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Agency

Office of Radiation Programs
Nonionizing Radiation Branch
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Development of a System to Measure the Response Time of Microwave Survey Instruments to Rotating Radar Antenna Patterns

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by

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DISCLAIMER

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Abstract

The Nonionizing Radiation Surveillance Branch of the U.S. Environmental Protection Agency conducts a program to assess environmental exposure levels of radiofrequency fields and to develop Federal regulatory guides to limit the exposure of the population to radiofrequency fields. An essential element of this program is the maintenance of an electromagnetic field measurement and instrumentation calibration capability. This report describes a project which developed a laboratory method for evaluating the response characteristics of microwave survey instruments used for assessing microwave exposure hazards. This project involved the development of a system for simulating, in a controlled fashion, the time varying microwave fields that would be present around a high-power radar antenna which rotates. A suitable synthesis of such fields provides a convenient and accurate way to evaluate the response time of survey instruments and therefore establish uncertainty limits for instrument readings obtained in similar environments.

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Purpose of Project

One of the functions of the Nonionizing Radiation Surveillance Branch (NRSB) of the U.S. Environmental Protection Agency is the measurement of intense electromagnetic fields which are radiated from a variety of sources. Common sources of electromagnetic radiation are radars. The NRSB is concerned with measurement techniques and the type of equipment best used for accurate determination of possibly hazardous electromagnetic fields. One method for measuring such fields is the use of broadband radiation monitors. Such devices measure the intensity of electromagnetic fields over a very wide range of frequency.

The best way to look at a radar signal is by using a spectrum analyzer. By examining a radar signal with a spectrum analyzer, all the important properties of the signal can be measured. Some of these properties are the pulse width, occupied bandwidth, duty cycle, peak and average power, and if the radar antenna is rotating, the apparent radiation pattern of the radar's antenna including the speed of rotation. Knowledge of all these properties of the signal may be necessary for certain analyses, but are not necessary for determining the field strength. Spectrum analyzers are very expensive and not suitable for "mapping out" field strength values over extensive areas since it is very cumbersome and requires AC power. A spectrum analyzer is also a complicated piece of equipment to operate and requires trained personnel to interpret the results. If only the field intensity of the signal is of interest it may be feasible to use a broadband radiation monitor (BRM) instead of a spectrum analyzer.

A broadband radiation monitor is an instrument which may be hand-held and operated from its own power source. Such a device usually outputs an analog signal indicating the power density or field strength of any field it is exposed to in its frequency range.

It may be feasible to use a BRM for rotating radar signals, although this can place severe constraints on the accuracy of the indicated field intensity depending on the beam width and rotational speed of the radar antenna. The purpose of this project is to evaluate the suitability of using a BRM such as the NARDA 8616 Electromagnetic Radiation Monitor with probe model 8621 for field intensity measurements of rotating radar antenna signals.

It is inconvenient to use a real radar signal for testing of the BRM since access to the required strong signals would most likely require the testing to be performed outdoors near a radar installation. To eliminate this problem, the major emphasis of this project is to synthesize a rotating radar signal pattern for use in the laboratory.

By creating a signal that closely resembles the signal emitted by a rotating radar antenna, the testing of a BRM may be performed in the laboratory under controlled conditions. Also, the parameters of the signal may be changed to facilitate further exploration of the instrument's response. The parameters which need to be capable of change are (1) the rotational duty cycle, (2) the carrier frequency, and (3) the intensity of the field.

The major concern is how the BRM responds to the radiation pattern created when a radar antenna rotates. If a radar antenna is not rotating, there is no problem in using a BRM. The analog reading will correspond to the power density of the field assuming the BRM has been properly calibrated. Any person or object occupying that particular location will be exposed to that particular power density. It is not so easy, however, to determine what power density one is exposed to if the antenna is rotating. The rotation of the antenna creates a continuously varying field intensity level. Using a BRM, one could take two values of data; the peak intensity observed and some lower value when the radar antenna is swung away from the instrument. The concern of this project is to determine how these readings may be used to compute the average power density; i.e., the power density as averaged over a complete rotation of the radar's antenna. The peak reading observed may not be the actual peak signal of the antenna. A slow time response of the BRM could cause a low peak reading. Using the synthesized radar signal in the laboratory, the response of the BRM may be observed under controlled conditions to determine if the time response truly presents a problem, and such a determination forms the crux of this project.

The most commonly used BRM in the microwave frequency range suitable for radar applications is the Narda 8616 Electromagnetic Radiation Monitor. The Narda high frequency probe Model 8621 (300 MHz to 26 GHz) uses thin-film thermocouples that provide true square-law response, i.e., their voltage output is linear with absorbed power. The probe contains three elements which are mutually perpendicular to each other in an x-y-z axes fashion, as shown in Figure 1. The summation of the DC signals from these three elements provide a measure of the total power density independent of the polarization of the RF signals. Since thermocouples are used, the average power density affects the output, thus it is not necessary to include pulses in the synthesized radar pattern as would be present in the actual radar's signal.

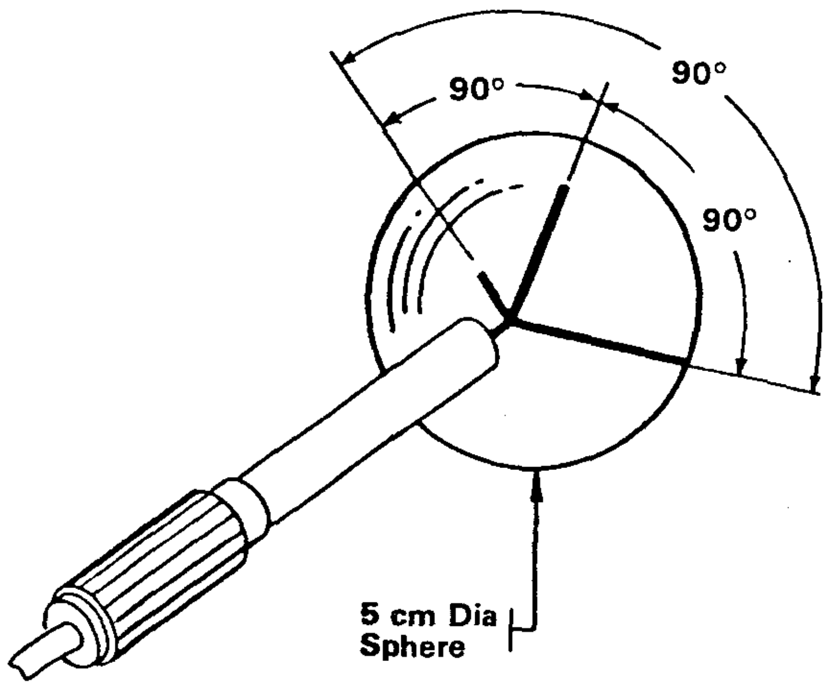


Figure 1.

Relationship of the three mutually orthogonal probe elements of a NARDA 8621 high frequency probe.

General Considerations for Radar Pattern Synthesis

In order to model a synthesized rotating radar pattern after a real pattern, it is necessary to collect data from an operating radar installation. Using sophisticated NRSB equipment such as a Hewlett-Packard 8566A spectrum analyzer interfaced with a Hewlett-Packard 9845B computer, the pattern of a rotating radar antenna may be stored in a numerical array and the CRT display of the 8566A may be reproduced onto paper through the use of the graphics capability of the computer. An example of a rotating radar antenna pattern obtained by this system is shown in Figure 2.

In order to synthesize the radar pattern, a carrier signal must somehow be amplitude modulated in such a way as to mimic the variation of the radiated signal amplitude as the radar antenna rotates. This may be accomplished by attenuating the carrier amplitude of a continuous wave (CW) generator as to simulate the actual variation in field intensity of the signal from a rotating radar antenna pattern. This synthesized signal will be amplitude modulated but will not be pulsed.

Since the attenuation must be rapidly changed to simulate the rapidly varying radar signal and must be reproducible, the use of a computer for instrumentation control is implied.

The carrier frequency should be in the range of 1 GHz to 10 GHz in order to simulate the carrier frequency of radar but need not be the same as the actual radar frequency since the BRM is sensitive to frequency between 300 MHz to 26 GHz.

RADAR ANTENNA ROTATIONAL DUTY CYCLE

Operator: Michael R. Molony 03/23/81. 2:51 PM
Location: LAB, EPA ROOM 521, BLDG C

Sweep Time = 20 sec Res BW = 3 MHz

Reference Level = 0 dBm
Scale Div = 10 dB/

Antenna Rotational Duty Cycle Center freq = 1.3311 GHz

Peaks measured at:
Location 1: 220 -16.60dBm Location 2: 827 -16.90dBm

Radar Rotation Rate:
Seconds/Rotation: 12.14 R P M 4.942

Main Beam Reference: -16.747 dBm

Antenna duty cycle: -20.581 dBm

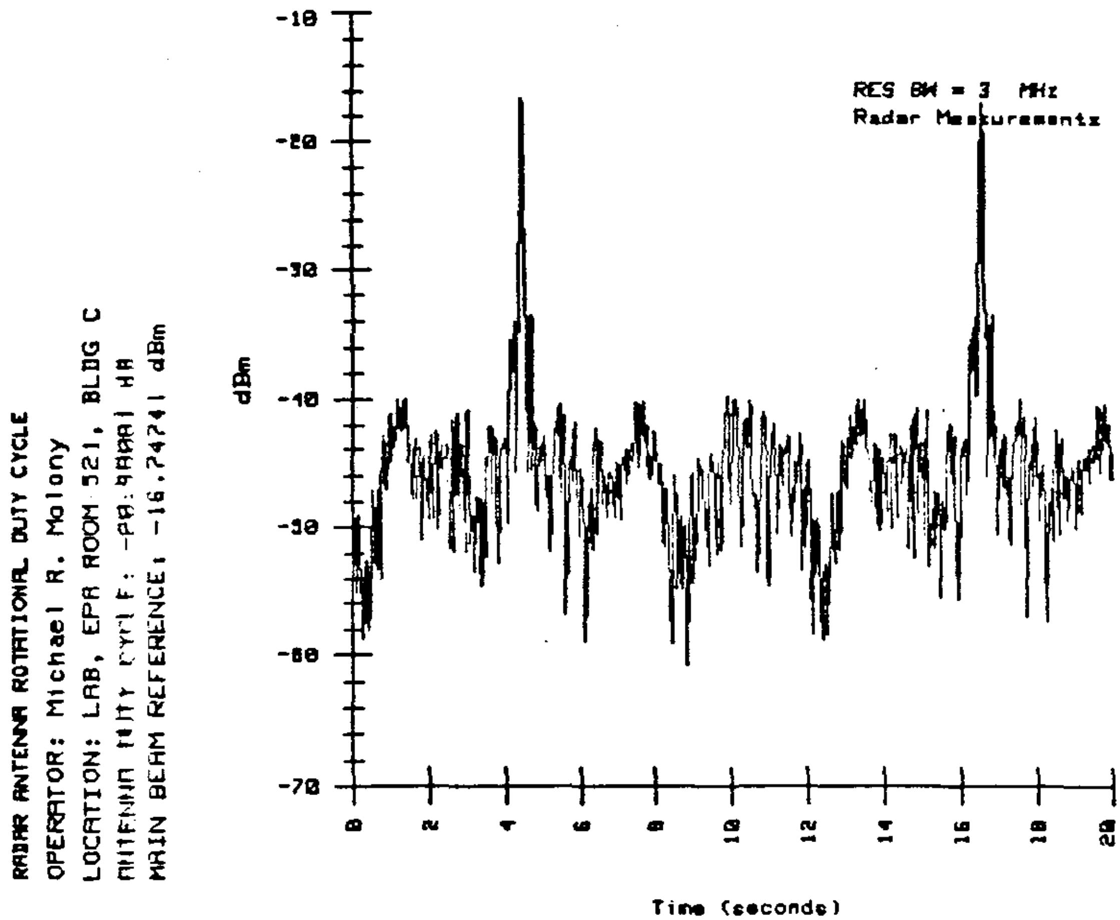


Figure 2.

Example of a rotating radar antenna pattern obtained from NRSB measurement system.

Alternative I

One alternative considered for use in synthesizing a rotating radar antenna signal pattern was to use a HP model 8620C sweep oscillator which may have its signal level varied by applying a DC voltage to the external amplitude modulation (AM) jack. A quickly changing DC voltage may then be generated by using a computer interfaced to a Digital-to-Analog Converter (DAC). A numerical array representing the required signal levels may be stored in the computer memory and when output to the DAC under program control, will provide the necessary amplitude modulation of the signal corresponding to the radar antenna pattern. This system is illustrated in Figure 3.

In order to test this system, a series of direct current (DC) voltages were applied to the External Amplitude Modulation (EXT. AM) jack located at the rear of the Hewlett-Packard (HP) 8620C sweep oscillator (see Figure 3). For each DC voltage applied, the corresponding power output to the power meter was recorded. These data were then fit to a curve in order to determine the mathematical function of voltage versus power. In order to test the reproducibility of this function, a randomly selected voltage was applied to the EXT. AM jack of the HP 8620C to observe if the predicted power would be output to the power meter. The power output was dramatically different from the predicted power. The error was in the order of 3 dB. The original voltages were then again applied to the system but the power output was not the same as it was originally.

After much experimentation, it was observed that the HP 8620C signal generator drifted in frequency. With this change in frequency the signal generator changed its output power, especially when lower powers were required. The frequency drift was too rapid to periodically check and correct. After other techniques were tried to compensate for the frequency drift, the use of the HP 8620C signal generator was considered impractical since a rapid amplitude modulation of the signal is required. Therefore, Alternative I was rejected for use in simulating a rotating radar antenna signal pattern.

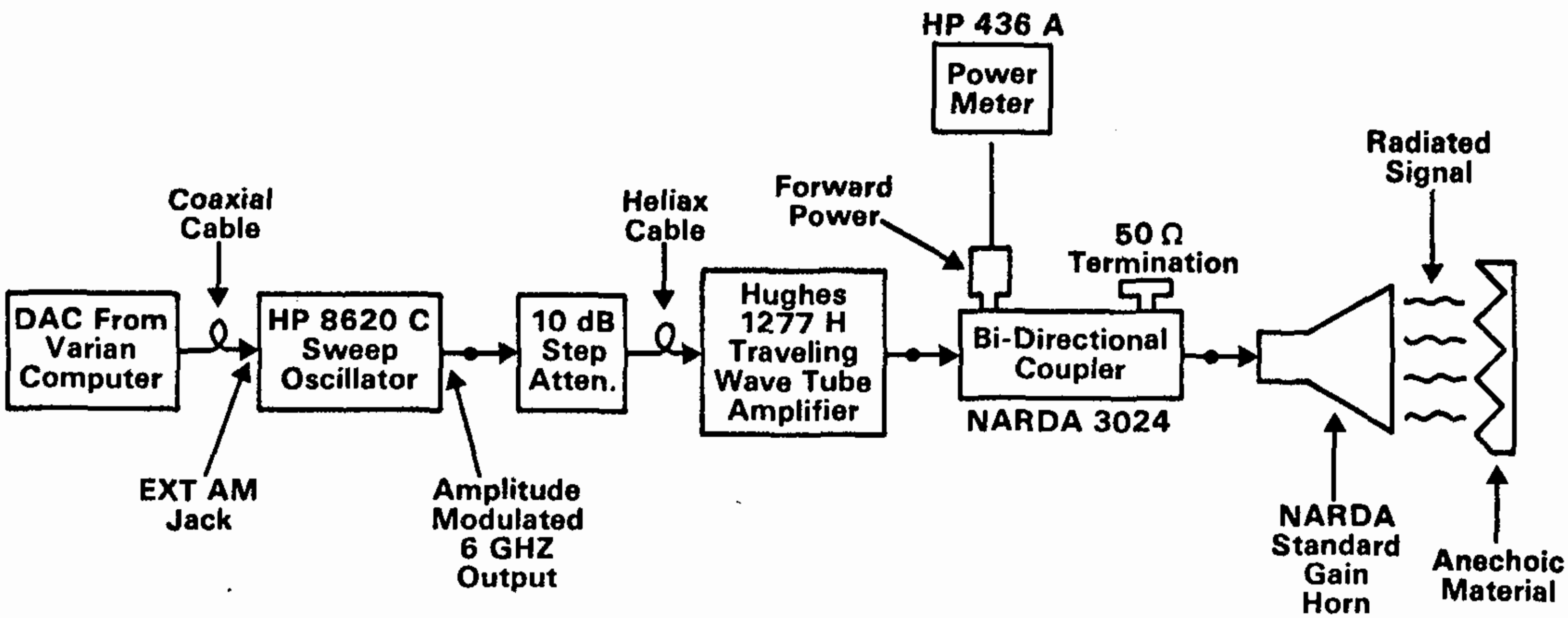


Figure 3.

Alternative I system. This system was considered but not used for simulating a rotating radar antenna pattern.

Alternative II

A second alternative considered for use in synthesizing a rotating radar antenna signal pattern is to use a positive-intrinsic-negative (PIN) diode modulator. This system is shown in Figure 4 and may allow a pulsed signal to be output from the HP 8620C sweep oscillator if desired.

This alternative was not initially feasible since a PIN modulator was not available to the Nonionizing Radiation Surveillance Branch (NRSB) of the Environmental Protection Agency (EPA) at the conception of this project. Since that time, however, a HP 8733B PIN modulator has been purchased by NRSB. The specifications for this modulator are shown in Table 1, and its dimensions are shown in Figure 5.

The function of the PIN modulator is to amplitude modulate the signal produced by the signal generator (refer to Figure 4). The amplitude modulation is controlled by applying a DC voltage as the bias to the bias port of the PIN. The DC voltage causes the PIN to attenuate the signal through it. A greater negative voltage applied to the bias results in a greater attenuation of the signal through the PIN. The DC voltage which is applied to the bias may be controlled by a computer. The computer outputs voltage from a Digital-to-Analog-Converter (DAC). This allows a very rapid change of voltages and therefore a rapid amplitude modulation of the signal since it will be controlled by the computer.

The first test performed on the PIN modulator was to simply determine if power out of the PIN for a given voltage into the bias was repeatable. A constant 10 dBm signal was output from a signal generator at 6 GHz (see Figure 6 for test set-up). The PIN modulator was attached to the signal generator and the power out of the PIN modulator was measured with a power meter as the DC voltage to the bias was changed. The DC voltage was supplied by a DC power supply and was monitored by a voltmeter at the bias. These sets of data were then taken several times and the results were reproducible within ±0.3 dB down to 30 dB of attenuation. Data for this test were not taken below 30 dB of attenuation because of the power detection limits of the HP 436A power meter.

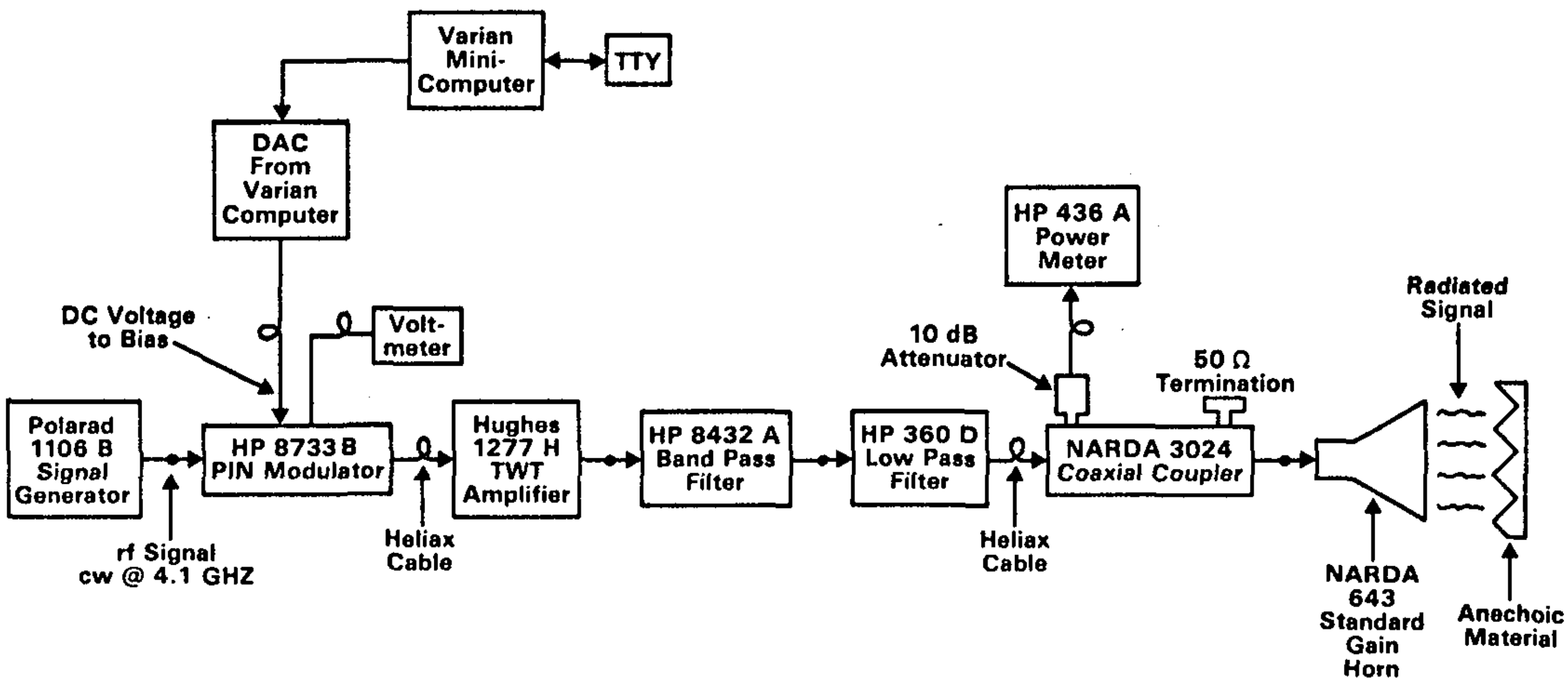


Figure 4.

System to synthesize an amplitude modulated signal simulating a rotating radar antenna pattern using a PIN diode modulator.

Table 1. Specifications

	8731A	8731B	8732A	8732B	8733A	8733B *	8734A	8734B	8735A	8735B
Frequency Range (GHz)	0.8-2.4	0.8-2.4	1.8-4.5	1.8-4.5	3.7-8.3	3.7-8.3	7.0-12.4	7.0-12.4	8.2-12.4	8.2-12.4
Dynamic Range (dB)	35	80	35	80	35	80	35	80	35	80
Min. Insertion Loss (dB)[1]	<1.5	<2.0	<2.0	<3.5[2]	<3.0	<3.0	<4.0	<5.0	<4.0	<5.0
Typical Rise Time (ns)[3]	40	30	40	30	30	30	30	30	30	30
Typical Decay Time (ns)[3]	30	30	30	30	30	30	30	30	20	27
SWR, Minimum Attenuation	1.5	1.5	1.5	1.6[4]	1.8	2.0	1.8	2.0	1.7	2.0
SWR, Maximum Attenuation	1.8	2.0	1.8[9]	2.0	2.0	2.2	2.0	2.2	2.0	2.2
Maximum Input Power, Peak or CW (watts)	1	1	1	1	1	1	1	1	1	1
Bias Limits (volts)[5]	+20, -10	+20, -10	+20-10	+20, -10	+20, -10	-20, -10	+20, -10	+20, -10	+20, -10	+20, -10
Typical Forward Bias Input Resistance (ohms)[6]	300	100	300	100	300	100	300	100	300	100
RF Connector Type	N[8]	N[8]	N[8]	N[8]	N[8]	N[8]	N[8]	N[8]	WG[7]	WG[7]
Weight (lbs)	3	5.5	3	5.5	2.5	3.5	2.5	3.5	2.5	3.5
Weight (kg)	1.4	2.5	1.4	2.5	1.1	1.6	1.1	1.6	1.1	1.6
Dimensions	Illustrated in Figure 3									

1. +5 Vdc bias
2. <4.0 dB, 4.0 to 4.5 GHz
3. Driven by HP 8403A Modulator
4. 2.0, from 4.0 to 4.5 GHz
5. Negative voltage applies forward bias to diodes
6. At attenuation levels of 10 dB or more
7. Fits 1 x 0.5 inches (WR 90) waveguide
8. Standard female type N
9. 1.5, from 1.8 to 4.0 GHz; 2.0, from 4.0 to 4.5 GHz

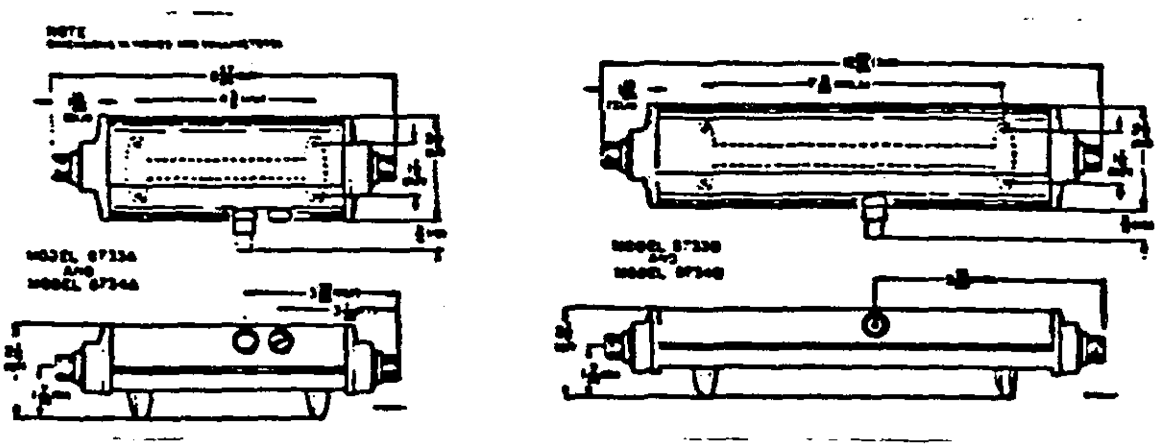


Figure 5.

General outside dimensions of the HP8733B PIN modulator.

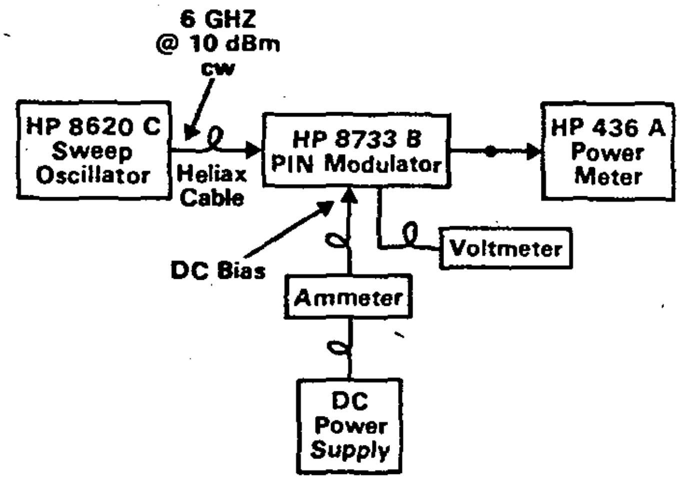


Figure 6.
Initial test of the PIN Modulator.

TWT Noise Reduction

Since the PIN modulator was performing satisfactorily, the Hughes 1277H traveling wave tube (TWT) amplifier was added to the system to determine a preliminary function of power out of the system versus voltage into the bias. The equipment set-up for this test is illustrated in Figure 7.

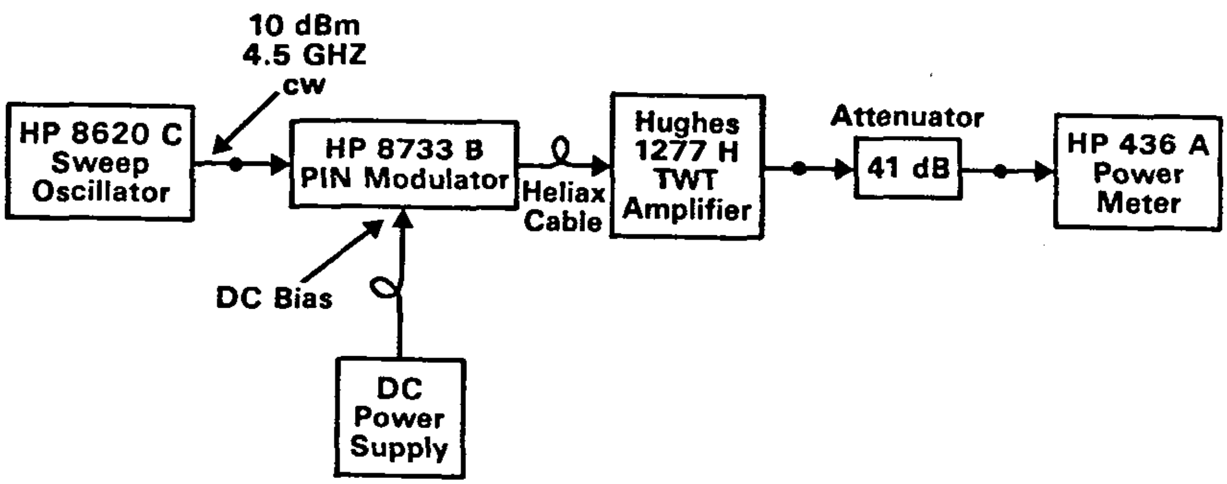


Figure 7.
Test of system with TWT.

The results of this test revealed a disturbing problem. The noise level of the TWT allowed only a small dynamic range of power levels. The data from this test may be seen in Table 2. It is observed that from -0.82 volts DC to -0.88 volts the power out of the TWT changed very little compared to the power changes from -0.55 to -0.78 volts. When the input to the TWT was removed, the output power was approximately -34 dBm.

Table 2. TWT Dynamic Range Test

Voltage Applied to PIN Bias	Power Out of 41dB Attenuator	
-0.55 (Volts)	+5.1 (dBm)	
-0.57	+4.3	
-0.59	+2.6	
-0.60	+1.6	
-0.62	-0.7	
-0.64	-3.5	
-0.66	-6.7	
-0.68	-10.0	
-0.70	-13.6	
-0.72	-17.1	
-0.74	-20.7	
-0.76	-24.0	
-0.78	-27.1	
-0.80	-29.6	Small change due to noise from TWT amplifier (-29.6 to -33.6)
-0.82	-31.4	
-0.84	-32.6	
-0.86	-33.3	
-0.88	-33.6	
-0.88	-34.2	← Input to TWT disconnected

The useful dynamic range of approximately 35 dB was considered as an unacceptable range for use in simulating a rotating radar antenna signal.

The first step to solving the problem of the TWT noise was to actually look at the noise output using a HP 8655A spectrum analyzer. The input of the TWT was terminated and a 10 dB attenuator attached to a 10 ft. piece of Heliax cable was connected from the output of the TWT to the input of the spectrum analyzer. The noise level of the TWT is shown in Figure 8. This figure was reproduced onto paper through the graphics capability of an HP 9845B computer which interfaces with the HP 8655A spectrum analyzer.

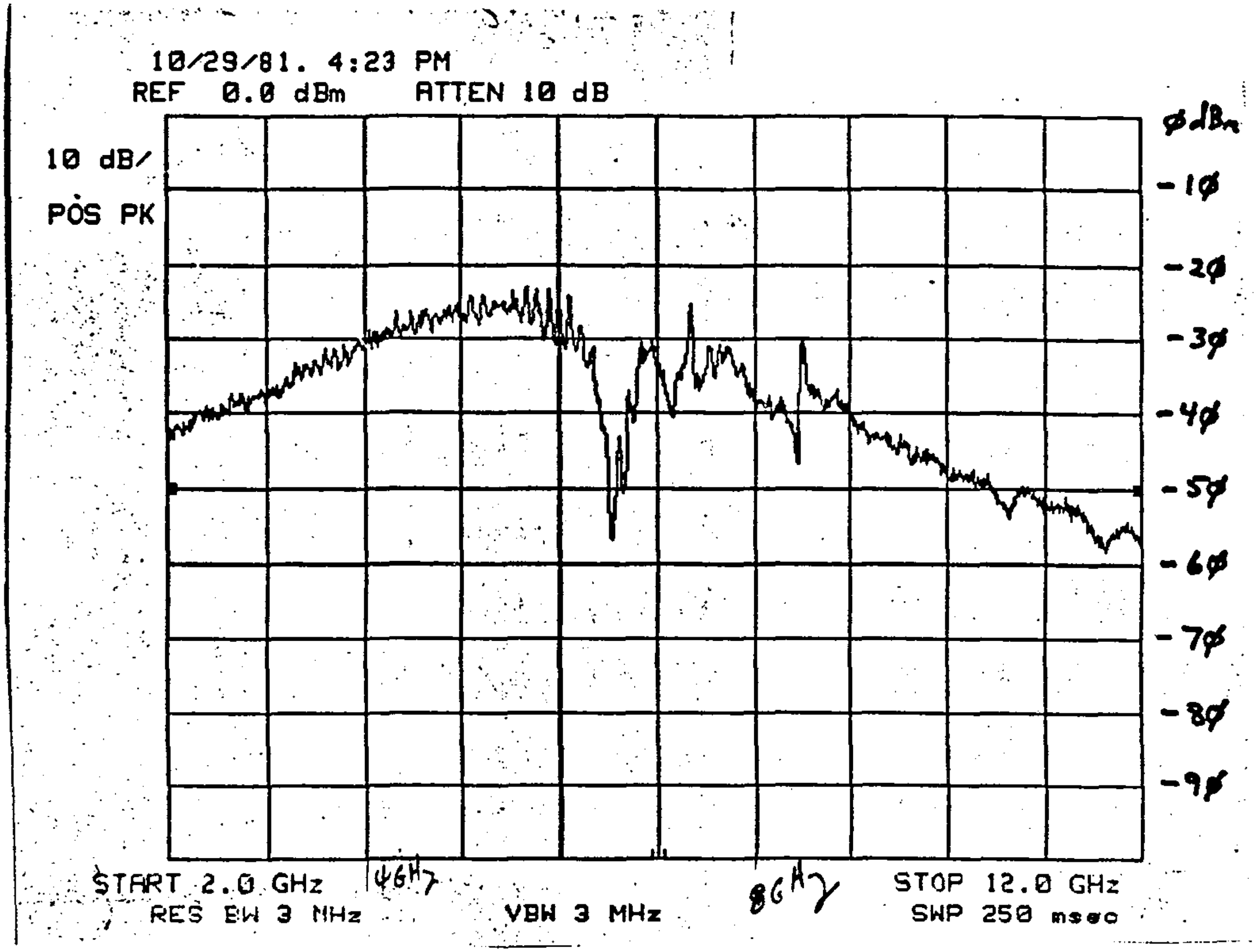


Figure 8

TWT noise from 2.0 to 12.0 GHz.

Hughes C Band TWT 1277 H 4.1GHz

Since the frequency being used for the simulation was ~~4.5~~ GHz, it was determined that a bandpass filter of 4 to 6 GHz would significantly reduce the noise from the TWT. A HP 8432A bandpass filter was tested to determine its true filtering capabilities. This test was performed using the equipment illustrated in Figure 9. The HP 8620C sweep oscillator was set up to sweep in frequency from 2.0 GHz to 8.0 GHz. The HP 8566A spectrum analyzer was set up to save and display only maximum values at each frequency point (max hold function). The result of this test is shown in Figure 10. It can be seen that the HP 8432A filter resulted in a band pass of approximately 3.86 to 6.2 GHz. This significantly reduces the noise from below 3.8 GHz, but there is still much noise allowed to pass above the operating frequency of 4.5 GHz. In order

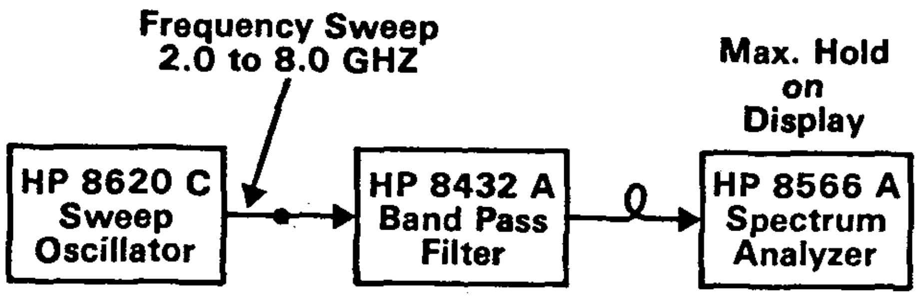


Figure 9.
Test of HP8432A bandpass filter.

to reduce the bandpass frequency range, a HP 360D low pass filter with a cut-off frequency of 4.1 GHz was put in series with the bandpass filter. The characteristics of the two filters in series was determined by the same method illustrated in Figure 9, except both filters were connected together in series. The results are shown in Figure 11. These results show that 4.5 GHz can no longer be used for an operating frequency since it is filtered by the low pass filter. A closer look at the filter characteristics revealed a low standing wave ratio (SWR) at 4.1 GHz. Therefore, since all the equipment used in the system is capable of operation at this frequency, 4.1 GHz became the new operating frequency for future testing.

Through the use of these filters, the dynamic range of the TWT was increased from 35 dB to approximately 50 dB. This range is sufficient for use in this project.

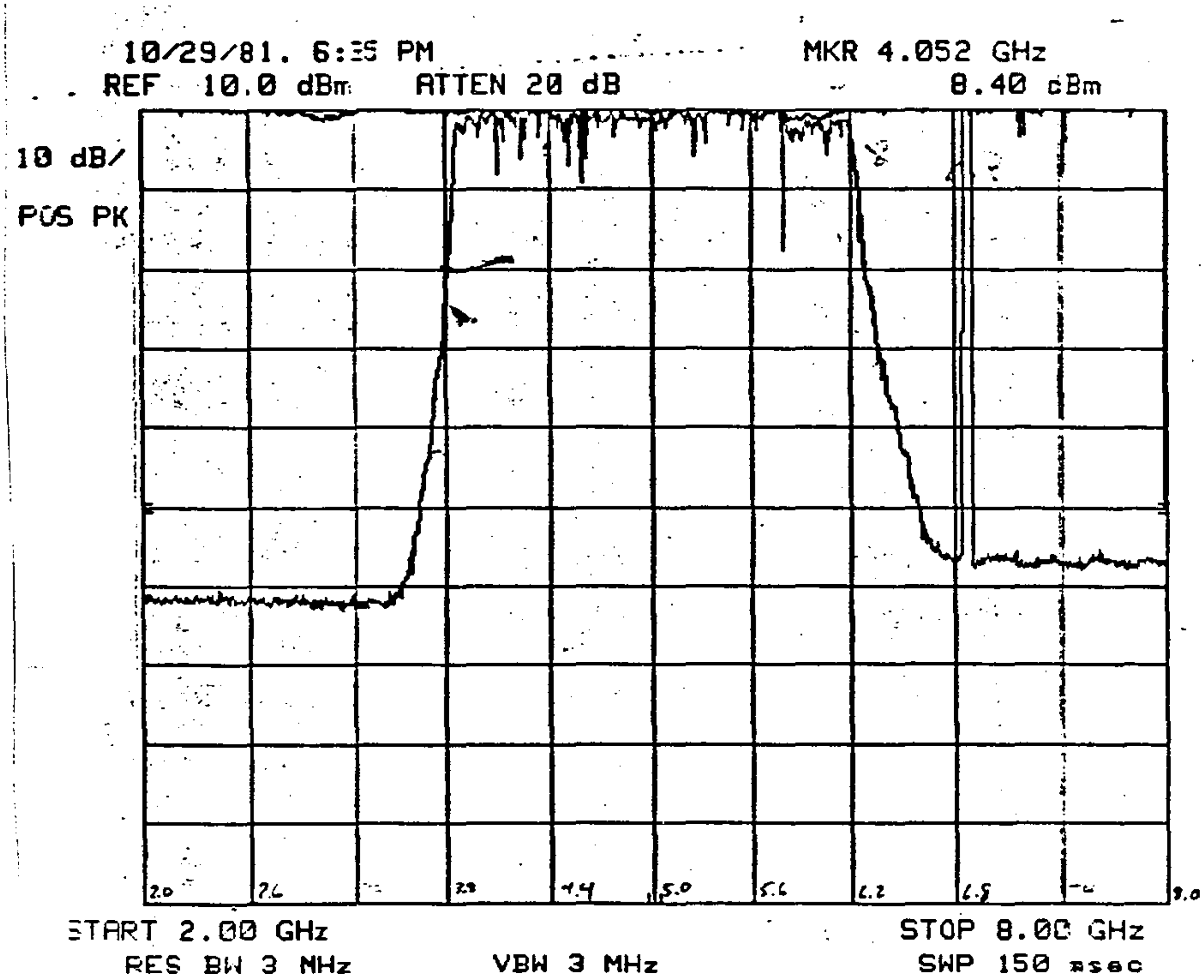


Figure 10.

Filtering characteristics of HP8432A bandpass filter.

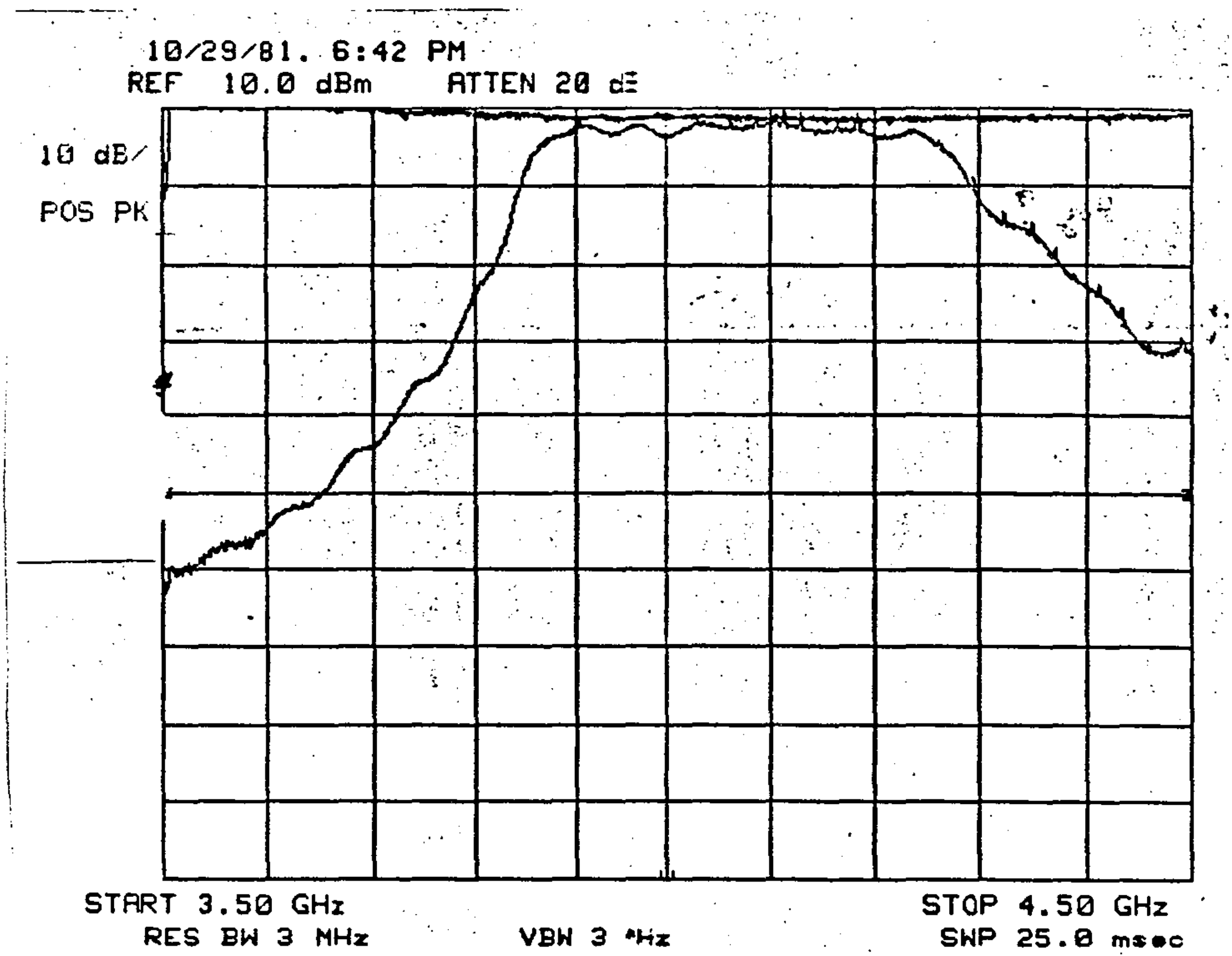


Figure 11.

Filtering characteristics of the HP8432A bandpass filter in series with the HP360D lowpass filter.

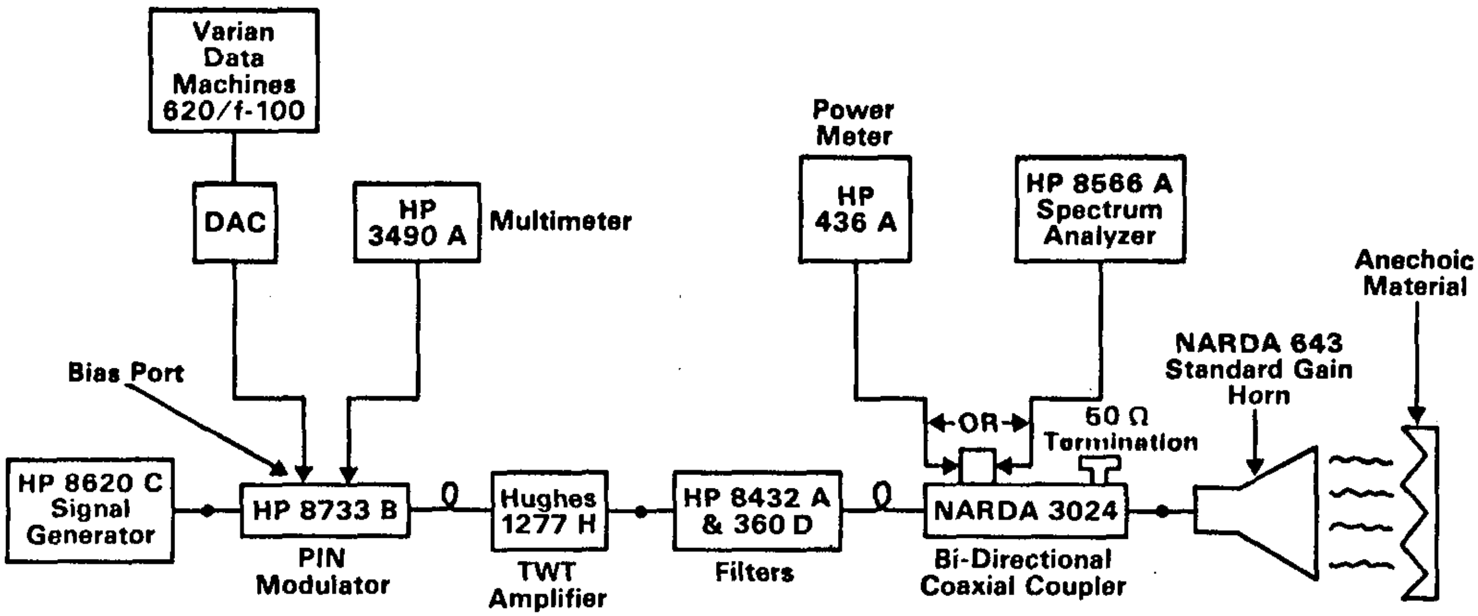


Figure 12.

Block diagram of the system to simulate the radiation pattern of a rotating radar antenna.

Determination of System Transfer Function

Since all of the components of the system were tested and determined to be acceptable, the whole system was assembled including the DAC from a Varian Data Machines computer. Figure 12 illustrates the equipment set-up of the whole system.

The entire system was tested to insure the repeatability of the power out of the directional coupler when a particular DC voltage is applied to the bias of the PIN. A BASIC program was written for the Varian computer to control the voltage from the DAC. The program allows the operator to input a particular value of voltage to be supplied from the DAC to the bias of the PIN. For each voltage supplied to the bias, the corresponding power out of the directional coupler was recorded. These data of DC voltage versus power were fit to a third degree polynomial by a curve fitting program on the HP9845B computer. This polynomial is the function necessary for a main computer controlling program which will automate the DC voltage supplied to the bias of the PIN modulator. These data are tabulated in Table 3 and the resulting curve is shown in Figure 13.

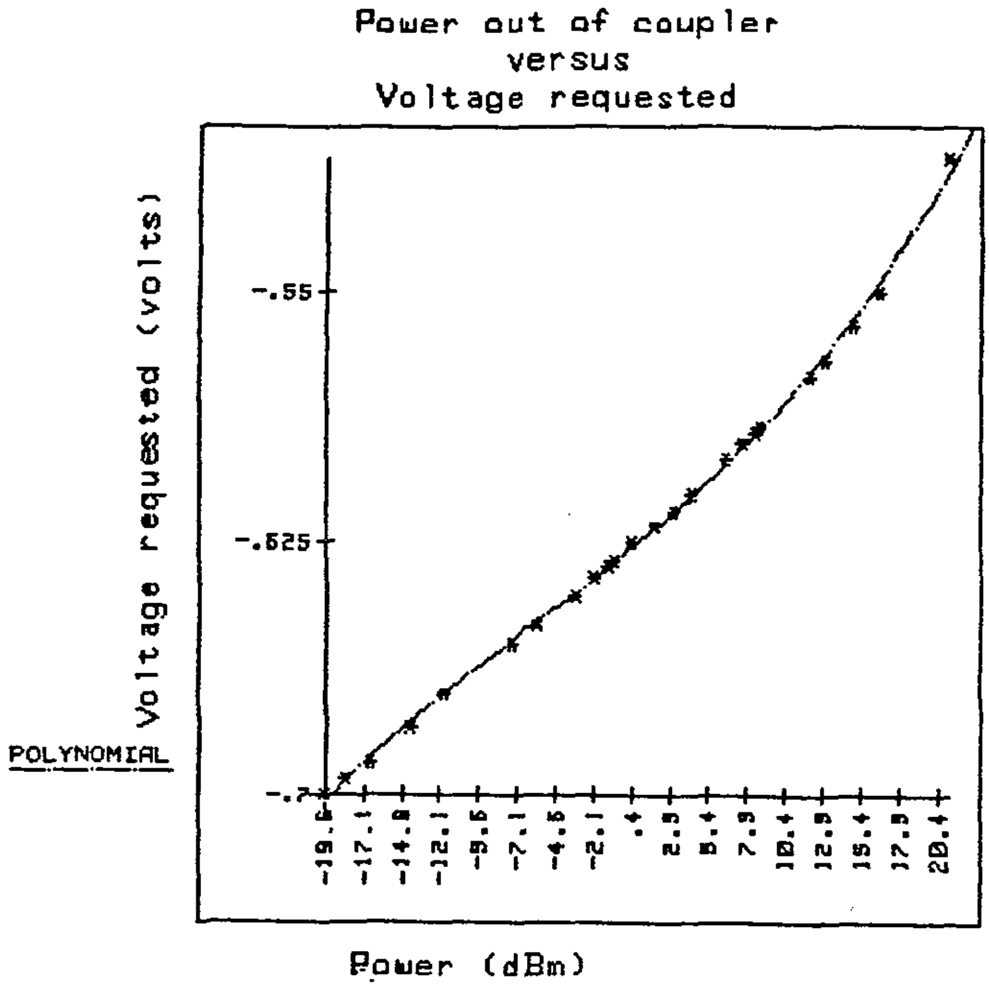


Figure 13.
Data plot of power versus voltage.

These data were collected three separate times and were repeatable to within ±0.05 dB . The polynomial to fit the curve was found to be:

$$V = 2.14\text{x}10^{-6}P^3 + 3.67\text{x}10^{-5}P^2 + 3.70\text{x}10^{-3}P - 0.63$$

where:

V = DC volts to the bias of the PIN modulator (volts)

P = Power out of the coupler (dBm)

Power is the independent variable so the computer operator may request the power level he would like output from the system. The computer will convert this requested power to the appropriate value to output the DC voltage from the DAC. This voltage from the DAC will cause the system to output the requested power.

Table 3. Power out versus voltage in.

DATA

Point #1:	X=21	Y=-.51
Point #2:	X=16.55	Y=-.55
Point #3:	X=14.84	Y=-.56
Point #4:	X=13.02	Y=-.57
Point #5:	X=12.05	Y=-.575
Point #6:	X=8.71	Y=-.59
Point #7:	X=8.43	Y=-.592
Point #8:	X=7.6	Y=-.595
Point #9:	X=6.51	Y=-.6
Point #10:	X=4.22	Y=-.61
Point #11:	X=3.02	Y=-.615
Point #12:	X=1.81	Y=-.62
Point #13:	X=.28	Y=-.625
Point #14:	X=-.96	Y=-.63
Point #15:	X=-1.28	Y=-.632
Point #16:	X=-2.24	Y=-.635
Point #17:	X=-3.44	Y=-.64
Point #18:	X=-5.97	Y=-.65
Point #19:	X=-7.51	Y=-.655
Point #20:	X=-11.83	Y=-.67
Point #21:	X=-14.05	Y=-.68
Point #22:	X=-16.67	Y=-.69
Point #23:	X=-18.3	Y=-.695
Point #24:	X=-19.6	Y=-.7

POLYNOMIAL MODEL: Y=A(M)*X^M+A(M-1)*X^(M-1)+...+A(1)*X+A(0)

Coefficients:

A(0)=-.627382389708
A(1)=3.69541202060E-03
A(2)=3.66672228630E-05
A(3)=2.14378444360E-06

Source	Df	SS	MS	F
Regression	3	.054	.018	6056.205
Residual	20	.000	.000	
Total	23	.054		

Correlation Coeff (r): .99890041109

Data Collection at McCarran Airport

In order to simulate a rotating radar pattern, it is necessary to first measure actual observed radar radiation patterns. This was done by using a unique system developed by the Nonionizing Radiation Surveillance Branch of EPA. This system uses a Hewlett-Packard (HP) model 9845B computer interfaced with a HP8566A spectrum analyzer. The software has been developed by NRSB to measure several different types of radio signals. This system is a mobile system which may be mounted in a Dodge Ramcharger as well as in the lab. The radar signal was received by a TECOM parabolic dish antenna mounted on top of the ramcharger. Data collected by the system may be saved on a floppy disk for retrieval at a later date.

The first step in making the field measurements was to test the measurement system and software in the laboratory. The laboratory is equipped with an Electro/Data Inc. Model AN112F log periodic antenna mounted on the roof of the building. This antenna is mounted horizontally and is capable of receiving microwave signals in the frequency range 1.0 - 12.4 GHz.

It was first determined that the radar installation located at McCarran International Airport would be a good radar to use as a model since it is easily accessible, produces a strong signal and is typical of the type of radar for which hazard survey measurements are commonly made.

A schematic of the measuring system used in the lab is illustrated in Figure 14. Although the laboratory measurements were intended only as a system check and an opportunity for the operator to become proficient in using the system, the results were worth saving. The results of the laboratory measurements are shown in Figures 15, 16, and 17.

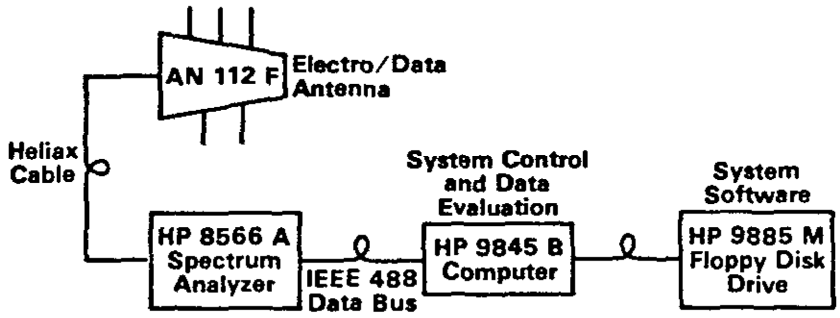


Figure 14.
Radar data collected in the Lab.

Figure 15 shows the CRT display of the HP 8566A spectrum analyzer resulting from a radar pulse width measurement. For this particular pulse width measurement, the spectrum analyzer was set up in the frequency domain with a frequency span of 12 MHz and the center frequency of 2.75 GHz which is the frequency of the radar signal. The horizontal axis is frequency and the vertical axis is power. The distance between the initial null and the terminal null is the mainlobe width which, in this case, was found to be 3.39 MHz. The pulse width is related to the mainlobe width by the formula:

$$\tau_{eff} = \frac{1}{(0.5)(MLW)}$$

where: τ_{eff} = pulse width (seconds)
MLW = mainlobe width (Hz)

In this case the pulse width was found to be 0.59 μsec. The pulse width measurement is not directly pertinent for use in this project, but this figure demonstrates the capability of the measurement system, and it is good practice to collect all the data one can while the measurement system is set up.

Figure 16 shows the CRT display of the HP 8566A spectrum analyzer during an antenna rotational duty cycle measurement. For this measurement, the spectrum analyzer is set up in the time domain, so a real time picture of the

RADAR TEST

Operator: ANDY MONHEISER
Location: LAB

10/21/81. 11:14 AM

Sweep Time = .05 sec

Res BW = 100 kHz

Reference Level = -10 dBm
Scale Div = 10 dB/

__lse Width Measurement__

Center freq = 2.7497 GHz

Place cursor on initial null
    Initial Null (X): 2.7481 GHz (Y): -74.374 dBm
Place cursor on terminal null
    Terminal Null (X): 2.7515 GHz (Y): -74.477 dBm

Main Lobe Width: 3.39 MHz
Pulse Width: .59 usec

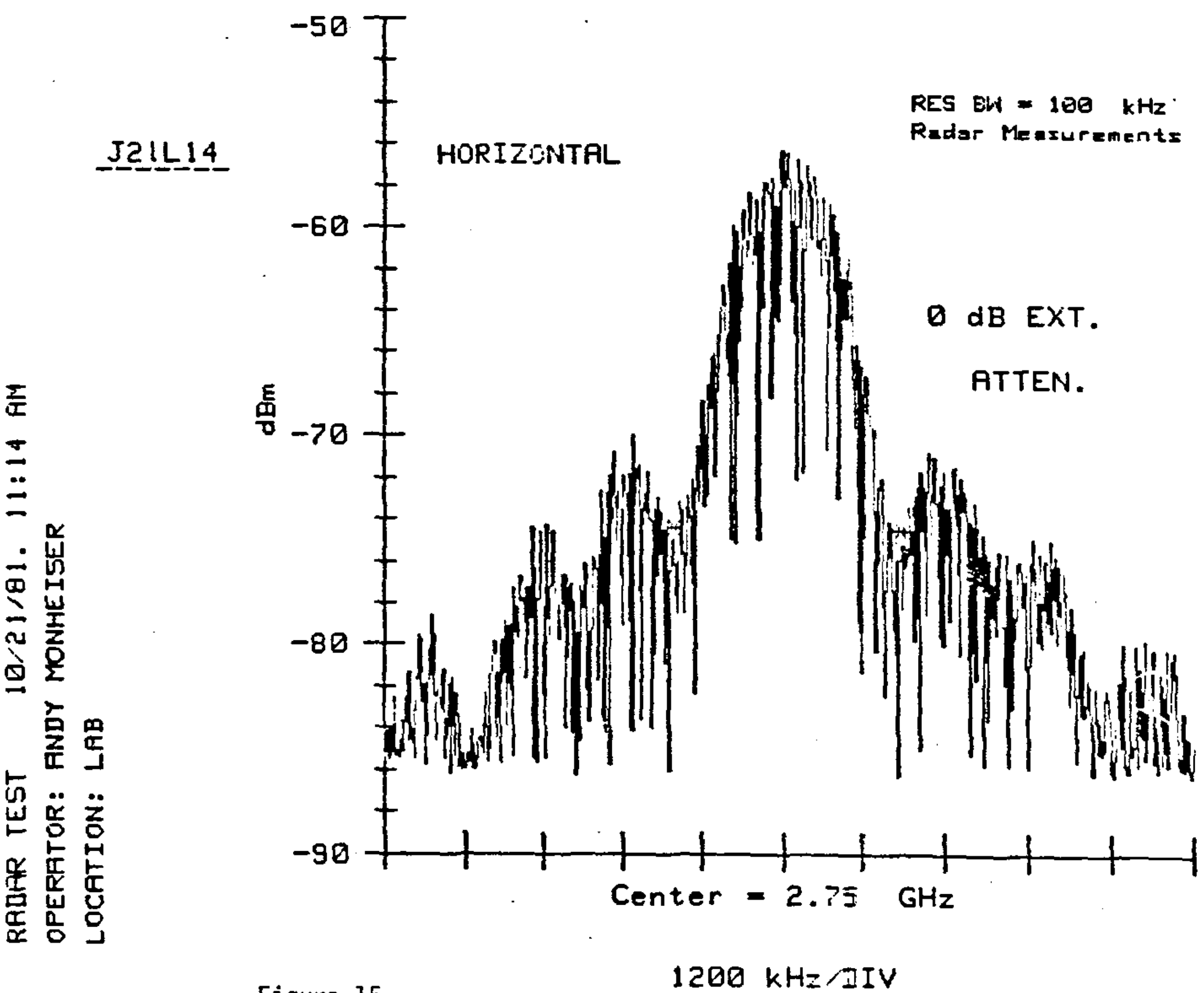


Figure 15.

RADAR TEST

Operator: ANDY MONHEISER
Location: LAB

10/21/81. 11:48 AM

Sweep Time = 6 sec

Res BW = 3 MHz

Reference Level = -30 dBm
Scale Div = 5 dB/

Antenna Rotational Duty Cycle

Center freq = 2.7497 GHz

Peaks measured at:
Location 1: 76 -36.05dBm

Location 2: 865 -36.10dBm

Radar Rotation Rate:
Seconds/Rotation: 4.73

R P M 12.674

Main Beam Reference: -36.075 dBm

Antenna duty cycle: -20.301 dBm

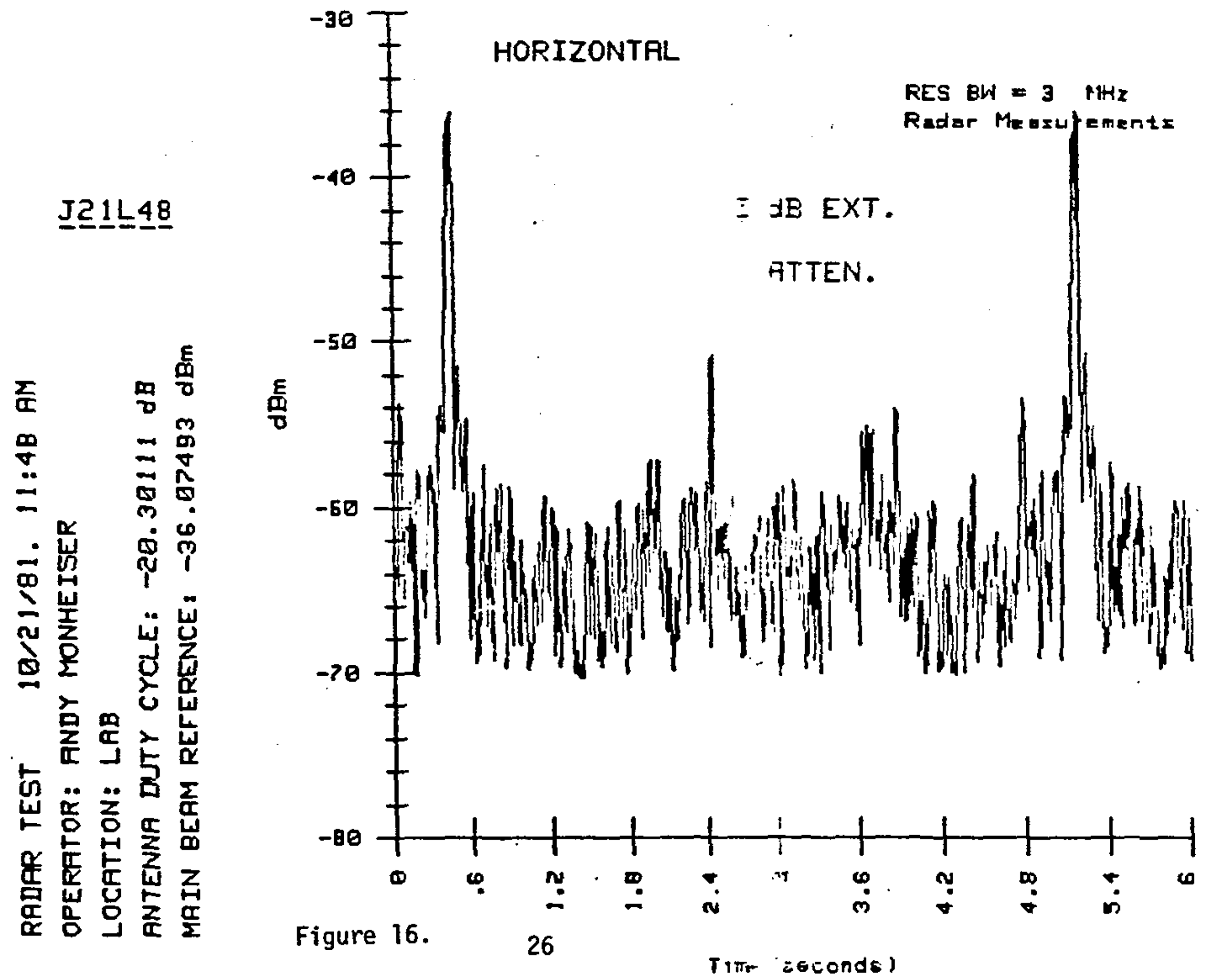


Figure 16.

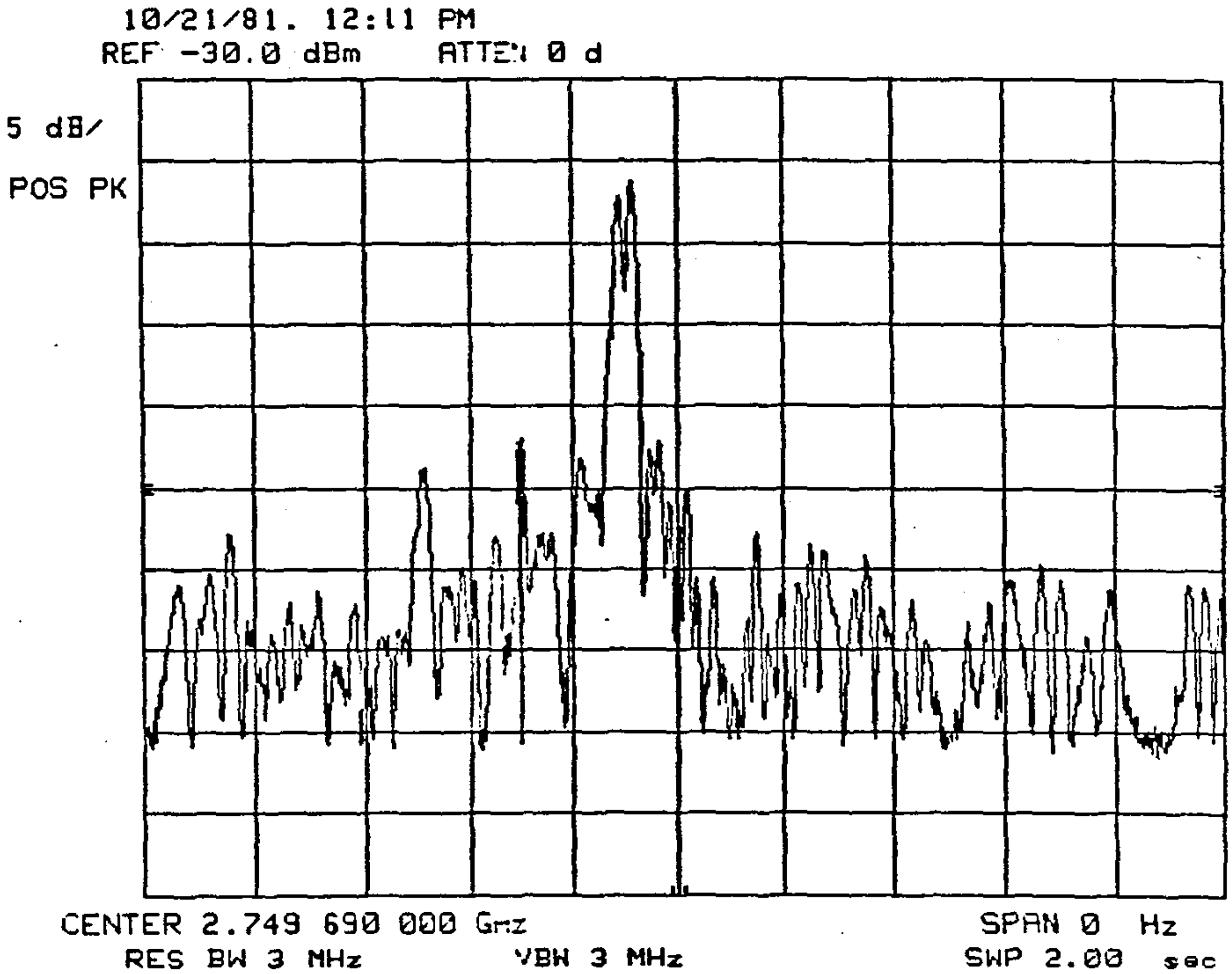


Figure 17.

Peak signal from rotating radar antenna. Measurement made in lab.

radar antenna's radiation pattern can be seen. A peak signal is produced when the rotating radar antenna is directed toward the receiving antenna. The antenna makes a complete rotation and is again directed toward the receiving antenna producing another peak signal. The time between the peak signals is the rotation rate of the antenna. The signal in Figure 16 shows a rotation rate of 4.73 seconds which is equivalent to 12.674 rotations per minute (RPM). This data is not just graphical, as shown in Figure 16, but associated with the graph is an array of 1001 values. Each value is a power level in dBm. The points are numbered from 0 to 1000 from left to right across the CRT display. This array is the key to reproducing the radiation pattern. The Varian mini-computer will convert this array to DC voltages to output from the DAC.

Figure 17 is an expanded view of the peak signal of the rotating radar antenna. This is also defined by 1001 points. This type of display does not show the whole 360 degrees of the antenna's rotation, but the peak signal is much better defined.

For actual measurements in the field, the system was mounted in a Dodge Ramcharger which was designed by NRSB to accommodate the measuring system. There was one major difference in the equipment used in the field. Instead of using the log periodic antenna (as shown in Figure 14), a TECOM parabolic dish antenna was used to receive the signal from the rotating radar antenna. The dish antenna is capable of receiving signals of either horizontal or vertical polarization. The mobile system is shown in Figures 18 and 19.

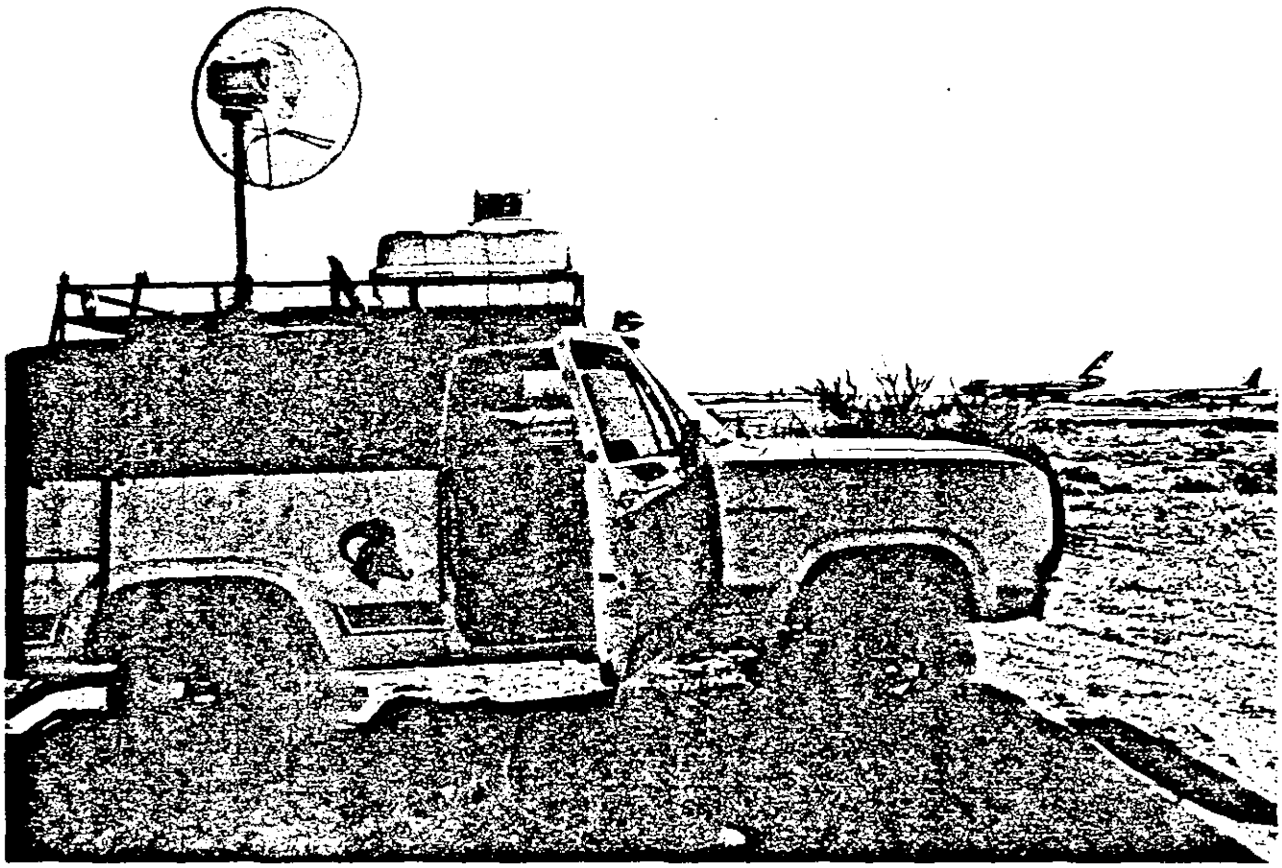


Figure 18.
Outside view of mobile measurement system.

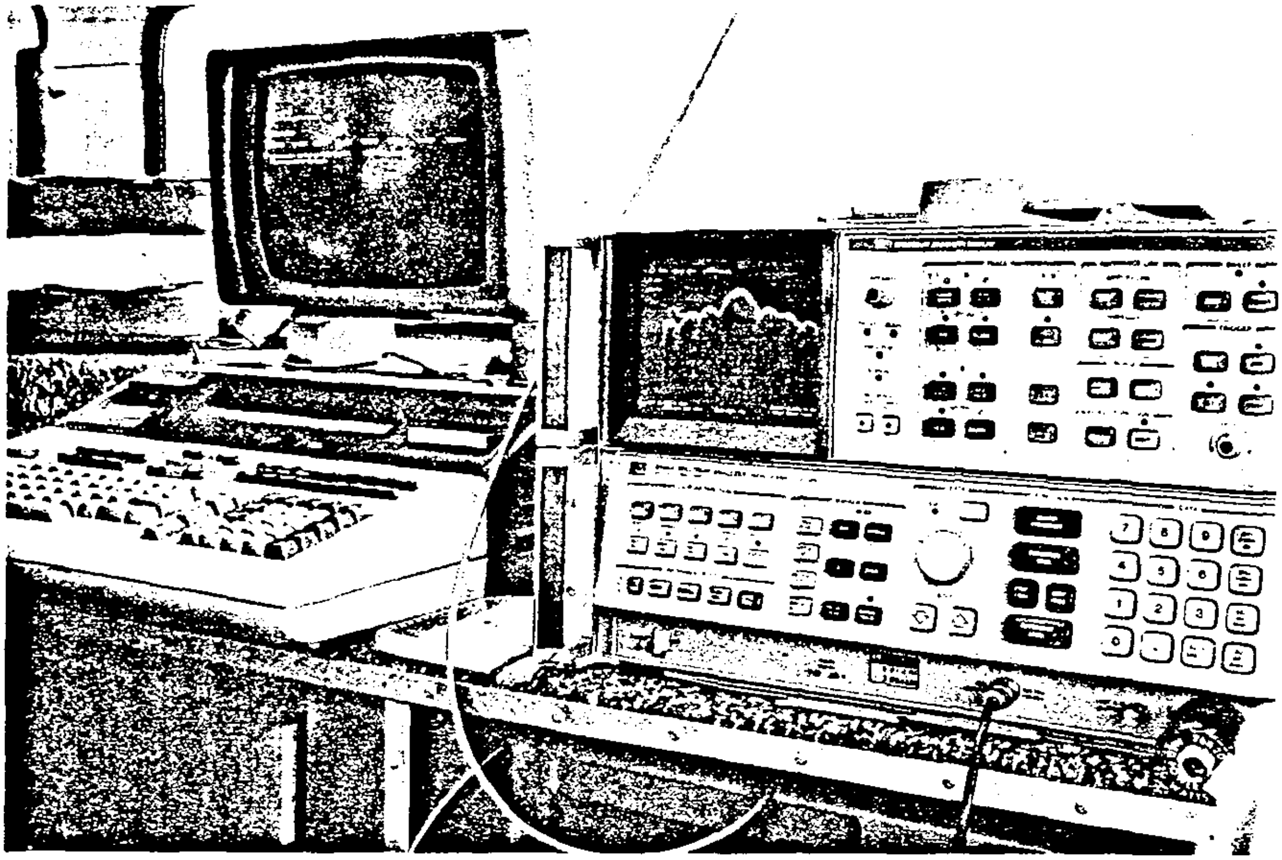


Figure 19.
Inside view of mobile measurement system.

The system was powered by a gasoline 1800 watt portable alternator which was removed from the vehicle and placed several feet away. The dish antenna was mounted on a Pelco pan/tilt unit which can position the dish vertically and horizontally. The dish antenna was directed toward the rotating radar antenna as shown in Figure 20.

Three different locations around the airport were used as measurement sites. All the sites provided good data, but location 2 was determined to be the best of the three locations because of the absence of nearby fences and buildings. The data from location 2 are shown in Figures 21, 22, and 23. These figures show the same type of data as shown in Figures 15, 16 and 17 except an external attenuation of 20 dB was attached to the front of the HP 8655A spectrum analyzer due to the strong signal at Location 2.

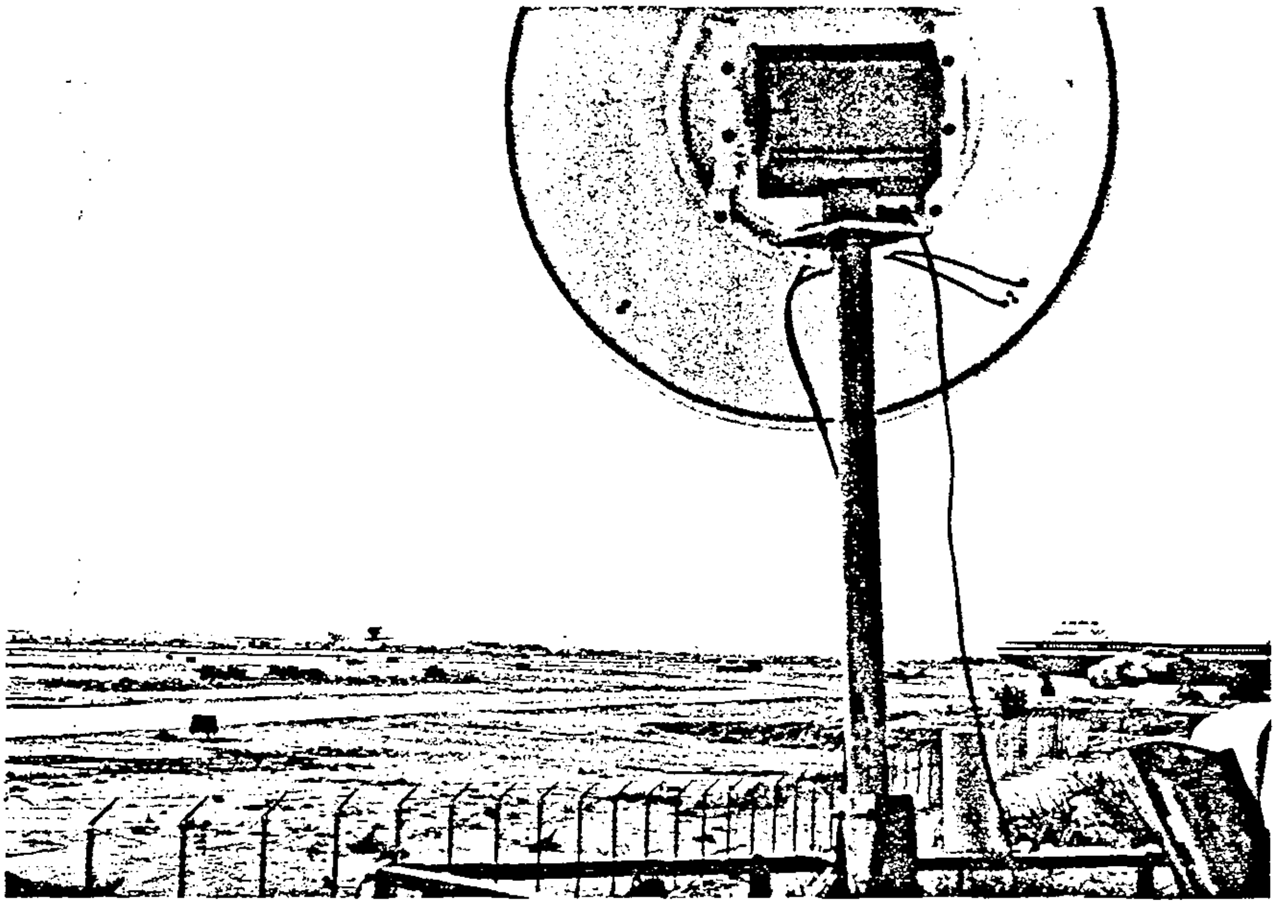


Figure 20.
Dish receiving antenna directed toward rotating radar antenna.

When the laboratory measurements were compared to the field measurements, the lab data appears to be sufficient for use in the project should the need arise to make additional measurements.

The data collected in the field will be used as a data array for the controlling computer program. The data may be manipulated for several different variations of the actual signal measured in the field.

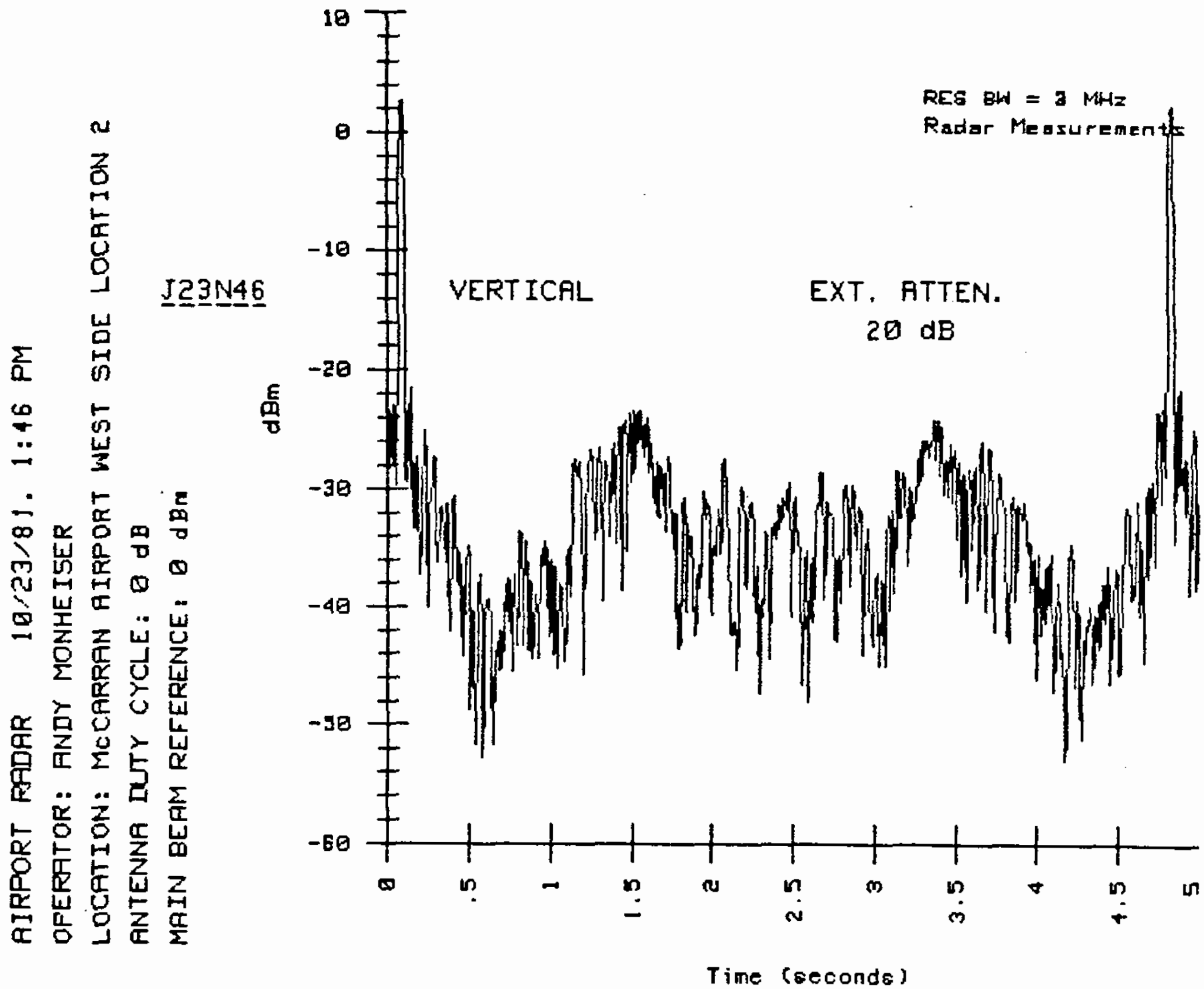


Figure 21.

Radar antenna rotational duty cycle measurement made at McCarran Airport. Vertical axis of receiving antenna used.

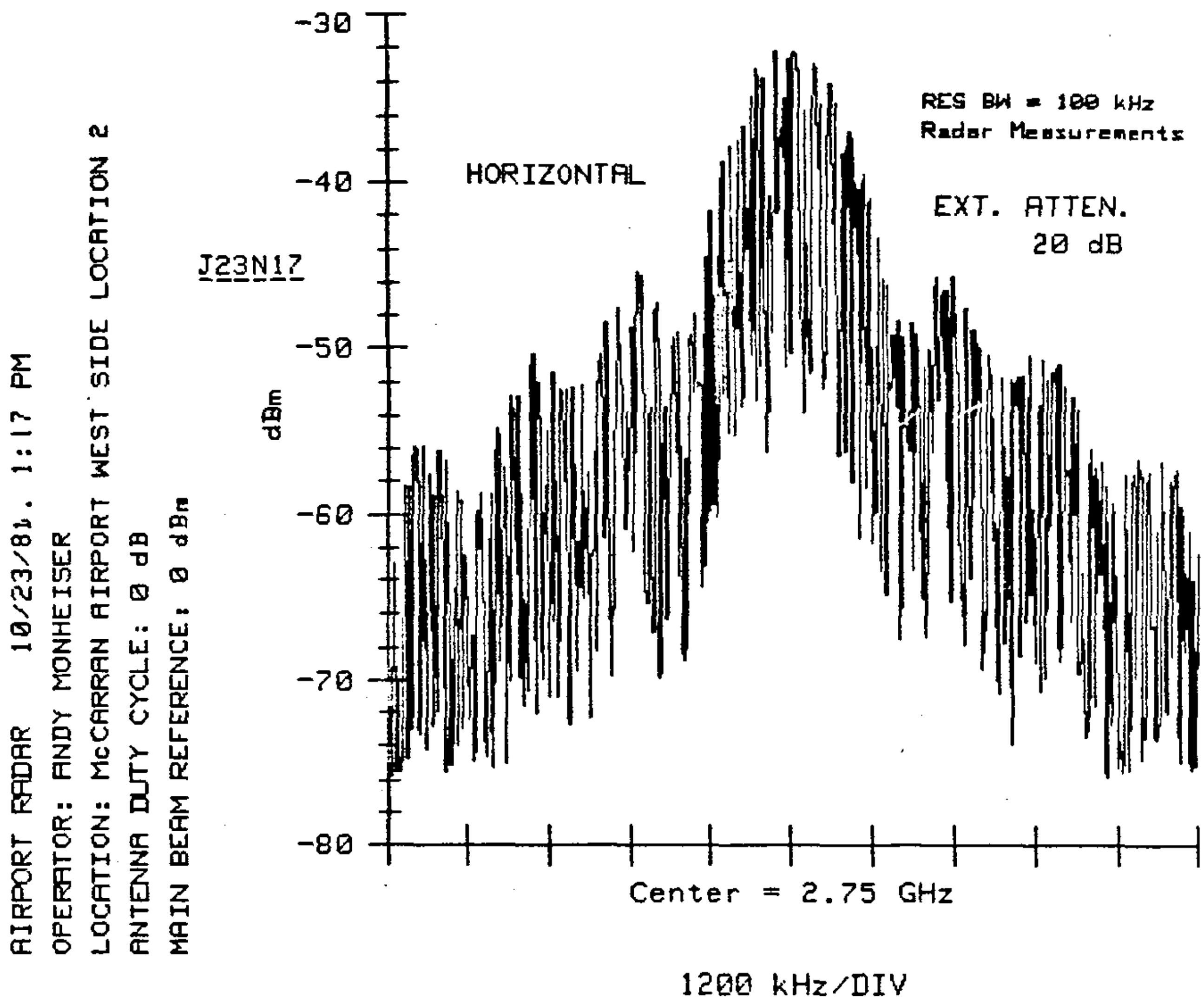


Figure 22.

Radar pulse width measurement made at McCarran Airport. Horizontal axis of receiving antenna used.

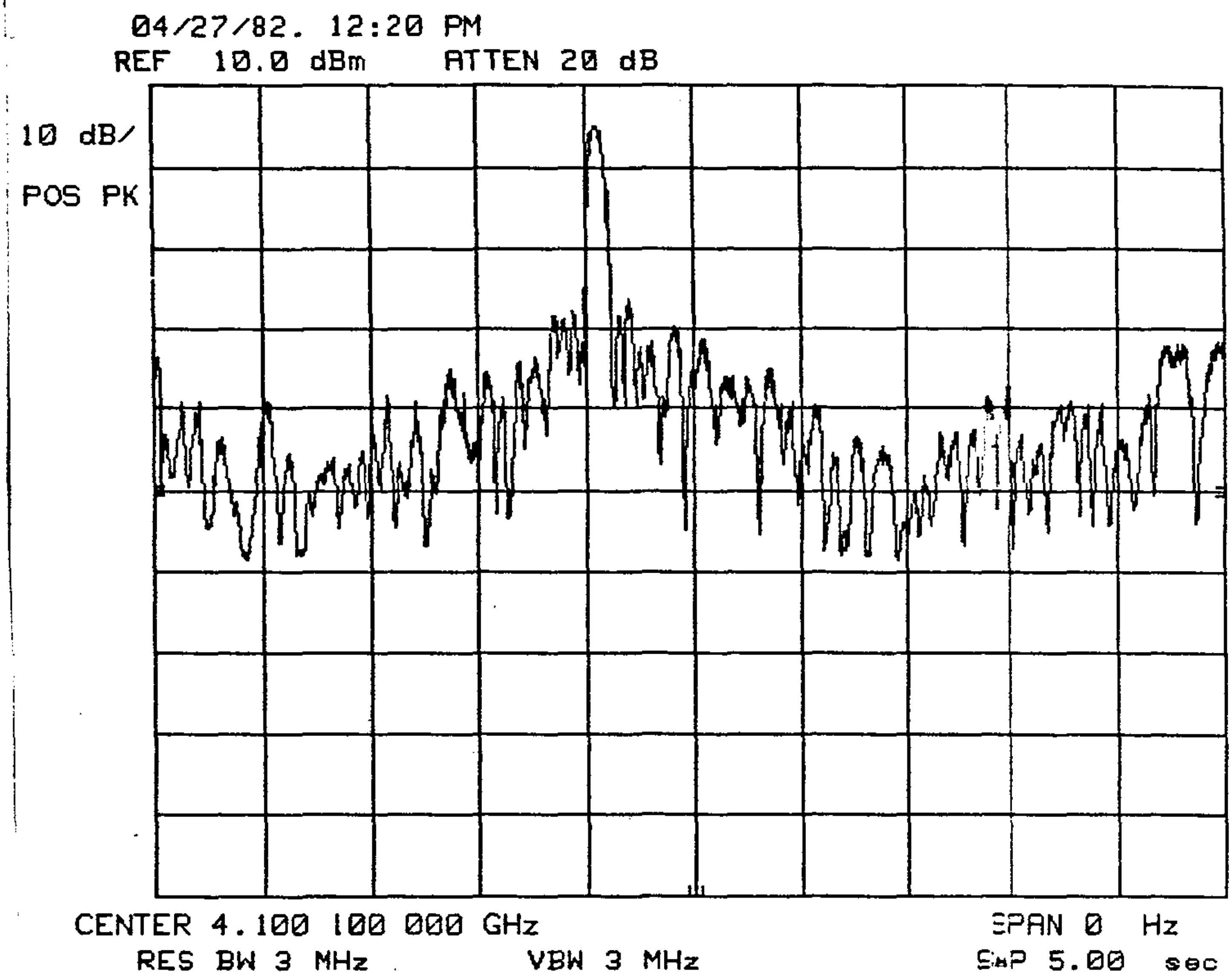


Figure 23.

Peak signal from rotating Radar Antenna. Measurement made at McCarran Airport. Horizontal axis of receiving antenna used.

Controlling Computer Program

As explained on page 9, the amplitude modulation of the signal is accomplished by using a PIN diode attenuator or modulator. The PIN diode attenuator is controlled by DC voltages supplied from a Digital-to-Analog-Converter (DAC), which is part of a Varian Data Machines 620/f-100 mini-computer. In order to simulate a rotating radar antenna pattern, a computer program was written in BASIC. This program was entitled "DRIVER." DRIVER uses actual radar measurement data, converts it to a voltage appropriate for the system by using the transfer function, and puts this new adjusted data into an array. These voltages are then output from the DAC in such a fashion as to simulate the rotating radar antenna signal strength variation. Since radar antennas have various rotational rates, DRIVER is capable of outputting the set of data over various time periods. DRIVER is capable of outputting 1000 data elements in less than one second. The output time is entered by the operator and DRIVER outputs the set of data continuously until it is manually stopped. This allows the signal pattern to be transmitted over and over in order to simulate a continuously rotating radar antenna. A listing of DRIVER is shown on page A2 of the appendix.

Data Transfer Between Systems

As described on page 23, measurements from a rotating radar antenna located at McCarran Airport were made using a measurement system consisting of a HP 9845B computer and a HP 8566A spectrum analyzer. The data from these measurements were stored on floppy disk and a magnetic tape cartridge. These data may be retrieved from the floppy disk or cartridge in the lab. These data on received power levels of the rotating radar antenna signal are represented in an array of 1001 elements. This array is the set of data necessary for the DRIVER data pool. The Varian mini-computer, however, is not capable of reading the data from the HP floppy disk or cartridge. The Varian has floppy disk drives, a high-speed paper tape reader, a cassette drive, and a hard disk unit for mass storage input/output. The floppy disk format, however, is not the same for the HP and Varian computers.

After considering several alternatives, it was decided that the data transfer could best be accomplished by using paper tape since a Facit 4070 paper tape punch was available. The Facit, however, was not directly compatible with the HP 9845B computer.

Pin	Signal	Pin	Signal
1	Ch1	14	–
2	Ch2	15	–
3	Ch3	16	–
4	Ch4	17	–
5	Ch5	18	–
6	Ch6	19	Ext
7	Ch7	20	Err. 1
8	Ch8	21	TL
9	Ch9	22	+ 24 V
10	SD	23	–
11	PI	24	+ 6 V
12	PR	25	0 V
13	–		

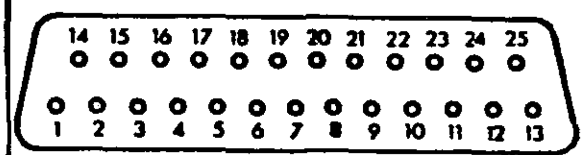


Figure 24.

Signal connector for Facit 4070 paper tape punch.

In order to interface the Facit paper tape punch with the HP 9845B computer, the voltage and logic requirements were considered. Figure 24 shows the function of each pin for the Facit interface jack.

Pins 1 through 8 are the eight data channels and pin 9 is for the feed hole track. Pins 11 and 12 are the punch instruction (PI) and punch ready (PR) signals. Pin 25 is ground and pins 10, 19, 20, and 21 were not used for this interface since the error signals, tape low signal, and the stepping direction were not considered necessary.

The Facit interfaces using positive-true logic. A high (true) signal is a logical 1 and a low (false) signal is a logical 0. A logical 1 corresponds to a +3.5 to +12 volt signal and a logical 0 corresponds to a -12 to +1.5 volt signal. Figure 25 shows the signal diagram necessary for the Facit to interface.

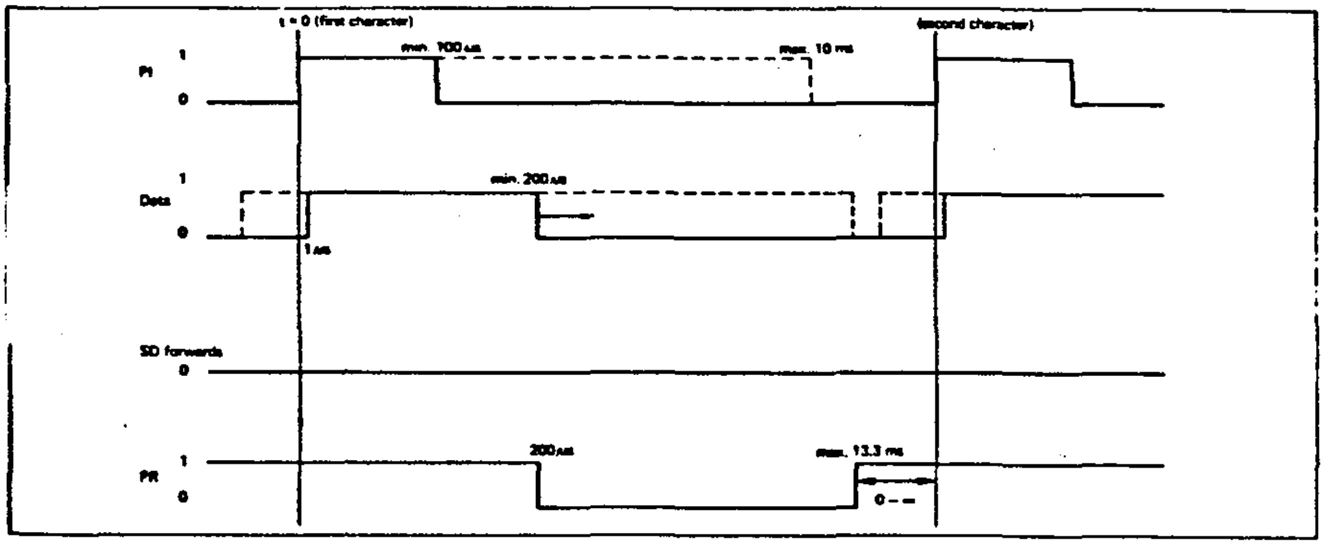


Figure 25.

Signal diagram for Facit interface.

There are only two instructions necessary for the Facit, the PI and the PR instruction. The stepping direction (SD) will always be forward and therefore corresponds to zero volts.

Figure 26 shows the function of each pin for the HP 98034A HP interface bus (HP-IB) connector and Table 4 defines the abreviations used.

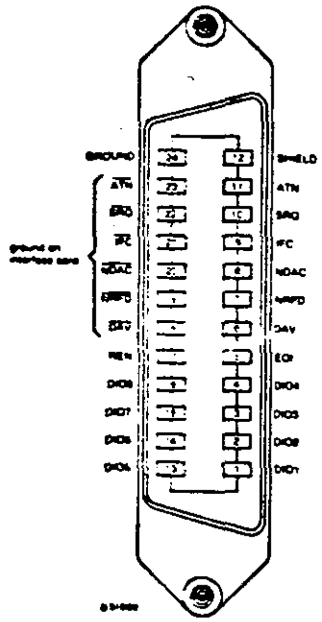


Figure 26.

HP-IB Cable Pinouts.

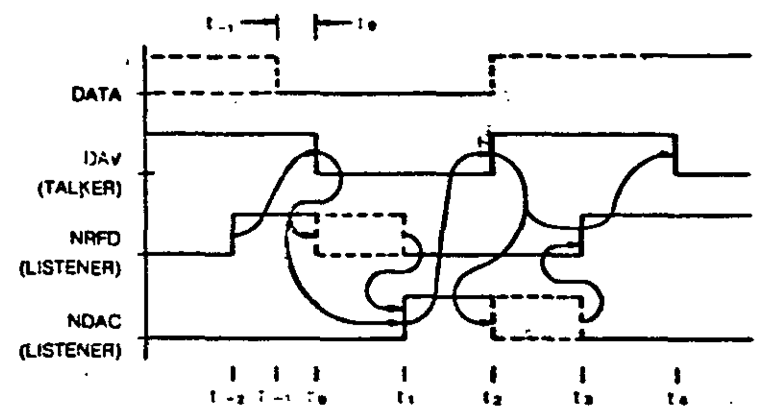
Table 4. **HP-IB Signal Lines**

DIO1	Data Input Output 1
•	•
•	•
•	•
DIO8	Data Input Output 8
DAV	Data Valid
NRFD	Not Ready for Data
NDAC	Data Not Accepted
IFC	Interface Clear
ATN	Attention
SRQ	Service Request
REN	Remote Enable
EOI	End or Identify

Pins 1, 2, 3, 4, 13, 14, 15, and 16 are the eight data channels. Pins 6, 7, and 8 are the data valid (DAV), not ready for data (NRFD), and not data accepted (NDAC) channels. Pin 24 is signal ground. The other pins were not used in this interface.

The HP 98034A Interface Card connects the HP 9845B computer to the HP Interface Bus (HP-IB), allowing the computer to interact with several different instruments such as the HP 8566A spectrum analyzer, the HP 2631G graphics printer, the HP 59313A Analog-to-Digital converter, and other such instruments.

The HP-IB interfaces using negative-true logic. A high (true) signal is a logical 0 and a low (false) signal is a logical 1. This is the opposite of the Facit logic. Also, for the HP-IB, a logical 1 corresponds to <0.4 volts while a logical 0 corresponds to >2.4 volts. Figure 27 shows the signal diagram necessary for the HP-IB to interface.



(The curved lines indicate interlocked signal sequence.)

t_{-2}	Listener becomes ready to accept data.
t_{-1}	Talker has put data on the lines
t_0	Indicates data is valid
t_1	Listener has accepted the data and no longer requires it held valid
t_2	Talker indicates the data is no longer valid and may change it.
t_3	Listener indicates it is ready for new data.
t_4	A new cycle begins (equivalent to t_0)
t_{-1} to t_0	Time that data is put on lines before DAV is set low

Figure 27.

Signal diagram for HP-IB.

In order to make the voltages and the logic compatible between the HP-IB and the Facit, a series of DC offset inverting operational amplifiers were constructed. A block diagram of the pin-to-pin interface through the amplifiers is shown in Figure 28.

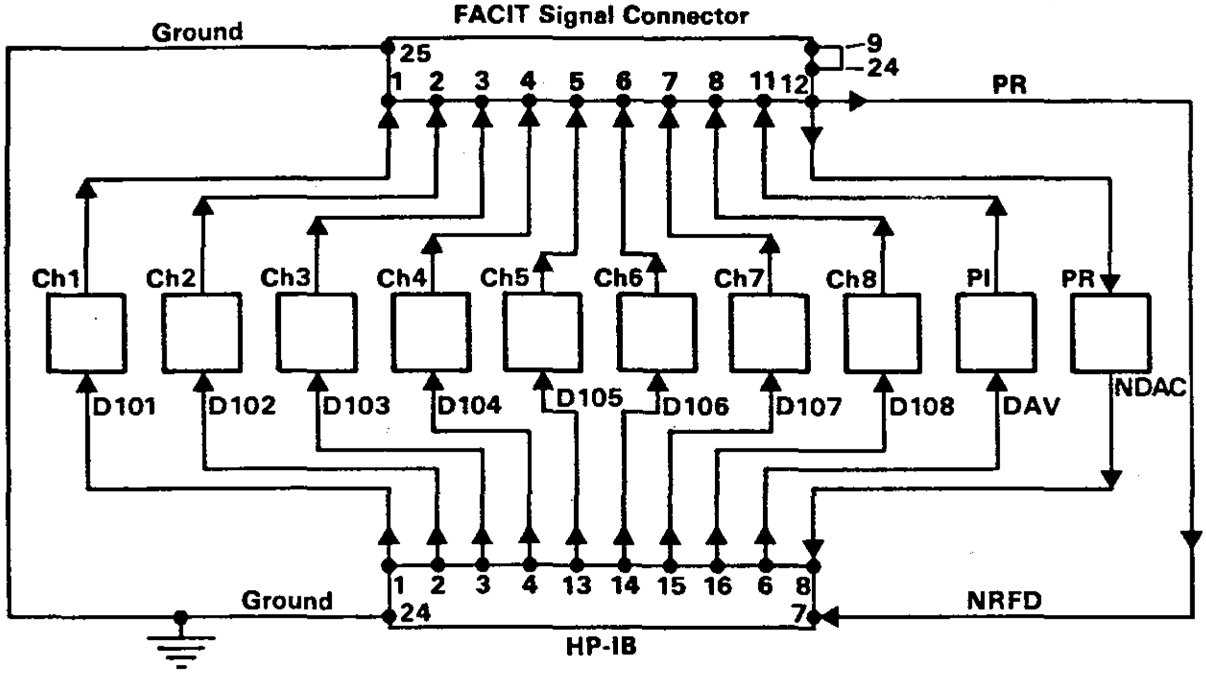


Figure 28.

Pin-to-pin connector of Facit to HP-IB.

Figure 28 shows ten amplifiers. Eight of these amplifiers are for the data channels, one is for the punch instruction, and one is for the punch ready instruction. Notice the direction of signal transfer is from the HP-IB to the Facit through all the amplifiers except the PR reply. The nine amplifiers are identical. Only the PR amplifier is different. Figure 29 shows a block diagram of one of the nine identical amplifier's input/output.

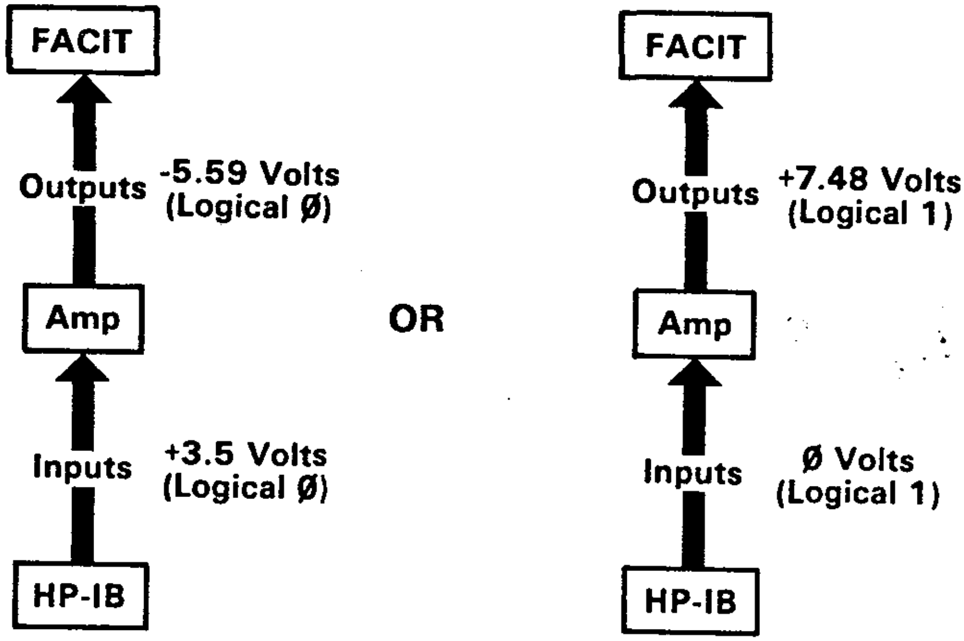


Figure 29.

Signal in versus signal out for data amplifier.

It can be seen that if a logical 1 (<0.4V) is output from the HP-IB then a logical 1 (+ 3.5 to +12V) is input to the Facit, and vice versa. Therefore, if a bit is set from the HP-IB, it will be set for the Facit. If the amplifiers were not present, a logical 1 from the HP-IB would be input to the Facit as a logical 0. The amplifiers match the logic between the Facit and the HP-IB. Figure 30 shows a schematic circuit diagram of a data channel amplifier. These amplifiers are DC offset by +7.5 Volts.

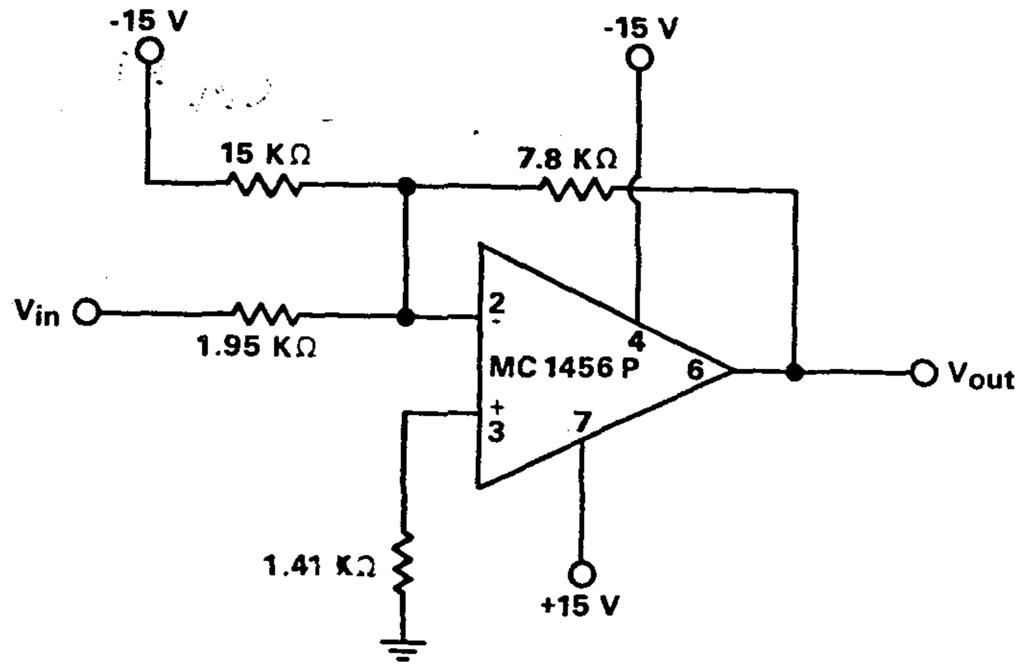


Figure 30.

Schematic of data channel amplifier. DC offset is +7.5 volts.

The PR to NDAC amplifier was DC offset by +3.5 volts since the signal is from the Facit to the HP-IB. Figure 31 shows a block diagram of this amplifier's input/output and Figure 32 shows a schematic circuit diagram.

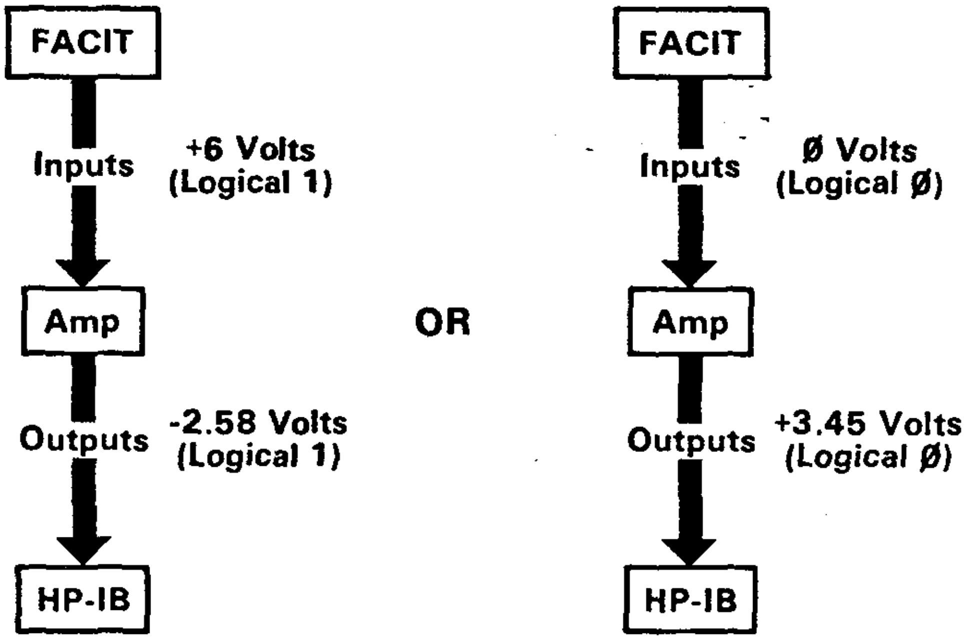


Figure 31.
Signal in versus signal out for PR to NDAC amplifier.

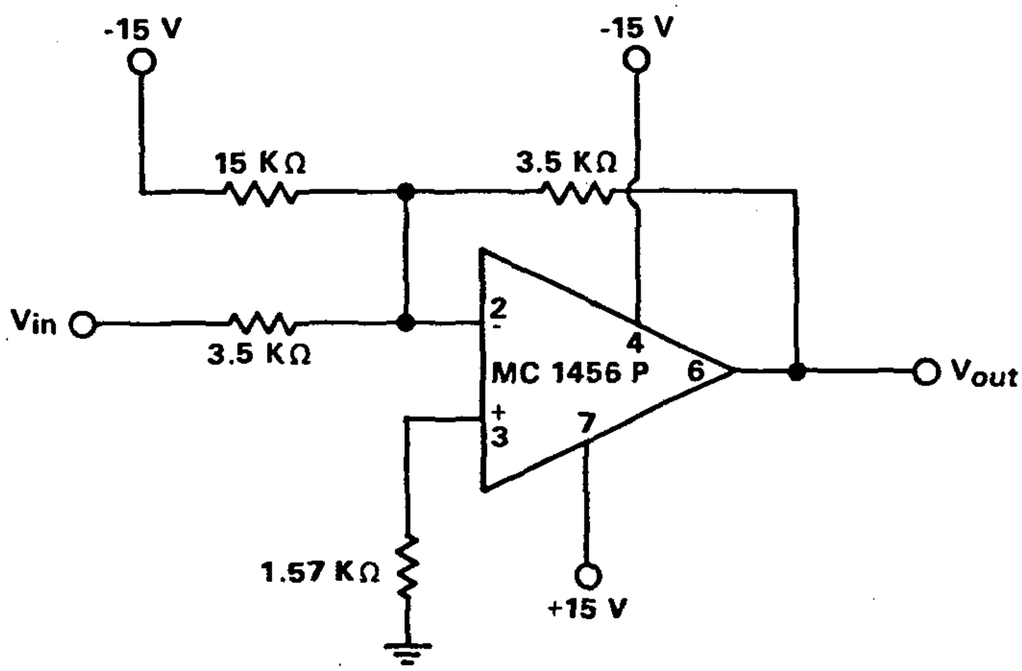


Figure 32.
Schematic of PR to NDAC amplifier. DC offset is +3.5 volts.

These amplifiers allow the HP 9845B computer to interface to the Facit 4070 paper tape punch via the HP 98034 HP-IB. It is now possible for data on a HP floppy disk or magnetic tape cartridge to be punched out on paper tape. The Varian mini-computer may now read in these data via its high-speed paper tape reader.

Procedure for Punching Data from HP 9845B

This is a step by step procedure to be used to transfer data saved on cartridge to paper tape using the HP 9845B computer. The procedure is as follows:

1. Put cartridge entitled "ANDY'S PROGRAMS" in either of the two cartridge drives on the HP 9845B.

2. Load the program "PHOTO" from the cartridge into the computer memory.

3. Run PHOTO and recall the saved data (PHOTO will guide the operator through this process).

4. When the statement "D(*) SHOULD BE THERE!!" appears, push STOP.

5. Load the disk entitled "ANDY'S DATA" into the disk drive.

6. Type ASSIGN#1 to "XFER:F"

7. Type PRINT#1; D(*)

8. Load the program "PTPV1" from the cartridge.

9. Connect the paper tape punch to the HP 9845B via the interface box (insure the interface box is plugged in).

10. Turn on the paper tape punch and make a leader on the paper tape.

11. Push RUN.

This procedure punches out the data from the specified file onto paper tape in the form of a program. The program contains DATA statements. An example of the format is shown on page A1 of the appendix.

System Set-up in Anechoic Range

The function of an anechoic range is to provide a microwave reflection free volume for radiated microwave testing and/or measurements. Such ranges may take the form of completely enclosed chambers such as a room with all surfaces covered with anechoic (non-reflective) material. This practically eliminates signal reflection off of walls, equipment, and other fixtures. Figures 33 and 34 show a different version of an anechoic range constructed by the Nonionizing Radiation Surveillance Branch (NRSB) of the U.S. Environmental Protection Agency (EPA).

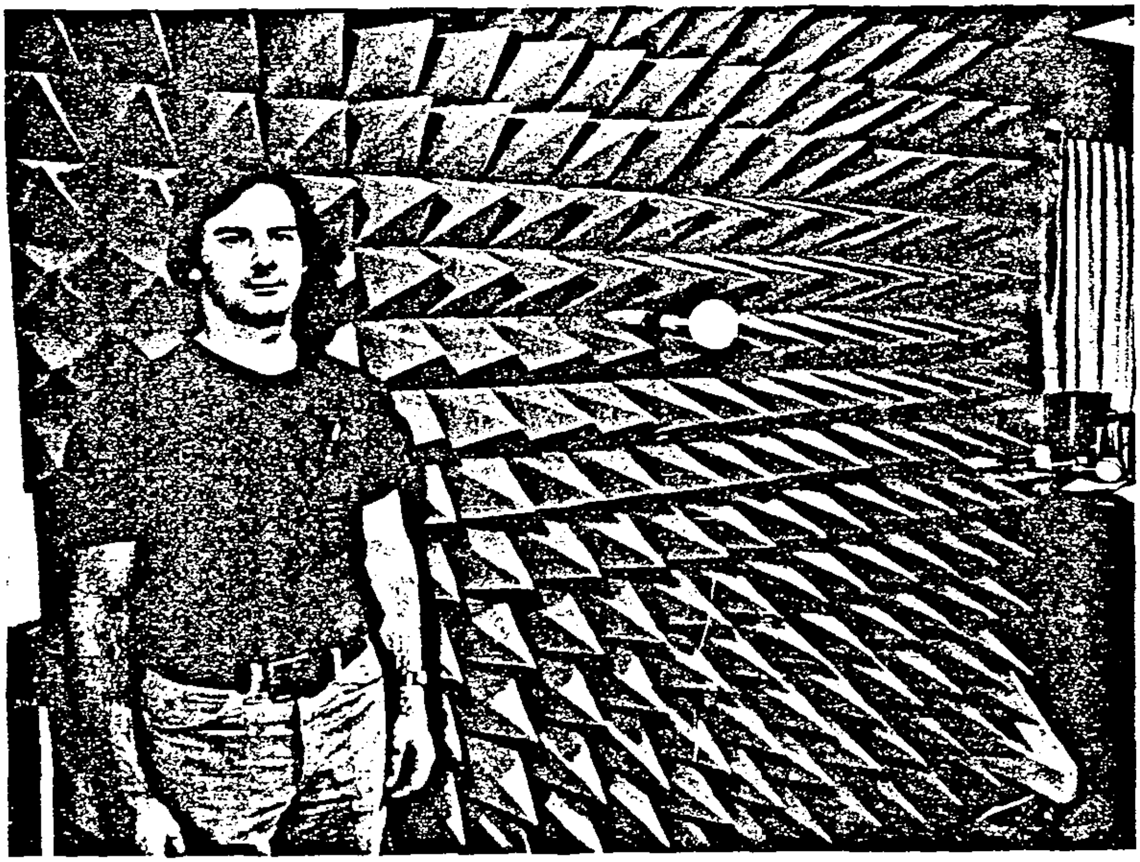


Figure 33.
Anechoic range panel for mounting of measurement probe.

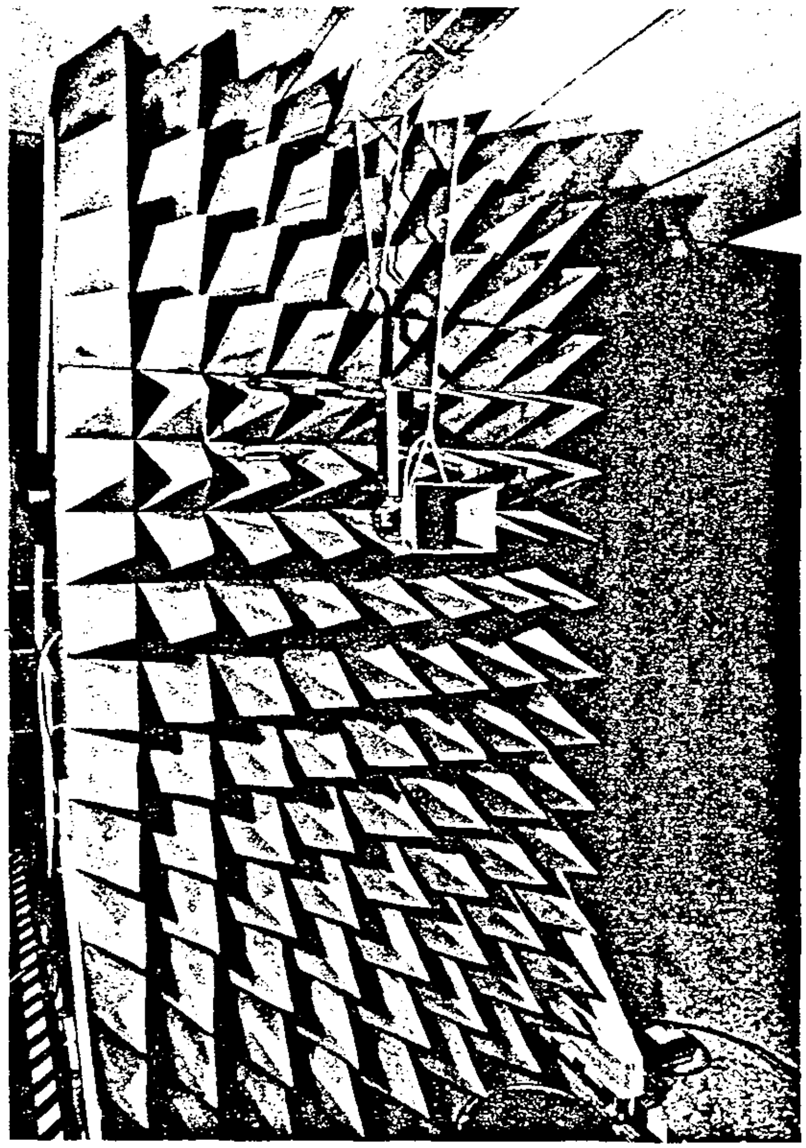


Figure 34.
Anechoic range panel for mounting of standard gain horn transmitting antenna.

The anechoic range consists of two wooden sleds mounted on casters so they may be separated by various distances by either rolling them toward or away from each other. The material mounted on the wooden sleds is carbon loaded foam rubber which absorbs microwave signals such as those transmitted from the Narda 643 standard gain horn antenna shown in Figure 34. This helps insure that the microwave measurement probe (shown in Figure 33 as a white spherical object) does not receive reflected signals but is exposed only to the signal radiated directly from the horn antenna. The horn antenna and the measurement probe are oriented toward each other as shown in Figure 35.

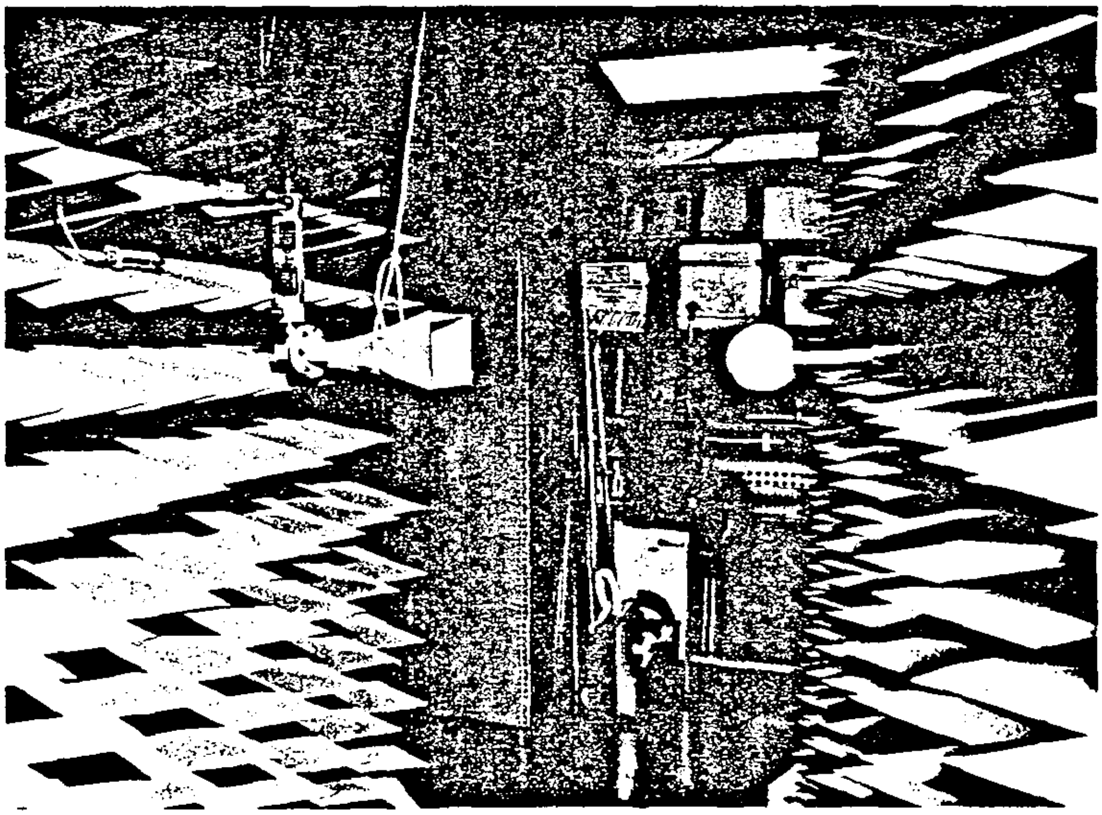


Figure 35.
Orientation of transmitting antenna and measurement probe in anechoic range. Note directional coupler attached to horn antenna to facilitate measurement of forward and reflected power at the input to the horn.

The radar simulation system was set up in the anechoic range as shown in Figure 36. This figure shows the back of the sled shown in Figure 34. Figure 36 shows all the components of the system described in Figure 12 except the

Varian mini-computer with its DAC is not shown although it is connected to the system. The NARDA 3024 coupler and the NARDA 643 standard gain horn are mounted on the other side of the wood frame. The HP8566A spectrum analyzer (bottom right) is used to monitor the simulated radar signal while the HP3490A multimeter (bottom left) is used to monitor the DC voltage applied to the bias port of the the PIN attenuator from the DAC. A Hughes 1277H traveling wave tube (TWT) amplifier is used to produce a radiated signal of sufficient intensity to be readily detectable by the hazard survey probe.

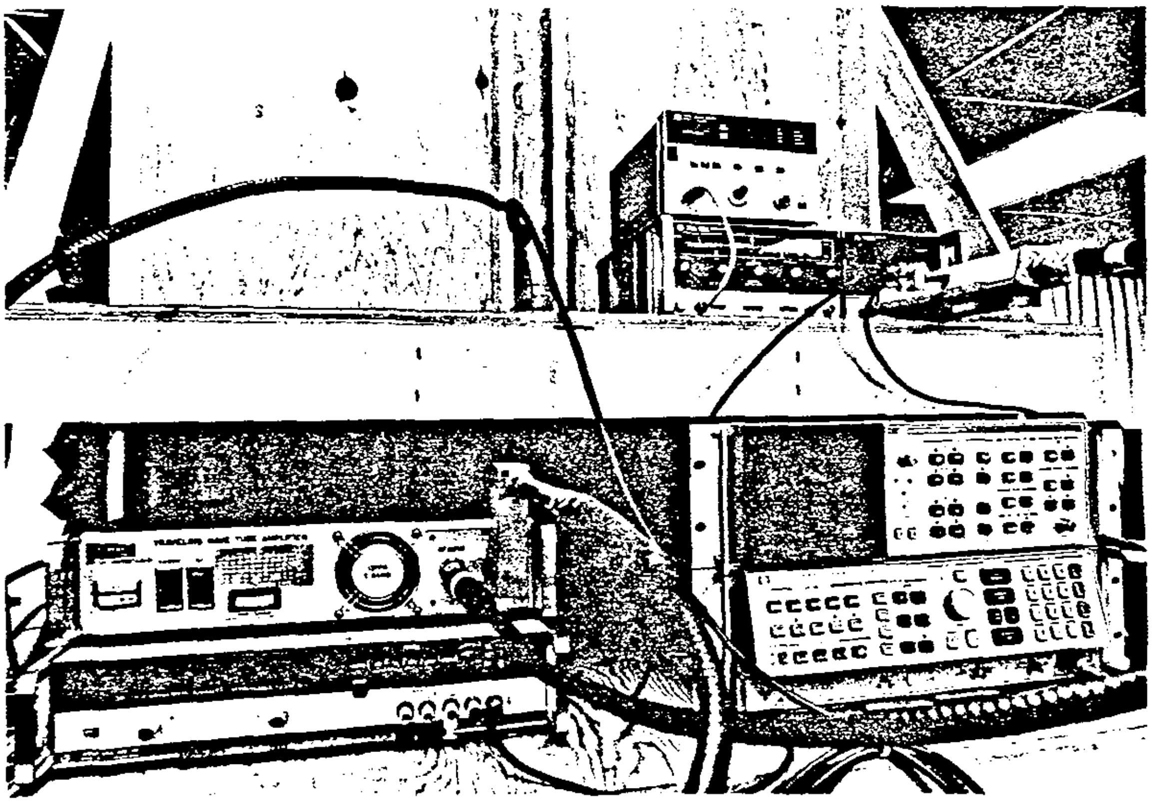


Figure 36.
Radar simulation equipment set up in anechoic range.

Figure 37 shows a NARDA 8616 electromagnetic radiation monitor mounted behind the sled shown in Figure 33. This instrument is connected to the probe in Figure 33. A piece of PVC pipe is used as a mount for the probe. Various other instruments to be tested or calibrated may be mounted in the same fashion.

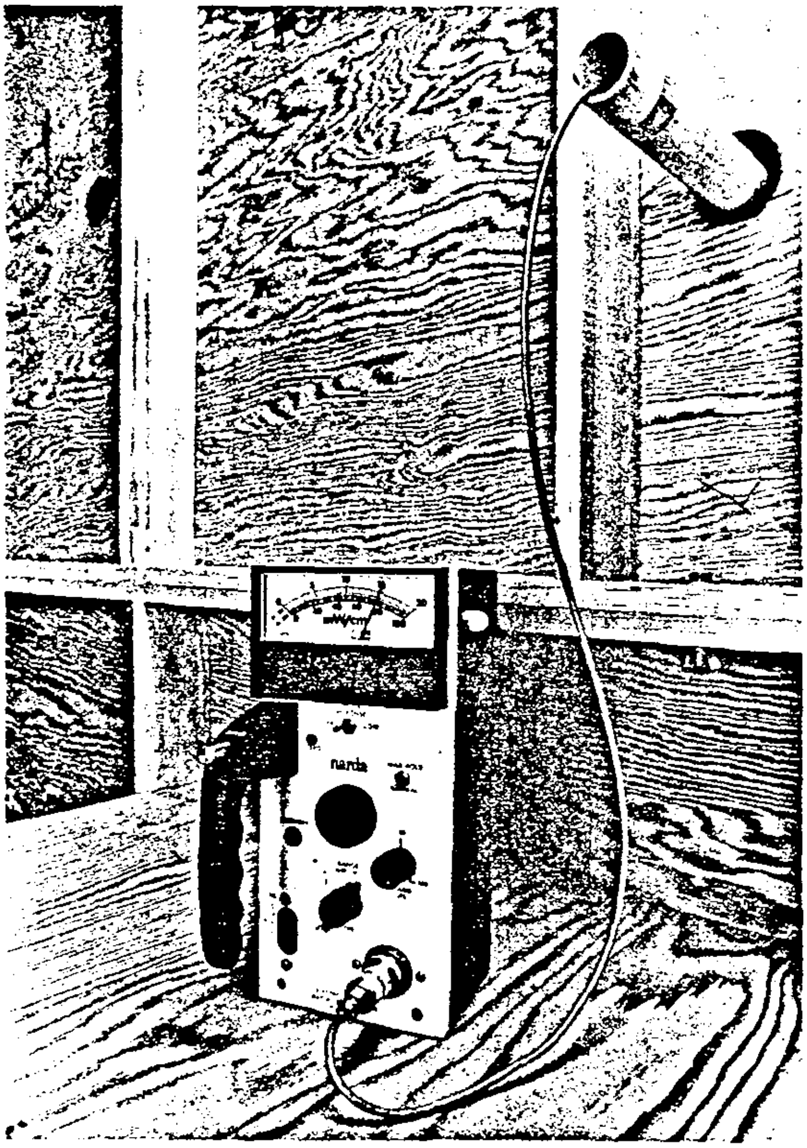


Figure 37.
Test equipment mounted in anechoic range.

The Varian Data Machines 620/f-100 mini-computer is shown in Figure 38. The DAC is located in the left panel with the cable leading to it. This coax cable runs across the lab to attach to the PIN attenuator located in the anechoic range.

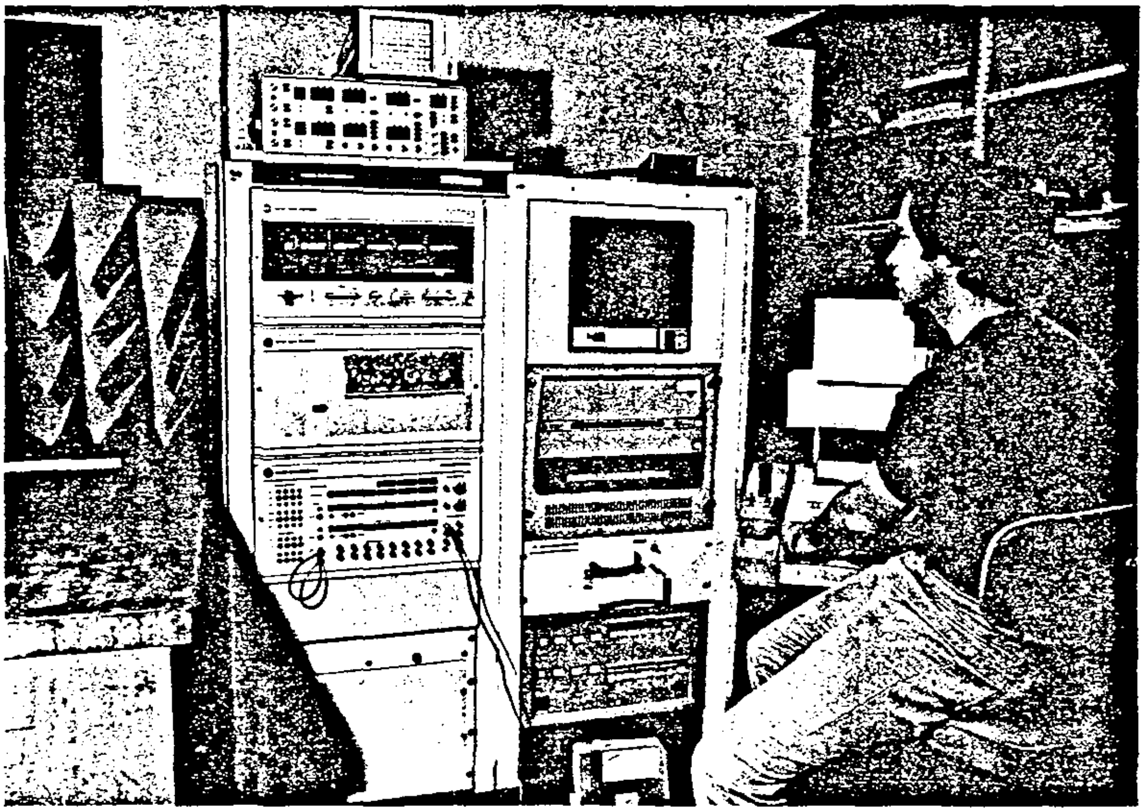


Figure 38.

Varian Data Machines 620/f-100 mini-computer with DAC.

Radar Signal Simulation

The crux of this project is to simulate the signal pattern of a rotating radar antenna. As stated earlier in this report, measurements of an actual rotating radar antenna were made at McCarran Airport. Several different locations around the airport were used to make measurements of the radar using the mobile measurement system described on page 28. Page 24 described several different measurements of the radar antenna's pulse width, rotational duty cycle, and peak signal. This project mainly deals with that portion of the radar's antenna radiation pattern which best describes the peak signal created at a given observation point by the rotating radar antenna. Figure 39 shows one such measurement. This figure shows the signal pattern of the rotating radar antenna as displayed on the CRT of the HP 8566A spectrum analyzer. These data were entitled WRDAR. The horizontal axis is in the time domain while the vertical axis shows the received power level in dBm. The peak signal is observed when the radar antenna swings toward the receiving antenna at the observation point and then disappears as the antenna swings away. Notice that the power level difference from the peak to the lower level indicated in Figure 39 is approximately 22 dB.

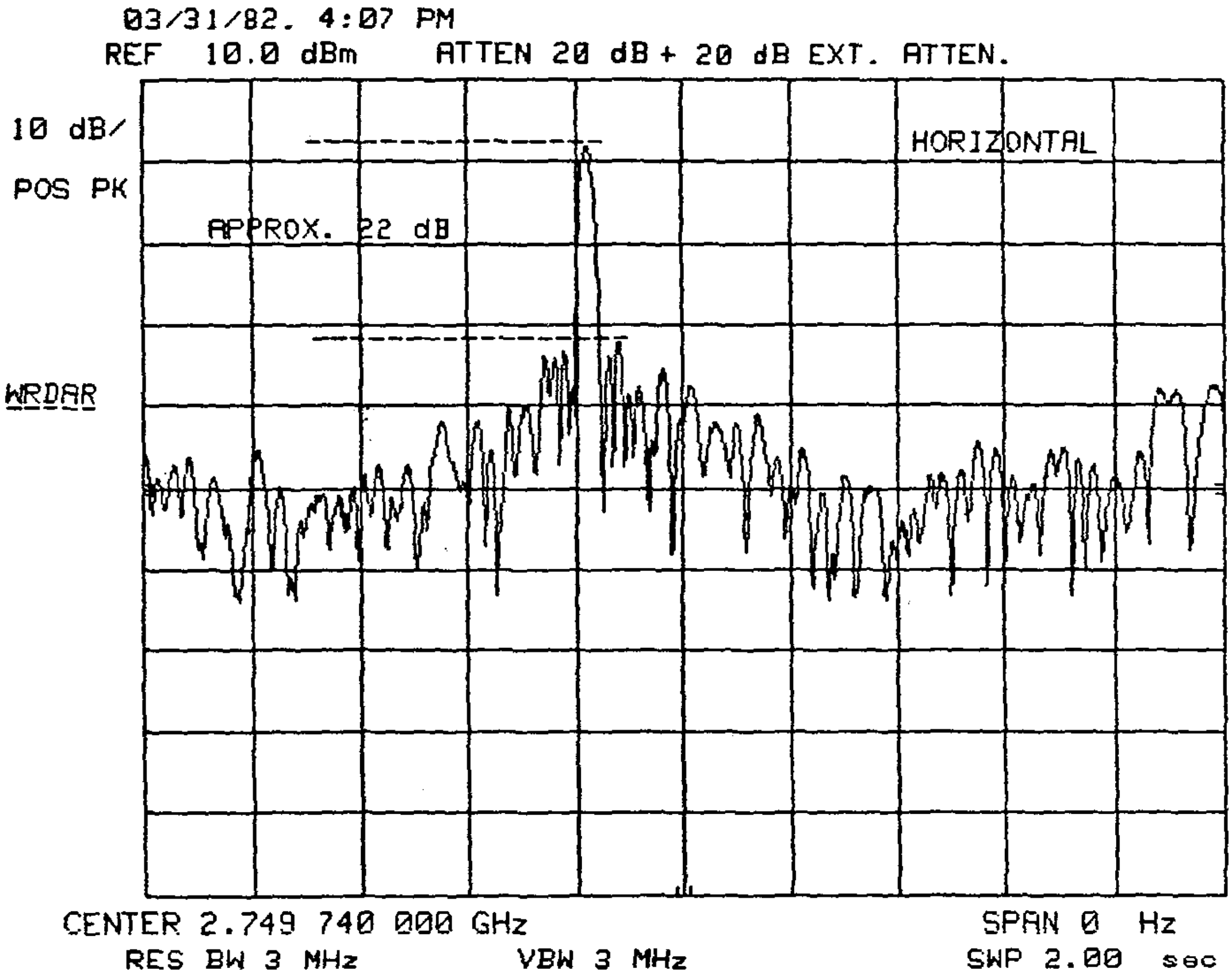


Figure 39.

Peak radar measurement made at McCarran Airport.

In order to simulate the signal pattern shown in Figure 39, the data for WRDAR were loaded into the Varian mini-computer. As previously described, the computer program DRIVER will manipulate these data to produce the appropriate DC voltages from the DAC to the system. The system was set up in the anechoic range and connected as shown in Figure 40.

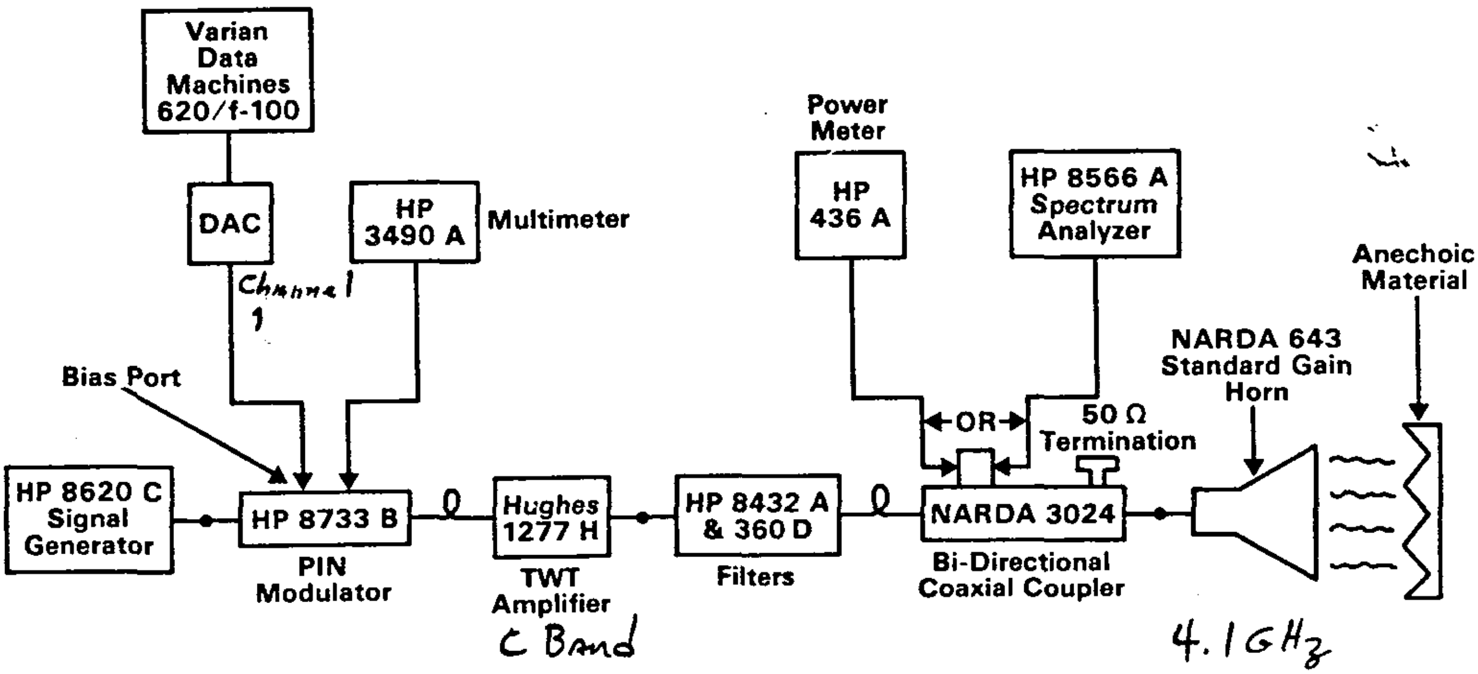


Figure 40.

System set-up in anechoic range.

In order to monitor the signal being transmitted from the horn antenna, the spectrum analyzer was connected to the forward port of the bi-directional coupler as shown in Figure 40. The computer program DRIVER was run and the horn antenna transmitted the simulated radar signal shown in Figure 41. The spectrum analyzer was set to the same sweep time as in Figure 39, but the center frequency is not the same. The actual radar signal of Figure 39 was received at 2.75 GHz and the simulated radar signal was transmitted at 4.1 GHz. Notice the difference in power level from the peak to the lower level indicated in Figure 41 is approximately 22 dB. This is the same as in Figure 39. Also the overall pattern is consistent between the two figures. This simulated pattern is quite acceptable for use in this project and in fact is a very precise simulation.

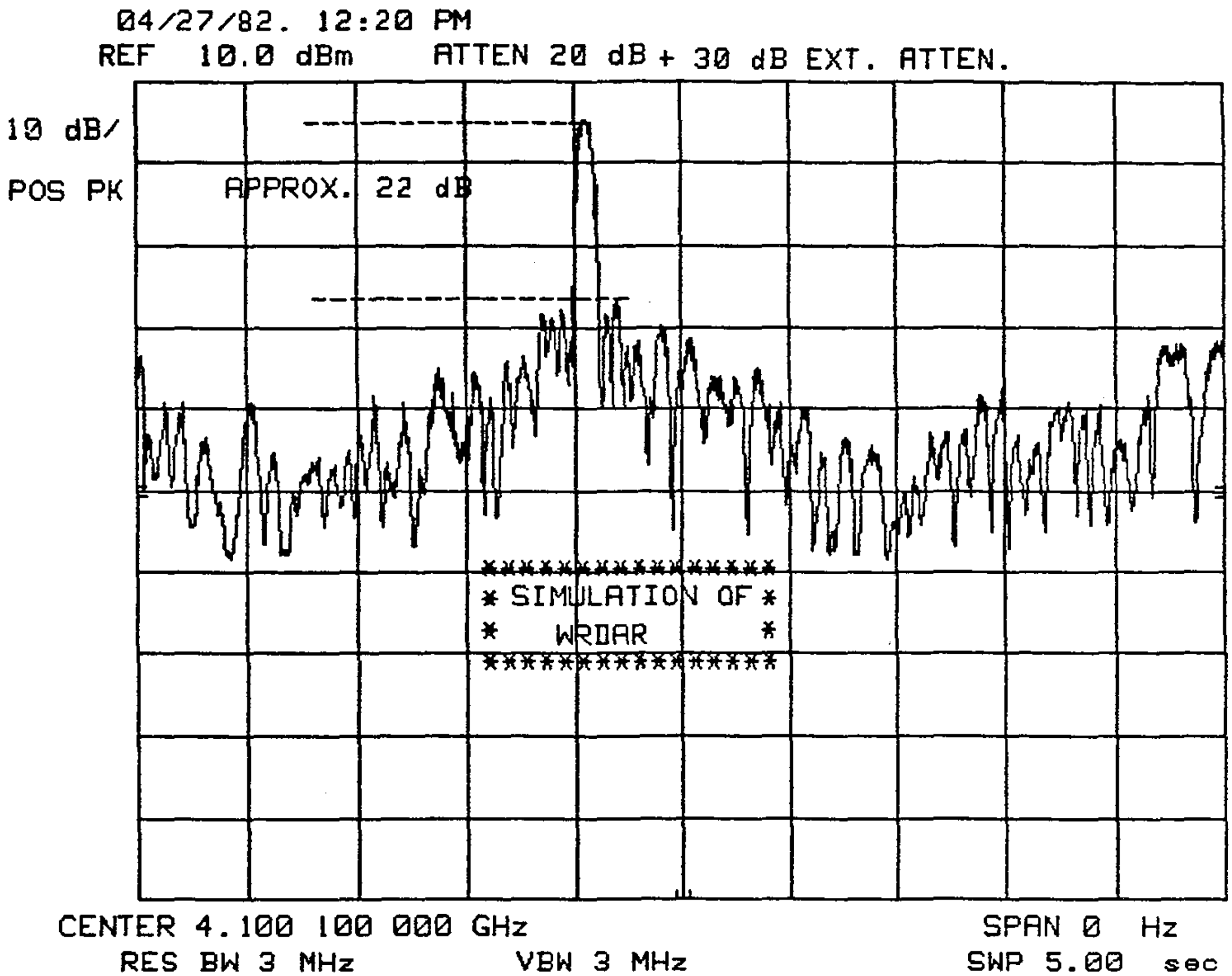


Figure 41.

Simulated radar signal pattern of WRDAR shown in Figure 17.

Time Response of the NARDA 8616 Electromagnetic Monitor

The purpose of this project is to test the time response of microwave survey meters (such as the NARDA 8616 electromagnetic monitor) to the time-varying signal patterns transmitted by rotating radar antennas. The concern about the time response is due to the fact that the high frequency probes used for the NARDA 8616 meter use thin-film thermocouples to detect the electric field. The thermocouples generate a DC signal which is proportional to the power dissipated in them. This process is inherently slow for measurements of time-varying signals. This slow time response will result in a lower power density reading of a rotating radar antenna pattern since the thermocouples simply cannot follow the rapidly changing power level of the signal.

In order to test the time response of the NARDA 8616 meter with the 8621 high frequency probe, it is necessary to be capable of monitoring both the transmitted signal and the NARDA's response simultaneously. The response of the NARDA may be monitored via its recorder output jack. The recorder output corresponds to a DC voltage of +3 Volts for a full-scale reading on the meter and 0 Volts for a zero reading.

The transmitted signal is monitored by connecting the HP 8566A spectrum analyzer (S/A) to the forward port of the coupler as shown in Figure 40.

In order to monitor the transmitted signal and the NARDA's response simultaneously, a computer program entitled "RESPNS" was written for the HP 9845B computer. This program interacts with the HP 59313A Analog-to-Digital (A/D) converter and the HP 8566A S/A as shown in Figure 42. A listing of RESPNS is shown on page A3 of the appendix.

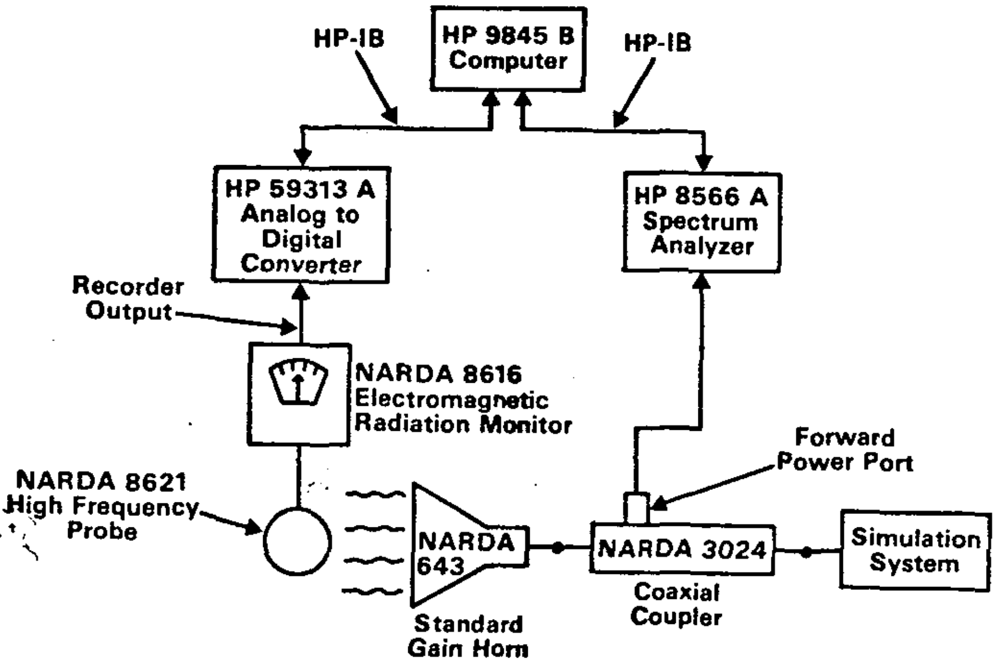
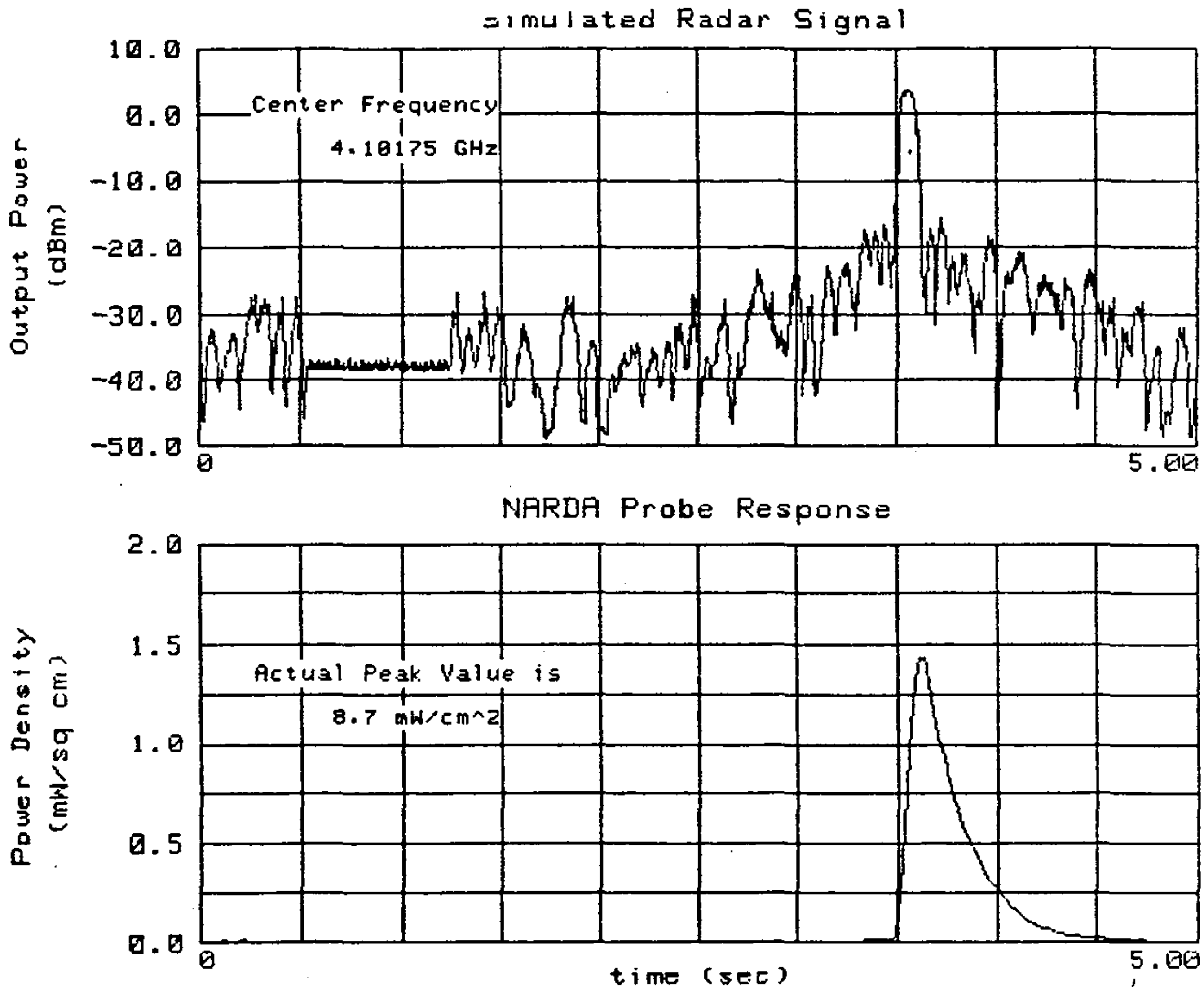


Figure 42.

Simultaneous monitoring of NARDA response time and transmitted signal.

The program RESPNS controls the interaction of the S/A and the A/D. The S/A triggers the A/D to begin collecting data from the NARDA's recorder output at the same time the S/A begins a sweep in time. While the S/A is taking a sweep the A/D is sending data to the HP 9845B. When the S/A completes a sweep it interrupts the A/D. This procedure insures that the data collected from the A/D corresponds to the sweep of the S/A. RESPNS then reads the data from the S/A and graphs both the transmitted signal and the response of the NARDA as shown in Figure 43.

The horizontal axes in Figure 43 represent the corresponding time from a beginning of a sweep from the S/A to the end of a sweep. The vertical axes represent power in dBm for the simulated radar signal and power density in mW/sq. cm for the NARDA probe response. It can be seen in Figure 43 that there is a difference in time between when the peak value of the simulated radar signal occurs and when the peak of the NARDA response occurs. The straight line present in the simulated radar signal is intentionally placed there by the Varian computer program so the beginning and end of a rotation may be observed.



change to log scaling

Figure 43.

Time response of NARDA meter to a simulated rotating radar antenna signal pattern.

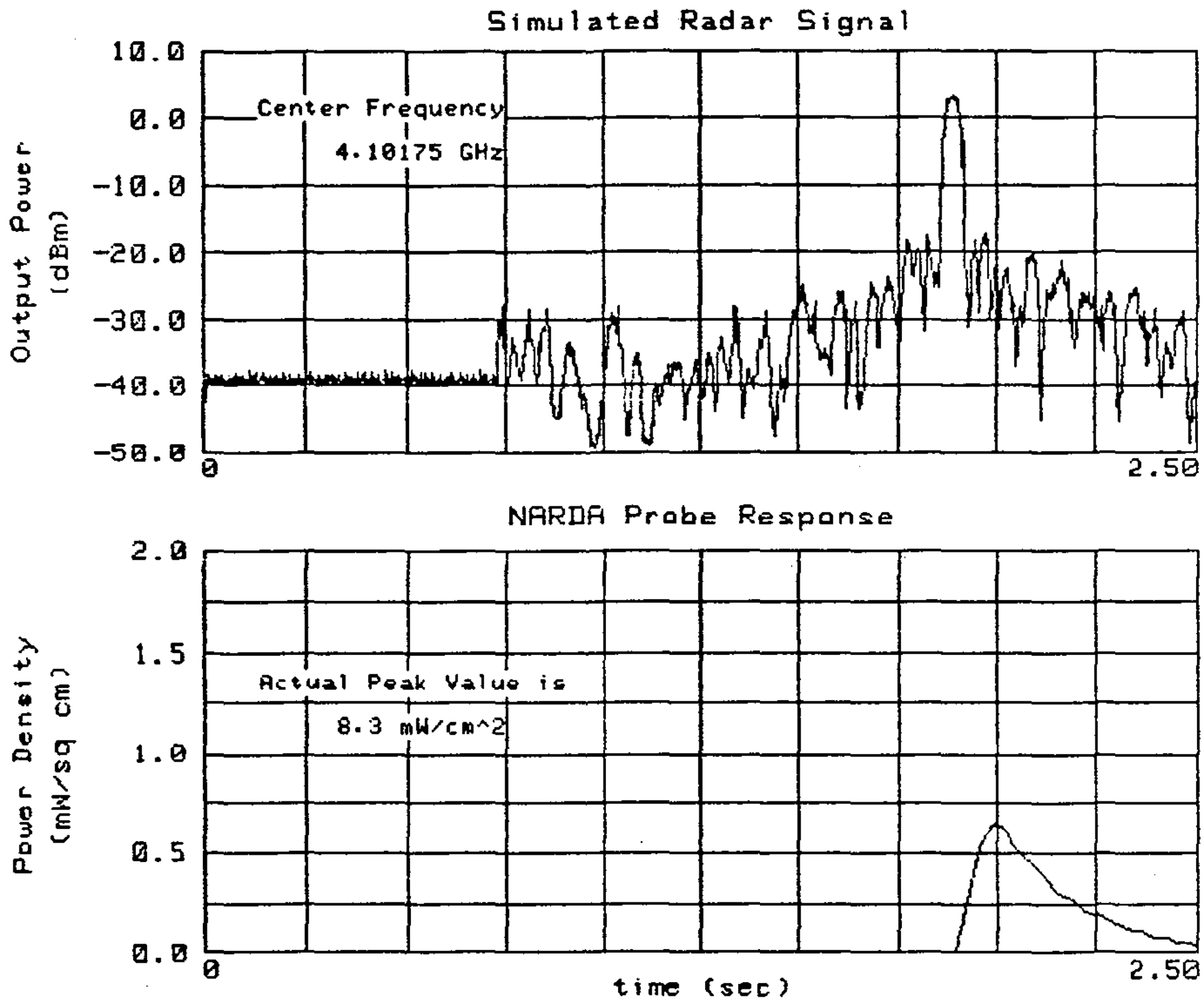


Figure 44.

NARDA time response to simulated rotating radar antenna signal pattern. Notice time of 2.50 seconds.

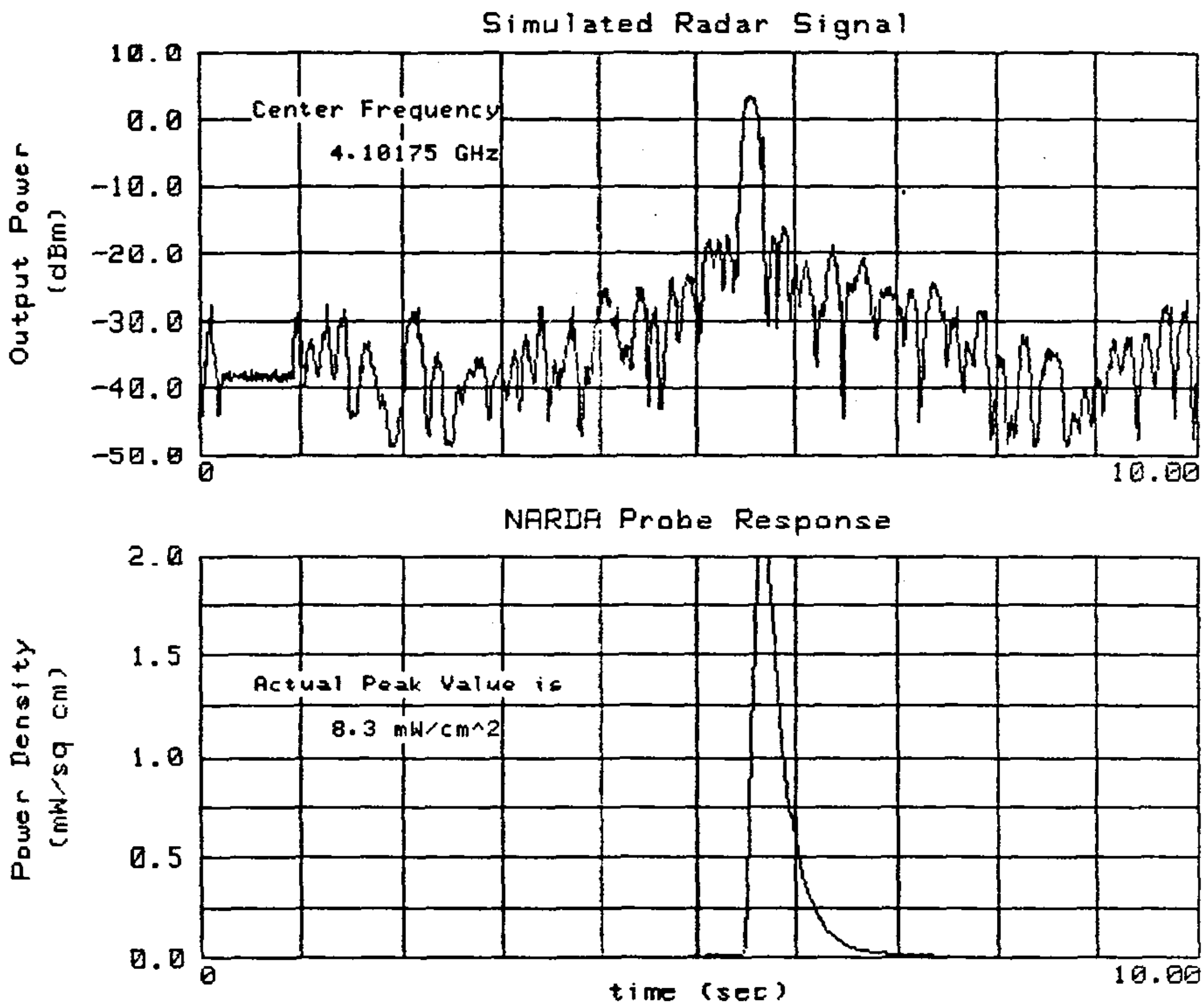


Figure 45.

NARDA time response to simulated rotating radar antenna signal pattern. Notice time of 10.0 seconds.

Also notice in Figure 43 that the actual peak value is 8.7 mW/sq cm. This is the reading that the Narda should display. The Narda only displays, however, a peak value of approximately 1.4 mW/sq cm.

Figure 43 corresponds to an antenna rotation rate of 5 seconds per rotation. Figure 44 shows the response of the Narda probe when the simulated rotation rate is increased to 2.50 seconds per rotation. As predicted, since the Narda has less time to respond to the peak signal, it reads an even lower value. It shoulld read 8.3 mW/sq cm. Figure 45 shows the response of the Narda when the simulated rotation rate is decreased to 10 seconds per rotation. The Narda has an increase amount of time to respond to the simulated rotation, and thus displays a higher value. Notice, however, that the peak signal is still approximately only 3 mW/sq cm instead of 8.3 mW/sq cm.

Summary

The purpose of this project was to develop a system to measure the response time of microwave survey instruments to rotating radar antenna patterns.

The main crux of the project was to develop the system to simulate and transmit a rotating radar antenna signal pattern.

The system was successfully developed to simulate the radar antenna pattern at McCarran Airport. This is not the limit of the system, however, since any set of data may be used by the controlling computer program, DRIVER.

This system has the capability to vary the rotational rate of the pattern by simply inputting the desired rotational rate into the computer when prompted to do so by the program.

This system does not transmit a pulsed signal as an actual radar signal does, but it is not necessary to do so for testing of the NARDA probe. This system does have the capability, however, to transmit a pulsed signal by applying a pulse train to the external AM jack of the HP8620C sweep oscillator. This could be useful for other applications of this system.

The response of the instrument under test (such as the NARDA 8616 Electromagnetic Radiation Monitor) may be recorded and evaluated through the use of the HP 9845B computer. The results may be graphed and analyzed all by the automation of the program RESPNS.

List of Abreviations Used

DAC	Digital-to-Analog Converter
dB	decibel
dBm	decibel with respect to one milliwatt
DC	direct current
EPA	Environmental Protection Agency
EXT. AM	External amplitude modulation
GHz	gigahertz
HP	Hewlett-Packard
NRSB	Nonionizing Radiation Surveillance Branch
PIN	Positive-Intrinsic-Negative
SWR	standing wave ratio
TWT	traveling wave tube

References

1. Facit Company, "Facit 4070 Tape Punch Technical Description," ATVIDABERG, Sweden.

2. Hewlett-Packard Company, "98034A HP-IB Interface Installation and Service Manual," 1976.

3. Narda Microwave Corporation, "Operation and Maintenance Manual for Model 8603/8601/8602 Broadband Isotropic Radiation Monitor."

Appendix I

Example of Paper Tape Program Format

```
880 DATA -38,-37.3,-37,-37.5,-37.6,-38.8,-40.4,-41.8,-43.3,-42.8
890 DATA -42.8,-41,-39.3,-38.8,-37.4,-36.6,-36.1,-36.3,-36.4
900 DATA -36.4,-37,-37.8,-39.2,-41.1,-43.5,-45.4,-46.9,-47.2
910 DATA -47.2,-46.7,-47.2,-46.6,-48.5,-45.7,-44.7,-42.4,-41.8
920 DATA -41.8,-40.4,-39.4,-39,-39.3,-38.8,-38.9,-39.4,-40.2
930 DATA -40.2,-41,-41.6,-42.3,-43.3,-43.4,-44.1,-45.1,-45.9
940 DATA -45.9,-45,-44.3,-45,-46,-46.2,-48.5,-50.5,-53,-53,-53.1
950 DATA -53.1,-53.3,-53.7,-52.8,-51.9,-50.2,-48.9,-46.9,-46.3
960 DATA -46.3,-44.8,-45.2,-42.7,-40.5,-39.3,-37.9,-36.8,-36.2
970 DATA -36.2,-35.9,-35.4,-35.6,-35.4,-35.6,-36.3,-36.8,-37.9
980 DATA -37.9,-38.2,-39.7,-40,-41.6,-43.3,-45.2,-48,-49.6,-49.7
990 DATA -49.7,-49.7,-44.7,-42.9,-41.6,-41.8,-40.8,-39.8,-40.2
1000  DATA -40.2,-41.1,-41.1,-43.2,-45.9,-49,-52.5,-53,-51.5,-51.1
1010  DATA -51.1,-51.9,-52.5,-52.8,-53.5,-50.2,-48.2,-45,-43.9
1020  DATA -43.9,-44.1,-43.8,-45.2,-45.8,-45.1,-44.5,-43.7,-43
1030  DATA -43,-42.2,-42,-42.2,-42.5,-41.8,-42.8,-42,-41.6,-40.9
1040  DATA -40.9,-40.9,-41.5,-41.4,-40.8,-40.8,-40.7,-41.6,-43.1
1050  DATA -43.1,-44.8,-46.8,-47.1,-47.5,-44.3,-44.1,-43.7,-42.8
1060  DATA -42.8,-42.3,-41.7,-41.9,-40.9,-41.1,-41.3,-43.4,-43
1070  DATA -43,-44.8,-44.7,-45.2,-44.2,-43.8,-41.8,-41,-40.4,-40.4
1080  DATA -40.4,-39.7,-41.1,-42.7,-45.8,-49,-45.9,-44,-41.3,-38.9
1090  DATA -38.9,-39,-38.2,-38.7,-39.8,-41.2,-40.6,-43.4,-42.6
1100  DATA -42.6,-42.7,-41.8,-40.3,-39.6,-38,-37.2,-37.4,-37,-38
1110  DATA -38,-39.2,-40.4,-42.4,-45.4,-46.9,-47.6,-44.1,-43.1
1120  DATA -43.1,-41.3,-41.2,-42.3,-42.6,-43.2,-43.8,-44,-42.1
1130  DATA -42.1,-42.9,-41.7,-41.3,-39.9,-38.7,-38.2,-37.9,-37.4
1140  DATA -37.4,-37,-38.2,-37.5,-39.2,-39.5,-42.1,-44.3,-47.9
1150  DATA -47.9,-49.8,-49.8,-47.2,-46.8,-44.2,-42.6,-41.7,-43.1
1160  DATA -43.1,-43,-45.1,-42.6,-42,-40.1,-37.6,-36.5,-36.3,-35.8
1170  DATA -35.8,-35.3,-34.7,-34.2,-33.4,-32.9,-32.4,-32.2,-31.7
1180  DATA -31.7,-32.1,-32.5,-33,-33.9,-35.3,-36,-36.5,-36.4,-36.8
1190  DATA -36.8,-36.7,-36.8,-37.6,-38.1,-38.9,-39.4,-39.7,-40.4
1200  DATA -40.4,-39.7,-39.6,-39.2,-39.7,-39.4,-40.8,-40.4,-41.6
1210  DATA -41.6,-39,-36.6,-35.6,-34.7,-34,-32.8,-32,-32,-31.9
1220  DATA -31.9,-32.2,-33.4,-34.8,-36.3,-39.2,-45.4,-47,-48.4
1230  DATA -48.4,-37.4,-36.1,-35.5,-35.5,-36.6,-37.5,-40.7,-44.7
1240  DATA -44.7,-53.1,-45.8,-45.5,-45,-42.6,-40.8,-38.6,-37,-34.3
1250  DATA -34.3,-31.8,-30.8,-30.3,-30.7,-31.6,-32.8,-35,-38.5
1260  DATA -38.5,-38.4,-38.2,-35.8,-35,-32.4,-32,-30.9,-31.2,-30.3
1270  DATA -30.3,-30.1,-30.2,-30.2,-30.3,-31.7,-32.5,-34.7,-35.2
```

Appendix II

Listing of Program "DRIVER"

```
10  REM THIS PROGRAM READS POWER LEVELS IN DBM FROM DATA STATEMENTS
20  REM WHICH ARE TO BE ATTACHED TO THIS PROGRAM USING A LOAD COMMAND.
30  REM THE DATA IS READ INTO AN ARRAY.  THE PROGRAM THEN
40  REM CONVERTS THE POWER LEVEL TO THE CORROSPONDING VOLTAGE TO
50  REM BE OUTPUT FROM THE DAC
60  DIM P(20,50)
70  DIM A(20,50)
80  REM ************************************************************
90  REM ************************************************************
100  REM THIS SECTION OUTPUTS A CALIBRATION  VOLTAGE FROM DAC
110  LET V=-.51
120  LET M( 1)=M( 2)= 1
130  LET A( 1)=INT( 827.4*V)
140  CALL  DATAO,M( 1),A( 1), 1, 50
150  PRINT "DAC IS NOW OUTPUTTING A CALIBRATION VOLTAGE."
160  PRINT "THE VOLTMETER SHOULD NOW READ APROX.  -0.50570 VOLTS"
170  PRINT "SET UP THE TWT TO OUTPUT A  POWER LESS THAN ITS SATURATION";
180  PRINT " LEVEL"
190  REM ************************************************************
200  REM ************************************************************
210  REM THIS SECTION READS FROM THE DATA POOL AND
220  REM OUTPUTS THE APPROPRIATE VOLTAGE FROM THE DAC
230  PRINT
240  PRINT
250  GOTO 800
260  PRINT
270  READ D
280  PRINT "MAX LEVEL OFFSET IS ";D
290  PRINT
300  PRINT "COMPUTING"
310  FOR J= 1 TO  50
320  FOR I= 1 TO  20
330  READ P(I,J)
340  REM INCREASE P(I,J) TO A MAX OPERATING LEVEL
350  LET P(I,J)=P(I,J)+D
360  NEXT I
370  NEXT J
380  PRINT "COMPUTING"
390  FOR J= 1 TO  50
```

Requires Subroutines "IOSS" "DISKA" "CRT"

Use Channel 1 DAC

```
400  FOR I= 1 TO  20
410  LET V= 2.14379E-06*P(I,J)↑ 3+ 3.66670E-05*P(I,J)↑ 2
420  LET V=V+ 3.69540E-03*P(I,J)- .6274
430  LET A(I,J)=INT( 827.4*V)
440  NEXT I
450  NEXT J
460  PRINT "INPUT THE ROTATIONAL RATE DESIRED (MILLISECONDS)";
470  INPUT S
480  PRINT
490  PRINT
500  PRINT "TO STOP THE PROGRAM HIT      ESC"
510  CALL    TTY
520  PRINT "HERE GOES"
530  CALL    CRT
540  CALL  DATAO,M( 1),A( 1, 1), 999,S
550  REM CONTINUOUS LOOP---- MUST MANUALLY STOP PROGRAM
560  WAIT  1000
570  GOTO 540
580  REM ************************************************************
590  REM ************************************************************
600  REM THIS SECTION ALLOWS THE DAC TO BE ZEROED (OUTPUT 0 VOLTS)
610  REM TO USE THIS SECTION  TYPE   RUN 500
620  PRINT "HI THERE"
630  LET B( 1)= 0
640  LET M( 1)= 1
650  LET M( 2)= 2
660  CALL  DATAO,M( 1),B( 1), 6
670  REM **************************************************************
680  REM **************************************************************
690  REM DATA IS ATTACHED BY LOADING IN THE DATA PROGRAM
700  REM THIS ATTACHES  DATA STATEMENTS STARTING AT THE NEXT LINE
710  END
READY
```

Appendix III

Listing of Program "RESPNS"

```
10    COM INTEGER A(1000)
20    SHORT Volts,Cn_max,Conv,C(1000),B(1000)
30    OVERLAP
40    DEG
50    Cn_max=3.5
60    Conv=Cn_max/1022
70    I=0
80    Scale=2
90    MAT A=(9999)
100   INPUT "Input NARDA's actual peak value before rotation  ",Pv
110   DISP "Press CONTinue when ready to read data from A/D"
120   PAUSE
130   DISP "Reading A/D"
140   OUTPUT 718;"R2"
150   OUTPUT 718;"S2"
160   IF NOT FRACT(I/5) THEN STATUS 718;L
170   IF L=68 THEN Talk
180   OUTPUT 706;"H4AJ"
190   ENTER 706 BFHS 2 NOFORMAT;A(I)
200   I=I+1
210   GOTO 160
220 Talk:   !
230   BEEP
240   DISP "Preparing Graphics"
250   OUTPUT 718;"R1"
260   IF A(I)=9999 THEN I=I-1
270   FOR J=0 TO I
280   C(J)=Conv*A(J)*Scale/3
290   NEXT J
300   OUTPUT 718;"ST OA"
310   ENTER 718;St
320   OUTPUT 718;"CF OA"
330   ENTER 718;Cf
340   Cf=Cf/1E9
350   OUTPUT 718;"O3 TA"
360   ENTER 718;B(*)
370   MAT SEARCH B(*),MIN;Ymin
380   MAT SEARCH B(*),MAX;Ymax
390   IF FRACT(Ymax/10) THEN Ymax=PROUND(Ymax/10+.5,0)*10
400   IF FRACT(Ymin/10) THEN Ymin=PROUND(Ymin/10-.5,0)*10
410   PLOTTER IS "GRAPHICS"
420   GRAPHICS
430   CALL Lgrid(0,St,10,0,Scale,8,2,1)
440   R=St/I
450   FOR J=0 TO I
460   PLOT R*J,C(J)
470   NEXT J
480   CALL Lgrid(0,St,10,Ymin,Ymax,10,2,2)
490   J=0
500   FOR I=0 TO St STEP St/1000
510   PLOT I,B(J)
520   J=J+1
530   NEXT I
540   SETGU
550   LORG 5
560   LDIR 90
570   MOVE 2.1,24.8
```

```
580   LABEL USING "#,K";"Power Density"
590   MOVE 5.8,24.8
600   LABEL USING "#,K";"(mW/sq cm)"
610   MOVE 2.1,75.2
620   LABEL USING "#,K";"Output Power"
630   MOVE 5.8,75.2
640   LABEL USING "#,K";"(dBm)"
650   LDIR 0
660   MOVE 70,1.7
670   LABEL USING "#,K";"time (sec)"
680   CSIZE 3.3
690   MOVE 70,98
700   LABEL USING "#,K";"Simulated Radar Signal"
710   MOVE 70,48.6
720   LABEL USING "#,K";"NARDA Probe Response"
730   GPRINT 115,140,"Actual Peak Value is"
740   GPRINT 150,120,VAL$(Pv)&" mW/cm^2"
750   GPRINT 115,400,"Center Frequency"
760   GPRINT 150,380,VAL$(Cf)&" GHz"
770   END
780   SUB Lgrid(Xmin,Xmax,Xdiv,Ymin,Ymax,Ydiv,Type,Xt)
790   DEG
800   DIM X$[80],T$[80],Y$[80]
810   LORG 2
820   IF Xt=1 THEN LOCATE 20,120,5,45
830   IF Xt=2 THEN LOCATE 20,120,55,95
840   SCALE Xmin,Xmax,Ymin,Ymax
850   CSIZE 3
860   Y_corr=(Ymax-Ymin)*.04
870   Grid_x=(Xmax-Xmin)/Xdiv-1E-10
880   IF Xt=1 THEN Grid_y=(Ymax-Ymin)/Ydiv-1E-10
890   IF Xt=2 THEN Grid_y=Ydiv
900   IF Type=1 THEN 930
910   GRID Grid_x,Grid_y,Xmin,Ymin
920   GOTO 940
930   AXES Grid_x,Grid_y,Xmin,Ymin
940   MOVE Xmin,Ymin-Y_corr
950   LABEL USING "#,D";Xmin
960   MOVE Xmax,Ymin-Y_corr
970   LORG 8
980   LABEL USING "#,4D.DD";Xmax
990   CSIZE 3.1,9/15
1000  FOR Y_label=Ymin TO Ymax+1E-6 STEP Grid_y*(3-Xt)
1010  MOVE Xmin,Y_label
1020  LABEL USING "#,MDDZ.D,A";Y_label," "
1030  NEXT Y_label
1040  SUBEXIT
1050  SUBEND
```

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report describes the development of a system which simulates rotating radar fields in a controlled environment. The measured time variations of the field generated by a real, rotating radar antenna were first recorded using a computer controlled spectrum analyzer. The data acquired were then used to modulate a carrier wave field in the laboratory to simulate the rotating radar far-field. Finally, response of a thermocouple based microwave hazard survey meter to this field was measured.

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