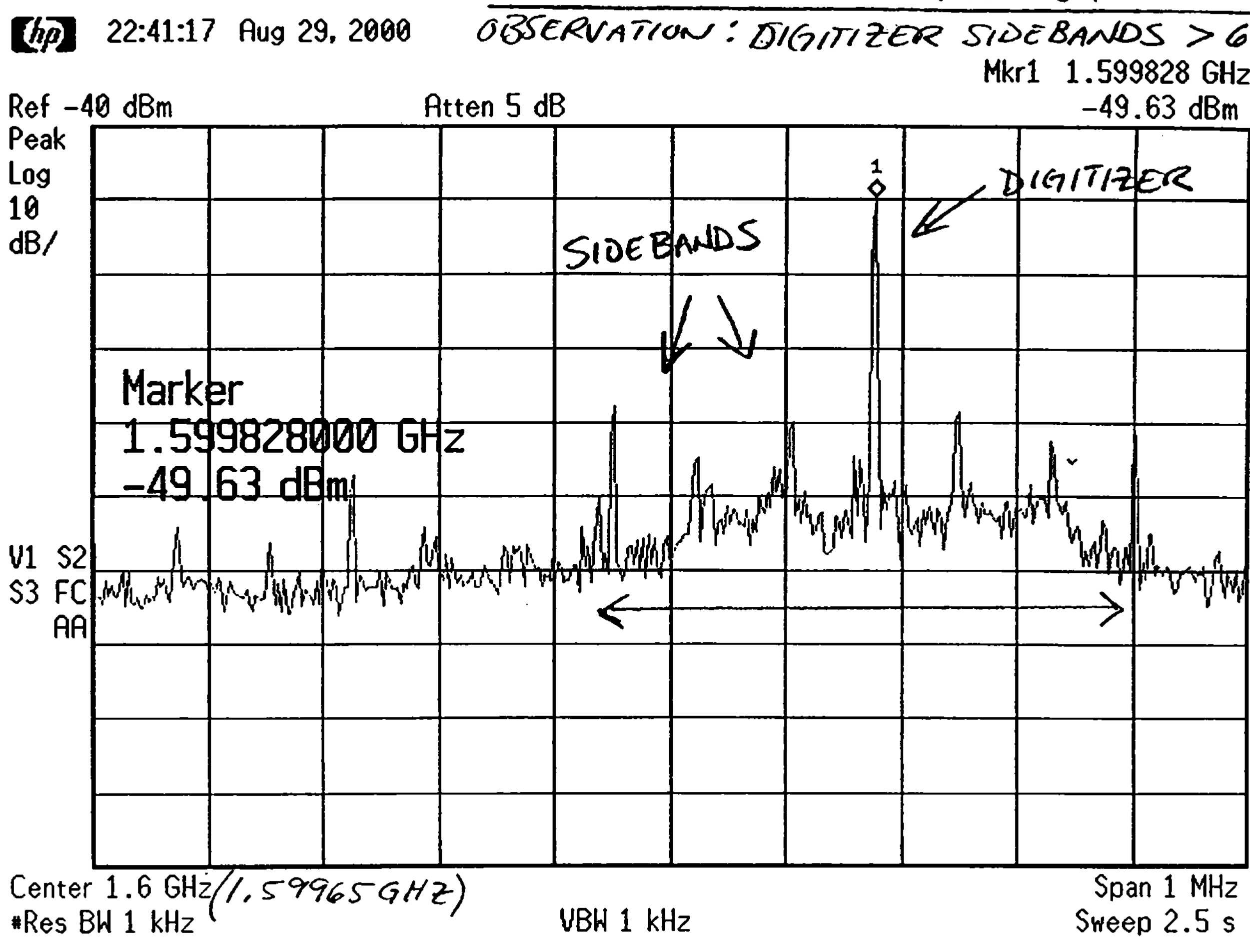


SETUP: USED 3 dB GAIN LS HORN WITH 34 dB GAIN LA

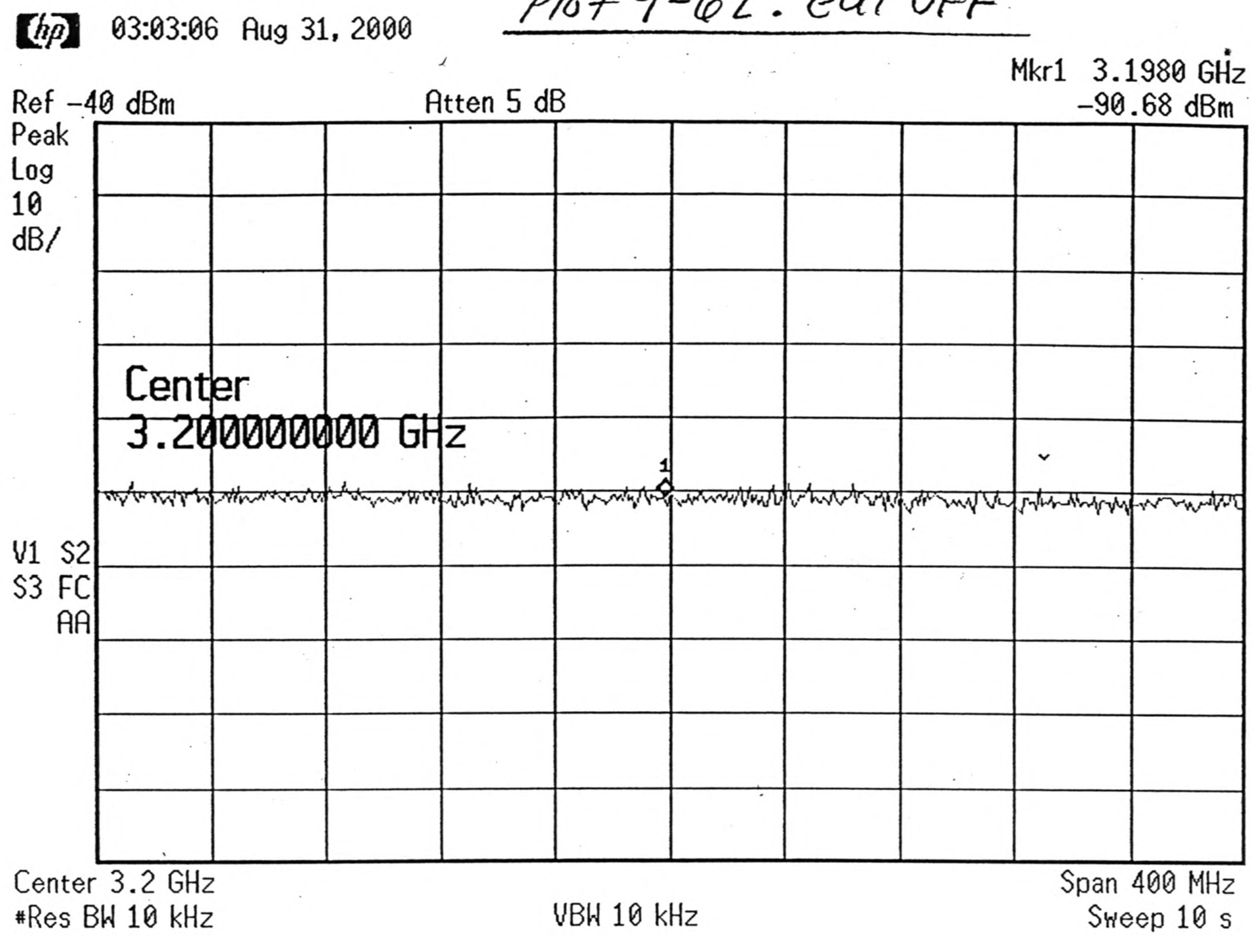
OBSERVATION: THIS PLOT IS USED IN COMPARISON TO PLOT 7-41 AS A METHOD TO CHARACTER DETECTION EQUIPMENT PERFORMANCE. RESULTS SUGGEST +/- 5 dB ACCURACY IN DETECTION OF DIGITIZER EMISSION.

Plot 8-44: EUT ON, AMCO DOORS OPEN,

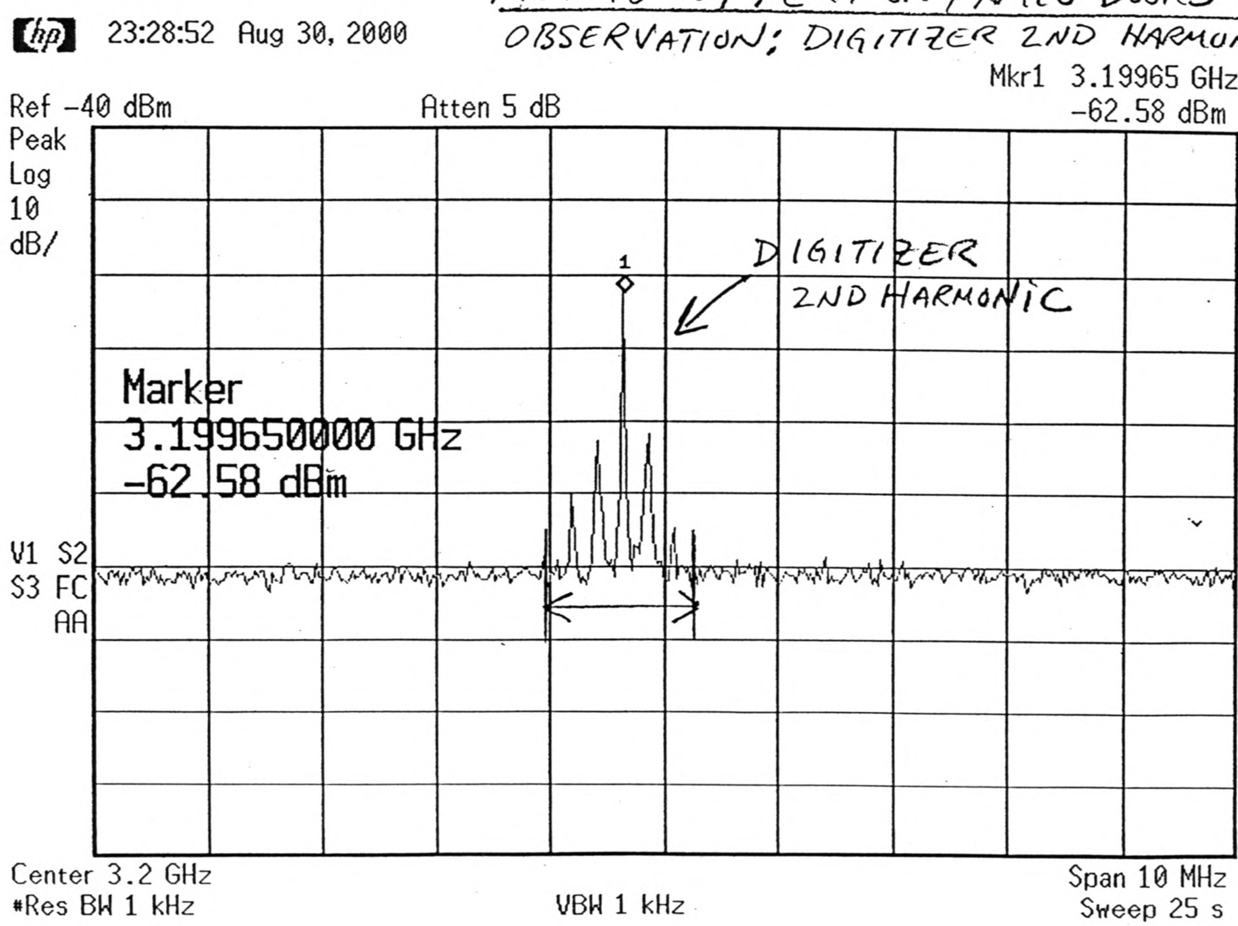
OBSERVATION: DIGITIZER SIDEBANDS > 600 KHz



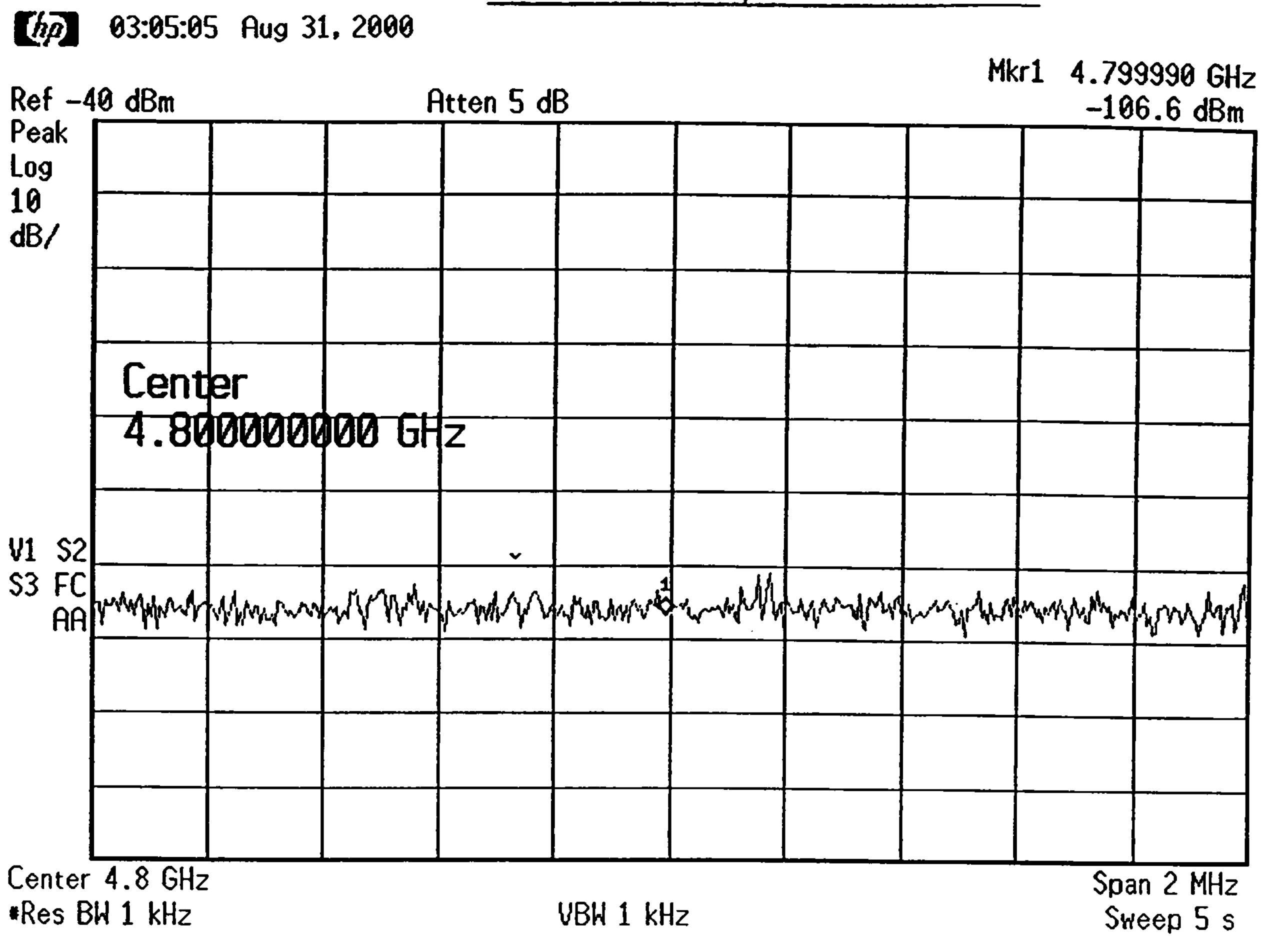
Plot 9-62: EUT OFF



Plot 10-64: EUT ON, AMCO DOORS CLOSED
OBSERVATION: DIGITIZER 2ND HARMONIC

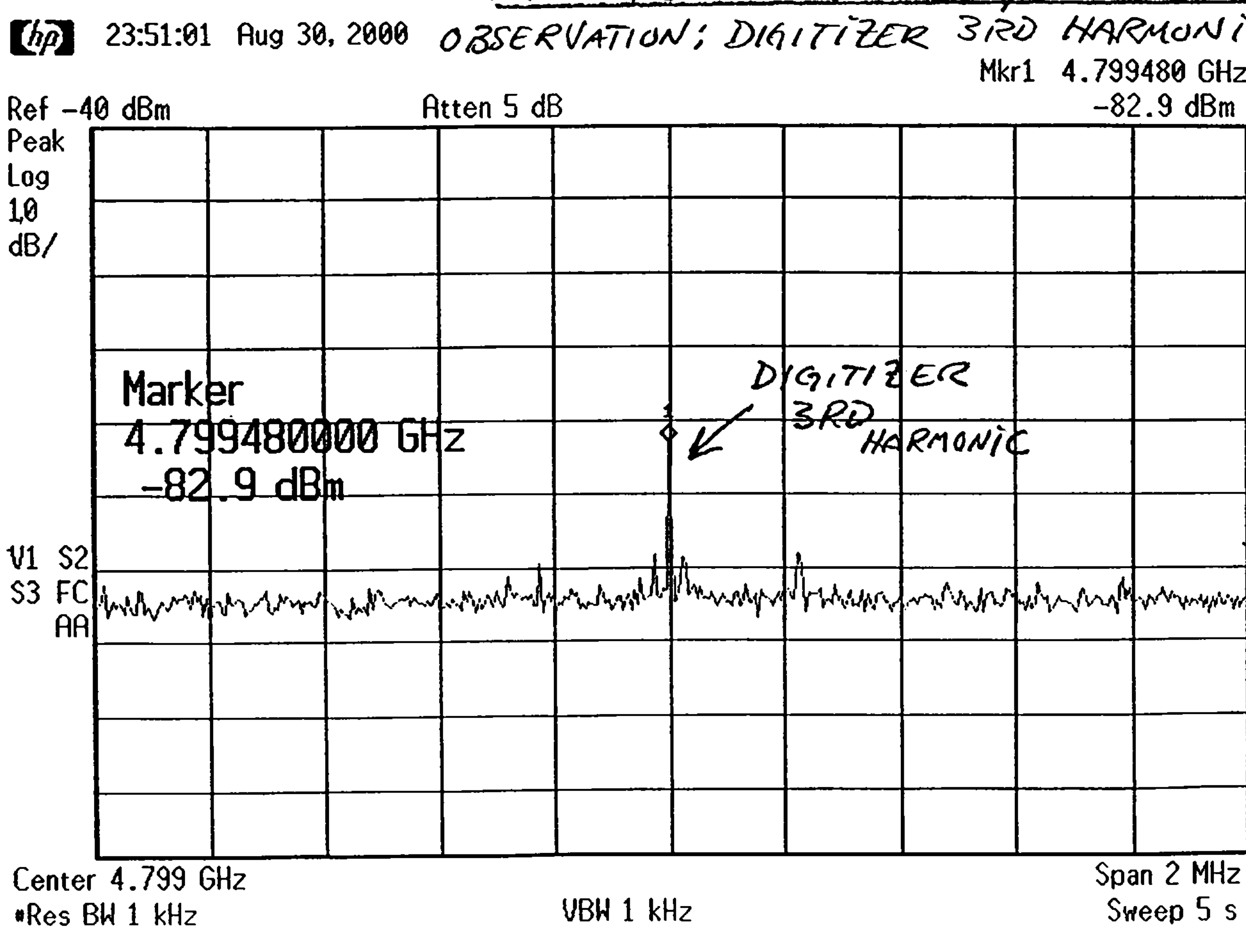


Plot 11-69: EUT OFF



Plot 12-70: EUT ON, AMCO DOORS CLOSE.

OBSERVATION: DIGITIZER 3RD HARMONIC



IVd) Comparison of Emissions to VLA Harmful Levels

Figures 4 through 7 compare the EUT radiated emissions to VLA harmful RFI levels

Figure 4: EUT Radiated Emissions 20 MHz-1 GHz
(4 strongest emissions of 13 shown; AMCO doors closed)

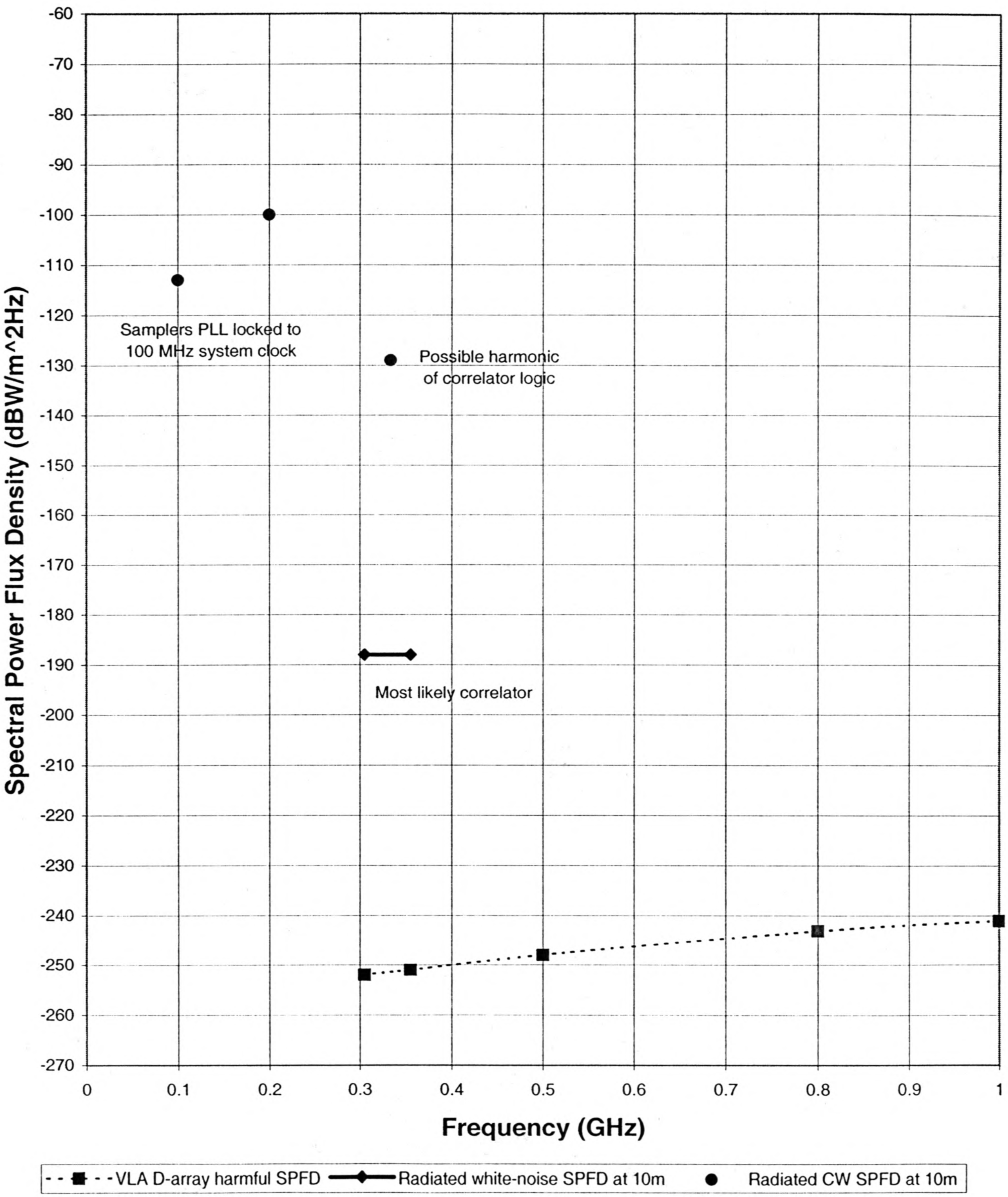
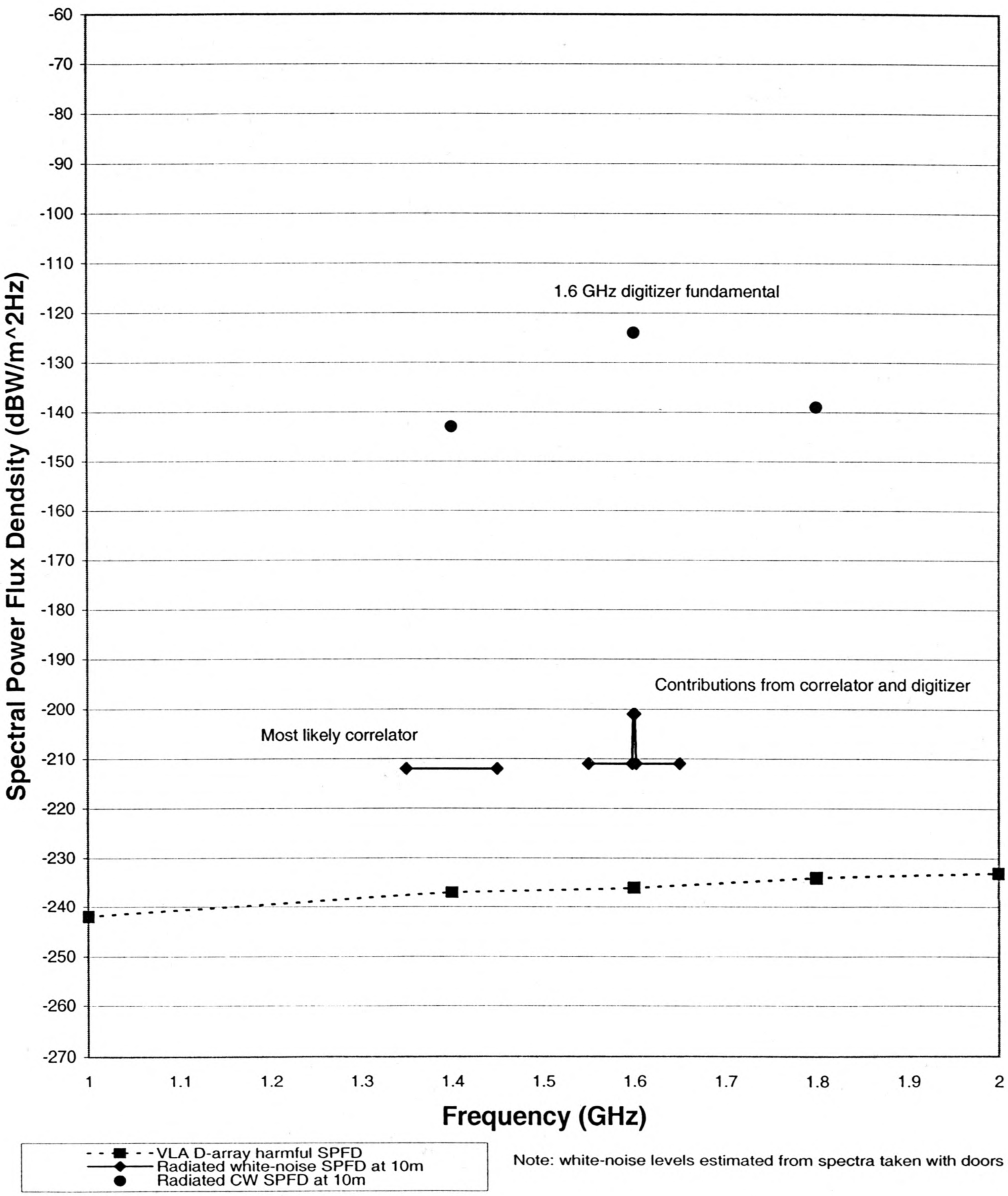


Figure 5: EUT Radiated Emissions 1-2 GHz
(5 of 16 emissions shown, including strongest; AMCO doors closed)



Note: white-noise levels estimated from spectra taken with doors oper

Figure 6: EUT Radiated Emissions 2-13 GHz
(2 strongest emissions of 7 shown; AMCO doors closed)

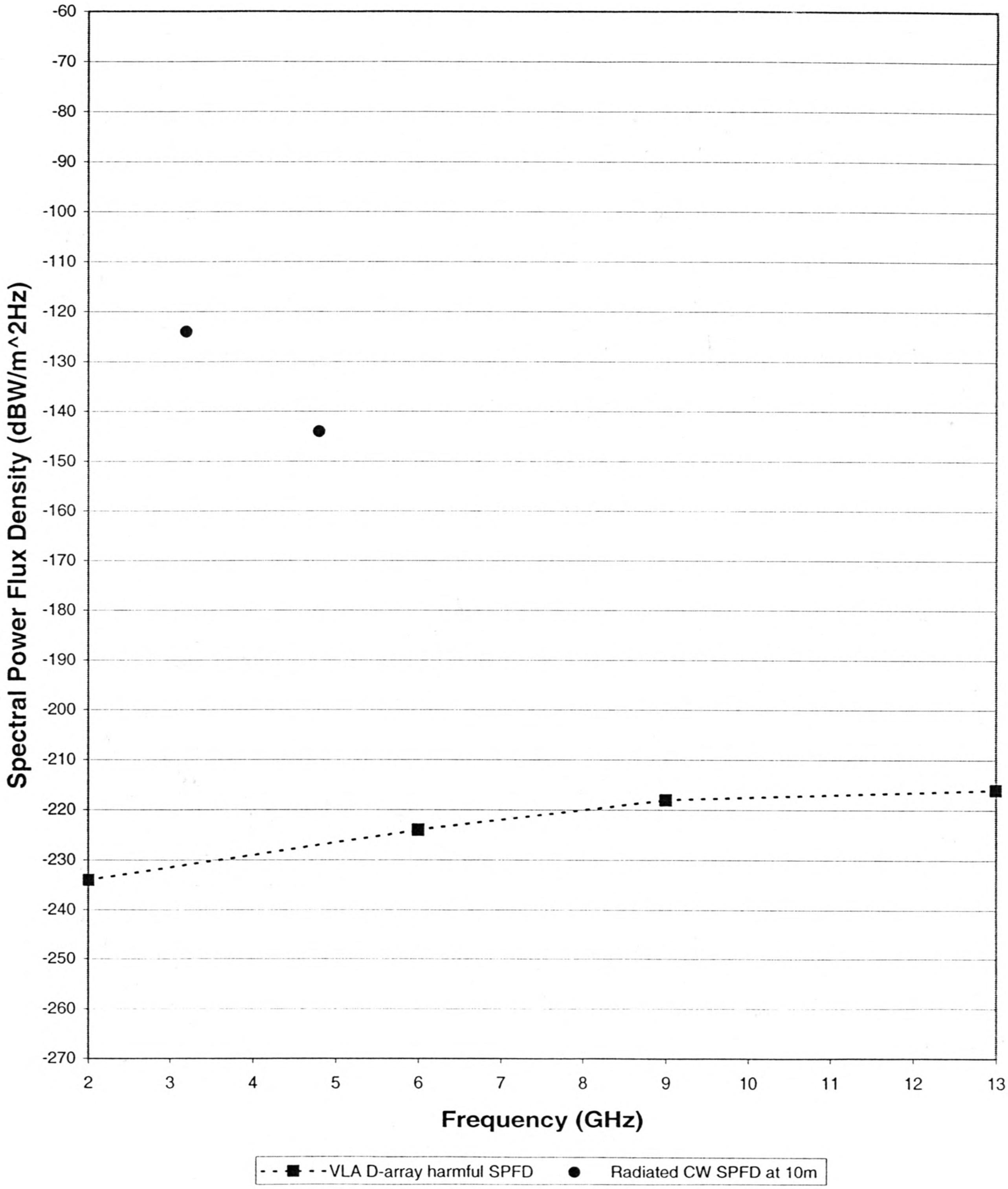
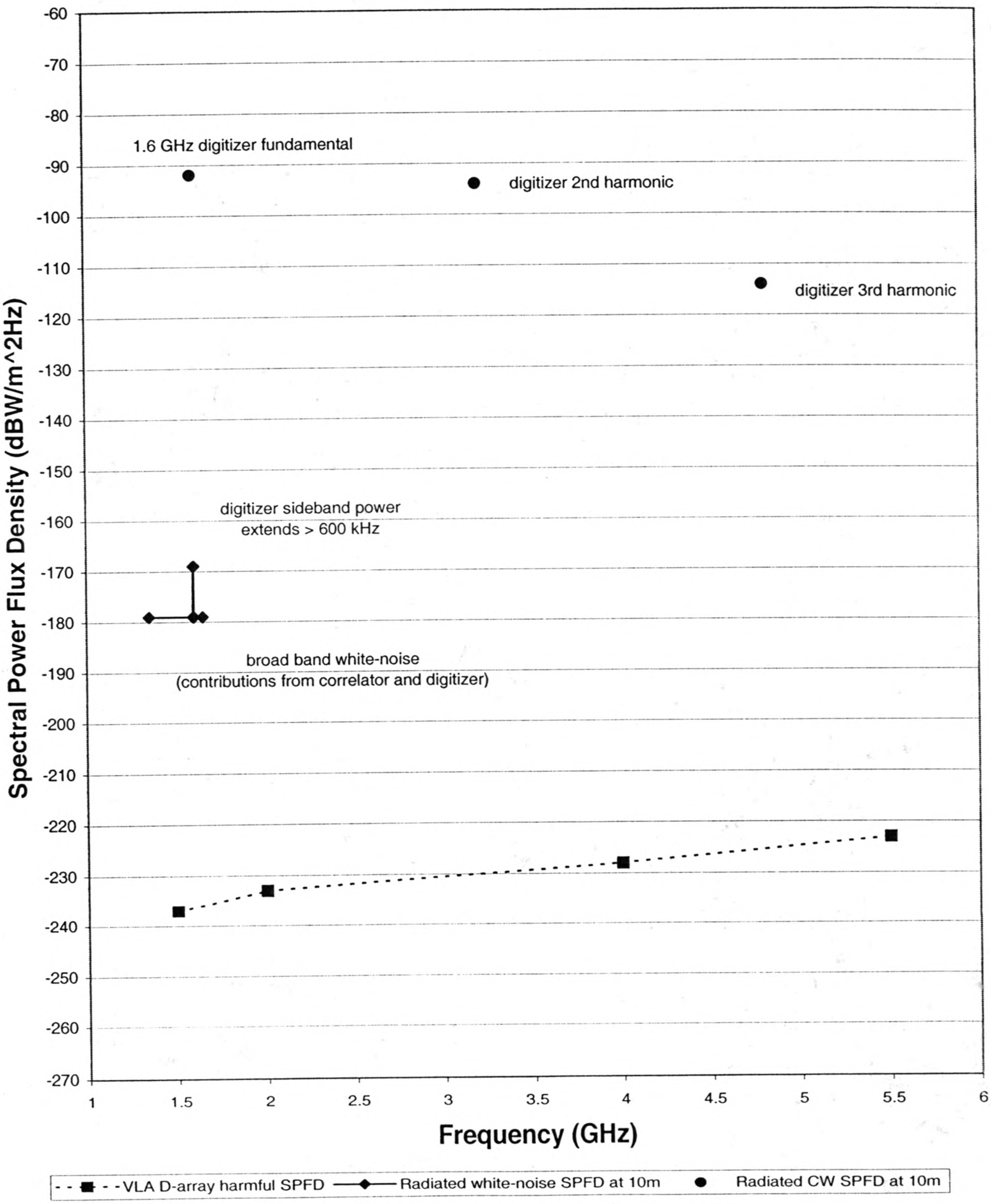


Figure 7: Digitizer Emissions over 1-6 GHz with AMCO Doors Open



IVe) Shielding requirements and available levels, commercial and TEMPEST enclosures

The calculations below are an attempt to quantify how harmful RFI from the ALMA test correlator and test digitizers may be to the VLA; several assumptions are made such as equipment location, distances, and shielding levels, and in some cases the actual source of the RFI considered. Figure 8 is the AMCO E^3 RFI enclosure, which the manufacturer claims, provides several dB more shielding than standard enclosures. Figure 9 is a shielding performance plot provided by AMCO comparing effectiveness for their commercial (FRF) and TEMPEST type (E^3) enclosures. Figure 10 is a 21-slot VME TEMPEST chassis manufactured by Tracewell Systems.

i) ALMA prototyping concerns

1) Digitizer

Equipment	ALMA test Digitizer
Location	ALMA antenna Vertex room
Frequency	1.6 GHz
Radiated EIRP (AMCO FRF doors open)	-61 dBW/Hz
Assumed Vertex room shielding	-20 dB
Assume ALMA antenna proximity to nearest VLA antenna is 100m:	
Estimated Space Loss at 100m	-51 dB
SPFD at 100m	-132 dBW/m^{2}Hz
ITU VLA D-array harmful level	-237 dBW/m^{2}Hz
Additional Shielding Required	**105 dB**
TEMPEST shielding available (AMCO E^3)	80 dB

2) Correlator - Emission at 333.5 MHz assumed to come from Correlator

Equipment	ALMA test correlator
Location	VLA Control Building
Frequency	333.5 MHz
Radiated EIRP (AMCO FRF doors closed)	-96 dBW/Hz
Nearest VLA antenna to Control Building is DW8 at 166m:	
Estimated space loss at 166m	-55 dB
SPFD at 166m	-151 dBW/m^{2}Hz
ITU VLA D-array harmful level	-253 dBW/m^{2}Hz
Additional Shielding Required	**105 dB**
Assumed VLA correlator room shielding	80 dB

3) Correlator - White noise emitted over 1350-1450 MHz assumed from Correlator

Equipment	ALMA test Correlator
Location	VLA Control Building
Frequency	1350-1450 MHz
Radiated EIRP (AMCO FRF doors closed)	-179 dBW/m^{2}Hz
Nearest VLA antenna to Control Building is DW8 at 166m:	
Estimated space loss at 166m	-55 dB
SPFD at 166m	-234 dBW/m^{2}Hz
ITU VLA D-array harmful level	-237 dBW/m^{2}Hz
Additional Shielding Required	**3 dB**
Assumed VLA correlator room shielding	80 dB

ii) EVLA concerns – Hypothetical example only

1) Digitizer - This assumes the EVLA digitizer will be as noisy as ALMA test digitizer:

Equipment	ALMA test Digitizer
Location	EVLA antenna Vertex room
Frequency of emission	-----
Radiated EIRP (AMCO FRF doors open)	-61 dBW/Hz (at 1.6 GHz)
Assumed Vertex room shielding	-20 dB

Assume distance from digitizer to feed via reflection off subreflector is on the order of 10m:

Estimated Space Loss at 10m	-31 dB
SPFD at 10m	-112 dBW/m^{2}Hz
ITU VLA D-array harmful level	-237 dBW/m^{2}Hz
Additional Shielding Required	**125 dB**
TEMPEST shielding available (AMCO E^3)	80 dB

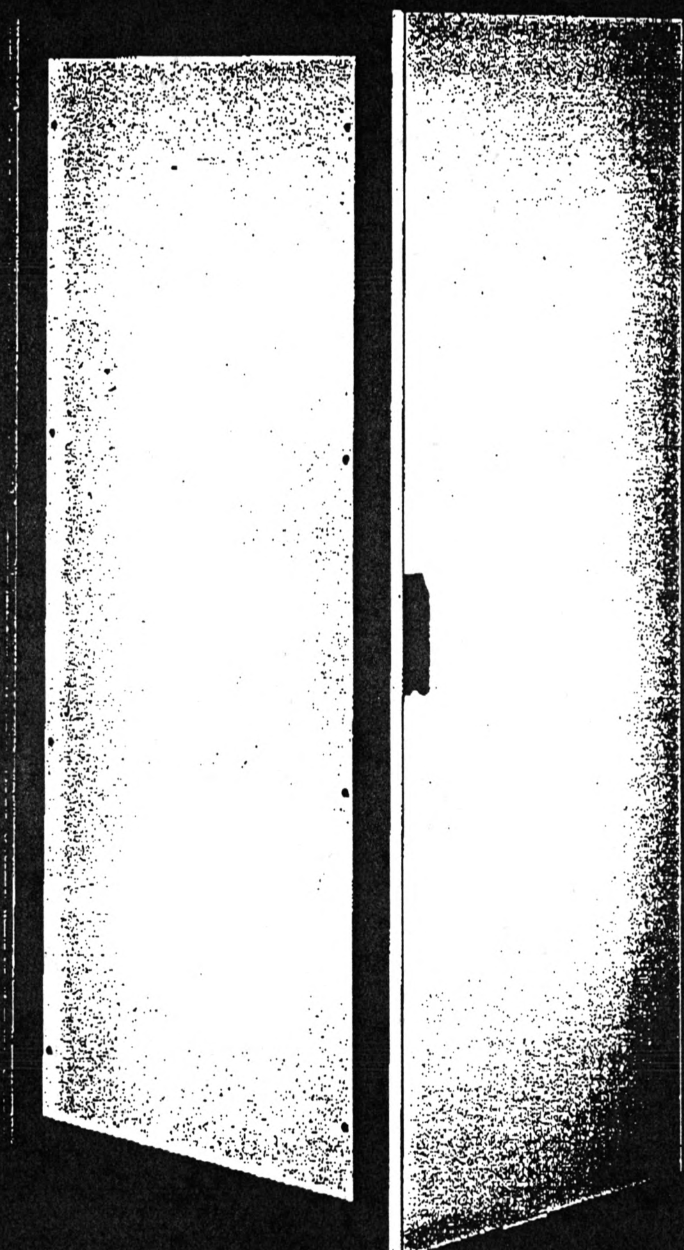
2) Digitizer - This assumes the EVLA digitizer will be as noisy as ALMA test digitizer, and that the 1550-1650 MHz white noise emission from the EUT is from the digitizer.

Equipment	ALMA test Digitizer
Location	EVLA antenna Vertex room
Frequency of emission	----------
Radiated EIRP (AMCO FRF doors open)	-148 dBW/Hz (at 1550-1650 MHz)
Assumed Vertex room shielding	-20 dB

Assume distance from digitizer to feed via reflection off subreflector is on the order of 10m:

Estimated Space Loss at 10m	-31 dB
SPFD at 10m	-199 dBW/m^{2}Hz
ITU VLA D-array harmful level	-237 dBW/m^{2}Hz
Additional Shielding Required	**38 dB**
TEMPEST shielding available (AMCO E^3)	80 dB
Commercial shielding available	30-50 dB

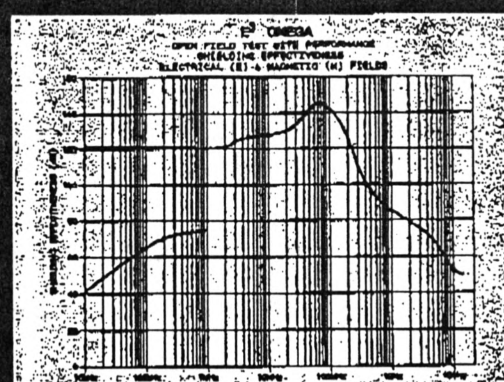
AMCO E^3 OMEGA



Ever since Amco created the first modular shielded cabinetry for the NASA Saturn program, we've been building a reputation for providing increasingly high levels of shielding.

The new Amco E^3 OMEGA line represents a breakthrough in enclosure design for protection against electromagnetic environmental effects. Amco presents a broad array of E^3 OMEGA shielded cabinetry configurations exceeding MIL-STD requirements for isolation from shock, vibration, nuclear and tempest type applications.

When it comes to shielded enclosures, Amco is constantly redefining state-of-the-art.



E^3 OMEGA provides a higher degree of shielding effectiveness compared to competitive enclosure manufacturers.

AMCO

Post-it® Fax Note 7671

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Co./Dept. Raul		From Dennis	
Phone #		Co. Amco	
Fax # 505-835-7027		Phone #	
		Fax #	

New Standard
Ultra-High Level Shielding

FIGURE 8: AMCO E^3 RFI ENCLOSURE

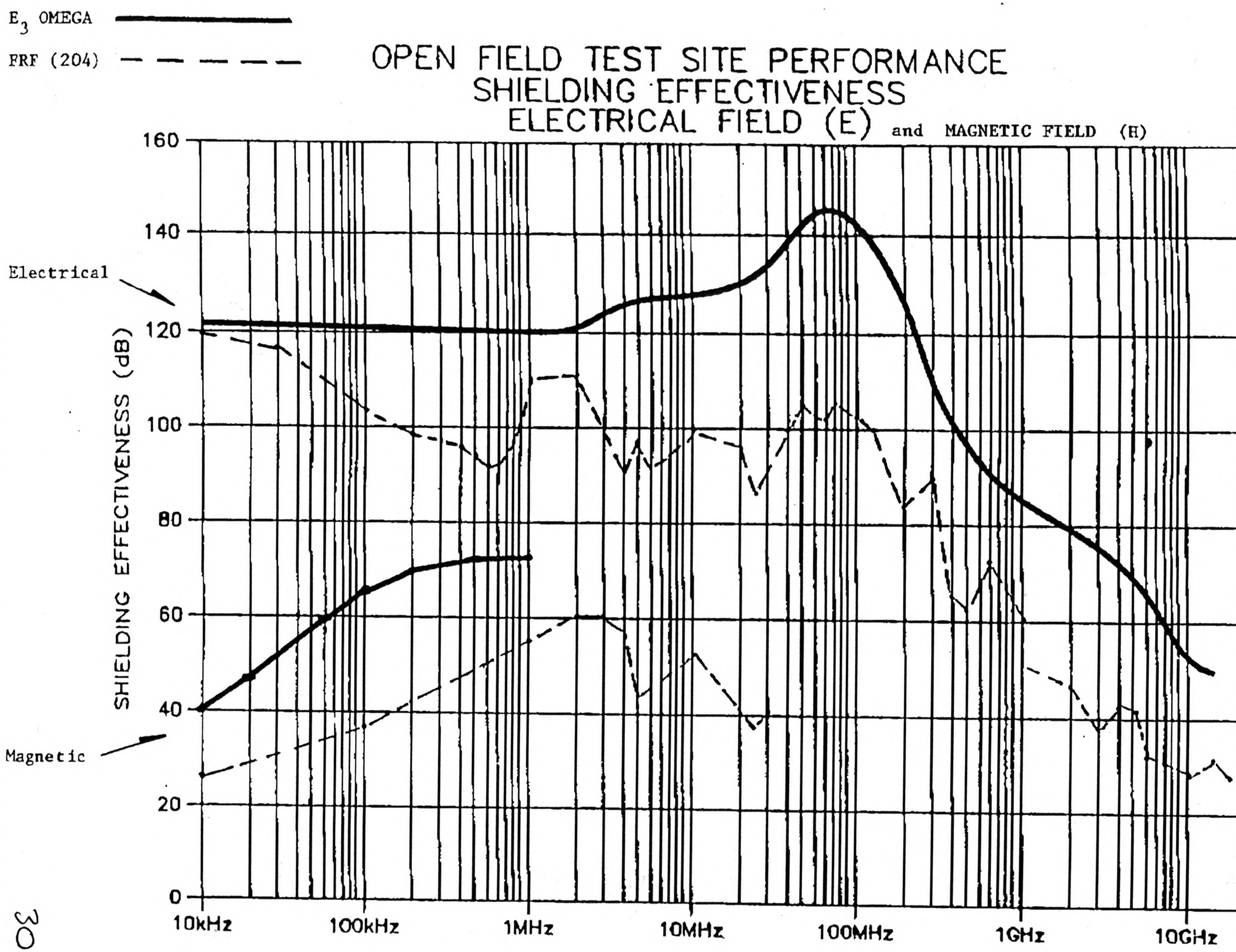

FIGURE 9: AMCO Shielding Comparison: Commercial vs. Military

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Date 10/27/00 # of pages ▶ 1
To Raul
From Dennis
Co./Dept.
Co. Amco
Phone #
Phone #

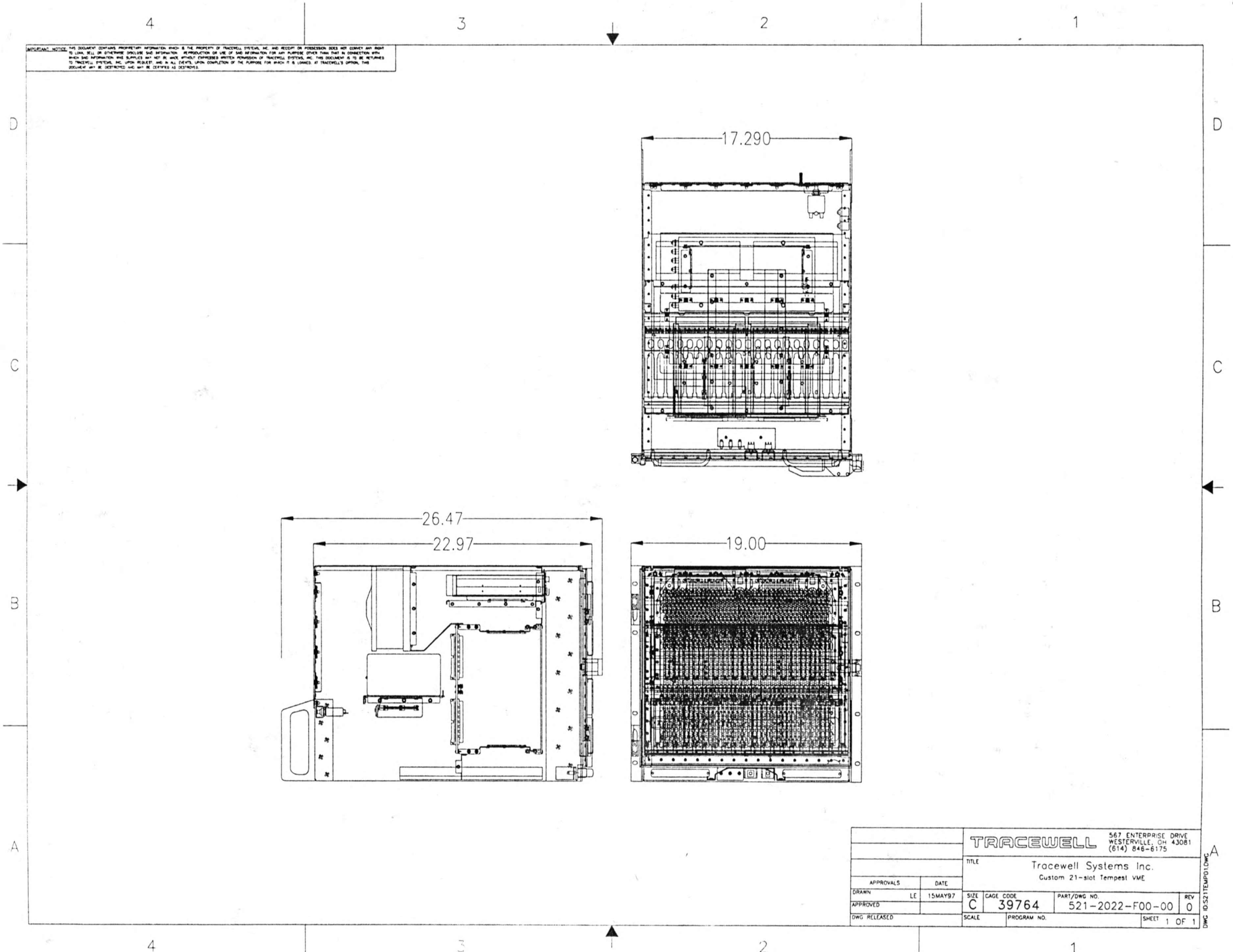


FIGURE 10: TRACEWell VME TEMPEST CHASSIS

V) Discussion on EUT Radiated Emissions

The RFI spectra with EUT in on are compared against ambient background spectra with EUT off. Plots 1-79 referenced below are located in section VI.

Va) 20-200 MHz (Plots 1-6)

Some RFI over this range was detected (compare plots 1, 2). Background RFI was stronger with the pick-up antenna in horizontal orientation versus vertical orientation and so all further tests DC-200 MHz were performed in horizontal orientation (compare plots 2, 3). The RFI over 65-75 MHz shown in plot 2 is most likely to be intermittent ambient noise and not from EUT (compare plots 2, 4). The EUT radiates a strong 100 MHz signal; this is most likely an amplification of the external system clock (compare plots 5, 6). In narrowing the RBW from 10 kHz to 1 kHz the power at 100 MHz did not change, therefore the bandwidth of the signal at 100 MHz is less than 1 kHz (compare plot 2, 6). The EUT radiates a CW at 200 MHz (compare plots 1, 2, 7). Attenuation provided by the VME cover plate and AMCO enclosure suppress the emissions to below the noise floor of the detection equipment. Emissions testing were performed with VME cover plate attached and the AMCO enclosure doors ~~open.~~ closed.

Vb) 200 MHz to 1000 MHz (Plots 7-12)

During its ~ 10 second Xilinx initialization sequence with system startup the EUT radiates white RFI over 200-450 MHz, and 1350-1450 MHz, raising the spectrum analyzer noise floor ~ 20 dB (a plot of this is not shown); after ~ 10 seconds the radiated power dropped about 15 dB but was still visible. The EUT radiates broad band noise over 200-450 MHz with CW signals at or near 300 MHz, 400 MHz, and 700 MHz (compare plots 7, 8). The EUT radiates broad band noise over 305-355 MHz, and a CW at 320 MHz (compare plots 9, 10). The EUT emits 4 CW signals over 332-334 MHz (compare plots 11, 12). Difficult to tell if EUT emits at 500 and 600 MHz; nothing seen at 800, 900, or 1000 MHz. No emissions at 610 MHz (plot 8).

Vc) 1050 – 1850 MHz (Plots 13-48)

Noisiest side of EUT:
Three of four positions around the EUT (each at a distance of 1 m) were spot checked for radiated emissions at 1.6 GHz, including the front face (position 1), right side (position 2), and back face (position 3), the left side was inaccessible. The front face was found to emit the most radiation and so all further measurements over 1-13 GHz were performed from this point of reference (compare plots 16, 17, 18). The strongest signal emitted from the EUT over 1-2 GHz is at the digitizing frequency of 1.6 GHz (compare plots 13 14, and 15, 16).

1050-1350 MHz (Plots 19-27): Possible emissions from external system clock over this range (compare plots 19 vs. 20, 22 vs. 23, 25 vs. 26). EUT possibly emits at 1160 and 1180 MHz (compare plots 23, 24). EUT possibly emits near 1322 and 1328 MHz (compare plots 26, 27). However these plots were obtained on different days and as such the added RFI is possibly ambient background noise and not from the system clock, nor EUT.

1350-1450 MHz (Plots 28-36): The EUT radiates quasi white noise over this range (compare plots 30, 31). The EUT radiates strong CW's at or near 1358, 1375, 1392, and 1400 MHz (compare plots 28, 30, 31). There was a strong signal at 1400 MHz either ambient, from the external system clock, or analog noise source (plot 32). The EUT either radiates its own signal at 1400 MHz, or amplifies the existing ambient signal (compare plots 32, 33). There was a strong, broadband signal at 1419 MHz, ambient or from the external system clock; this signal was switching noise which changed in power and frequency over time (compare plots 30, 34-36). During its ~ 10 second Xilinx initialization sequence with system startup the EUT radiates white RFI over 200-450 MHz, and 1350-1450 MHz, raising the spectrum analyzer noise floor ~ 20 dB (a plot of this is not shown); after ~ 10 seconds the radiated power dropped about 15 dB but was still visible.

1450-1650 MHz (Plots 37-44): With AMCO doors closed no emissions seen 1450-1550 MHz (compare plots 37, 38). The EUT emits quasi white noise over 1550-1650 MHz (compare plots 41, 42). The EUT radiates a strong signal at the digitizing frequency of 1.6 GHz (compare plots 14, 16, 39, 40). Most the power at 1.6 GHz is contained in a 1 kHz bandwidth (compare plots 40, 41). The sidebands about 1.6 GHz extend at least 600 kHz, with sidelobes near +/- 80 kHz, +/- 160 kHz, and +/- 240 kHz from the fundamental (compare plots 43, 44). The large AMCO enclosure provides at least 30 dB of shielding to the 1.6 GHz signal (compare plots 41, 42, and 43, 44).

1650-1850 MHz (Plots 45-48): The EUT emits CW's at 1.7 and 1.8 GHz (compare plots 45-48).

Vd) 1.850-13.000 GHz (Plots 49-79)

Above 2.7 GHz no emissions from EUT were observed other than at 3.2 and 4.8 GHz which are the 2nd and 3rd harmonics of the digitizer.

1.850-2.150 GHz (Plots 49-53): No emissions from the EUT were detected over this range. The RFI shown around 1962 MHz and 1990 MHz is ambient background noise and not from the EUT.

2-3 GHz (Plots 54-61): The EUT radiates at 2.2, 2.3, 2.4, 2.5, and 2.7 GHz; it is difficult to tell but probably also radiates at 2.1 and 2.6 GHz (compare plots 54 vs. 55, 58 vs. 59, 60 and 61 vs. 54).

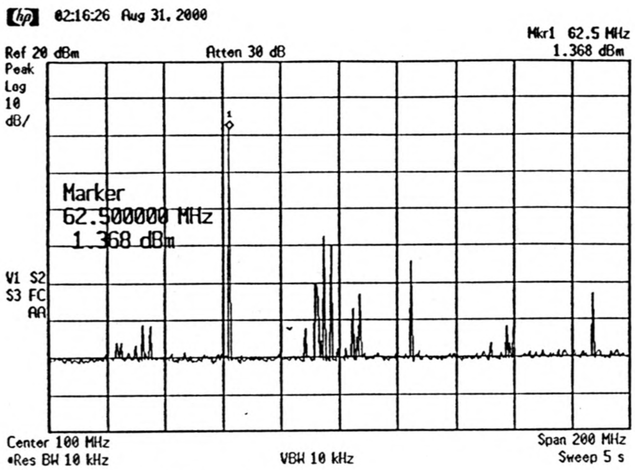
3-4.2 GHz (Plots 62-67): EUT sampler radiates at 3.200 GHz which is the 2nd harmonic of the digitizer (compare plots 62, 63). Most of the radiated power at 3.2 GHz is confined to a 1 kHz bandwidth (compare plots 63, 65); with sidebands extending over 1 MHz with sidelobes near +/- 240 kHz, and +/- 480 kHz from 3.2 GHz (plots 64, 65). No emissions detected over 3.4-4.2 GHz (plots 66, 67).

4-4.810 GHz (Plots 68-70): EUT sampler radiates at 4.800 GHz, which is the 3rd harmonic of the digitizer (compare plots 68-70). No emissions were detected over the VLA C-band range of 4.810-4.910 GHz, nor from 4.801-5.000 GHz (plots 70, 71).

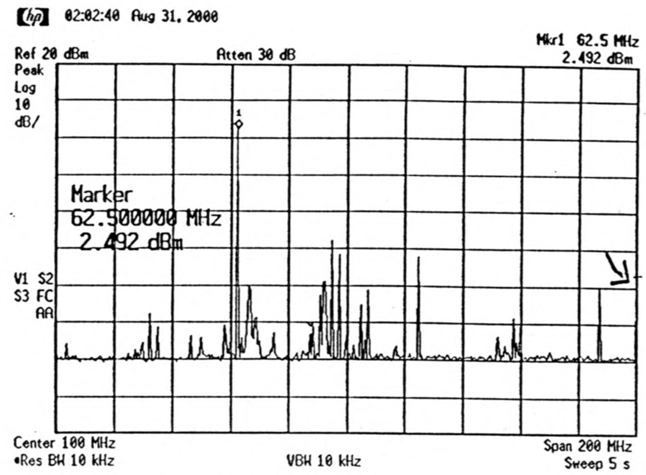
4.810-13 GHz (Plots 71-79): No emissions were detected over this range (plots 71-79). The 4^{th} digitizer harmonic at 6.4 GHz, and higher harmonics are expected but were below the noise floor of the detection equipment (plot 72). No emissions were detected over the VLA X-band range of 8.410-8.510 GHz (plot 75).

VI) Plots of Radiated Emissions and Background Noise

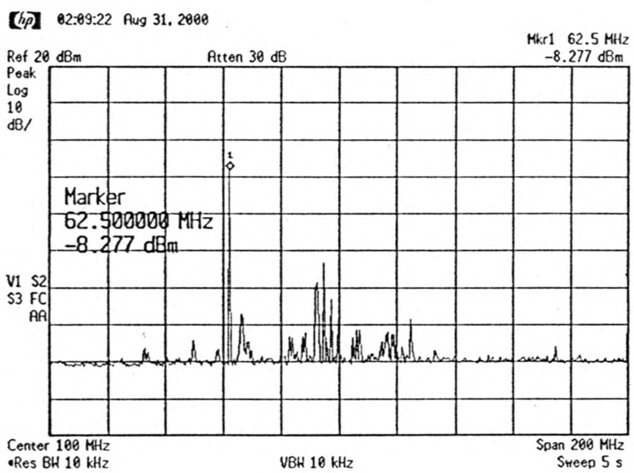
20-200 MHZ Biconical RECEIVE ANTENNA



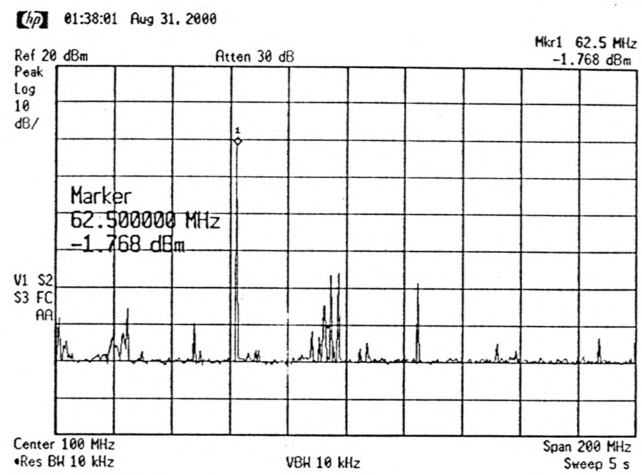
EUT OFF
SYSTEM Clock off PlOT 1
ANTENNA HORIZONTAL



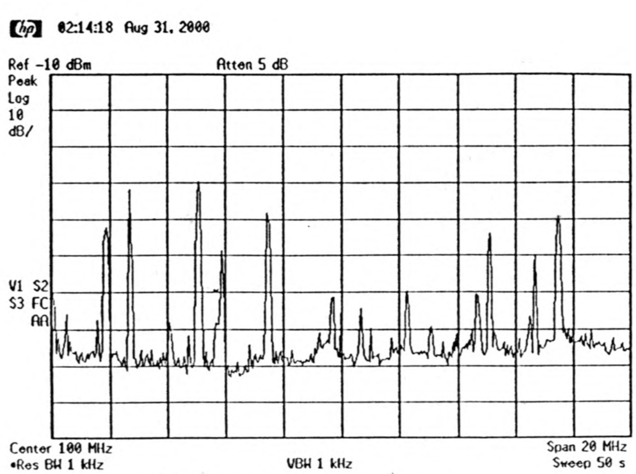
EUT ON
SYSTEM Clock ON PlOT 2
ANTENNA Horizontal



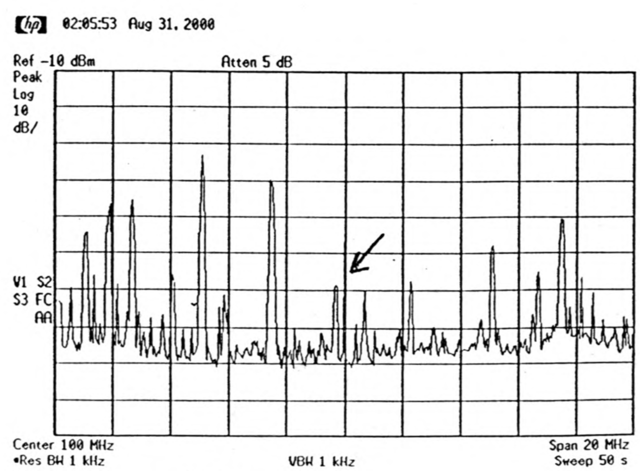
EUT ON PlOT 3
SYSTEM CLOCK ON
ANTENNA VERTICAL



EUT ON
SYSTEM Clock ON PlOT 4
ANTENNA HORIZONTAl

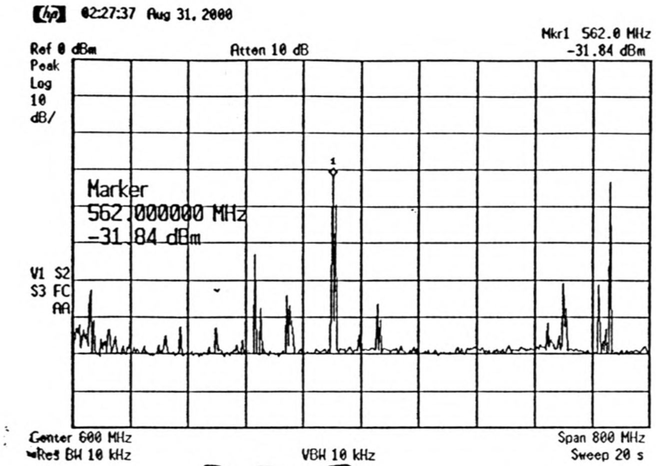


EUT OFF
SYSTEM clock off PlOT 5
ANTENNA HORIZONTAL

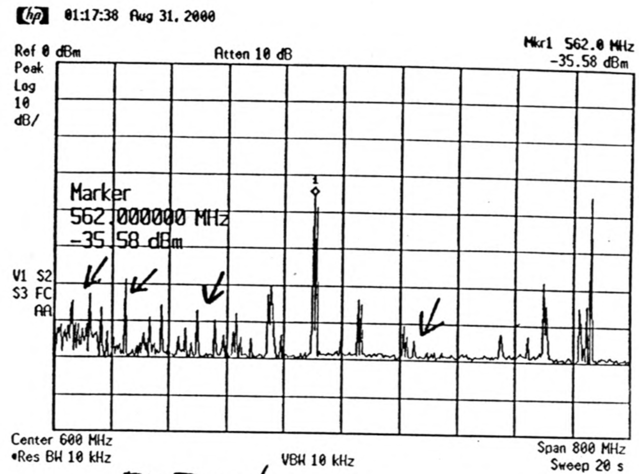


EUT ON
SYSTEM Clock ON PlOT 6
ANTENNA HORIZONTAL

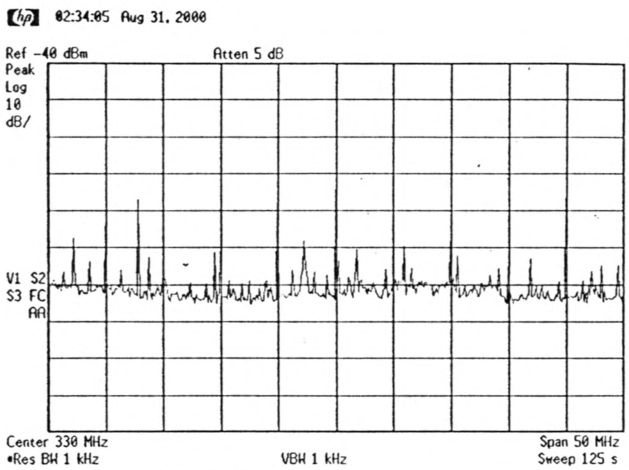
200–1000 MHz CONICAL LOG SPIRAL RECEIVE ANTENNA



EUT OFF
SYSTEM Clock off PlOT 7

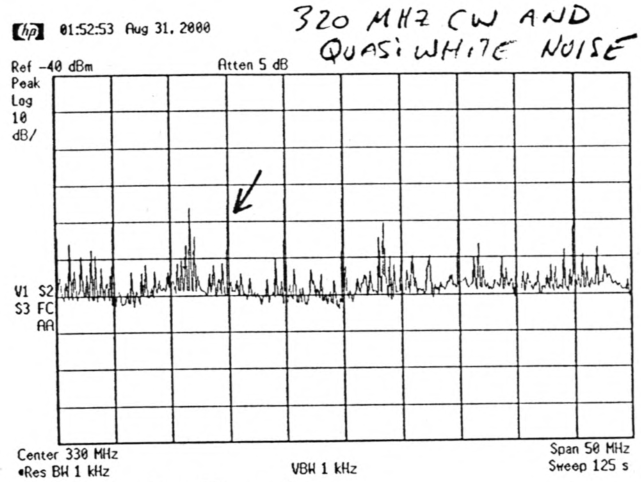


EUT ON
SYSTEM CLOCK ON PlOT 8

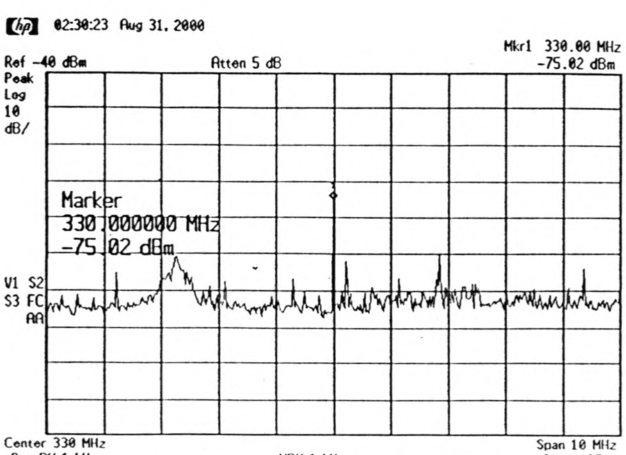


EUT OFF
SYSTEM Clock OFF PlOT 9

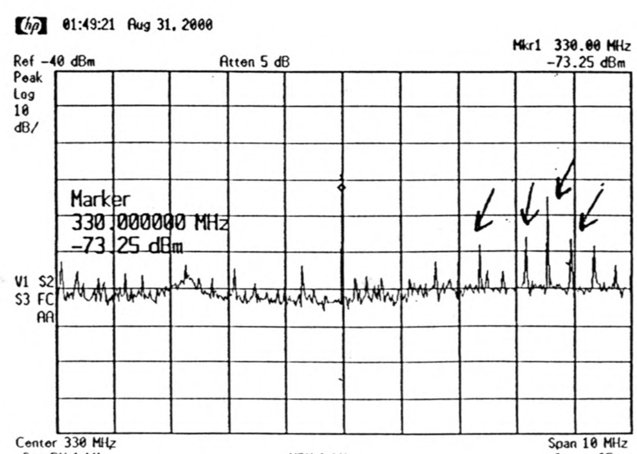
320 MHz CW AND
QUASI WHITE NOISE



EUT ON
SYSTEM ClocK ON Plot 10

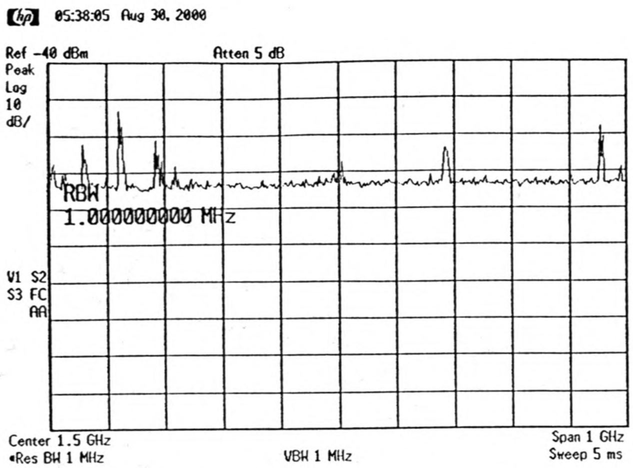


EUT OFF
SYSTEM Clock off PlOT 11

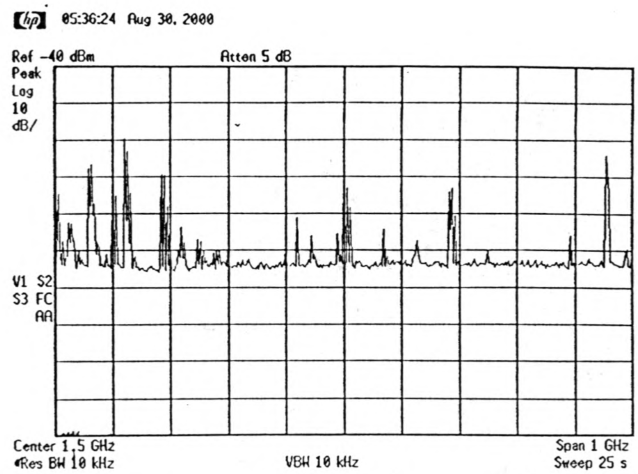


EUT ON
SYSTEM Clock ON PlOT 12

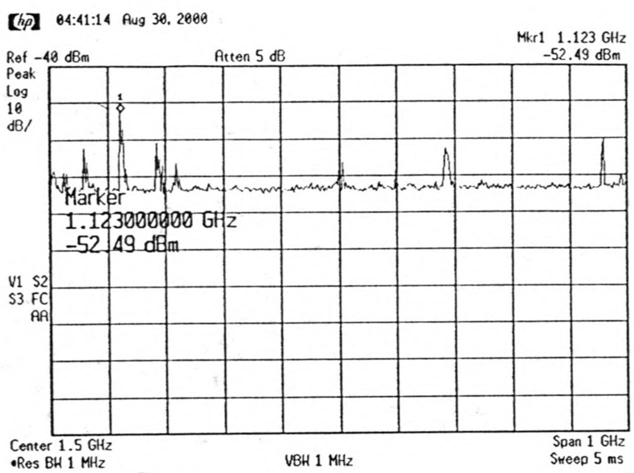
TCK PMS 1-46: 1-10 GHz conical log spiral Receive anten



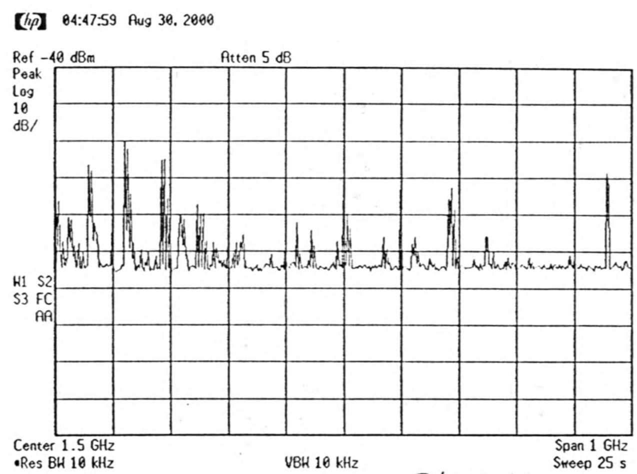
EUT off PLOT 13
antena at position 1
EXTERNAL system clock ON



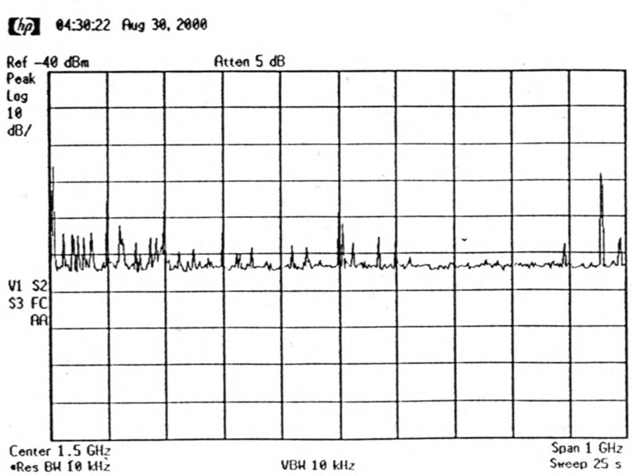
EUT off PLOT 14
antenna at position 1
EXTERNAL SYSTEM CLOCK ON



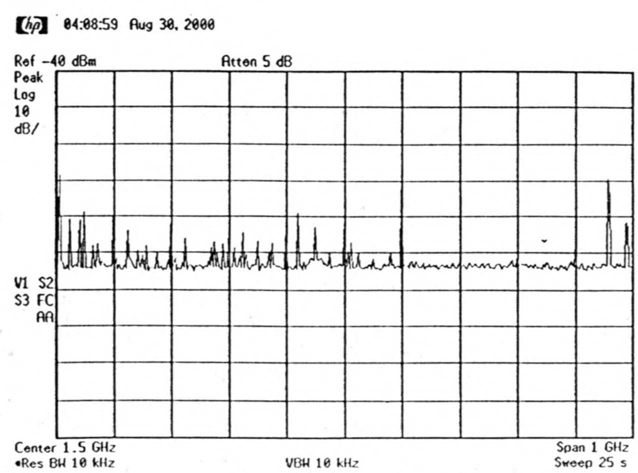
EUT ON PLOT 15
Antena at position 1
EXTERNAL System Clock ON



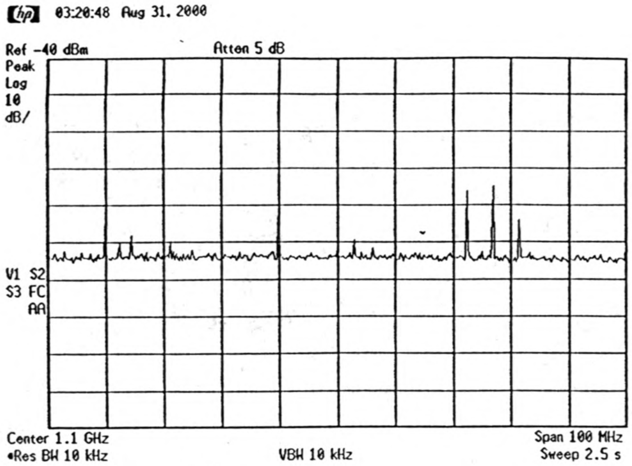
EUT ON PLOT 16
Antena at position 1
EXTERNAL System Clock ON



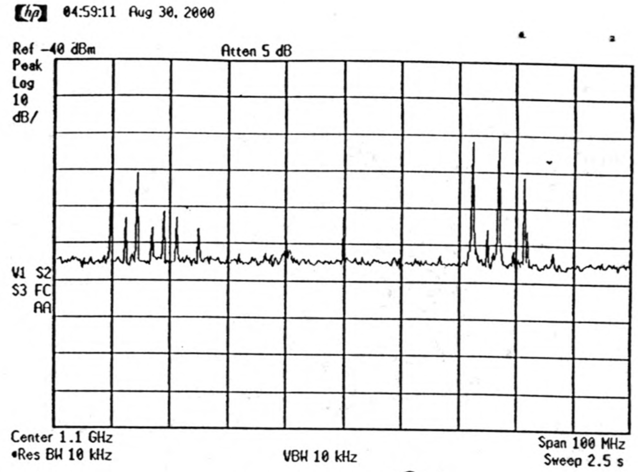
EUT ON PLOT 17
Antena at position 3
EXTERNAL SYSTEM CLOCK ON



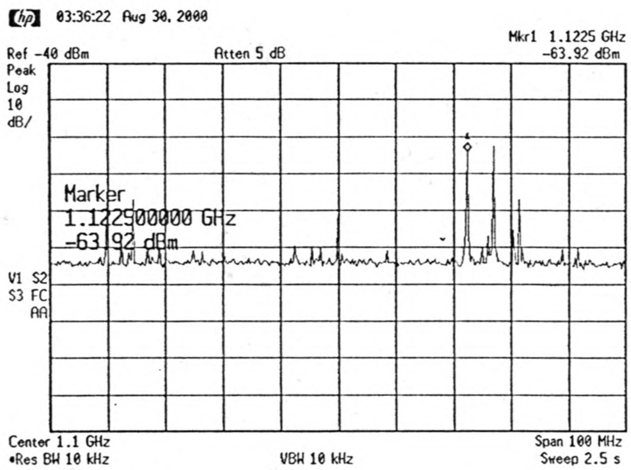
PLOT 18 EUT ON
Antena in Position 2 3
EXTERNAL System
Clock ON



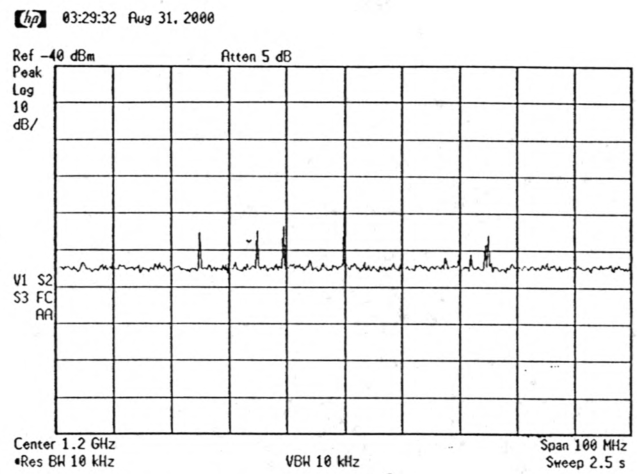
EUT off
External System clock off
PlOT 19



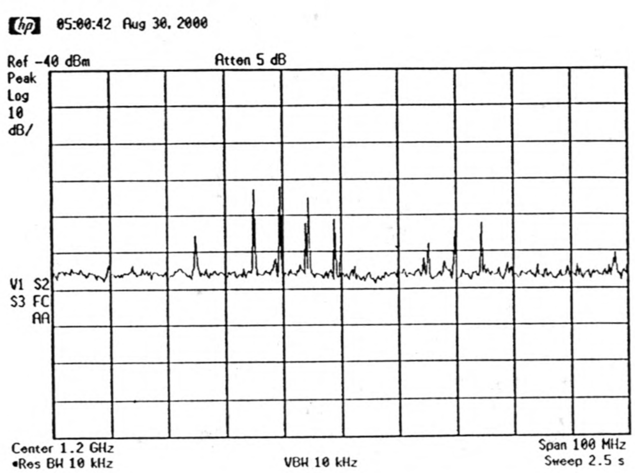
PlOT 20
EUT off
External System clock ON



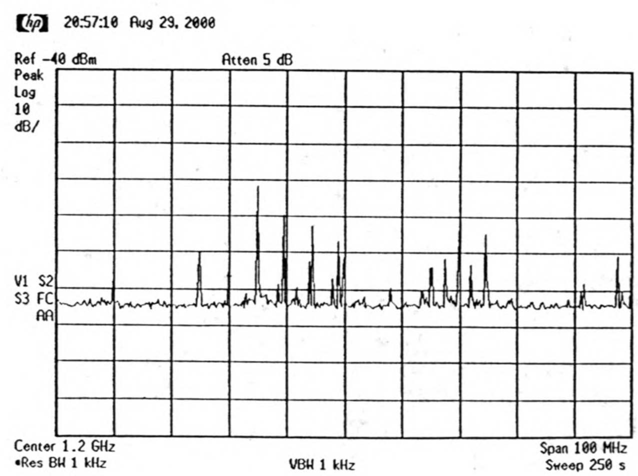
EUT ON
External System clock ON
PlOT 21



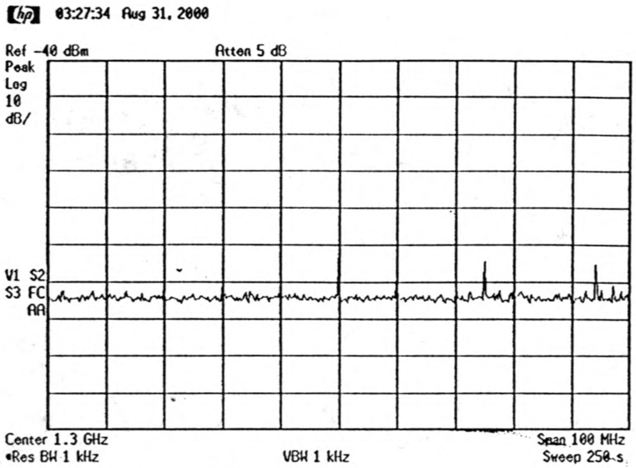
PlOT 22
EUT off
External System clock off



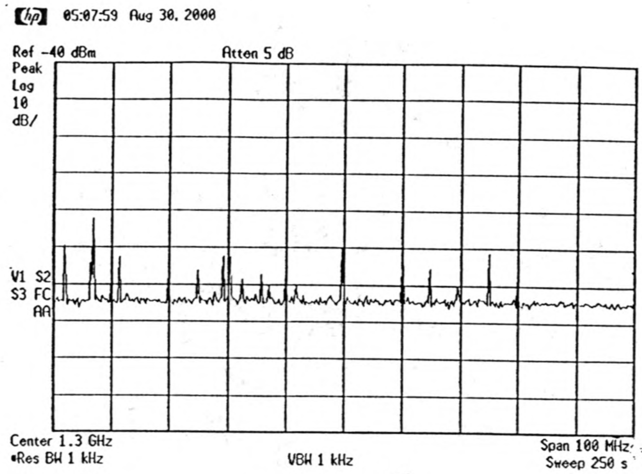
EUT off
External System clock ON
PlOT 23



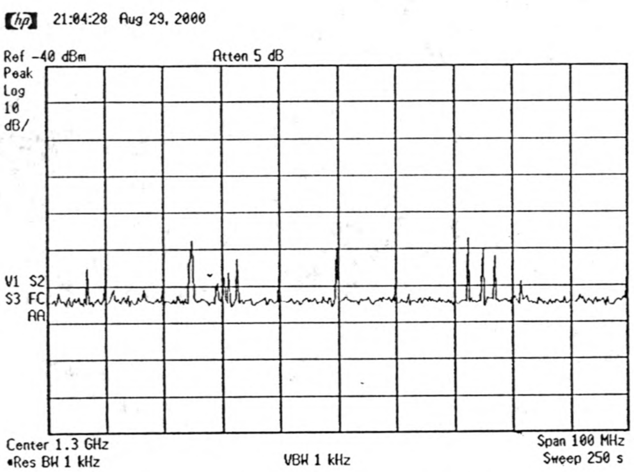
PlOT 24
EUT ON
External System clock ON



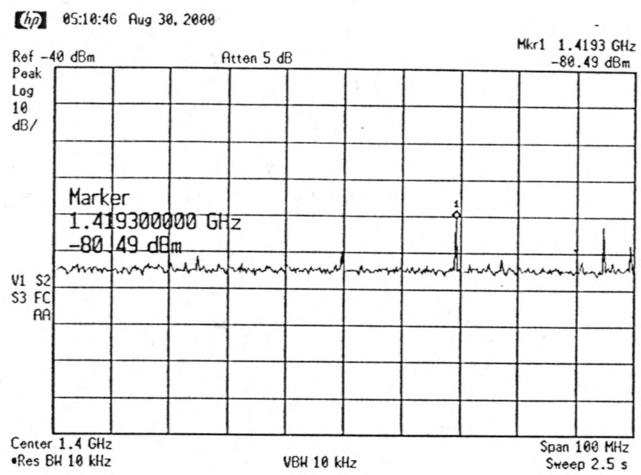
EUT off
External System clock off
Plot 25



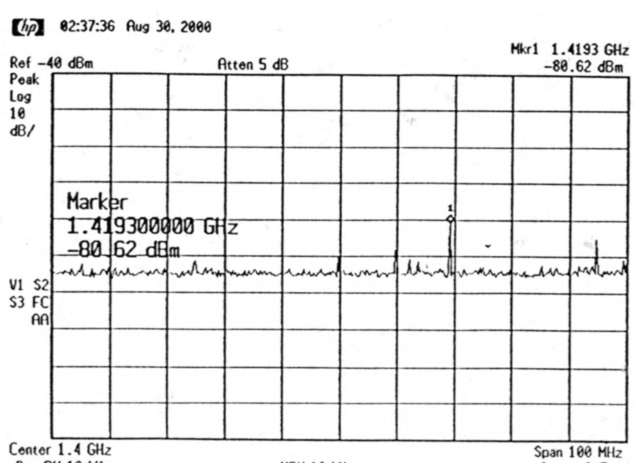
Plot 26 EUT off
External System clock On



EUT ON
Plot 27
External System clock ON

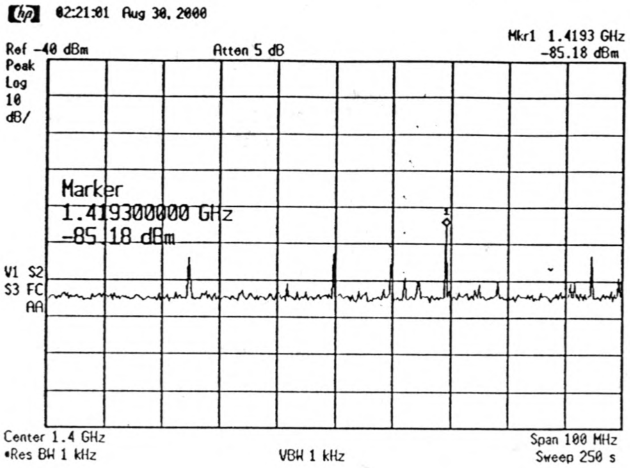


Plot 28 EUT off
External System clock On



EUT ON
Plot 29
External System clock ON

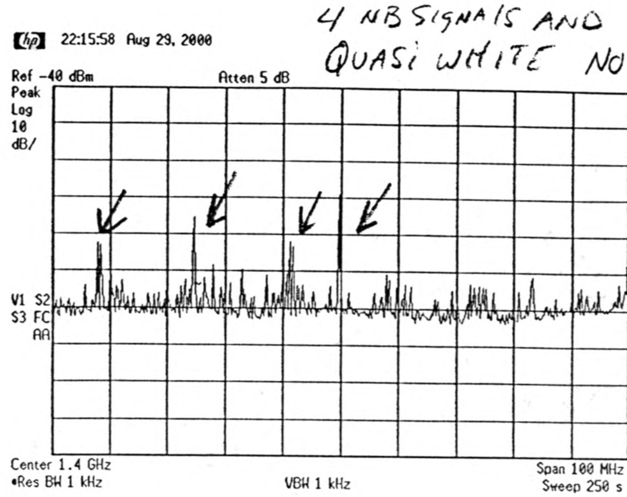
External system clock on for plots 30-48



Plot 30

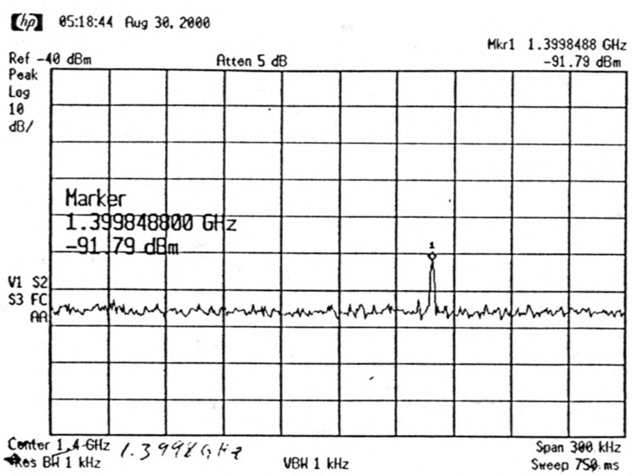
EUT ON
Both doors closed

4 NB SIGNALS AND
QUASI WHITE NOISE



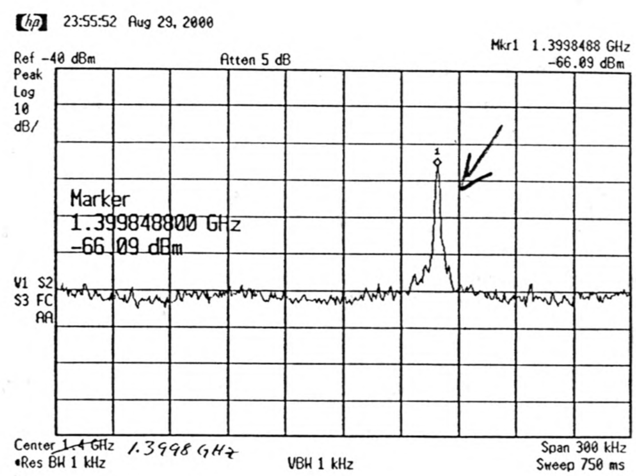
Plot 31

EUT ON
Both doors open



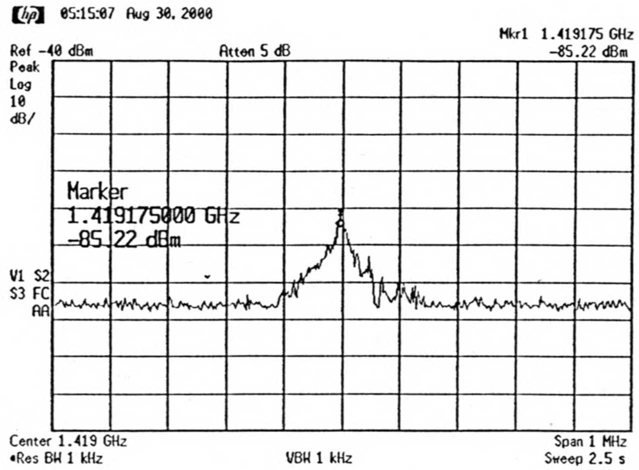
Plot 32

EUT off
Both doors closed



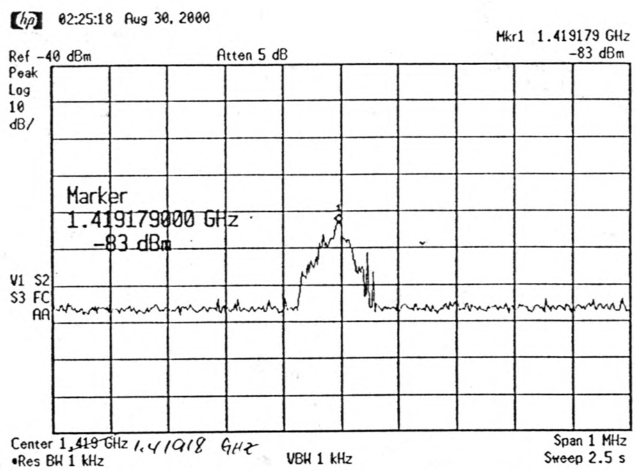
Plot 33

EUT ON
Both doors open



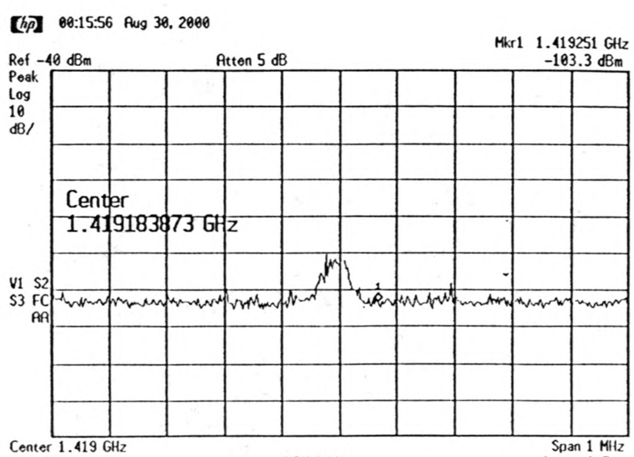
EUT off

Plot 34



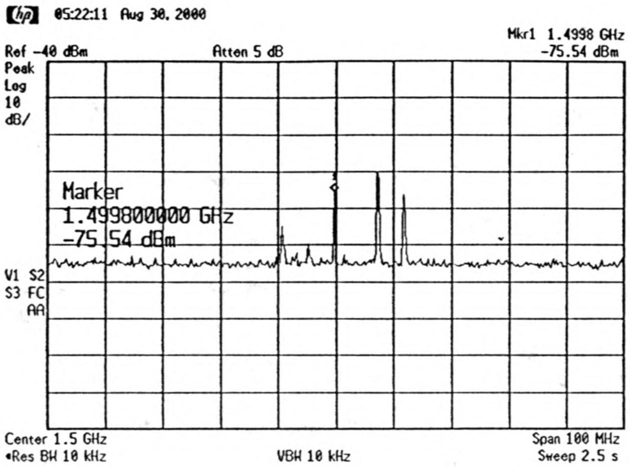
Plot 35

EUT ON
Doors closed



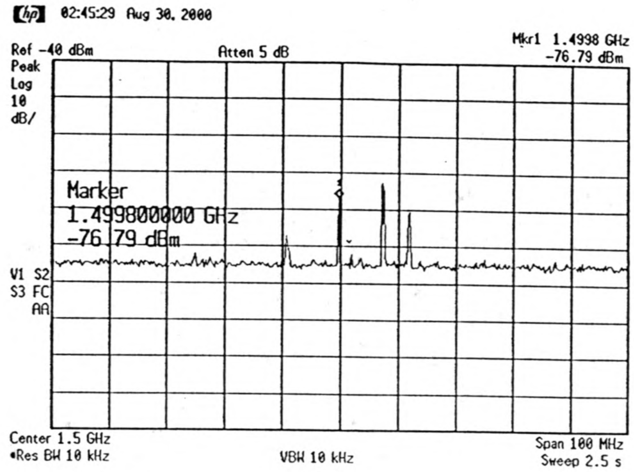
Plot 36

EUT ON
Doors open



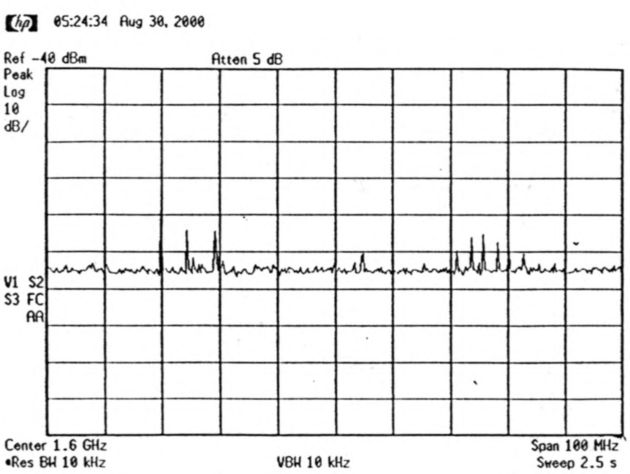
EUT off

PLOT 37



EUT ON

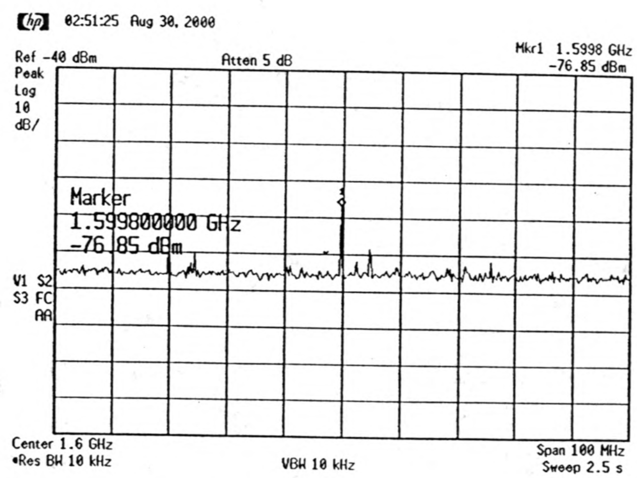
PLOT 38



PLOT 39

EUT off

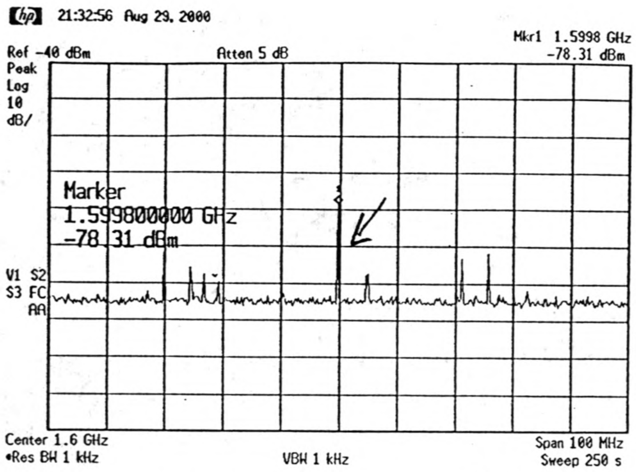
both doors closed



PLOT 40

EUT ON

both doors closed

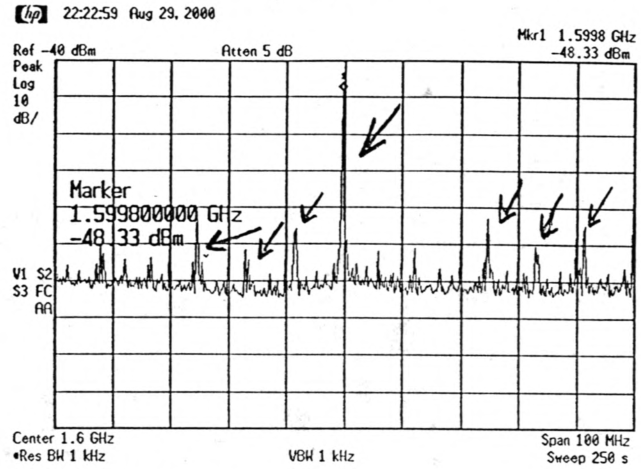


Plot 41

EUT ON

both doors closed

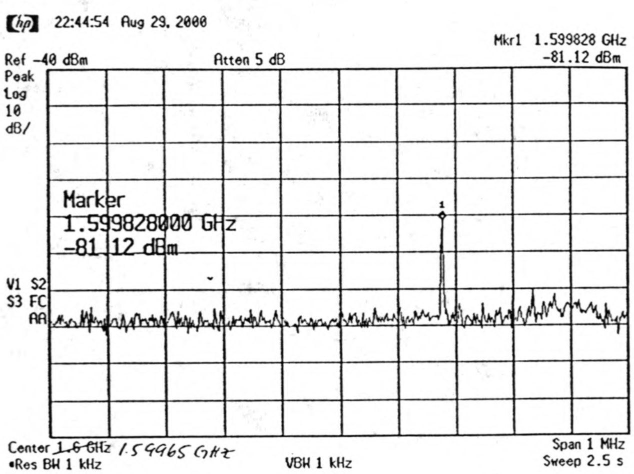
1.6 GHz Digitizer and white noise



Plot 42

EUT ON

Both doors open

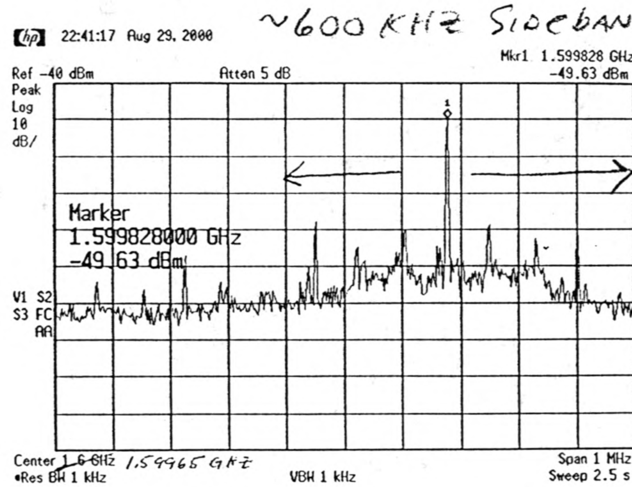


Plot 43

EUT ON

Both doors closed

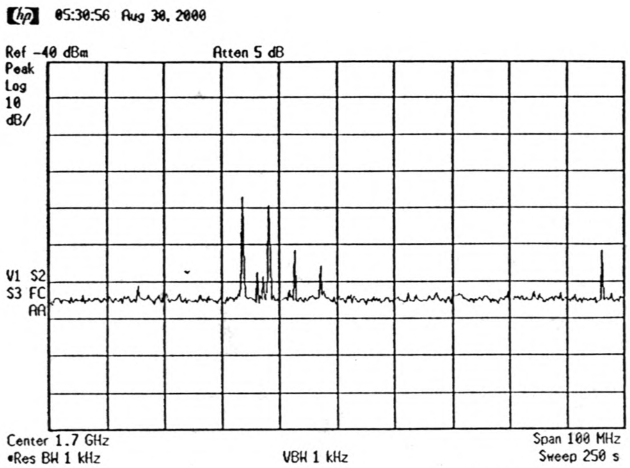
~600 KHz Sidebands



Plot 44

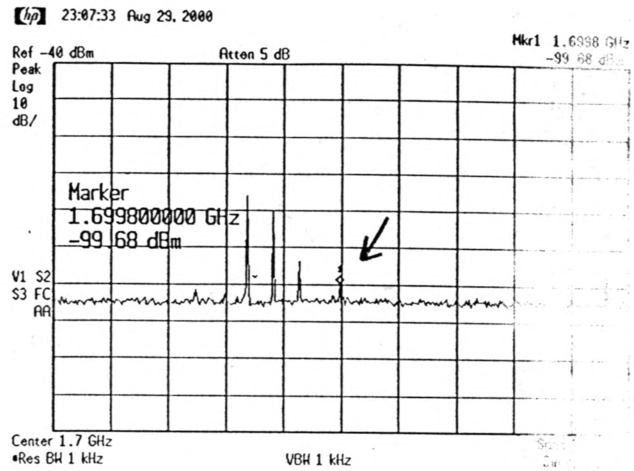
EUT ON

Both doors open



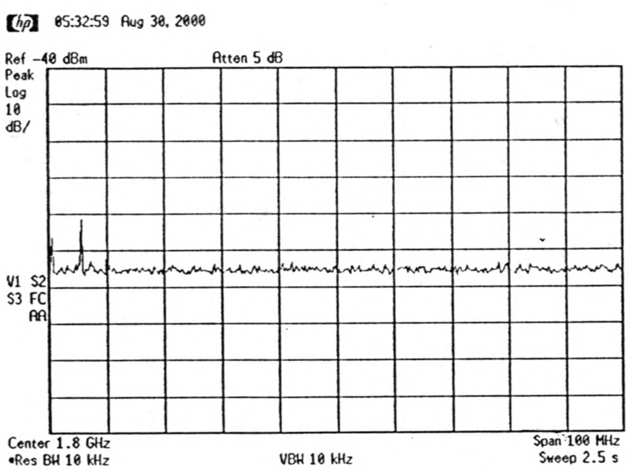
Plot 45

EUT off



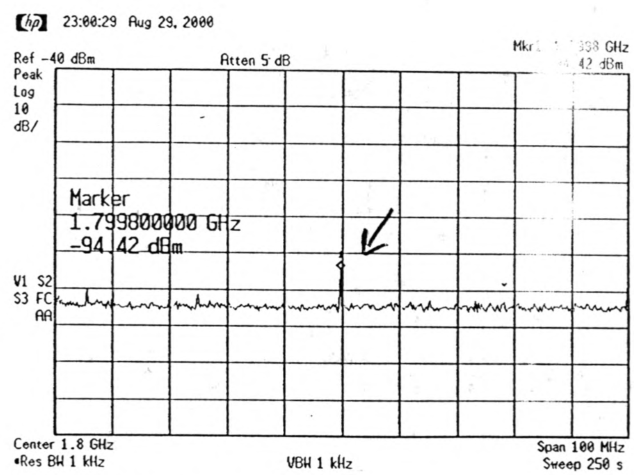
Plot 46

EUT ON



Plot 47

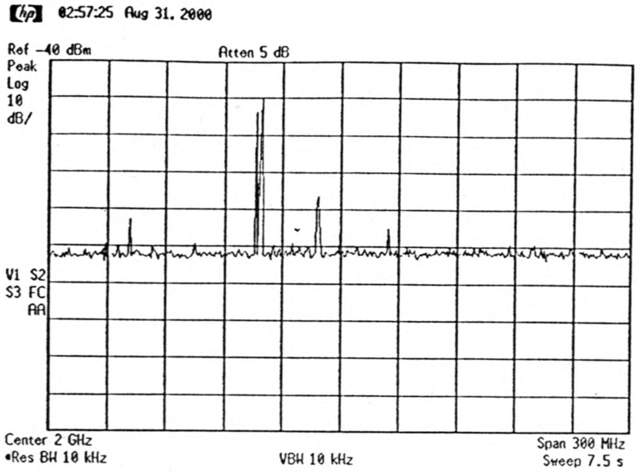
EUT off



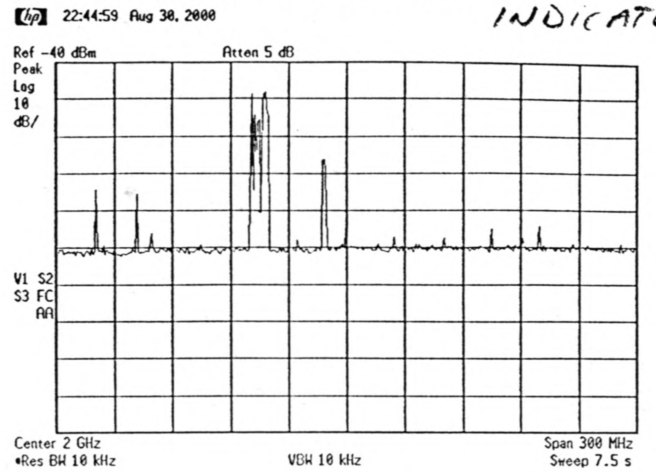
Plot 48

EUT ON

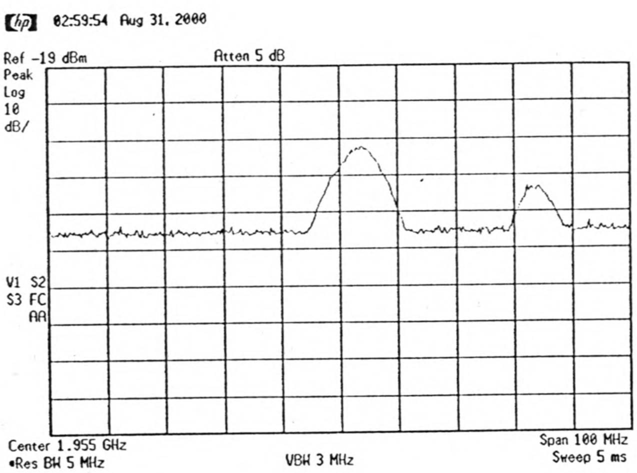
.FOR PLOTS 49-79: 2-18 GHZ HORN Receive ANTENNA
EXTERNAL SYSTEM CLOCK ON UNLESS OTHERWISE INDICATED



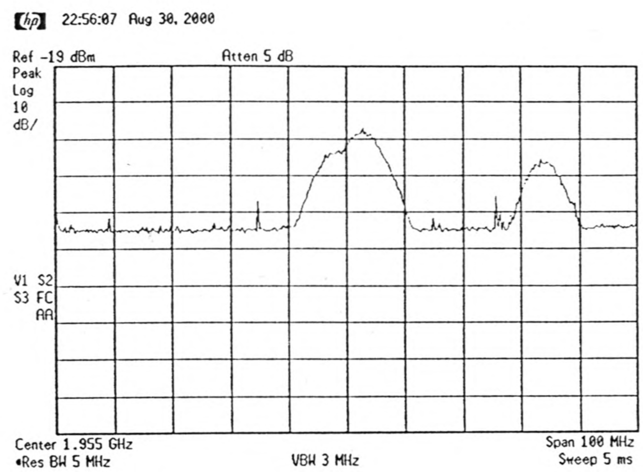
EUT off Plot 49
External System clock off



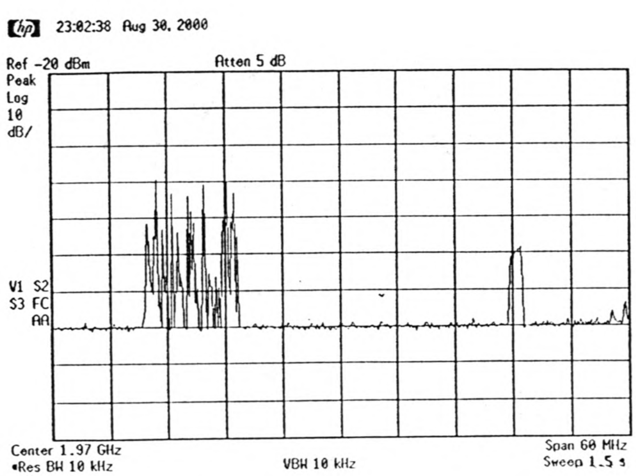
Plot 50 EUT ON



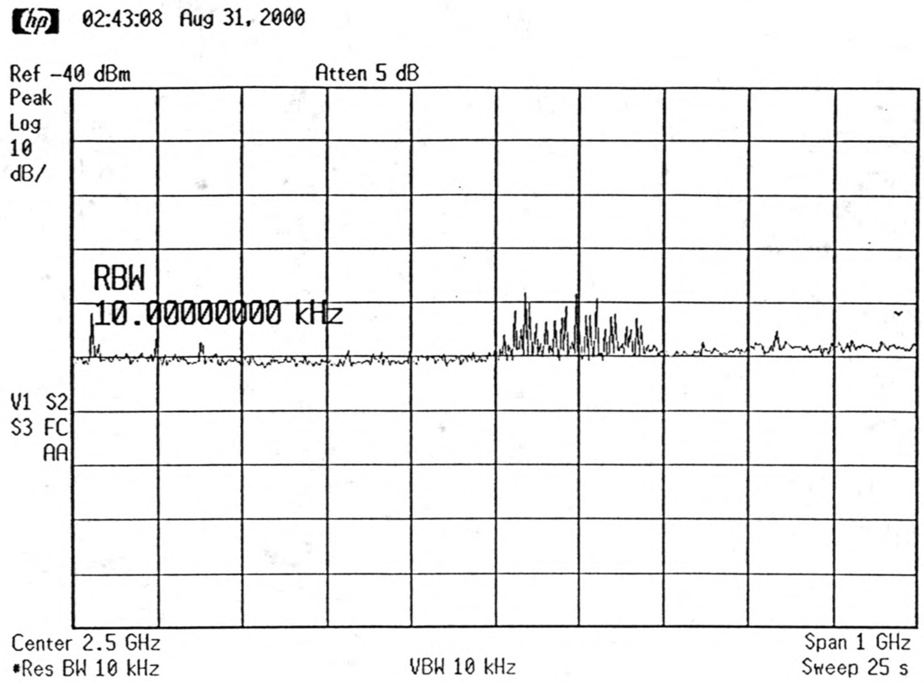
Plot 51 EUT off
External System clock off



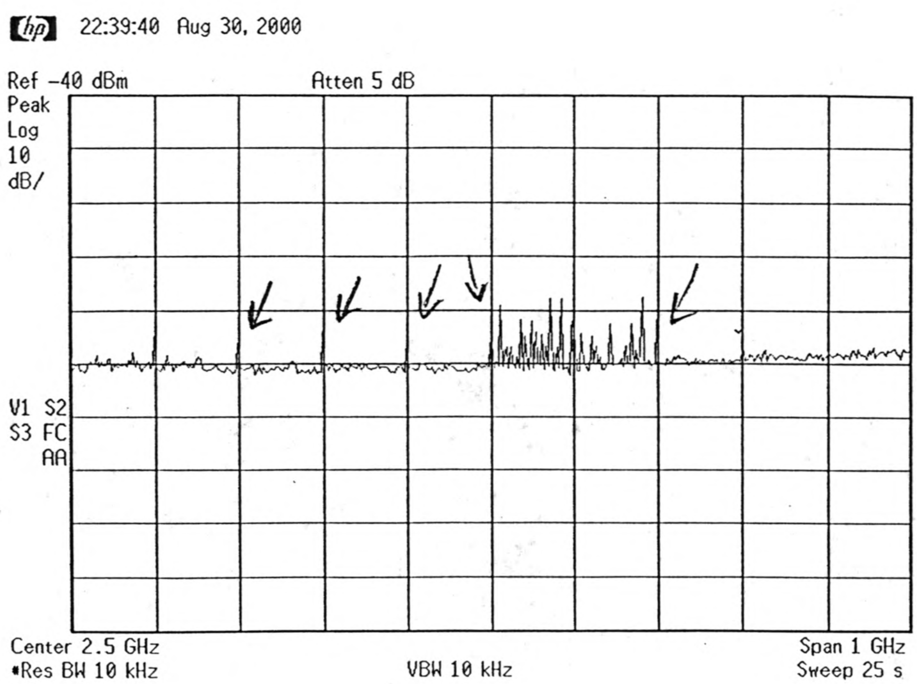
EUT ON Plot 52



EUT on Plot 53

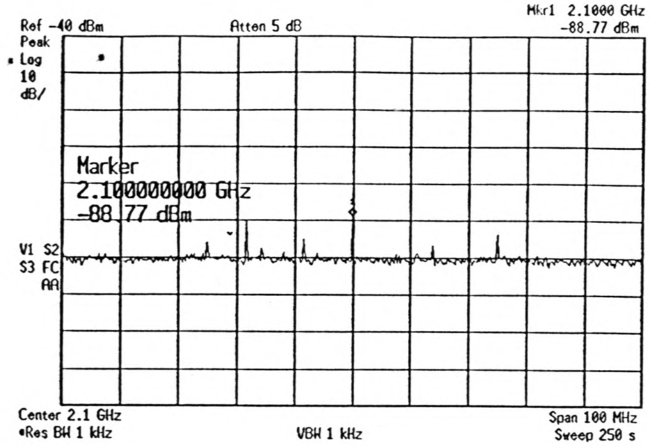


EUT off
External System clock off
Plot 54

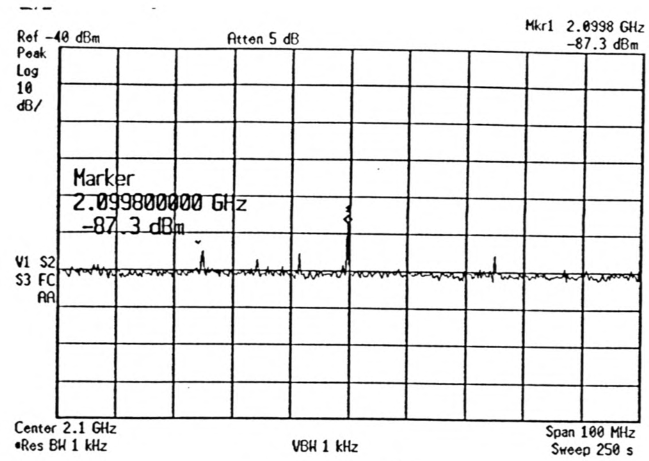


EUT ON

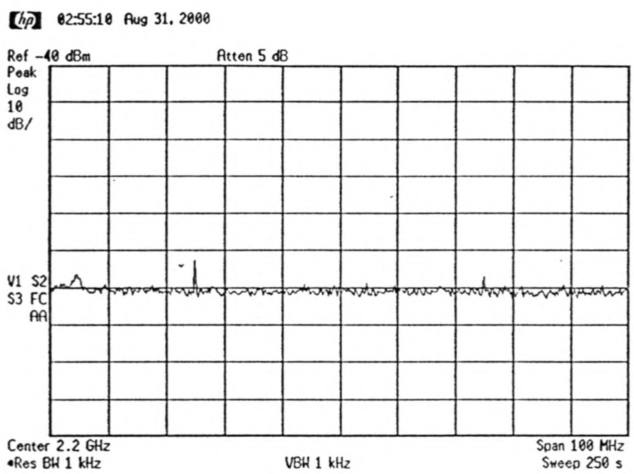
Plot 55



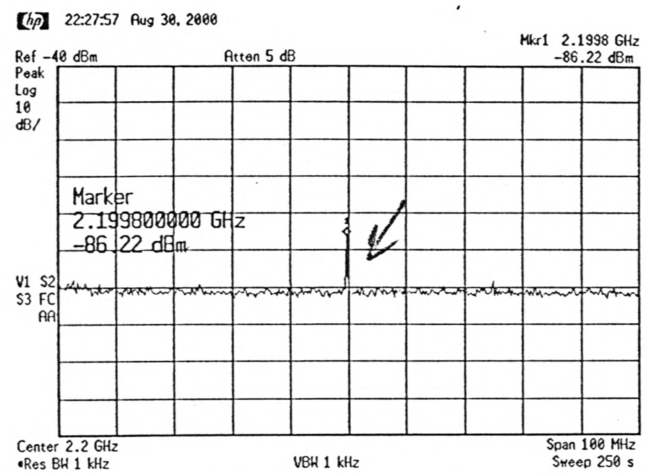
EUT off
External System clock off
Plot 56



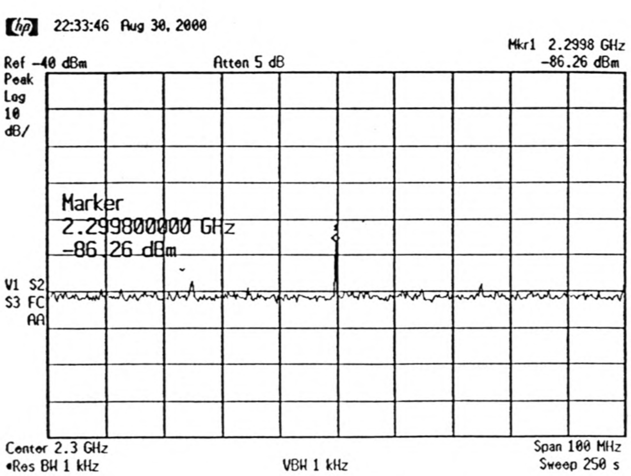
EUT ON
Plot 57



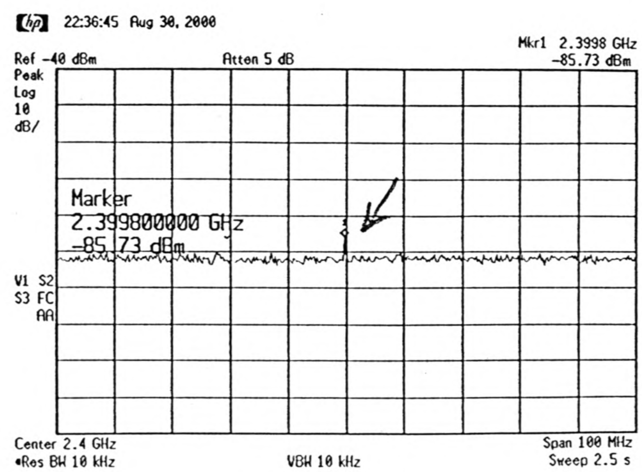
EUT off
External System clock off
Plot 58



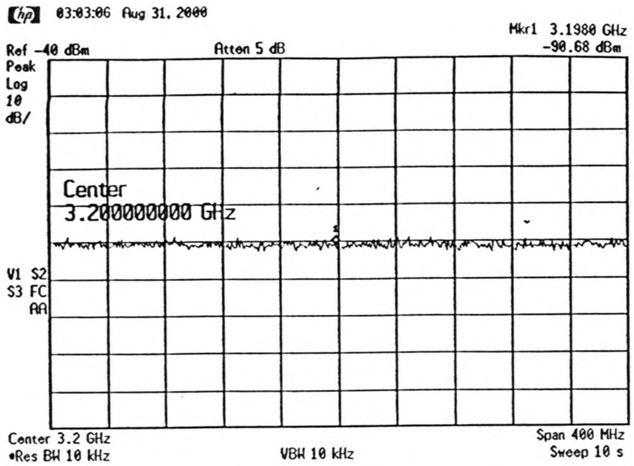
EUT ON
Plot 59



Plot 60
EUT ON

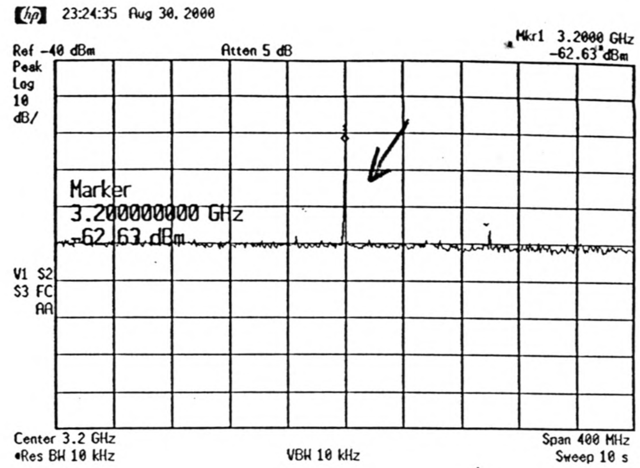


EUT ON
Plot 61

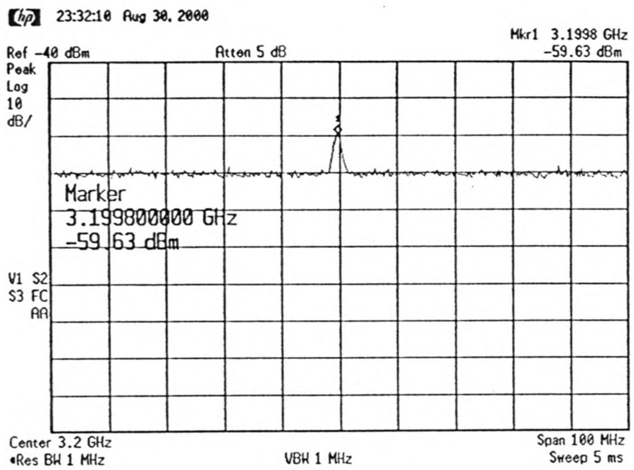


EUT off Plot 62

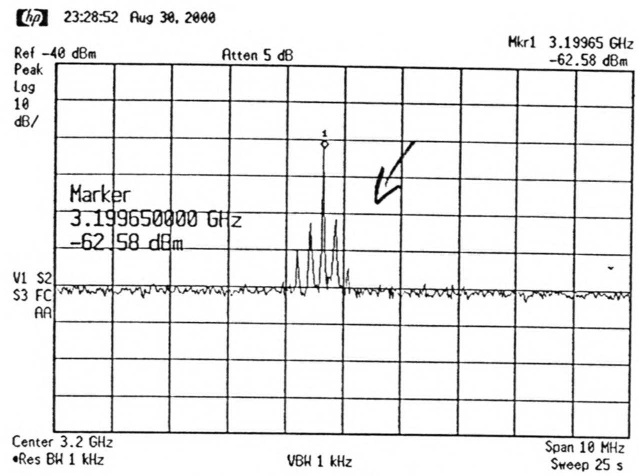
External System clock off



Plot 63 EUT ON

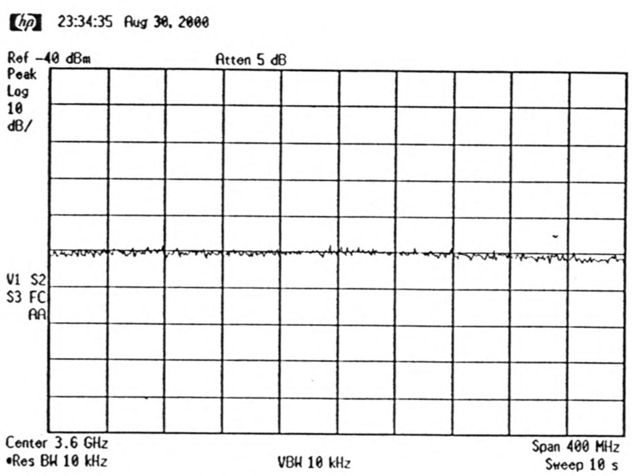


EUT ON Plot 64

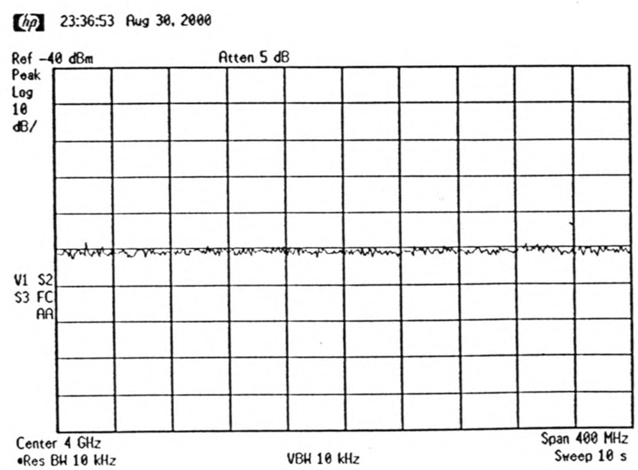


EUT ON Plot 65

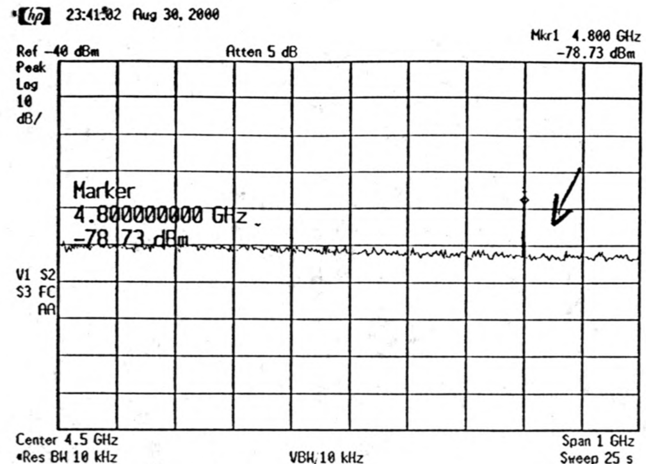
Doors closed



EUT ON Plot 66

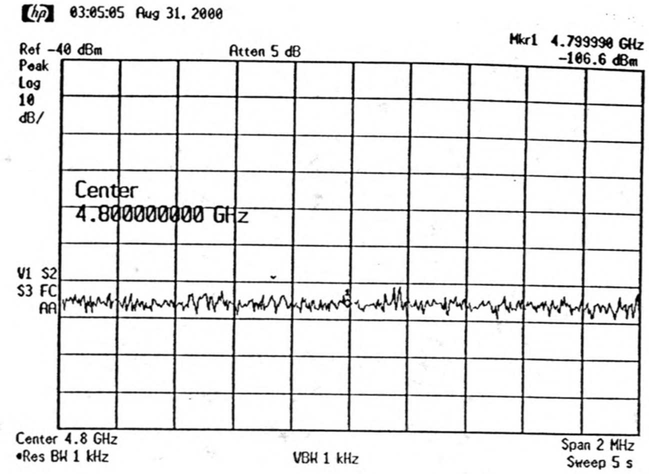


Plot 67 EUT ON

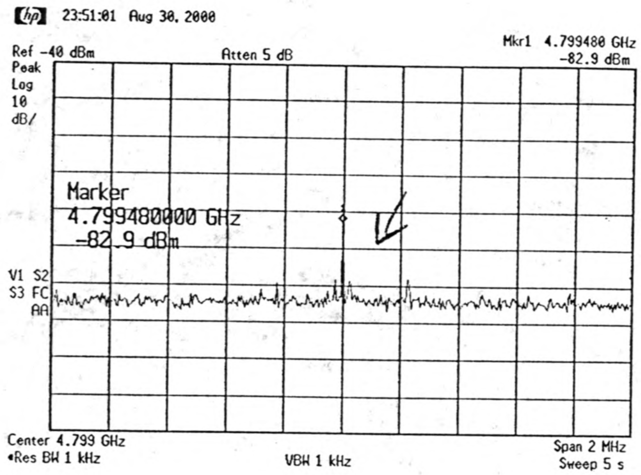


EUT ON

Plot 68

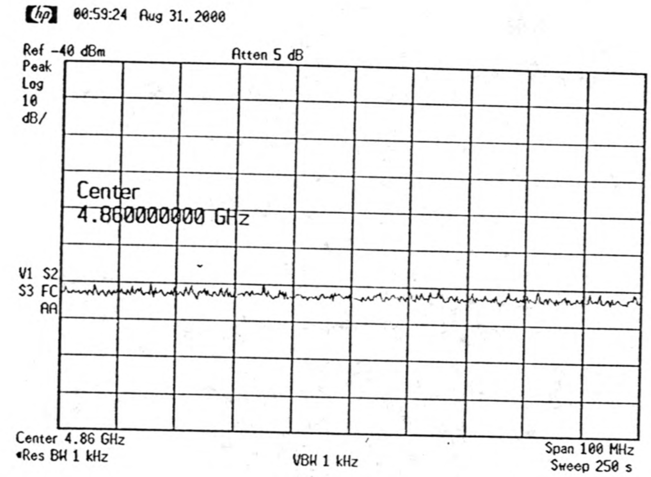


Plot 69 EUT off
External System [illegible]

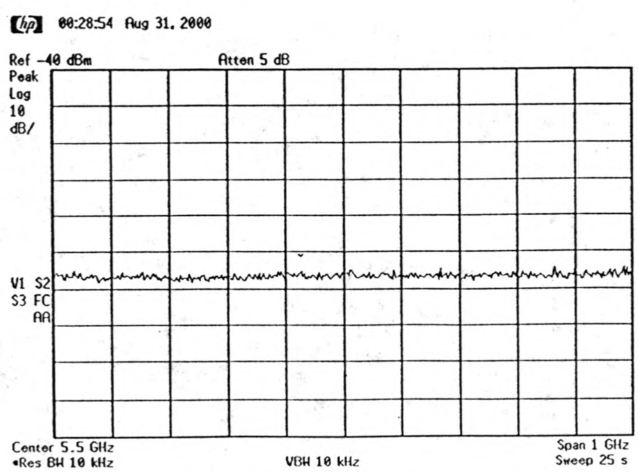


EUT ON

Plot 70

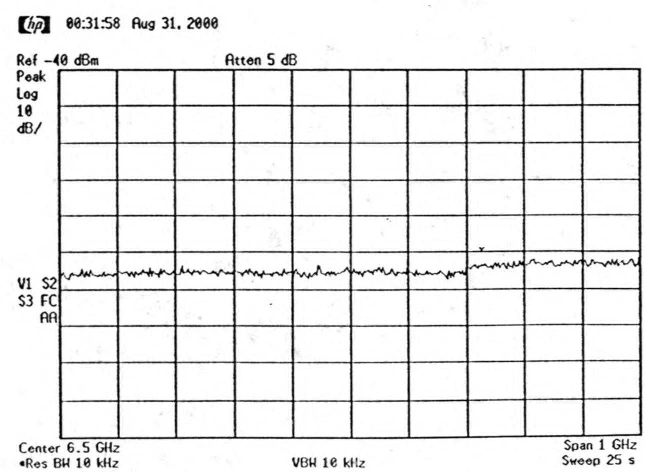


Plot 71 EUT ON

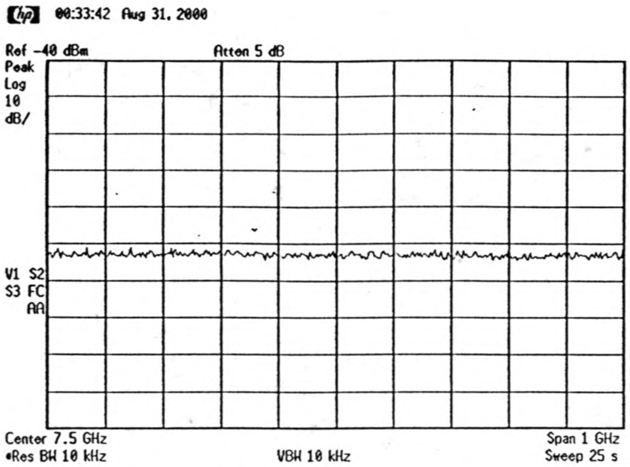


Plot 72

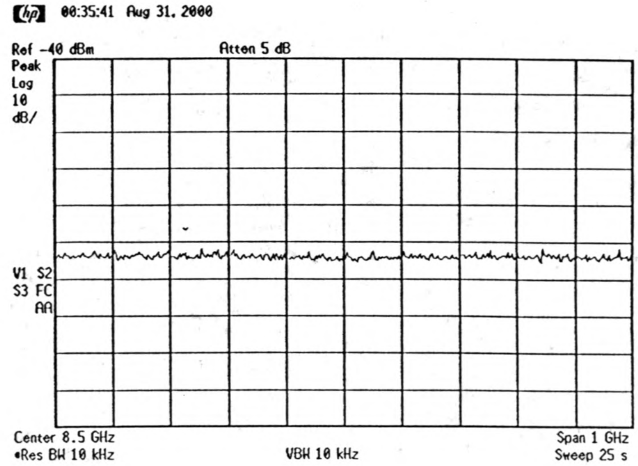
EUT ON



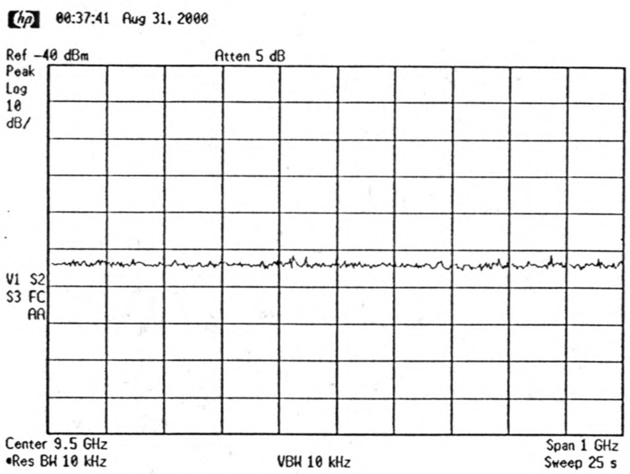
Plot 73 EUT ON



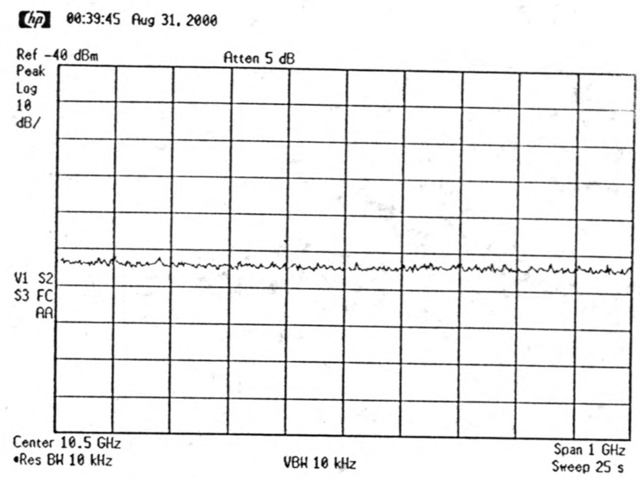
Plot 74
EUT ON



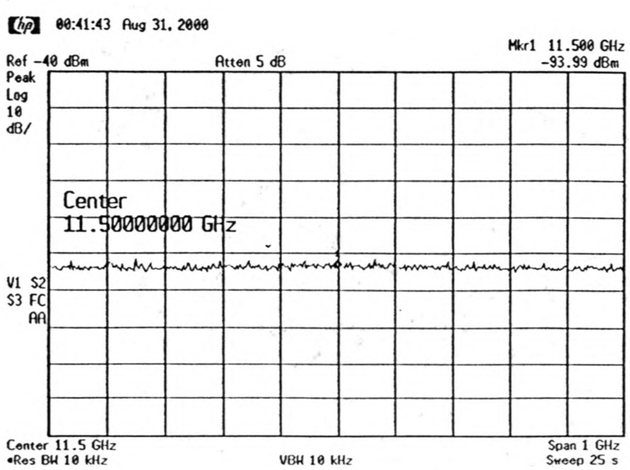
Plot 75 EUT ON



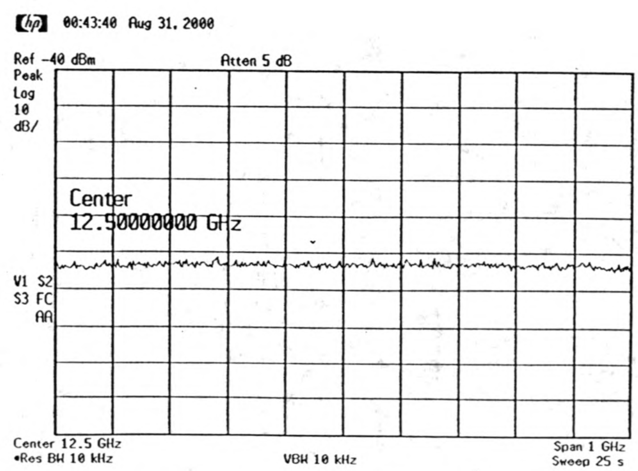
EUT ON Plot 76



Plot 77 EUT ON



EUT ON Plot 78



Plot 79 EUT ON

Appendix 1

Test Equipment and Calibration of Test Equipment

Test equipment:

1) Spectrum Analyzer: HP E4408B 9 kHz-26.5 GHz ESA-L Series 50 Ohm input
2) Cable: Ailtech 90933-6, 6 foot

Antennas:

3) 20-200 MHz Biconical, linear polarized, Singer 94455-1, s/n 114
4) 200-1000 MHz Conical log spiral, circular polarized, directional, Singer 93490-1, s/n 165
5) 1-10 GHz Conical spiral, circular polarized, directional, Stoddart 93491-2, s/n A06718
6) 2-18 GHz Horn antenna, linear polarized, GTE Sylvania, AN10-F

Low noise amplifiers:

7) Amplifier s/n 1002, 10 MHz-1GHz specified, 15 dB gain DC-1 GHz (measured), flat
8) Miteq AM-2A-1020, s/n 43599, 1.2-1.8 GHz specified, provides 17 dB gain over 1-2 GHz (measured), ~ flat response
9) JCA Tech. JCA24-F01, s/n 134, 2-4 GHz specified, provides 30-34 dB gain over 1-5 GHz (measured), ~ flat response
10) Wooden tripod and non-metal antenna mounting adapters
11) Printer: Deskjet 890C

Calibration of Equipment

1) Transmission line and all LNA's and were characterized at AOC prior to testing.
2) Results from the 2 L-band antennas used are compared in plots 7-41 and 7-41a in section IVc. Results suggest a +/- 5dB accuracy at 1.6 GHz.
3) The gain provided by the 4 receive antennas used in this report were characterized via transmit-receive tests in the IPG lab at the AOC on 8/21/2000, and results compared to antenna gain patterns and correction factors. Room reflections can corrupt results. Of the four receive antennas characterized the results for the biconical antenna deviated greatly from its correction factor. However this could have been due to transmit antenna problems.

Transmit antenna	Frequency	Receive antenna	Expected power in SA	Detected power in SA
Small discone	129 MHz	Biconical (vertical)	-52 dBm	-72 dBm
Large C.L.S.	500 MHz	Large C.L.S.	-38 dBm	-30 dBm
Small C.L.S.	1.5 GHz	Small C.L.S.	-48 dBm	-40 dBm
Small C.L.S.	5 GHz	GTE Horn	-49 dBm	-49 dBm
Additional test:				
Small C.L.S.	5 GHz	WJ L.P.	-55 dBm	-52 dBm

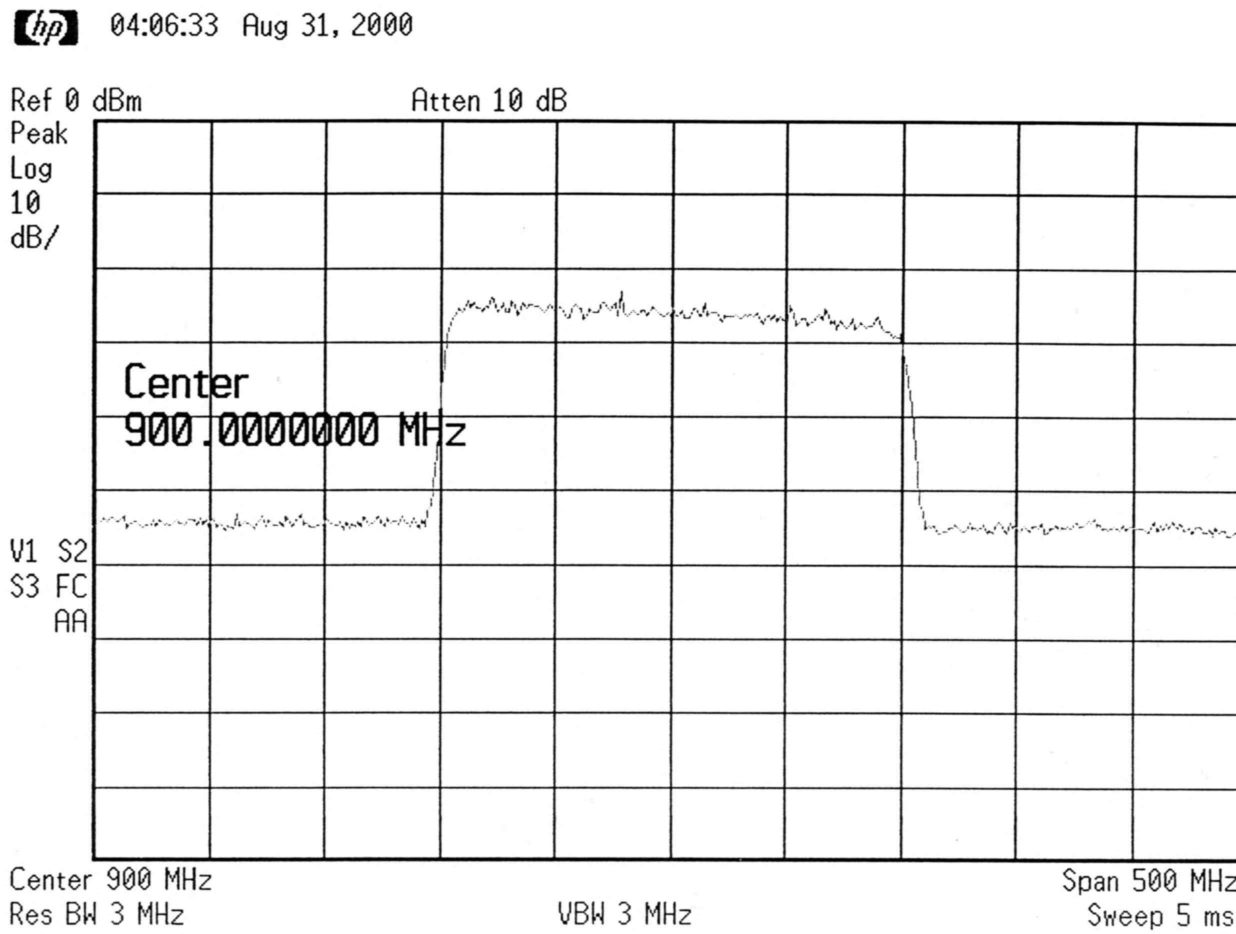


FIGURE 11: 800-1000 MHz WHITE NOISE

ANALOG INPUT SIGNAL TO TWO 1.6 GHz SAMPLERS

Antenna Correction Factors
Model 94455-1 Biconical Antenna

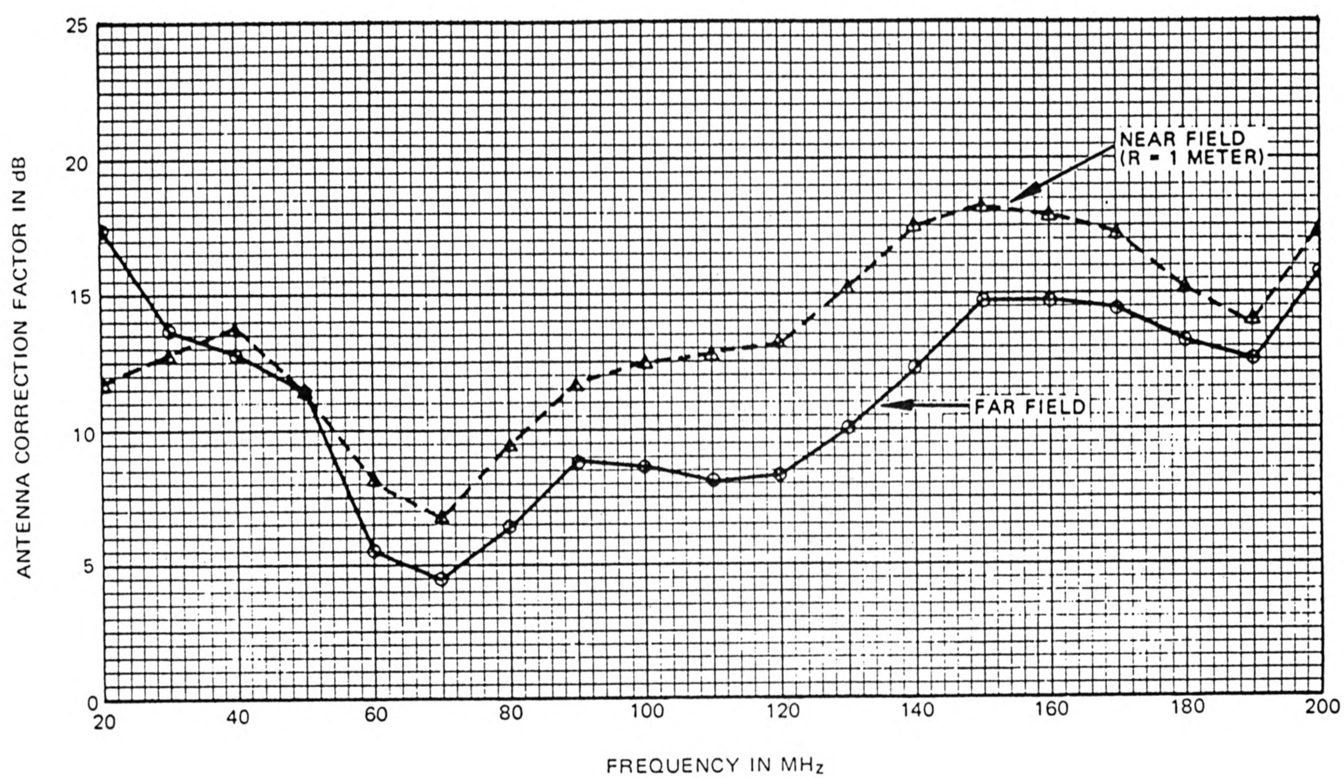


CHART 2

FIGURE 12: 20-200 MHz ANTENNA CORRECTION FACTOR

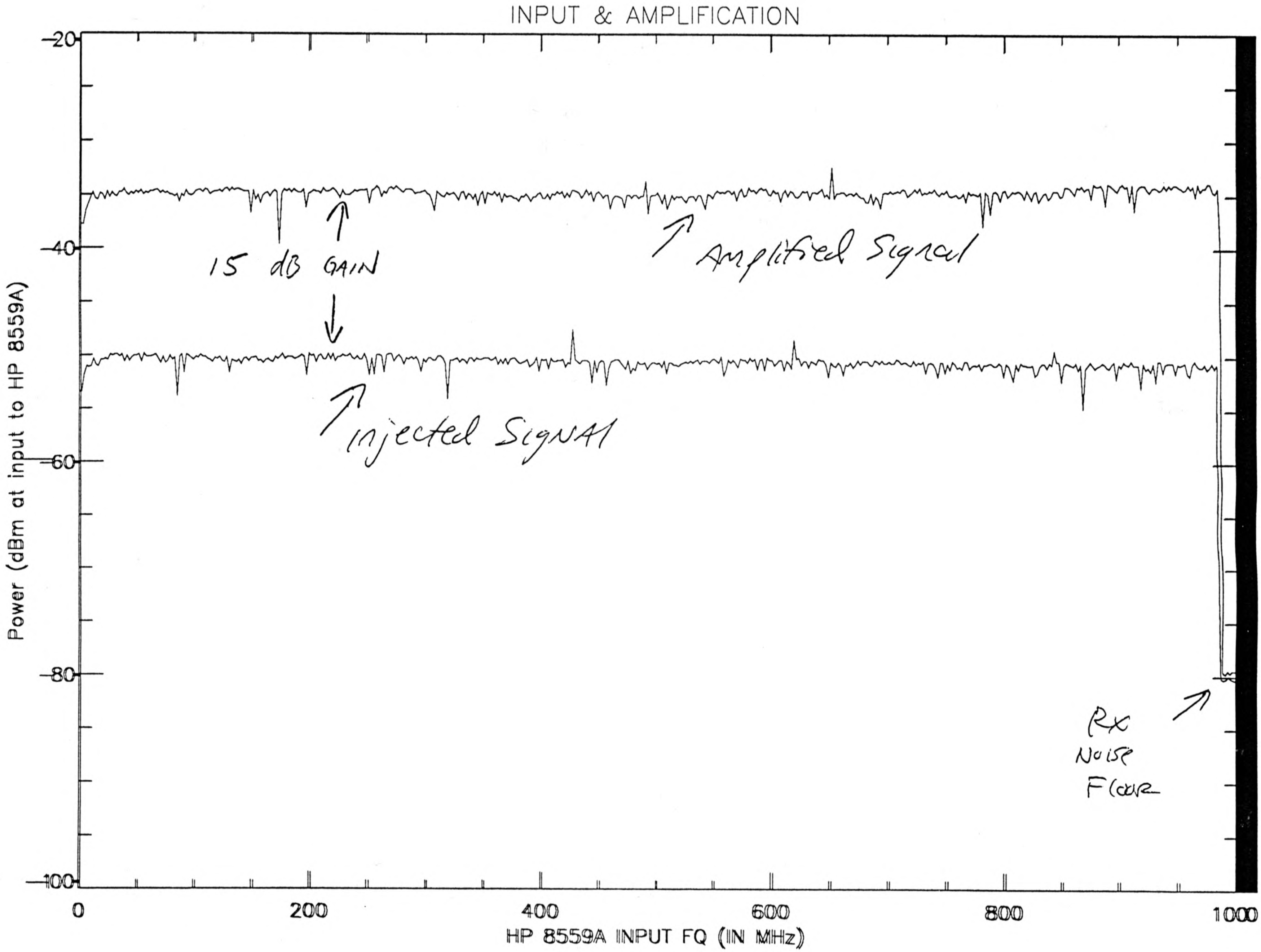
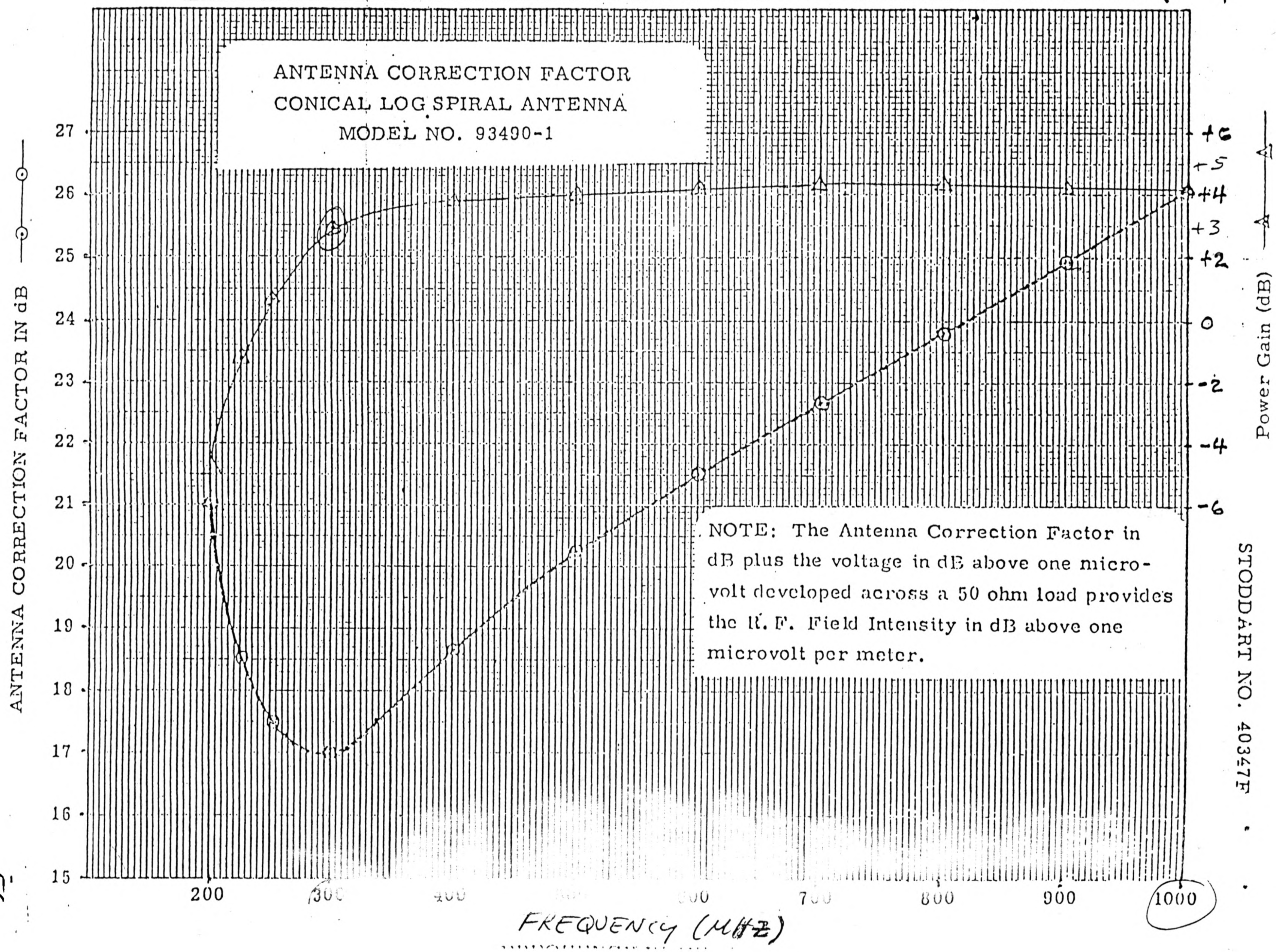


FIGURE 13: AMPLIFIER S/N 1002, 10 MHZ - 1GHZ, GAIN

FIGURE 14: 200-1000 MHz ANTENNA CORRECTION FACTOR



95

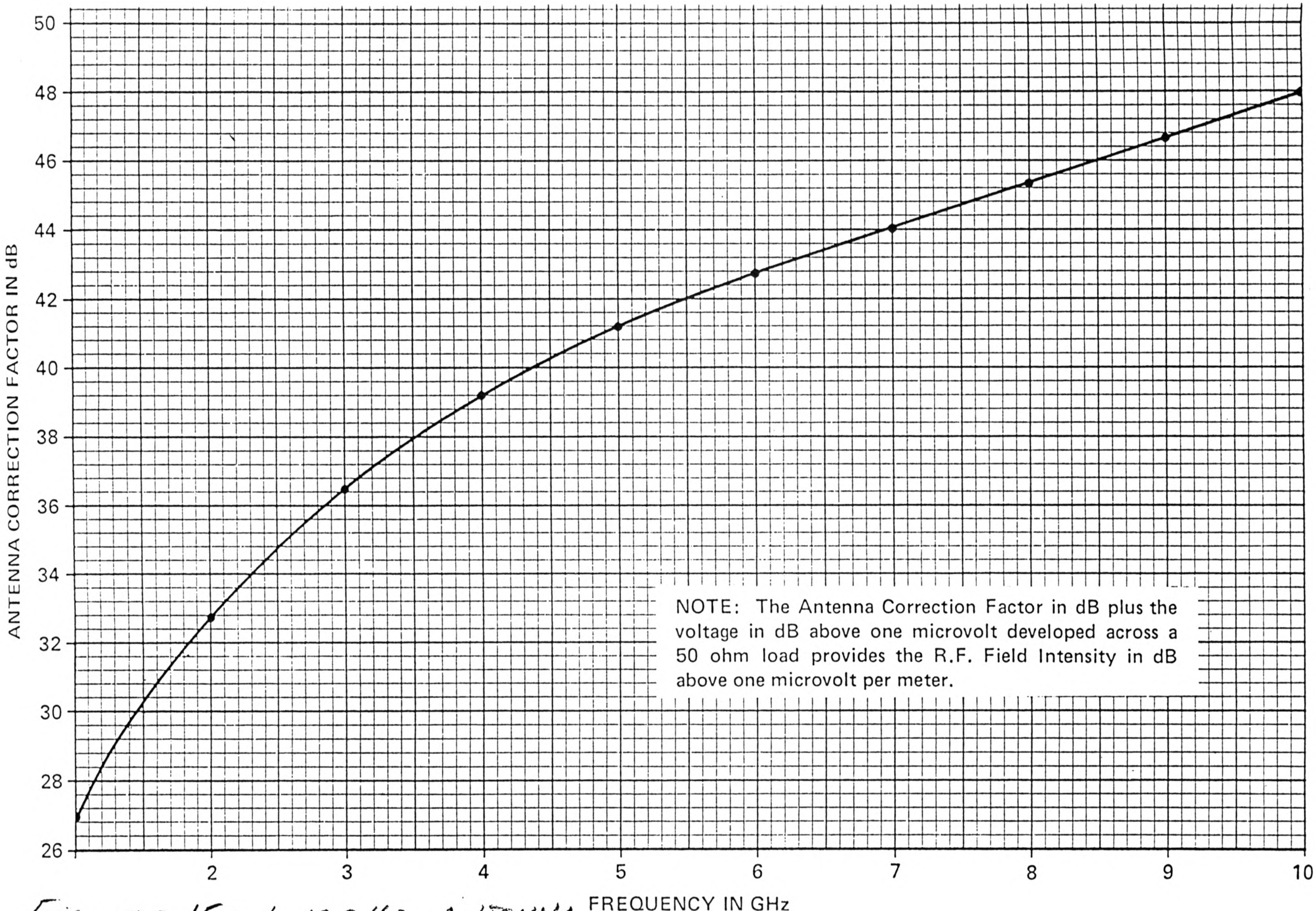


FIGURE 15: 1-10GHz ANTENNA CORRECTION FACTOR

[redacted]. Antenna Correction Factors, Model 93491-2 Conical Log Spiral Antenna

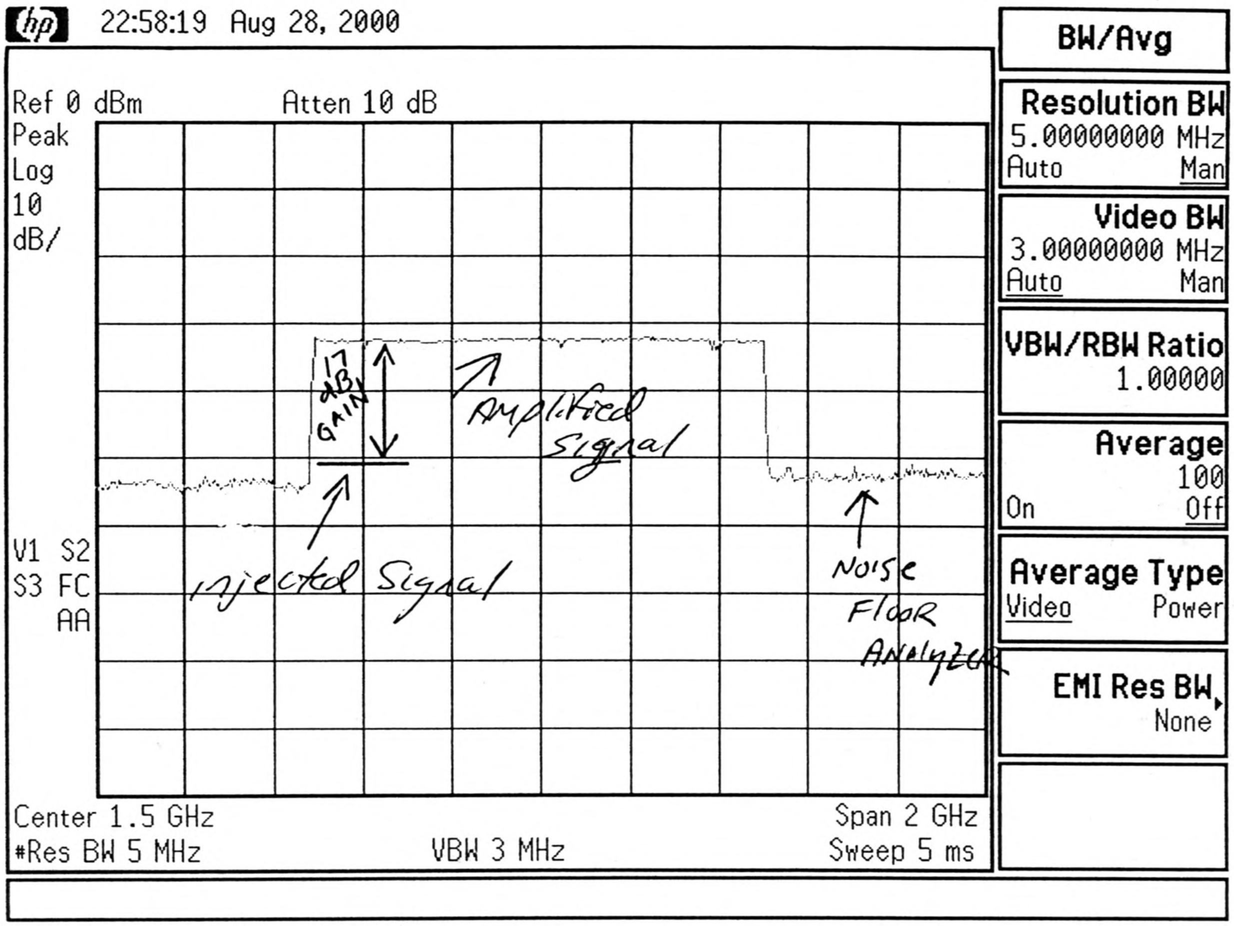


FIGURE 16: L-BAND AMP GAIN, 1-2 GHZ

L-BAND AMP Miteq AM-2A-1020 S/N 43599

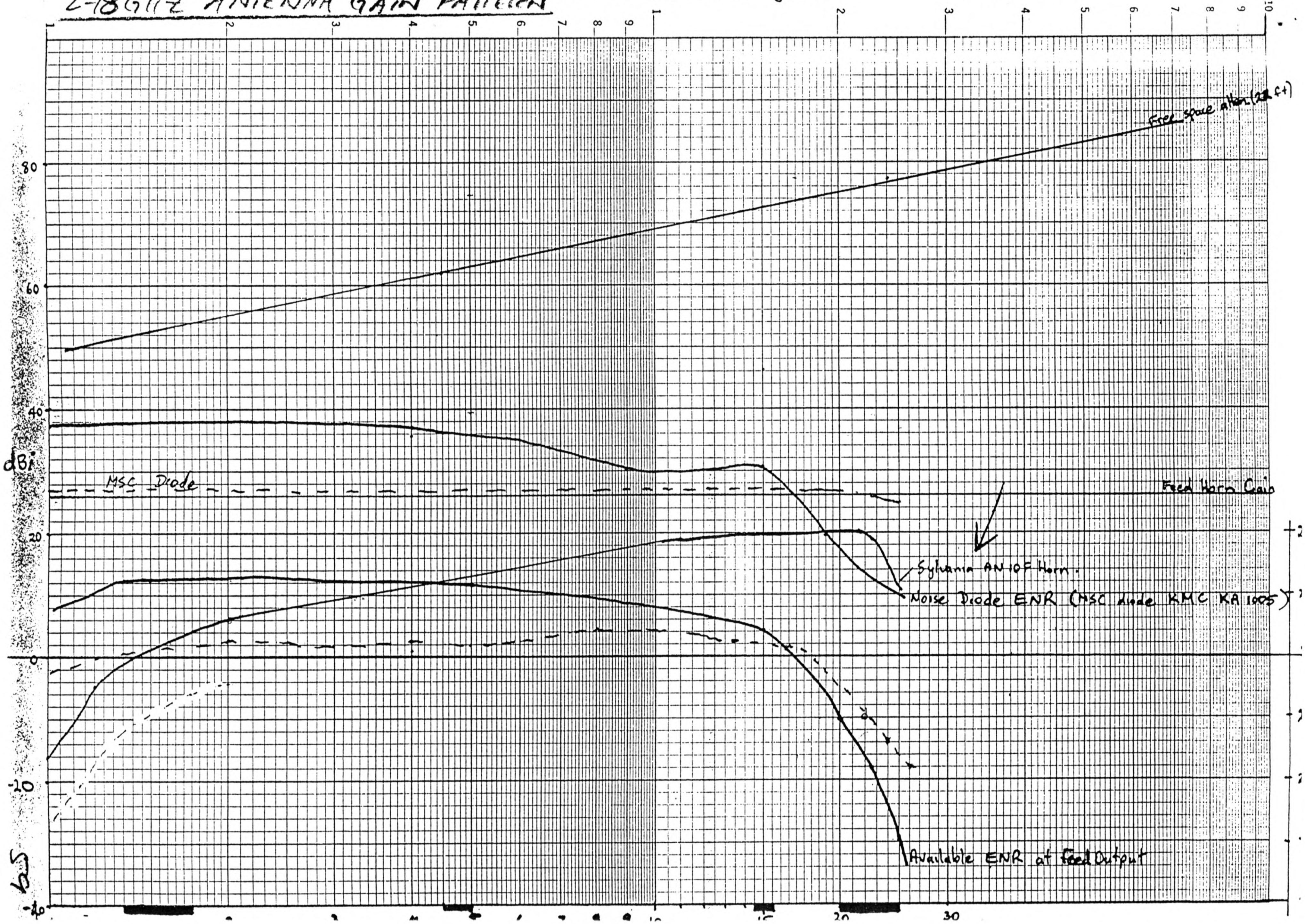
1.2-1.8 GHz specified range.

injected Swept Signal of -50 dBm over 1-2 GHz.

FIGURE 1.7 : 2-18GHZ ANTENNA GAIN PATTERN

VLA Calibration System

GTE SYLVANIA RIDGED HORN AN10-F
SERIAL 002



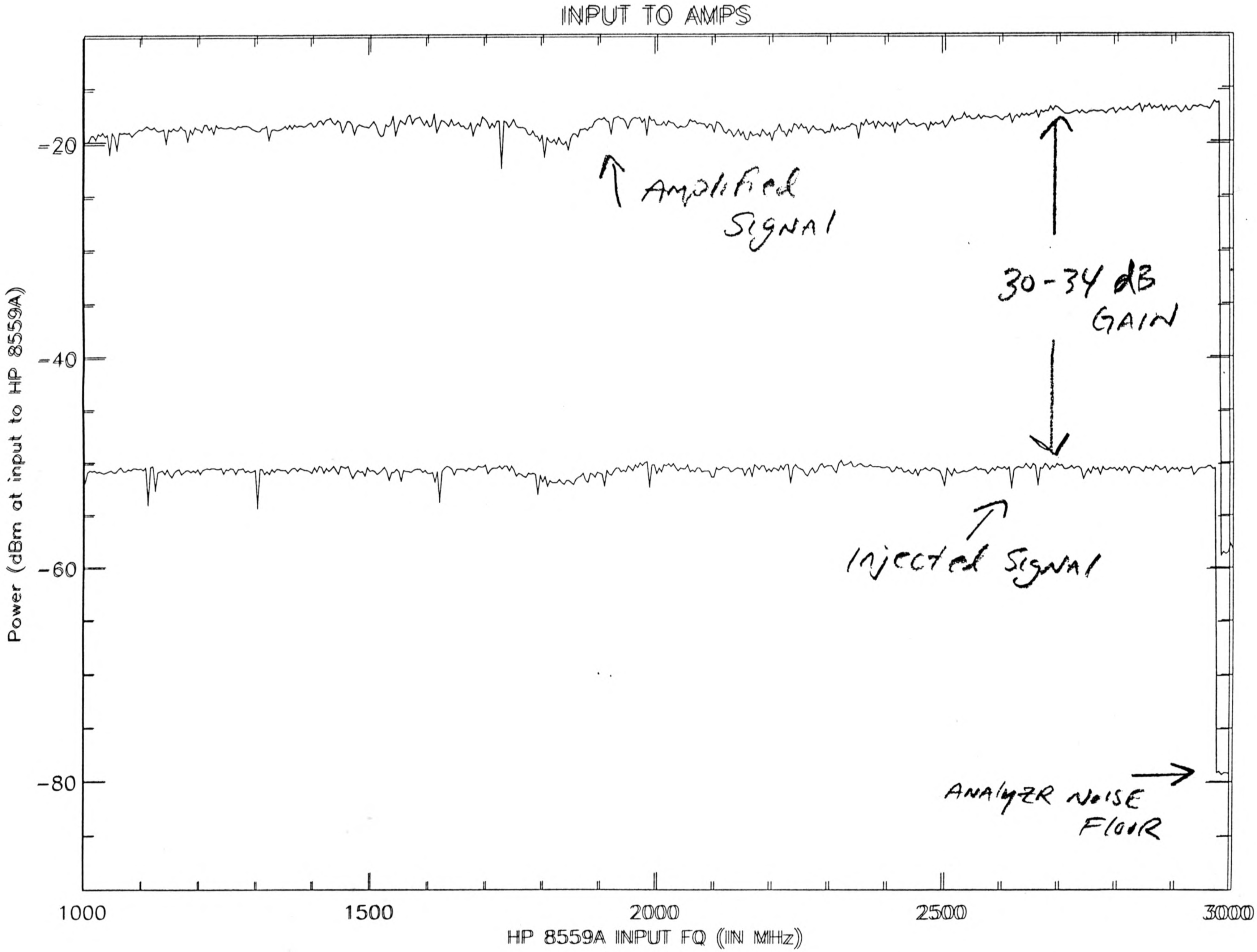
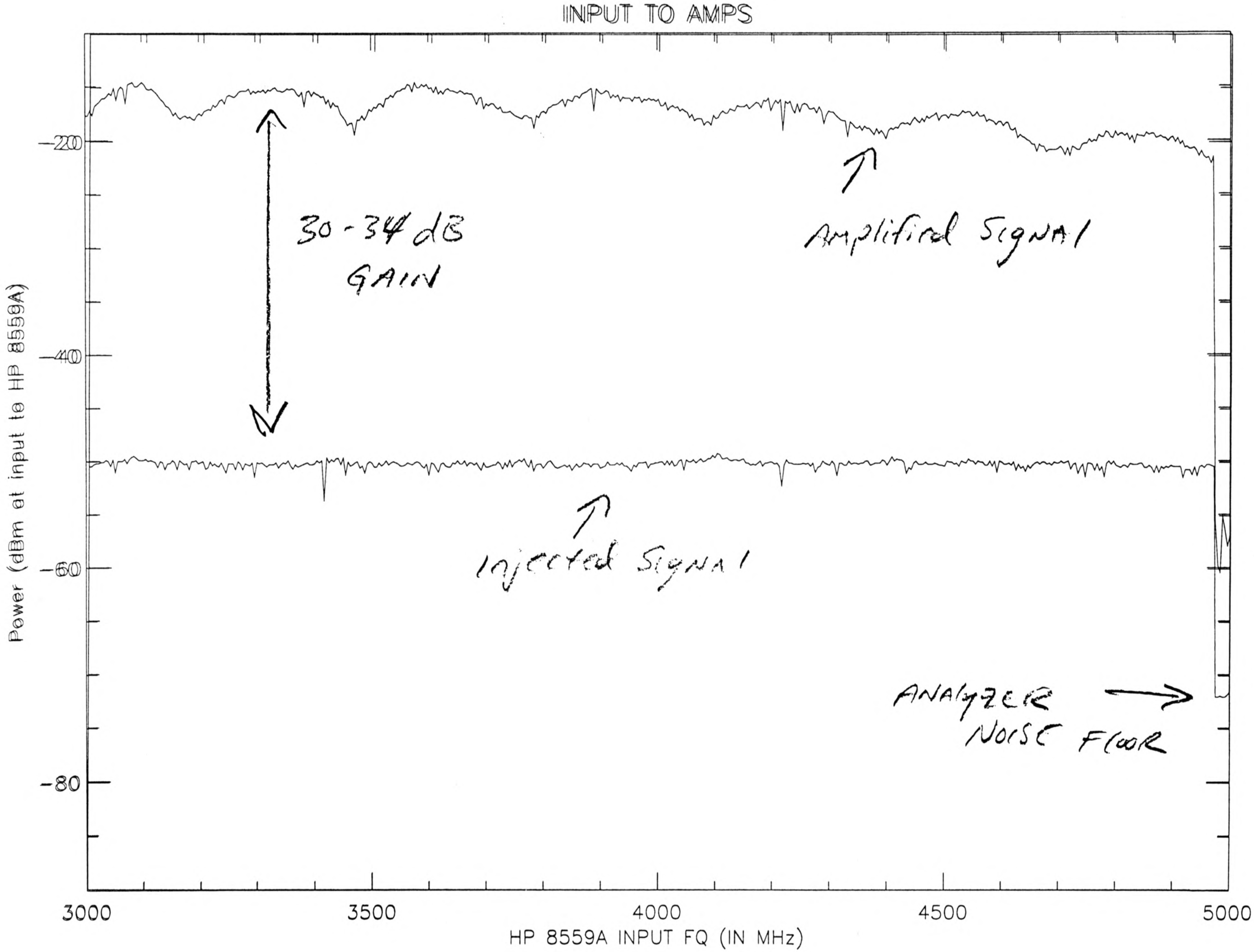


FIGURE 18a: JCA TECH JCA24-F01 S/N134 AMP GAIN, 1-5GHz

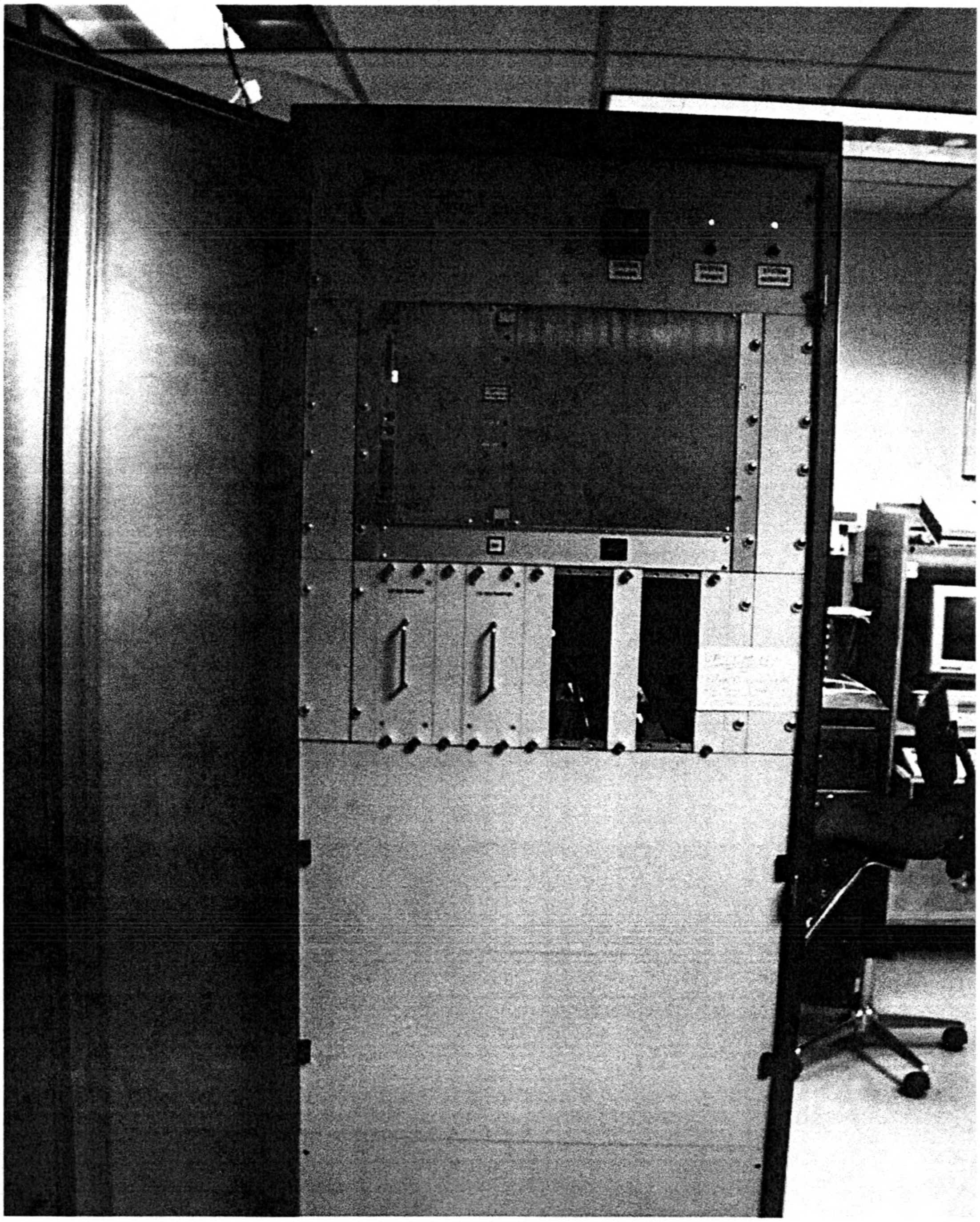


19

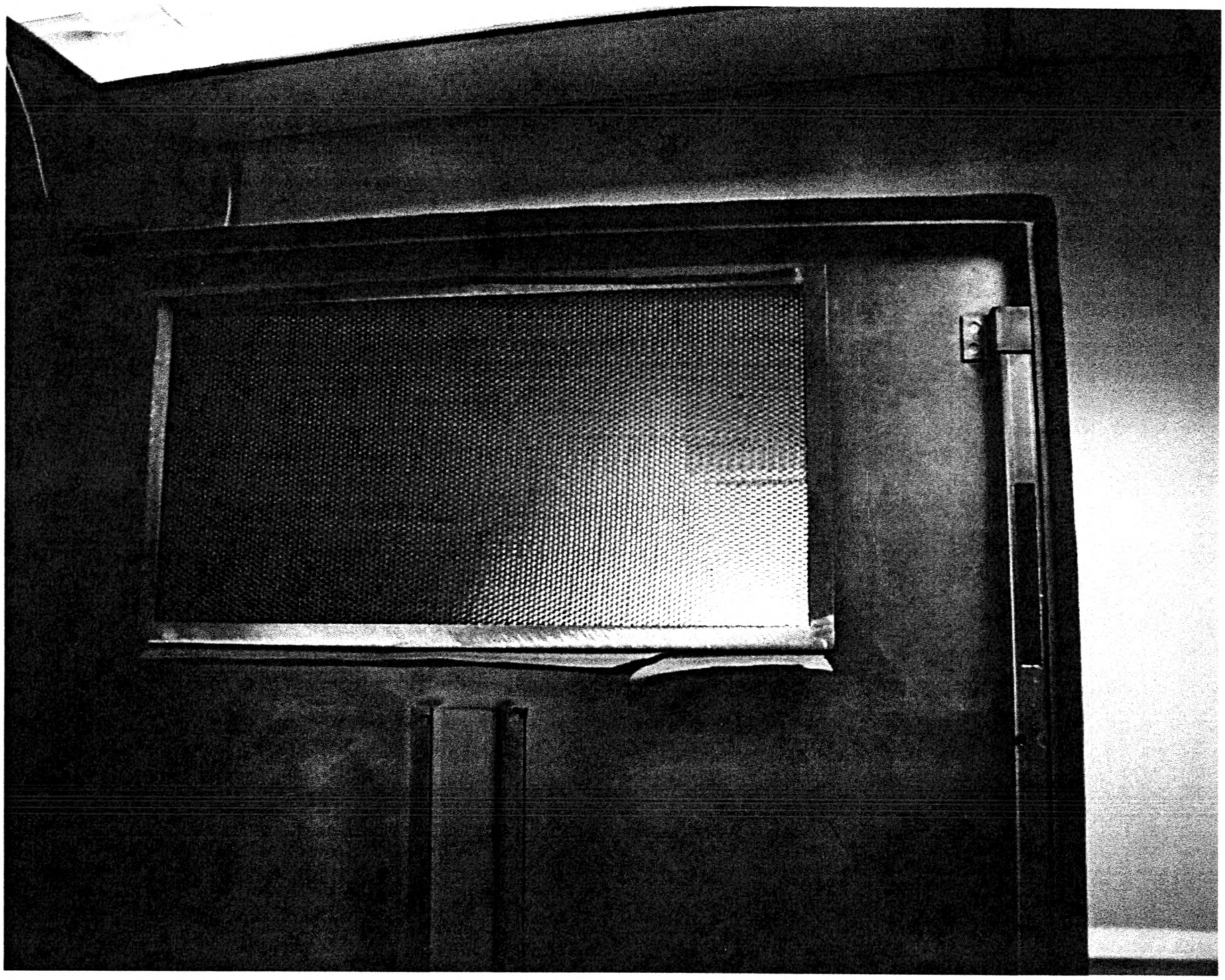
FIGURE 18b: JCA TECH JCA24-F01 S/N 134 AMP GAIN, 1-5 GHZ

Appendix 2

Photographs of Equipment under Test and Test Setup



Picture 1: Rack for Correlator and [illegible]



PICTURE 2: Honeycomb vent on AMCO enclosure,
AND METAL GASKET ON
[illegible]

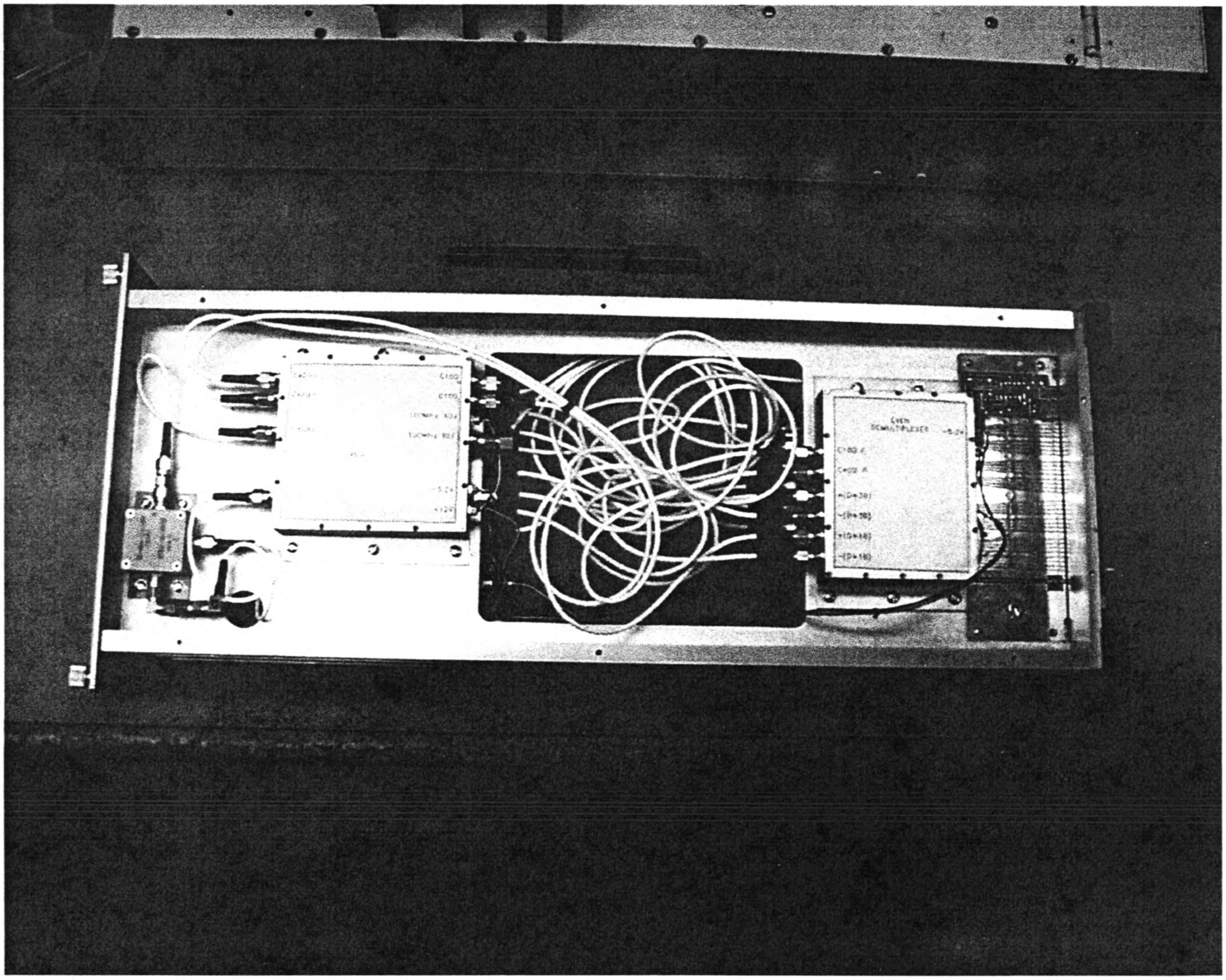
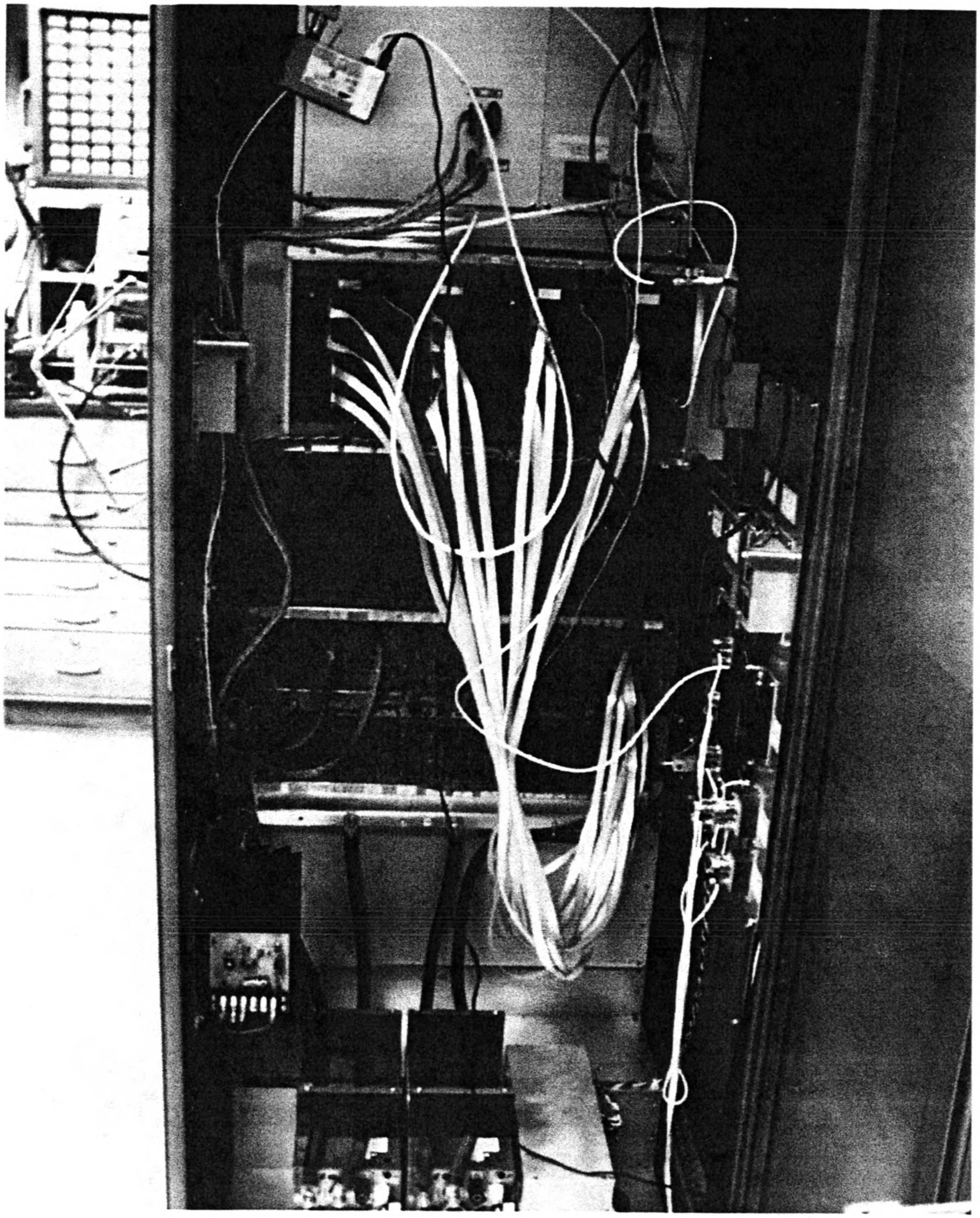
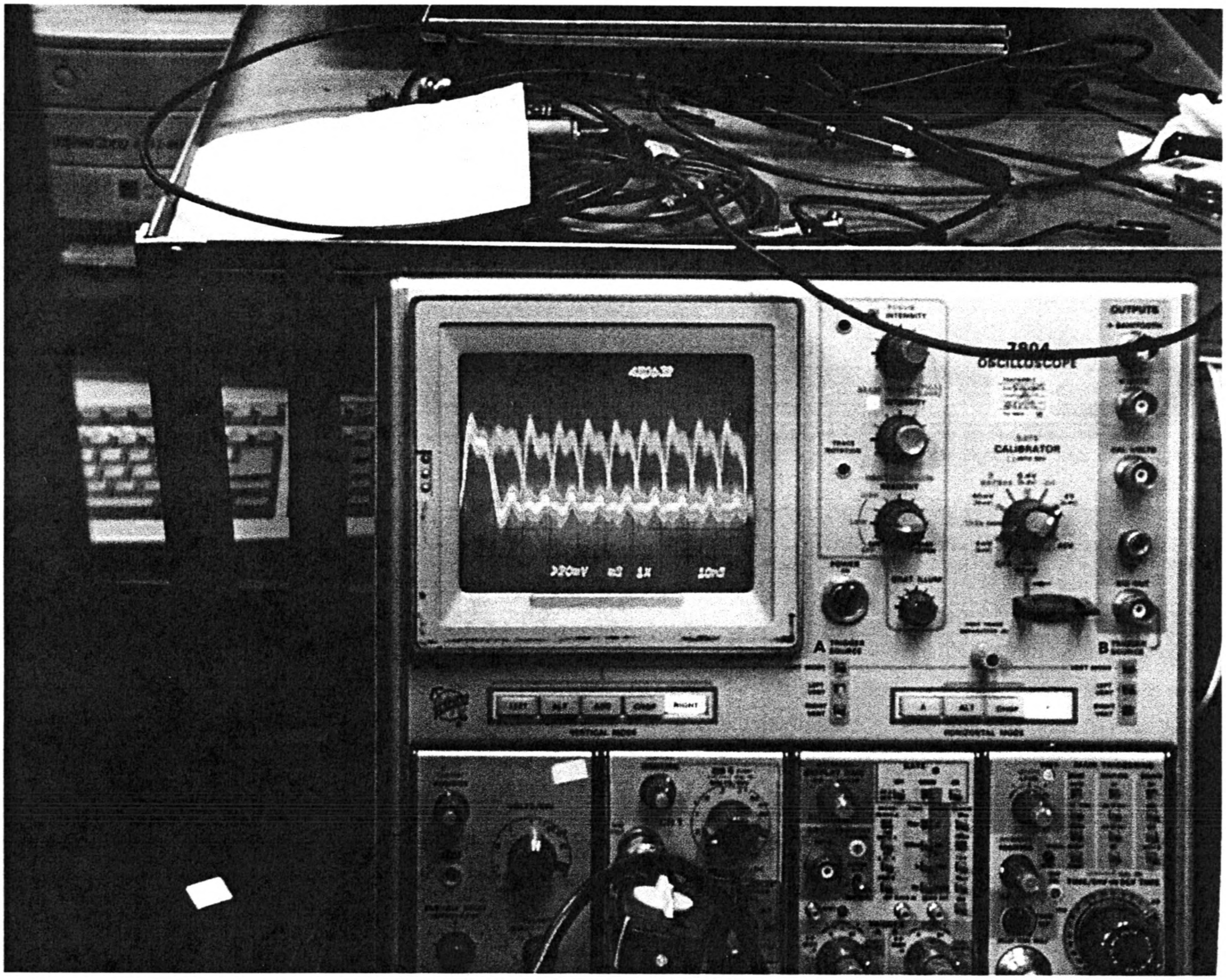


PLATE 3: 1.6 GHz DIGITIZER

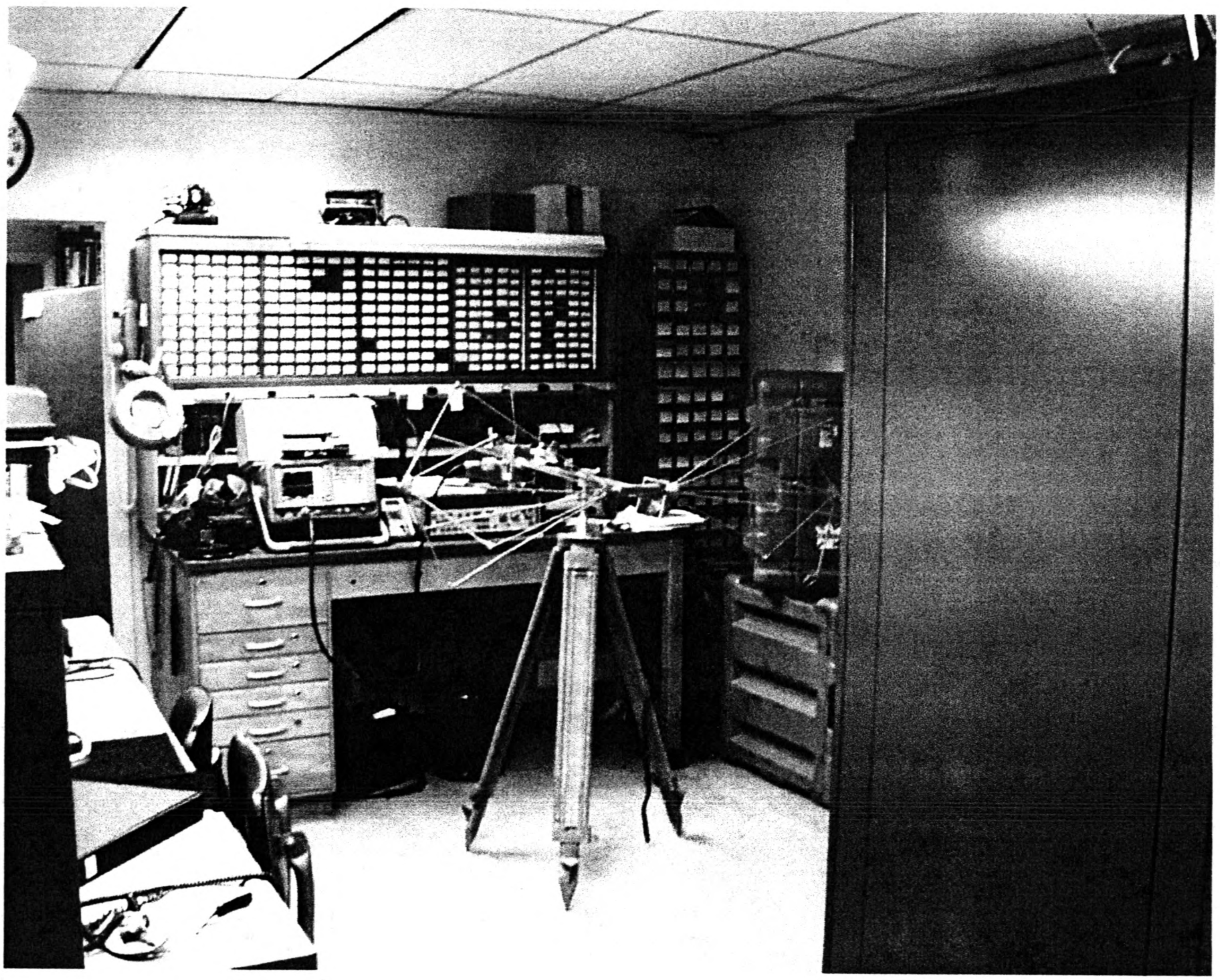


Picture 4: Ribbon Cables Between Digitizers AND CORRELATOR



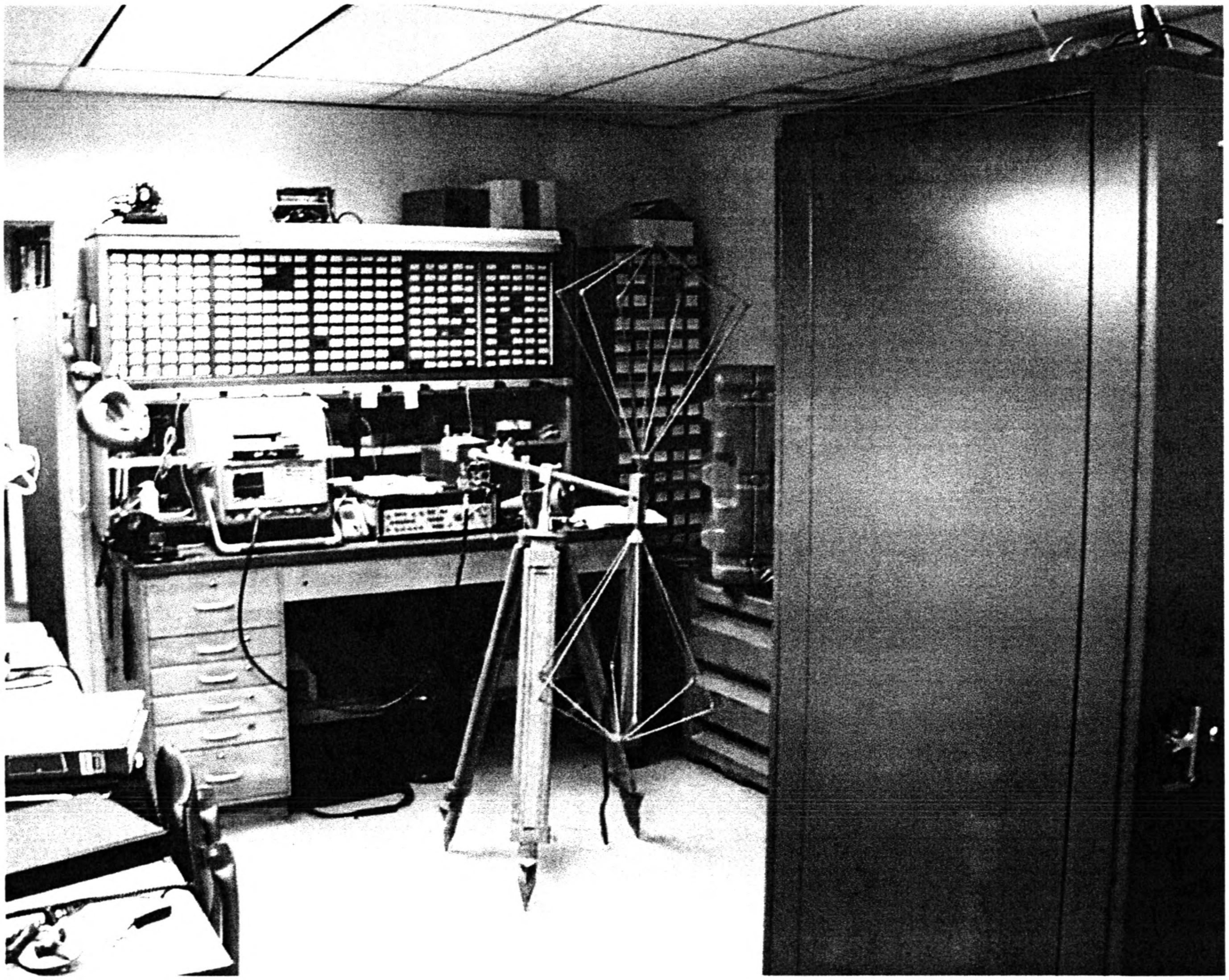
ECL 100 MHz

Picture 5: Digital [illegible]



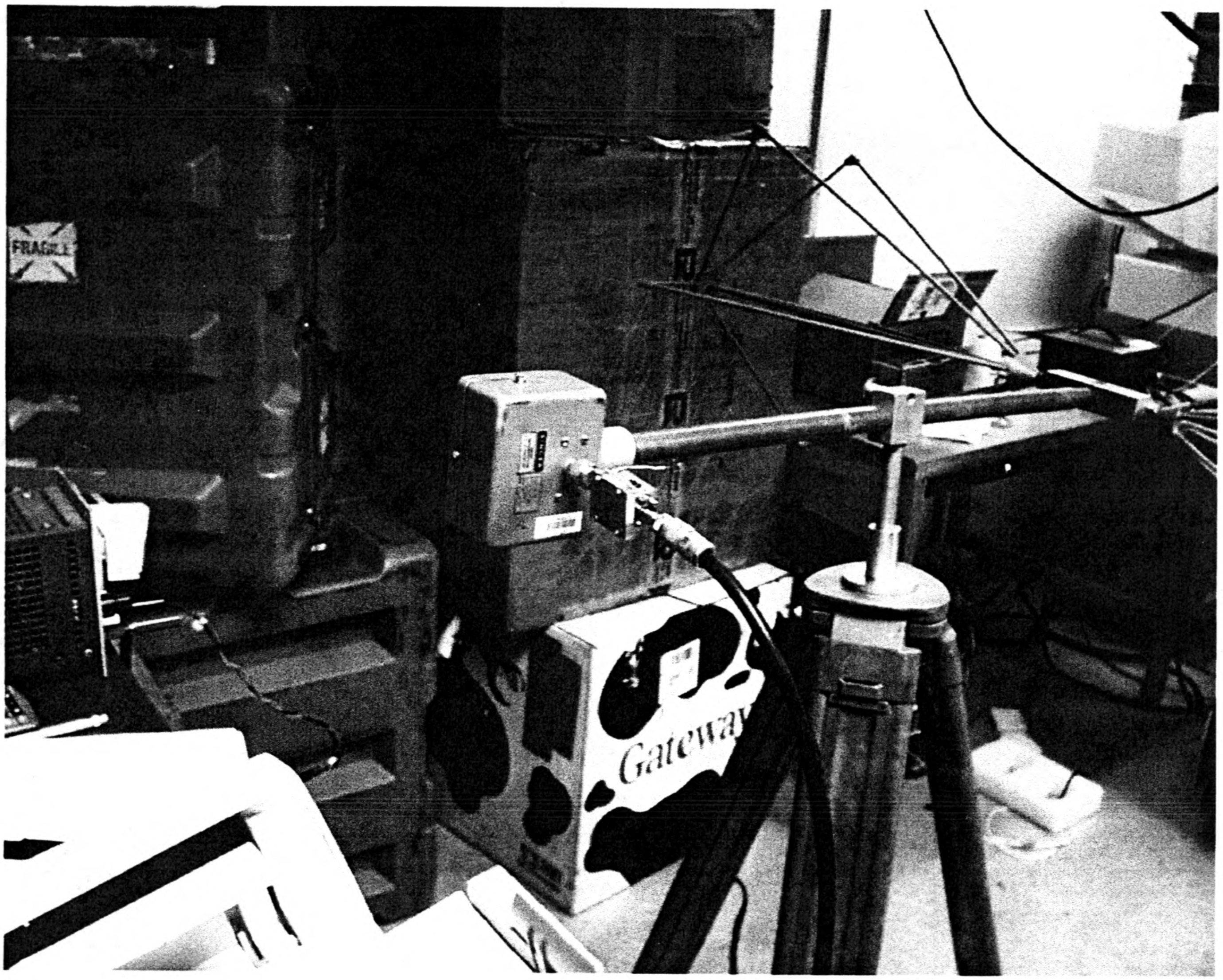
Picture 6: Biconical Pickup Antenna

30-200 MHz

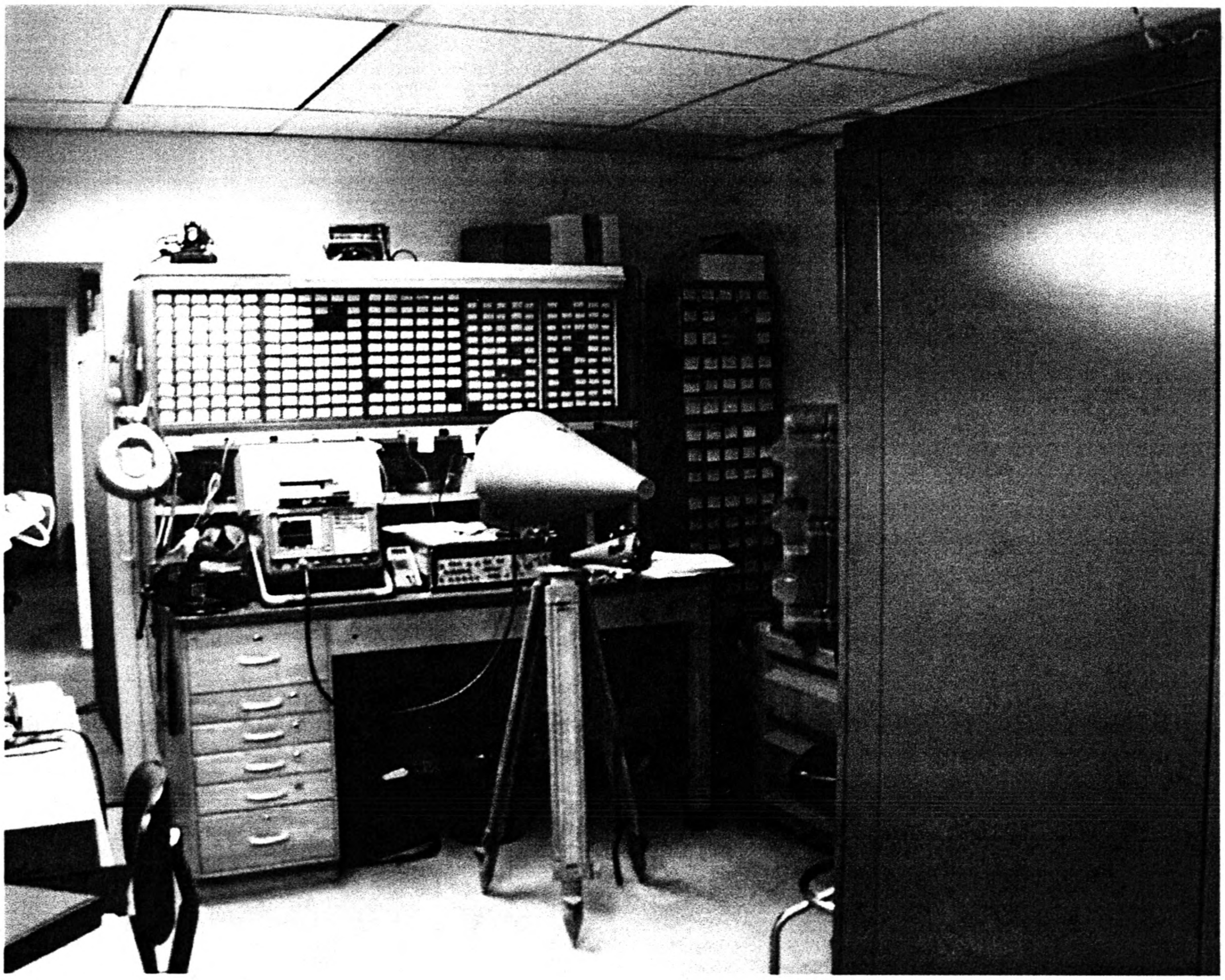


Picture 7: Biconical Pickup Antenna

30 - 200 MHz

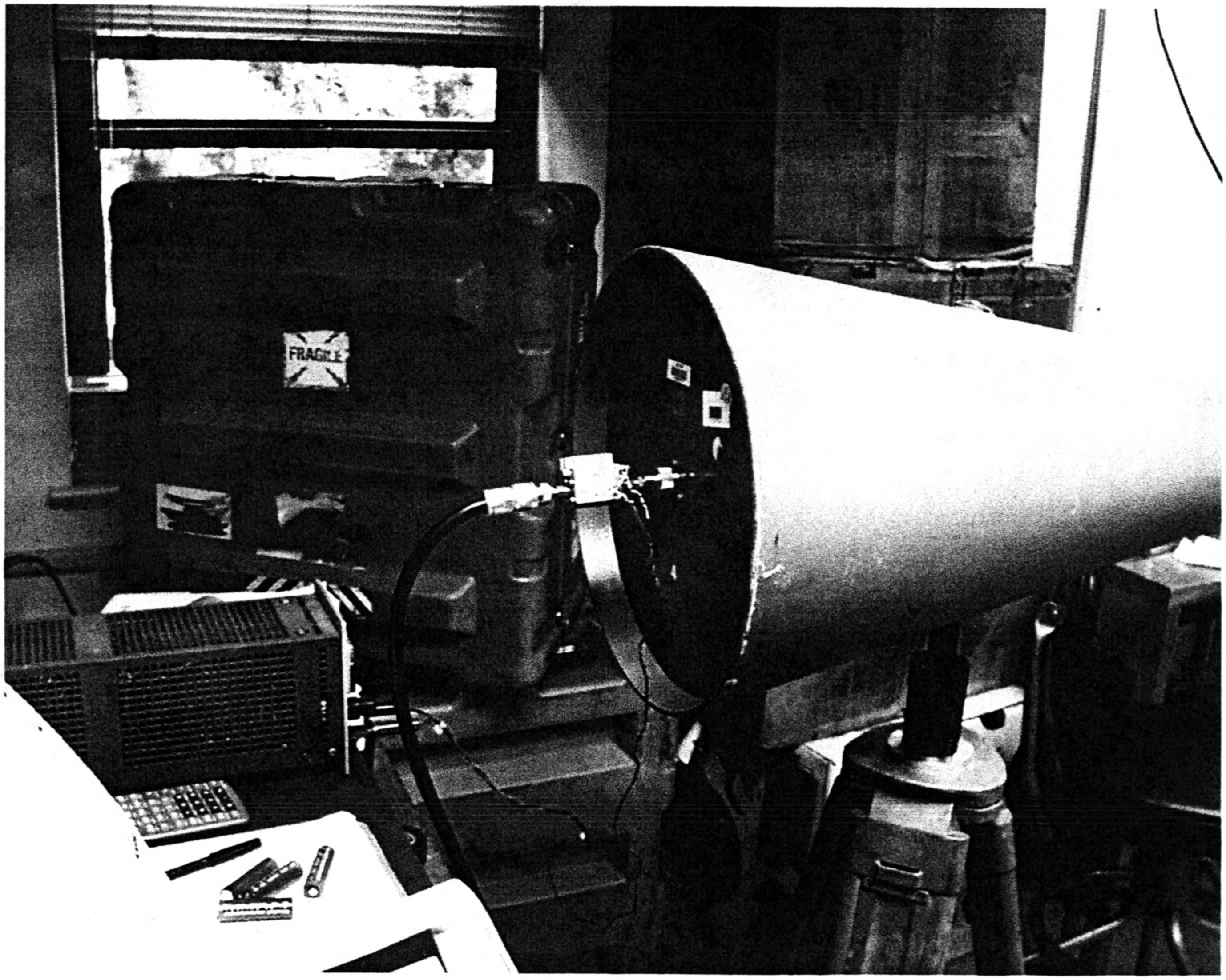


Picture 8: LNA at output of Biconical

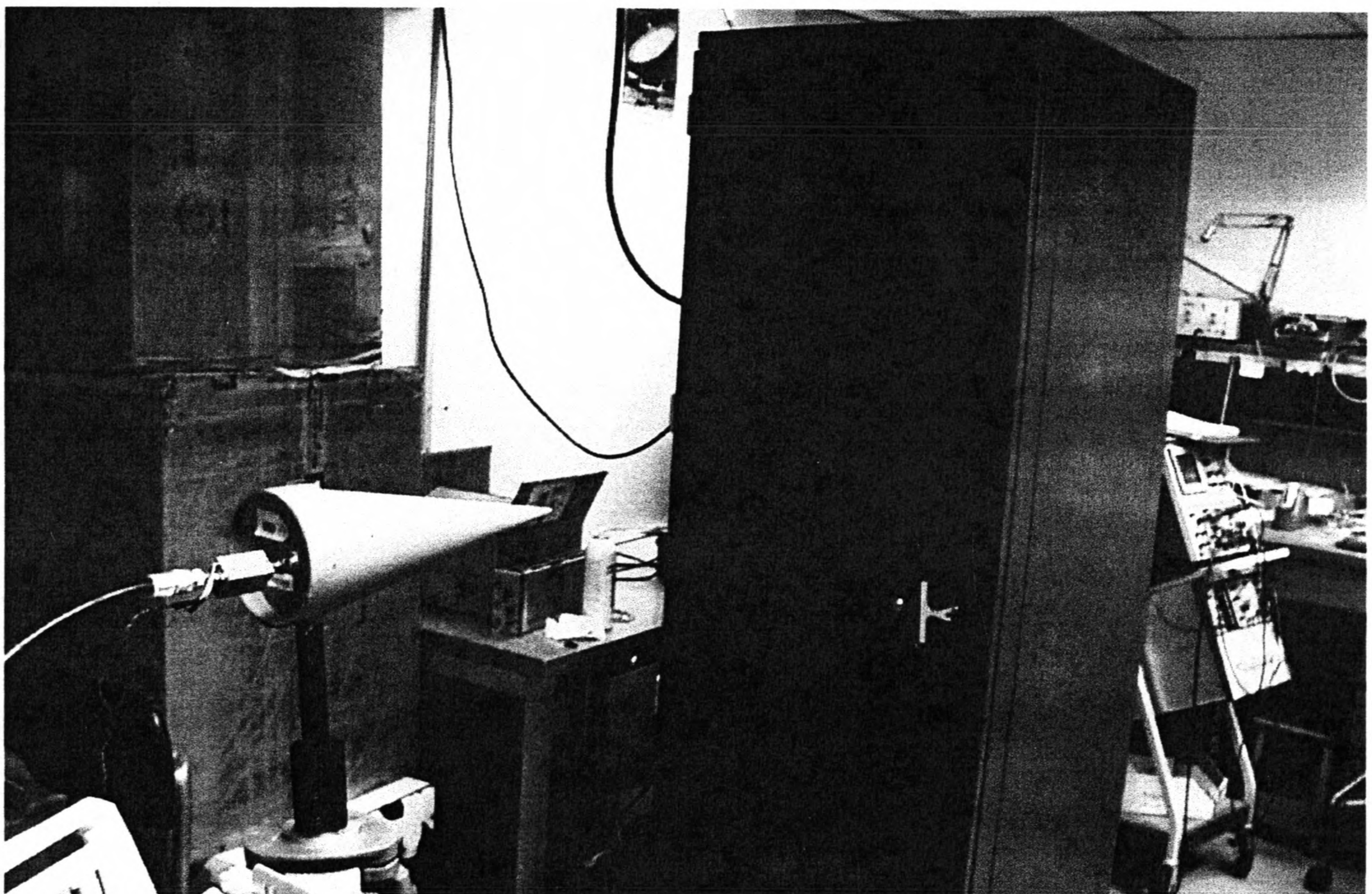


Picture 9: Conical log Spiral Antenna

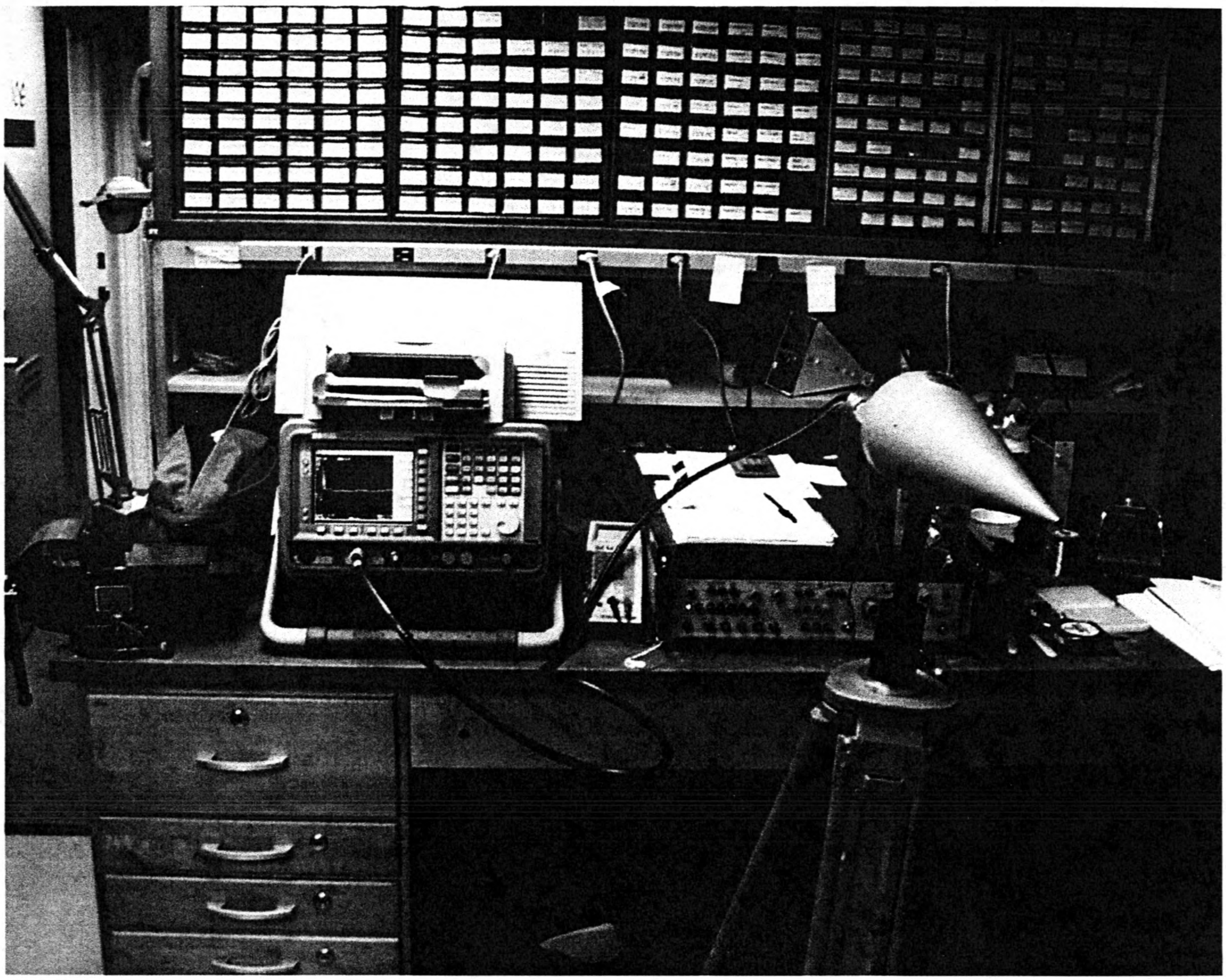
200-1000 MHz



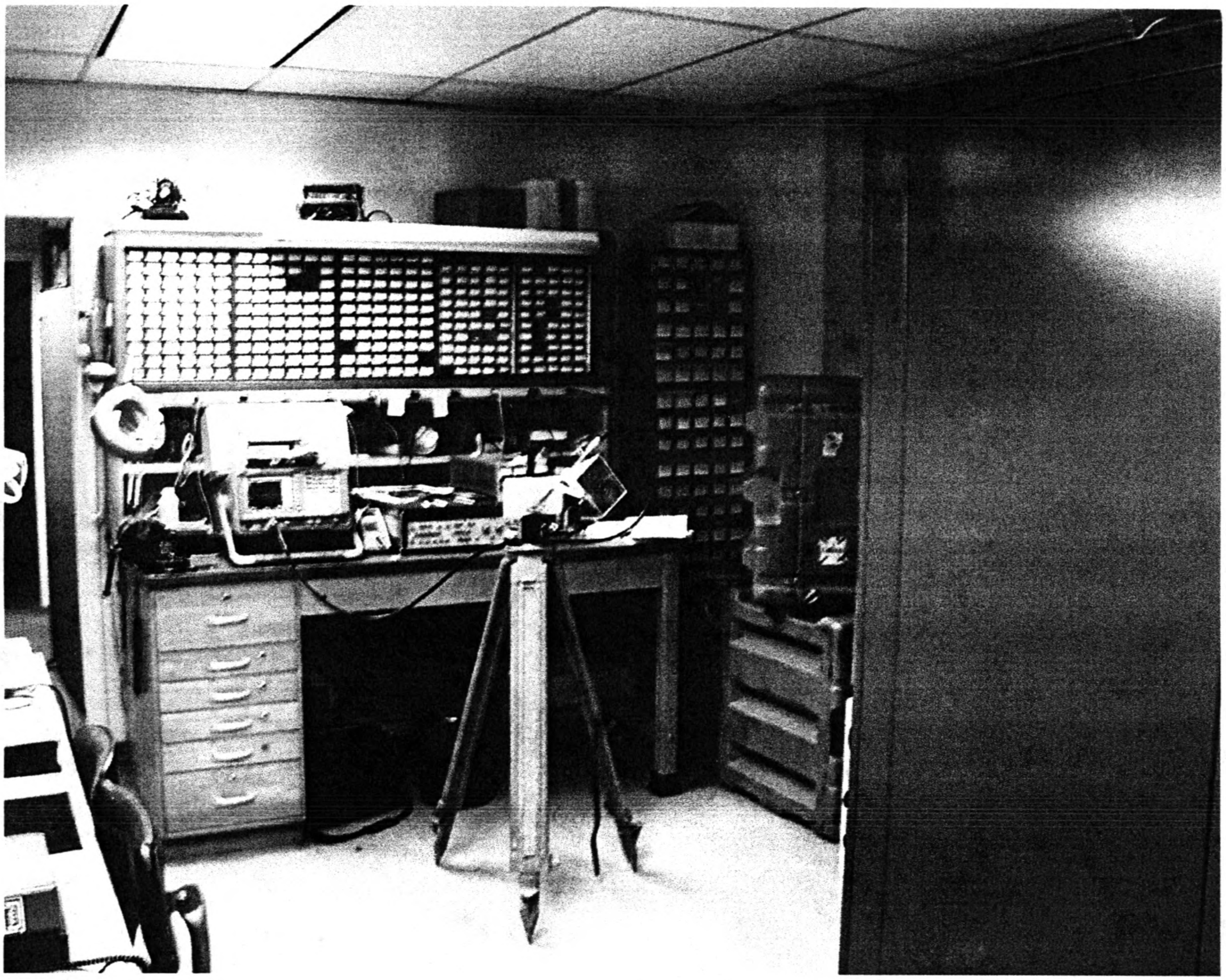
Picture 10: LNA at output of CLS



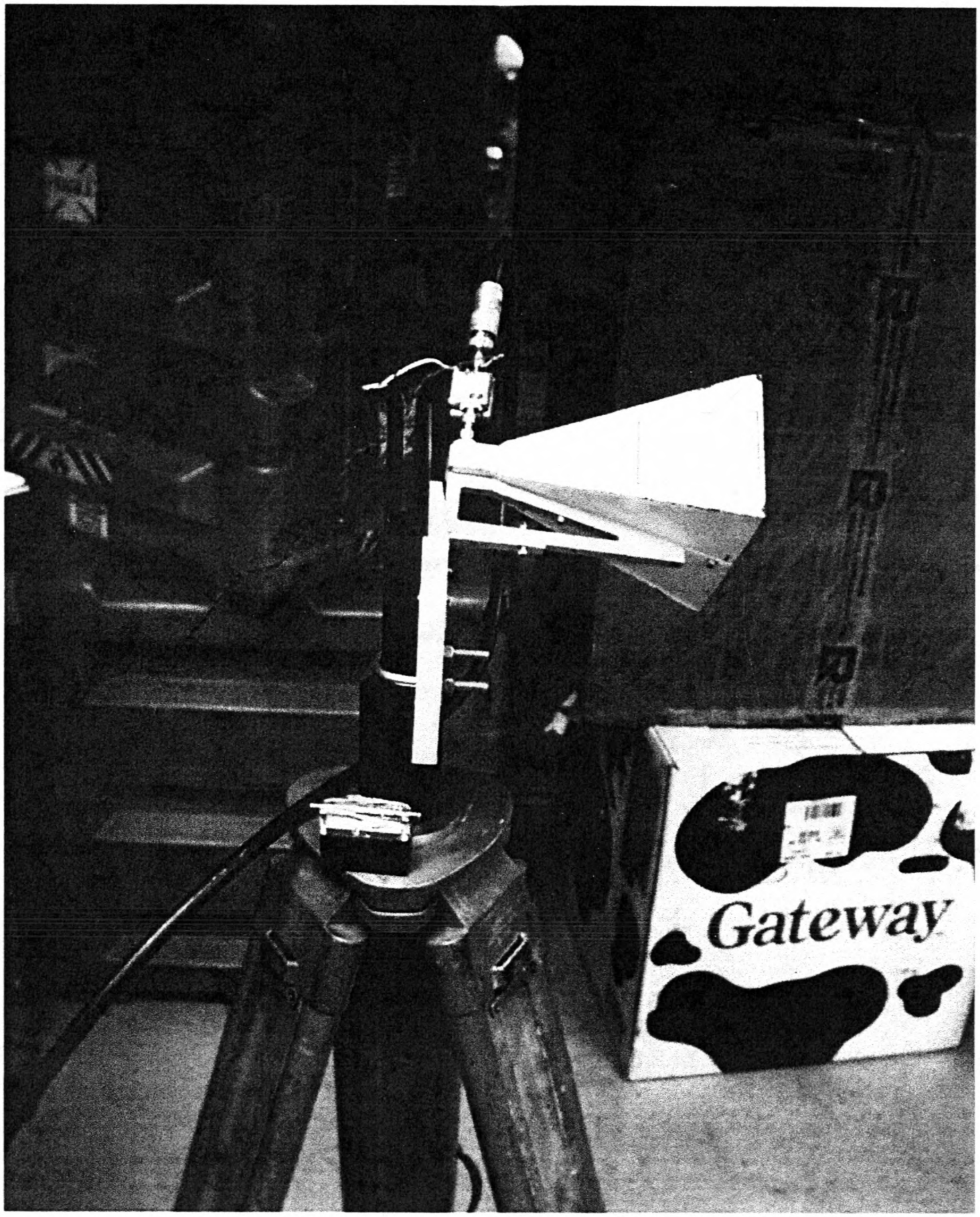
Picture 11: Conical log spiral antenna
1-10 GHz
AND LNA AT INPUT



Picture 12: Connection to Spectrum ANALYZER.



PICTURE 13: HORN ANTENNA 2-18 GHZ



Picture 14: LNA at output of horn

Appendix 3

Technical Information on ALMA Test Correlator and Digitizers

Alma Correlator overview

Chapter 1: Overview

1.1.0) Introduction

This manual describes the ALMA Test Correlator, built for the ALMA Test Interferometer. The correlator is built in a single rack with four 1.6 Ghz samplers in one bin and the digital electronics in a second bin. A third bin contains a VME chassis with an MV2700 Power PC processor board and an interface board that receives data from two Long Term Accumulators in the digital electronics bin. The system contains 64 correlator chips, each with 1024 lags, distributed among 4 correlator cards. Thus, there is a total of 65,536 hardware correlators in the test correlator. (See Fig. 1.0 for a rack layout of the ALMA Test Correlator).

The test correlator is designed to process data from two antennas, each of which has two channels. In order to satisfy the requirement for cross correlations between these channels, the ALMA Test Correlator has had modifications made to the correlator cards. Due to some restrictions in the sampler distributor design, the memory cards in the correlator have also been modified from their original design. The correlator and memory card modifications are both completely reversible in the event the correlator needs to be reconfigured for use beyond the Test Interferometer System. The modifications to these cards are treated in more detail in the chapters pertaining to each card.

The system has four 1.6 GHz samplers and, hence, can process telescope outputs up to 1.6 GHz in total bandwidth per antenna using the high-speed samplers. The high-speed samplers are 2-bit, 3-level digitizers. At the maximum bandwidth, the RF input to a high-speed sampler is from 1.6 GHz to 2.4 GHz at a nominal level of -14dBm. The explicit reference to high-speed samplers throughout this text is in contrast to the 100Mhz samplers that were used in the GBT.

A minimum of 16 correlator chips are required to process each baseband output when these high-speed samplers are used in their full bandwidth mode, hence the 65,536 hardware lags circuits can produce only 4,096 spectral points. See Table 1.1 for a list of the major modes possible using the ALMA Test Correlator.

The ALMA Test Correlator is designed in a single "quadrant" which contains all of the system correlators (the term quadrant is used here because the original design using existing cards was for the GBT correlator which had 4 quadrants. For this reason, the test correlator is sometimes referreed to as the GBT clone). This single quadrant can be programmed in several different modes during an observation if desired.

The ALMA Test Correlator works on a fundamental 1.31072 millisecond memory cycle and all parts of the system partake in some fashion in this cycle. The system memory cycle can be synchronized, upon computer command, to a telescope time tick signal. Normally, this synchronization is done at the start of an observation after which the correlator free runs on the internally generated, but of precise duration, 1.31072 millisecond cycle.

Illustrations in this manual come in two types: figures drawn expressly for the manual and drawings that are formally part of the ALMA drawing system (in some cases, released drawings still have the GBT drawing numbers indicating that they are identical to the corresponding GBT element). Most of the released drawings are in volume 2 of this manual. However, for convenience, some drawings are reproduced in both volumes of the manual.

TABLE 1.1. ALMA Test Correlator PERFORMANCE

A definition of the modes possible in the ALMA Test Correlator is given below.

correlator mode	number of samplers	sample rate	bandwidth per sampler	# channels per sampler	cross products	auto products
1 *	4	1.6 GHz	800 MHz	512	0R X 1R 0L X 1L 0R X 1L 0L X 1R	
2	4	1.6 GHz	800 MHz	1024	0R X 1R 0L X 1L	
3	4	1.6 GHz	800 MHz	1024		0R X 0R 0L X 0L 1R X 1R 1L X 1L
4 *	4	200 MHz	100 MHz	4096	0R X 1R 0L X 1L 0R X 1L 0L X 1R	
5	4	200 MHz	100 MHz	8192	0R X 1R 0L X 1L	
6	2	200 MHz	100 MHz	16384		0R X 0R 0L X 0L
7	2	200 MHz	100 MHz	16384		1R X 1R 1L X 1L

* Indicates polarization cross products are computed.

1.2.0) Block Diagram

Two block diagrams have been drawn for the ALMA Test Correlator. One diagram, drawing number 08020000z010 (computer file Z010D01.CAB), emphasizes the system block diagram from the signal flow viewpoint. The second block diagram, drawing number 08020000k002 (computer file K002D01.BLK), places the emphasis on computer and microprocessor communication within the correlator.

The Z010 drawing shows every card in the correlator and the signal interconnection between them. At the top of this drawing, the high-speed samplers are shown. Each pair of two high-speed modules share a single sampler motherboard. There are two sampler motherboards in the sampler bin.

Flat cables, 8-signals wide, connect the sampler motherboards of the sampler bin with the sample distributor card in the bin below it. Each 8-signal cable carries 1/4 of the output bits from a given sampler.

Block diagram Z010 shows how samples flow within the rack. Each one of the four memory cards in the "quadrant" drives 100-MHz data signals into each of the four correlator cards, where the generation of correlation lags of sampler outputs occur. Short-term integrations from the correlator cards drive into the LTA cards for long-term accumulation with each LTA card handling the output of two correlator cards. The LTA cards shift finished integrations into the interface card where they are read over the VME bus by the VME computer. There are two types of control cards seen in the Z010 block diagram. One is the correlator control card and the other is the system monitor card for system control, memory cycle timing, and analog monitoring.

The K002 block diagram shows all of the microprocessors in the correlator and how they communicate with the VME computer and a local terminal. There are two serial communication buses in the system and every microprocessor in the system can communicate over these two links. One is a bidirectional link with the VME computer. The data rate over this bus is 57.6 kbaud and it is the main bus for control and monitoring of the correlator by the VME computer. The other link is a local terminal bus running at 9600 baud (8-bits, no parity). Within the correlator, both serial links are differential RS-422. Outside the correlator, the signals are RS-232.

While both serial links are two-way party line buses, there is no way for a microprocessor to initiate a communication session over either bus, nor is there any way for one microprocessor to communicate with another microprocessor. The VME may broadcast commands to two or more of the individual microprocessors (see appendix 1 for the serial communication protocol).

1.3.0) Clock Distribution

The 100-MHz site clock at the VLA drives the correlator with an input level of 0 dBm. This signal drives an RF power amplifier to develop a high level 100 MHz sinewave clock. This power amplifier and the RF power splitters seen in drawing A35208Z015 (computer file Z015D01.CLK) split the high level 100 MHz sinewave many ways. Every card requiring 100 MHz clock receives a ~2.0 VPP 100 MHz sinewave from the power splitter, and wave shaping circuits on each card use this sinewave input to develop 100 MHz ECL and TTL on-card clock signals.

Each 1.6 GHz sampler has a 1.6 GHz phase-lock loop to generate its sample clock from the system 100 MHz clock.

1.4.0) High Speed Operation

The high-speed samplers sample at a rate of 1.6 GHz. The correlator chips, however, can only run at a maximum 100 MHz clock rate. In order to match the clock rates of the samplers and the correlator cards, the high-speed sampler outputs are de-multiplexed by a factor of 16 (that is, every high-speed sampler has 16 parallel 2 bit outputs on the system 100 MHz clock, where any given output carries bits from every 16th sample). In order to simplify the correlator architecture, an unconventional way of providing correlators for the high-speed samplers was used.

Instead of employing the convential method of using a two dimensional (16 X 16) array of small correlators, a RAM memory card was designed to reorder the 16 parallel sampler outputs. This RAM card writes the samples into a large (32K X 64 bit) RAM at the equivalent of the 1.6 GHz sample rate and extracts sixteen 100 MHz outputs from the RAM, where each output carries short bursts of time contiguous sample bits.

Figure 1.1 illustrates the operation of the RAM memory card. The RAM buffer can be thought of as a circular buffer into which a high-speed sampler output is written at the full 1.6 GHz sample rate. Thus, the write address generator is a free-running 15-bit counter that goes around and around the circular RAM buffer storage space. The 16 outputs of the memory card are each apportioned 1/16 of the RAM storage space. In the time the write function takes to write the entire buffer, the read operation for, say, correlator chip #1 can exactly read its 1/16 part of the RAM. During this read, the memory card output into correlator chip #1 consists of 131,072 contiguous samples, originally taken at 1.6 GHz but now slowed down to 100 MHz.

When memory card output #1 reaches the end of its allotted part of the RAM, it starts over at the start address which now will have fresh samples stored in it since the old samples would have been completely overwritten during the 1.31072 msec the previous read cycle took. Since there are 16 outputs from the memory card, all of the original samples will find their way to a correlator chip.

There are two sources of inefficiency in this process. First, when a given memory card output ends a scan of its allotted RAM addresses and starts a new scan, a discontinuity in time in the sample stream occurs. It will take 1024 100-MHz clocks for this time discontinuity to propagate through a 1024 lag correlator chip, and the chip must be blanked during this period (because the two inputs of a given correlator lag circuit, the "delayed" input from the lag generating shift register, and the "prompt" input that goes to all 1024 correlator circuit inputs in parallel may come from samples on opposite sides of the time discontinuity). In modes where 1024 lag correlator chips are connected in series to produce more lags, individual chips must be blanked for more than 1024 clocks. For example, if 2 correlator chips are connected together to produce 2048 lags, the first chip is blanked for 1024 clocks after the time discontinuity, the second for 2048. This complexity is used to minimize the loss of efficiency. Lag normalization before Fourier transformation removes this stepped integration time from the final spectrum.

A second source of inefficiency is the fact that samples on either side of a boundary between two memory card output segments never get correlated against each other. With a large RAM buffer, however, both of the effects are minimal.

The memory card is also used in the ALMA test correlator as a delay line. Since the correlator must generate cross correlations between two physically separated antennas, some means of delay compensation must be provided. Part of the large RAM buffer on the memory card is used to support the delay function. The correlator control card can program memory cards in the system with a delay value for proper interferometer delay tracking.

1.5.0) correlator Test Capability

The ALMA Test Correlator has a limited capacity to do stand-alone end-to-end testing of itself. This test requires a test sampler module. This module is built just like a high speed sampler but has a pseudo random data generator in it instead of a real sampler. This data generator can be synchronized to the system memory cycle by connecting a coax cable from the system monitor card connector J2 to the SMA connector on the front of the test sampler. A schematic of the test sampler is seen in drawing 35208L008 (computer file L008D01.SCH).

The test sampler data generator produces a pseudorandom data pattern that repeats itself exactly every 1.31 msec memory cycle. Thus, if correlator card integrations on this signal are taken, the integration results should exactly repeat every time.

1.6.0) correlator System Monitor

The system monitor card in the ALMA Test Correlator monitors system DC voltages and temperatures. All power supply voltages go to the analog multiplexors on the system monitor for monitoring. A temperature sensor, positioned over the digital bin, is also connected to the system monitor card for measurement. The system monitor card will continually scan all of the analogs in the system and keep a file of measurements in its memory. Measurements can be viewed on a local terminal or can be sent upon request to the VME computer. If a dangerous voltage or temperature is found during an analog scan, the system monitor card may shut down power to the system.

1.7.0) correlator Interface

The ALMA Test Correlator interface can be seen in drawing 35208K003 (computer file K003D01.BLK). The interface signals include:

4 RF inputs up to 800 MHz wide at -14 dBm to the high-speed samplers
2 3-wire 9600 baud 2-way RS-232 serial links
1 100 MHz sinewave 0 dBm clock
1 50-ohm TTL single ended time tick signal
1 ethernet connection

1.8.0) Power Requirements

The ALMA Test Correlator power requirements can be seen in drawing 35208Z007 (computer file Z007D01.RAK). The system has a single 3-phase 208 volt power connection for the sampler and digital portions on the system and a single 1-phase 120 volt circuit for the VME crate. Power load on the 3-phase circuit is less than 1 kW.

Appendix 4

Model numbers for EUT Shielded Enclosures

AMCO FRF enclosure: see manufacturer quote below.

VME chassis:
Solutions Systems Technologies
11-07R12J12-P500, s/n 4060A

Digitizers: module mounted in AMCO enclosure.

attachment to NRAO P.O. # 101409

AMCO

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A005				1-BAY EMI/RFI CONSOLE CONSISITNG OF THE FOLLOWING:					
A010									
A015	1	EA	FRFD70-24-30LR	FRAME ASSY FRFD	A	895.00		895.00	895.00
A020	1	EA	BFC-24-30	BASE ASSY BFC	A	113.00		113.00	113.00
A025	1	EA	DRF70-24L	DOOR ASSY DRF-5	A	477.00		477.00	477.00
A030	1	EA	DRFOTB70-24R	DOOR ASSY	A	518.00		518.00	518.00
A035	2	EA	SPRF70-30	SIDE PANEL ASSY SPRF	A	149.00		149.00	298.00
A040	1	EA	S-27290-14	PANEL ASSY TBPSF-24-30		84.00		84.00	84.00
A045	3	EA	HCRF6	HONEYCOMB ASSEMBLY, MTD W/ S-27290-14		143.00		143.00	429.00
A050	1	EA	TBPOF-2-24-30	PANEL ASSY FLAT TBPOF-2	A	89.00		89.00	89.00
A055	3	EA	HCRF8	HONEYCOMB		143.00		143.00	429.00
A060	1	EA	PSRF	COVER PLATE ASSY SOLID TOP TBPOF-2-24-30	A	16.00		16.00	16.00
A065	4	EA	CA1-RF	CASTER ASSY CA1-RF, INSTALLED		9.00		9.00	36.00
A070	1	EA	BBRF70	BUS BAR ASSY, HINGE SIDE REAR		78.00		78.00	78.00
A075	1	PR	MRFX-70	MTG CHANNEL ASSY MRFX MTD CENTER		43.00		43.00	43.00
A080			SPECIAL NOTE	ASSEMBLE REF: DWG 78814A-SH1 AMCO-					
A085				24" BAY ONLY FOR THIS ORDER.					

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