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RECOMMENDATIONS AND COMMENTS CONCERNING DOCUMENTATION ON THE MICROWAVE ACTIVE SPECTROMETER SYSTEMS

Job Order 75-415

Prepared By

Lockheed Electronics Company, Inc.
Systems and Services Division
Houston, Texas
Contract NAS 9-15200

For

EARTH OBSERVATIONS DIVISION
SPACE AND LIFE SCIENCES DIRECTORATE

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FIGURES

LIST OF ACRONYMS

Acronym	
A/D	Analog to Digital Converter
AM	Amplitude Modulation
BW	Bandwidth
cm	Centimeter
CRES	Center of Research and Engineering Science
CW	Continuous Wave
dB	deciBell
dBm	deciBell below 1 milliwatt reference
DC	Direct Current
E-H	Electric-Magnetic Planes
f/D	Focal to Diameter ratio
FM	Frequency Modulation
GHz	GigaHertz
G_R	Gain of Receive Antenna
G_T	Gain of Transmit Antenna
HP	Hewlett Packard
HH	Horizontal, Horizontal Polarization
HV	Horizontal, Vertical Polarization
Hz	Hertz
IF	Intermediate Frequency
JSC	Johnson Space Center
KHz	KiloHertz
LO	Local Oscillator

Acronym	
M	Meter
MAPS	Microwave Active and Passive Spectrometer
MAS	Microwave Active Spectrometer
Max	Maximum
MHz	MegaHertz
Min	Minimum
MSAS	Microwave Signature Acquisition System
mV	milliVolt
mW	milliWatt
mΩ	Megaohm
NASA	National Aeronautics and Space Administration
NF	Noise Figure
OSC	Oscillator
RF	Radio Frequency
RMS	Root Mean Square
SPDT	Single Pole Double Throw
TWT	Traveling Wave Tube
VH	Vertical, Horizontal Polarization
VSWR	Voltage Standing Wave Ratio
VV	Vertical, Vertical Polarization
W	Watts

1. INTRODUCTION

1.1 PURPOSE

The purpose of this document is to summarize the information available presently on the two Microwave Active Spectrometer (MAS) Systems operated by the University of Kansas for NASA management and to assist NASA management in determining what additional information should be obtained from the University of Kansas concerning these systems.

1.2 BACKGROUND

Two MAS systems are operated by the University of Kansas. Backscatter measurements on a large variety of targets have been made using both the low frequency (currently 1-8 GHz) and high frequency (currently 8-18 GHz) systems. These measurements have been made and reported over a period of several years.

It is often assumed that measurements made at a particular frequency can be directly compared with measurements made at that same frequency made at another time. This assumption is not necessarily true. Both system configurations have undergone numerous changes and improvements, some of which may change the bias errors in the data reduction algorithm. Throughout most of these changes a Luneberg lens has been used as a calibration target. However, early systems used a metal sphere as a calibration target.

To gain appreciation of the problems involved in obtaining accurate data, a short discussion on sensor systems follows in the next section.

1.3 THE SENSOR SYSTEM

We shall define a sensor system as an integrated assemblage comprised of propagation media, electronic, electrical, and mechanical hardware for reception and conversion of the energy in waves or fields utilizing an appropriate platform, along with appropriate algorithms, data recording, storage, transmission and processing facilities utilized for the purpose of determining and reporting certain specific properties of interest associated with a selected target area.

For purposes of analysis, algorithm building, practical applications and decision-making, remotely sensed data must be in a processed form to be useful. For our purposes, we assume that the desired information is present at the target or field of view in the form of scattered, reflected, and/or emitted electromagnetic waves. In addition to the desired information, some undesired information or noise is also generally present at or in the vicinity of target of interest.

The purpose of the sensor system is to acquire the information of interest about the target and convert it to a usable form with the distortions and noise content in the output held to an acceptably low level for the desired task. Obviously, a perfect sensor system would accept only correct information at its input and deliver only a set of correctly converted information at its output with no noise or distortion. Such a sensor would deliver to its output only as much information as was present at its input. It would not and could not create information, it could only process it and convert it to another form. It would, however, process it and convert it without loss, distortion, or the introduction of noise. Obviously, no such perfect sensor has ever existed or ever will exist. The concept of a perfect sensor has been presented here to emphasize that a sensor system cannot create information, it can only accept, transmit, and convert information. In a real sensor system, these functions are performed imperfectly with some distortion and/or noise being added at every stage. It should be noted that the noise and distortion present in the sensor system output can be reduced in some cases by very careful design of the data processing algorithm to partially compensate for known deficiencies in other parts of the system.

In many cases in times past the effects of the media through which electromagnetic waves propagate from source (if external to the target) to target to sensor, the sensor hardware itself, the data recording subsystem, the playback system, data reduction algorithms, data reduction machine, and data quality functions have been considered separately, or in some cases, some factors are not considered at all.

Incomplete or inaccurate modeling or characterization of portions of a sensor system can lead to unnecessary degradation in the quality of the system's output data. A uniform and complete approach is needed to prevent such degradation.

1.4 OUTLINE OF REPORT

In this report an attempt is made to determine the presently available information at JSC on the MAS systems and assist NASA/JSC management in determining what additional information should be obtained from the University of Kansas. This task is pursued by discussing the different levels of documentation which JSC might desire and their purposes in section 2. These are presented in section 2 to assist NASA/JSC management in determining the level of documentation desired.

Section 3 describes the historical development of the MAS systems and the modifications which have been published and are known up to the present.

Section 4 discusses the general form of the equation used in computing normalized backscatter (σ^0) as published for each of the MAS systems.

Section 5 discusses the information needed to provide different levels of documentation for the two MAS systems. Recommendations and conclusions are given in this section.

2. LEVELS OF DOCUMENTATION - HARDWARE

The amount and type of documentation required on the MAS systems will depend on the required uses for the information. In other words the level of documentation required will depend on what applications are to be made of the information. Some possible uses are public information releases, presentations to management, operation of the system, storage of the system, maintenance of the system, development and/or verification of algorithms, error budget analysis, system modeling, system analysis, system calibration, and system reproduction.

2.1 SYSTEM DESCRIPTION

This is the simplest level of documentation. This would simply be a very general description of the system adequate to answer a newspaper reporter's "Who?, What?, Where?, Why?, When?, and How?" questions in layman's language. This level of documentation is easily met and would be useful only for public information releases and informative presentations to non-technical high level management. The information presently available if up to date is adequate for a system description.

2.2 SYSTEM SPECIFICATIONS

This is the lowest level of technical information. It will be useful for feature articles in technical magazines, to accompany data published in the technical journal, and for in depth presentations to management.

The most critical specifications are for precision and accuracy. Both of these parameters will be a function of frequency, target backscattering cross section, angle of incidence, background scattering, and probably certain environmental factors. In short, certain conditions must be met by the operating environment for valid data to be obtained. These restrictions should also be specified.

A fairly complete list of other system specifications would include:

General

- Operating frequencies
- Range of σ^{o}'s measured
- Incidence angles range
- Maximum operating range
- Size, shape, and depth of field of view (what limits field of view, antenna or signal processing?)
- Allowed operating environment
- Operating requirements
  - Power
  - Operators
- Storage requirements
- Size
- Weight
- Measurement precision
- Measurement accuracy
- Dynamic range
- Linearity
- Speed of measurement
- Positioning type
- Positioner precision/accuracy
- Boresighting method
- Boresight precision/accuracy

Platform and Supporting Vehicles

- Type
- Size
- Weight
- Limitations
- Maximum speed
- Fuel consumption
- Boom-length
- Type
- Load capacity
- Environmental restrictions
- Boom stability in the presence of wind

Antennae

- Type
- Size
- Shape
- Beamwidth (half power and null to null) (azimuth and elevation)
- Sidelobe levels
- Cross polarization levels
- Voltage Standing Wave Ratio (VSWR)
- Polarization
- Gain
- Insertion loss
- Other specifications based on antenna type

  Example: dish
  - focus/diameter ratio
  - feed type
  - illumination taper
  - surface accuracy
  - spillover

Transmitter

Type

Frequency range

Frequency stability short term

Frequency stability long term

Power output (peak and average)

Pulse length (if pulse system)

Pulse repetition rate

Frequency sweep (FM-CW) (Frequency Modulated-Continuous Wave)

Modulation rate

Modulation type

Receiver

Type

Frequency range

Noise figure

Radio Frequency (RF) bandwidth

Intermediate Frequency (IF) bandwidth

IF center frequency

Detector type

Video bandwidth

Integrator type

Integration time

Analog/Digital (A/D) converter or voltmeter type

Input dynamic range

Spurious response levels

Transmit - receive isolation

Calibration

Internal type

External type

Calibration target

Data Acquisition

Precision

Accuracy

Sample rate

Integraticn time

Recording type

Recorder specifications

2.3 SYSTEM ERROR ANALYSIS

To perform a system error analysis, sufficient data must be supplied about each component/subsystem to establish the maximum deviation from ideal performance for each piece. Sufficient information must also be supplied about how they interact and are interconnected in order to combine the individual error contributions. An accuracy prediction can be generated using limits or specifications which components meet or exceed but such a prediction will generally be pessimistic. To list all the parameters required to generate an error budget would become extremely long and in this case impossible because a complete list of components is not available. To sum up what is required is an expressed limit or limits on the deviation from ideal performance or in some cases, the maximum uncertainty in a particular performance parameter.

Undoubtedly the simplest way to find out if enough information is available would be to try to do an error budget and see what is missing.

The purpose of an error budget would be to establish limits on measured data values--in short, to tell whether or not the instrument really measures with sufficient precision and accuracy to support the conclusion drawn. An error budget is necessary to establish confidence in the data taken, unless of course, other considerations make it reasonable to accept the data and results on faith.

2.4 SYSTEM MODELING

To be able to accurately model a sensor system requires a depth of knowledge greater than any specified yet in this report. Before such a task is undertaken, a decision to use the information in sensor and target modeling should be made. To be able to model a sensor system accurately will require careful measurement of the transfer function of each component including its nonlinearities, imperfect isolation, deficiencies in calibrations, etc. However, the potential gains to be obtained from accurate sensor modeling are impressive. First, a high degree of confidence in the accuracy and precision limits of the measured data will be achieved. Second, improved algorithms for more accurate data from the sensor system may be developed. Third, empirical target models can be developed which will lead to an ability to simulate and optimize specifications for advanced experimental and operational sensor systems with a minimum of cost impact.

2.5 CALIBRATION AND OPERATION PROCEDURES

A detailed description of calibration and operational procedures is needed if confidence in the data already acquired is to be established. Such information would also be necessary if JSC were to operate the sensor system without the assistance of University of Kansas personnel.

This procedure should include turn on instructions, warm-up characteristics, a description of all operating controls and their function, description and specification of internal and external calibration devices, a description of steps taken in the actual calibration, a sample of complete calibration calculations, precautions taken to insure freedom from spurious data inputs, and a test history of the calibration/test results, traceable if possible to the National Bureau of Standards.

The operating procedure should specify maximum and minimum ranges for targets, steps taken to insure the required number of independent samples, precautions to observe to make certain that noise, background reflection, and/or saturation effects have not degraded the data.

Problems encountered in the past in calibration and their solution should be detailed.

2.6 MAINTENANCE

To maintain the system, a complete schematic diagram of the system is required.

A complete parts list which gives the specifications of each component is required. One or more vendor sources should be specified for any non-standard parts. Long lead time items should be identified.

Any trouble shooting information available for isolating problems and special precautions for the protection of the system parts and personnel should be noted. Disassembly instructions and sequencing instructions for power up and power down are also needed.

2.7 SYSTEM REPRODUCTION

If the Joint Soil Moisture Experiment or Radar Agriculture programs are expanded additional ground systems may be required. Replacement of the system in the event of an accident or natural catastrophe is also a possibility. In this case, virtually all the information described in sections 2.1 to 2.6 would be required along with the drawings used to build the mechanical components, interface the boom to the truck, printed circuit board layouts and any other drawings or engineering laboratory notes used to construct, debug, calibrate, or operate the system. To assemble this level of documentation would require several man months of effort.

3. HISTORICAL DEVELOPMENT AND MODIFICATIONS OF THE TWO MICROWAVE ACTIVE SPECTROMETER SYSTEMS (MAS)

The original configuration of the present 2-8 GHz MAS system was that of a pulse system (ref. 1). The pulse system is briefly discussed in section 3.1. This pulse system was modified so as to become an FM-CW system operating from 4-8 GHz (ref. 2). Difficulties in making the pulsed system operate to the 16m minimum range required by the then existing ground based truck mounted configuration dictated the need to change to a FM-CW system. The 4-8 GHz FM-CW system and its subsequent modifications are discussed in section 3.2. A second 8-18 GHz MAS system was designed and built in 1972/1973 and reported upon in 1973 (ref. 3). This system and its modifications are discussed in section 3.3. For the three systems that are discussed in this section, only the system configurations are discussed. No attempt is made here to analyze the systems or even to discuss them in terms of their respective operation, individual merits or weaknesses.

3.1 PULSE SYSTEM SCATTEROMETER

Personnel at the University of Kansas designed and built a pulsed system scatterometer which was first used in 1969 (ref. 4), but produced "calibrated spectral responses only in 1970," and was modified to become a FM-CW system during 1970/1971. Because this original pulse system has been replaced, only a block diagram is given here in Figure 1 (ref. 1). Table 1 is presented to give what information was presented in ref. 1. Information that was missing for various individual blocks is denoted by an asterisk.

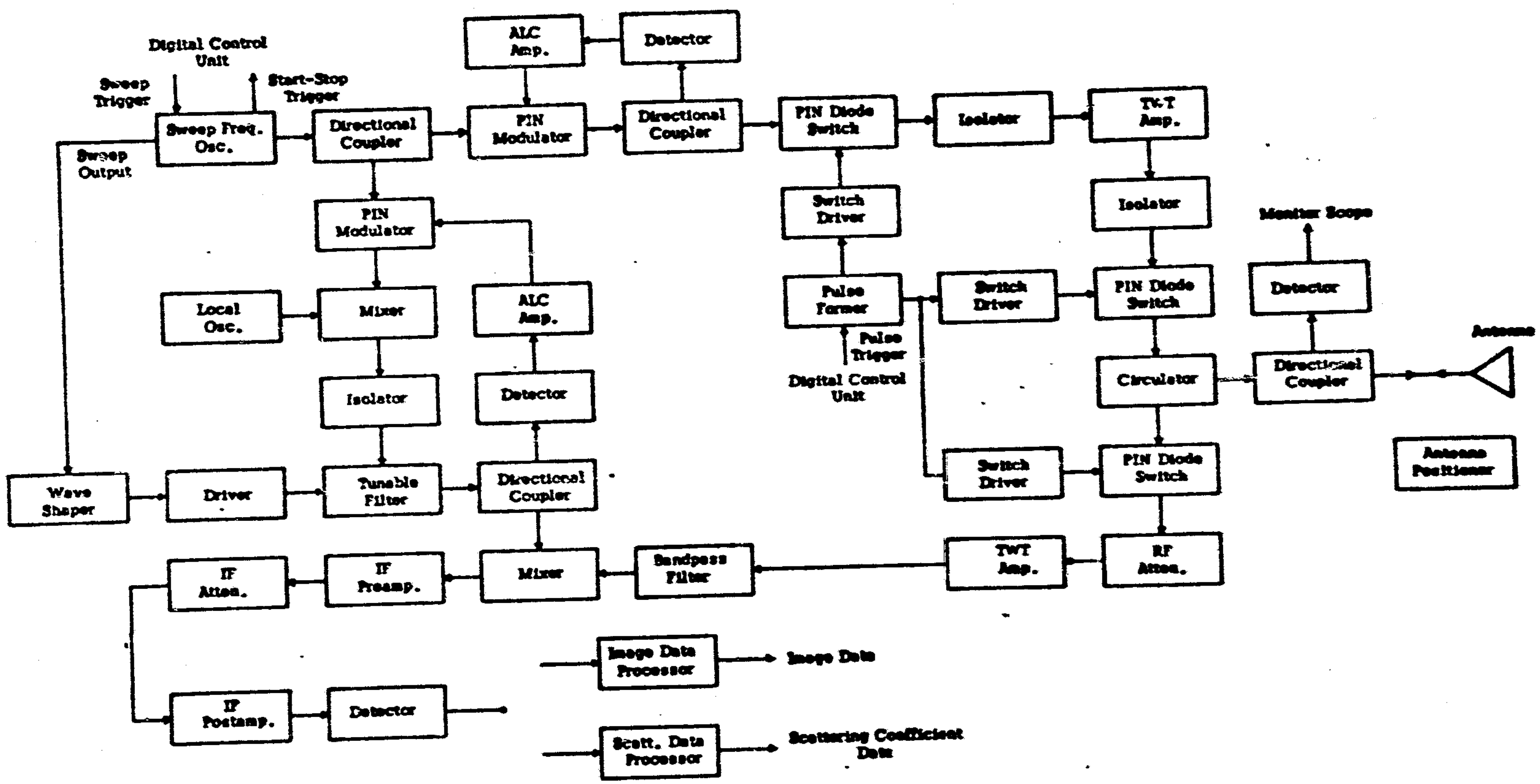


Figure 1. Pulse Scatterometer System Block Diagram (ref. 1)

TABLE 1 - PULSE SYSTEM SCATTEROMETER COMPONENT DESCRIPTION (Ref, 1). (Unavailable information is denoted by an asterisk.)

---

1 Antenna: Frequency 3.95 - 8.2 GHz standard 3-foot (Scientific Altanta 22-3/A or 6-foot (Scientific Atlanta 22-6/A) parabolic reflectors. Appropriate dual polarized rigid waveguide feeds are used, Models 2.8 - 3.9/3 or 2.8 - 3.9/L. E-plane patterns are given in Figure 2.

2* Directional Coupler:

3* Detector:

4 PIN Diode Switch: HP Model CD043 3603 A
1.5 dB max insertion loss, 60 dB min isolation for 4 - 8 GHz.

5 Isolator: Melabs Model H-317-264-T
Max insertion loss ≈ .4 dB, min isolation = 18 dB for 4 - 8 GHz.

6 TWT Amplifier: Alto Scientific Co. Model 20C 4.0 - 8.0 Q60. 20W CW rated, 60 dB small signal, NF = 35 dB.

7 Isolator: Melabs Model H-317-264-T
Max insertion loss = .4 dB, min isolation = 18 dB for 4 - 8 GHz.

8 PIN Diode Switch Modulator: HP Model 3570
1.5 dB max insertion loss, 3 - 8 dB min isolation for 4 - 8 GHz

9 Directional Coupler: Narda 3044-20 dB

10* PIN Diode Modulator:

11 Detector: Hewlet Packard 423A

12* ALC Amplifier:

13 Directional Coupler: Narda 4 - 10 dB

14 Sweep Frequency Oscillator: Hewlet Packard 8690A Main Frame, Hewlet Packard 8693B plug in unit.

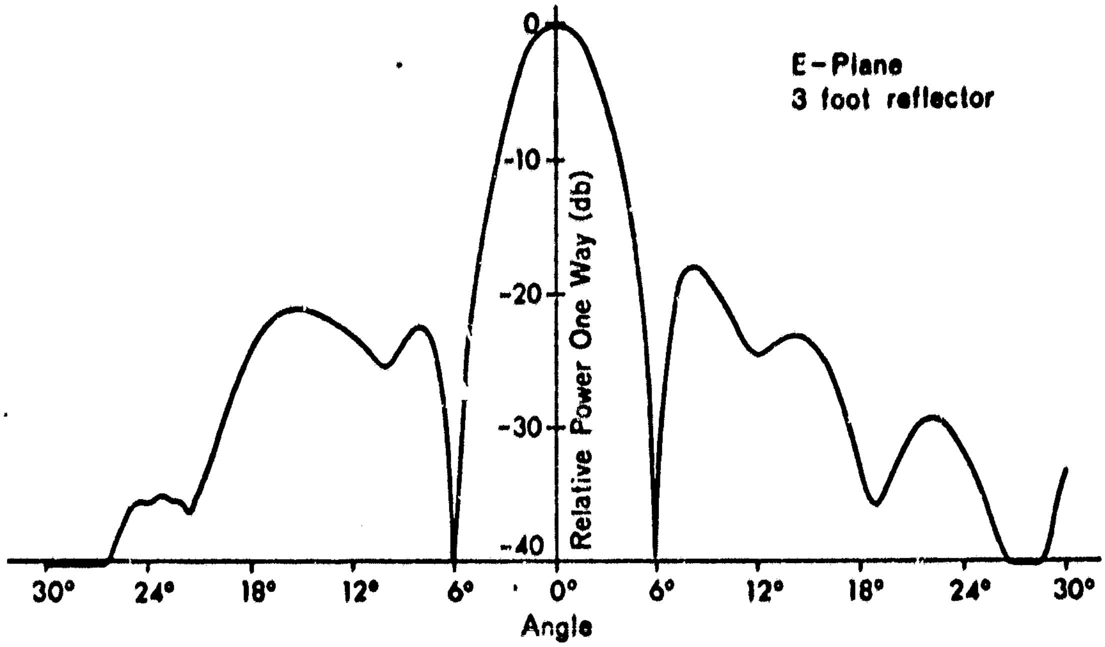
15 Circulator: Melabs Model H-317-264
Max insertion loss = .4 dB, min isolation = 18 dB for 4 - 8 GHz.

TABLE 1 - Continued.

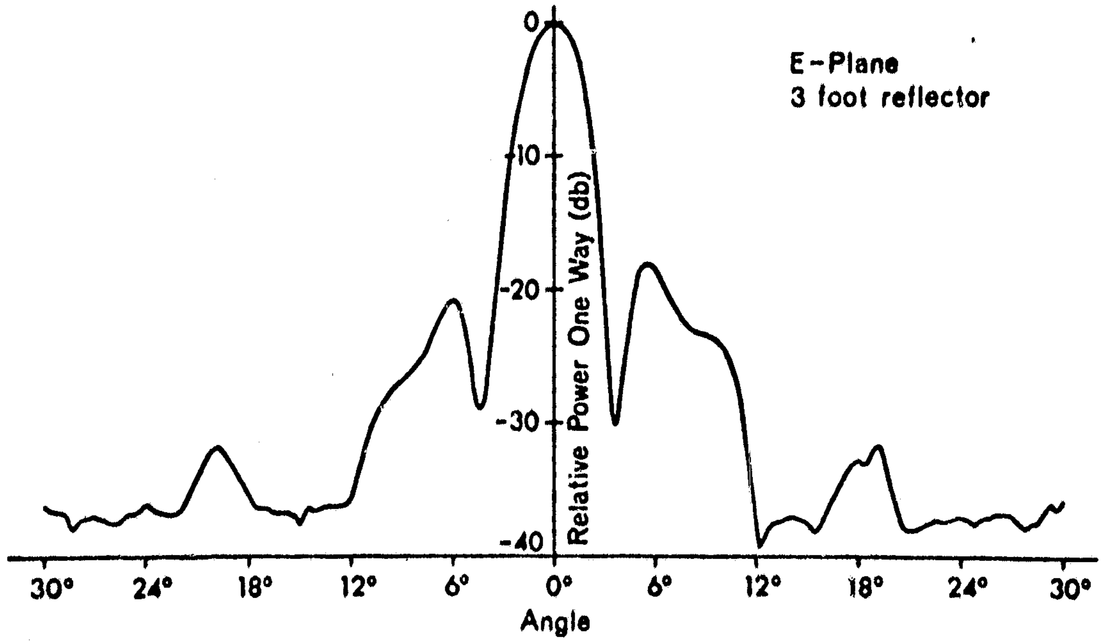
16	PIN Diode Switch Driver: See Figure 3.
17	Pulse Forming Network: See Figure 4.
18	PIN Diode Switch Driver: See Figure 3.
19	PIN Diode Modulator: HP Model C0043 3603A.
20	Local Oscillator: 250 MHz Frequency Sources Inc. Model FS-7R, cavity controlled oscillator P = 260 MW @ 250 MHz 5 percent tuning range, ± 5 percent stability for - 30°C to + 70°C.
21	Mixer: Aertech Model 8000 mixer/modulator 1 MW out in upper side band over 4 - 8 GHz input signal.
22*	Isolator:
23*	ALC Amplifier:
24*	Detector:
25*	Wave Shaper:
26	Tunable Filter Driver: Watkins Johnson WJ-922-4 tunes over 4.25 - 8.25 GHz.
27	Tunable Filter (YIG): Watkins Johnson Model W3-617-8 3dB BW = 50 MHz, max insertion loss = 5 dB, 70 dB isolation 24 dB/octave selectivity.
28*	Directional Coupler:
29	PIN Diode Switch Driver: See Figure 5.
30	PIN Diode Switch: HP Model 3570.
31*	RF Attenuator:
32	Receiver TWT Amplifier: Watkins-Johnson-423, Saturation @ + 13 dBm, max NF = 7.3 dB, min small signal gain = 31.8 dB for 4 - 8 GHz.
33	Receiver Bandpass Filter: HP Model 8435A, 4 - 8 GHz, max insertion loss = 2 dB, 45 dB rejection @ 10 percent from band.

TABLE 1 - Concluded.

34	Integrated Mixer/IF Amplifier: RHG Electronics Laboratory Model MP-4-8/437. Signal BW = 4 - 8 GHz, IF BW = 100 MHz. NF = 4 dB, mixer-preamplifier powergain = 23 dB-.
35*	IF Attenuator:
36	IF Linear Amplifier: RHG Electronics Laboratory Model EBT 106 MGC, centered at 250 MHz, BW = 100 MHz, gain = 55 dB, NF = 5 dB. or IF Logrithmic Amplifier: RHG Electronics Laboratory Model LT 16040 RFI centered at 160 MHz, BW = 40 MHz, gain = 62 dB, NF = 8 dB.
37*	Detector:
38	Image Data Processor: See Figure 6.
39	Scattering Data Processor: See Figure 7.
40	Antenna Positioner: Scientific Atlanta Model 4112, indicator, Scientific Atlanta Model 4422-3 with precision ± .03 azimuth and elevation.

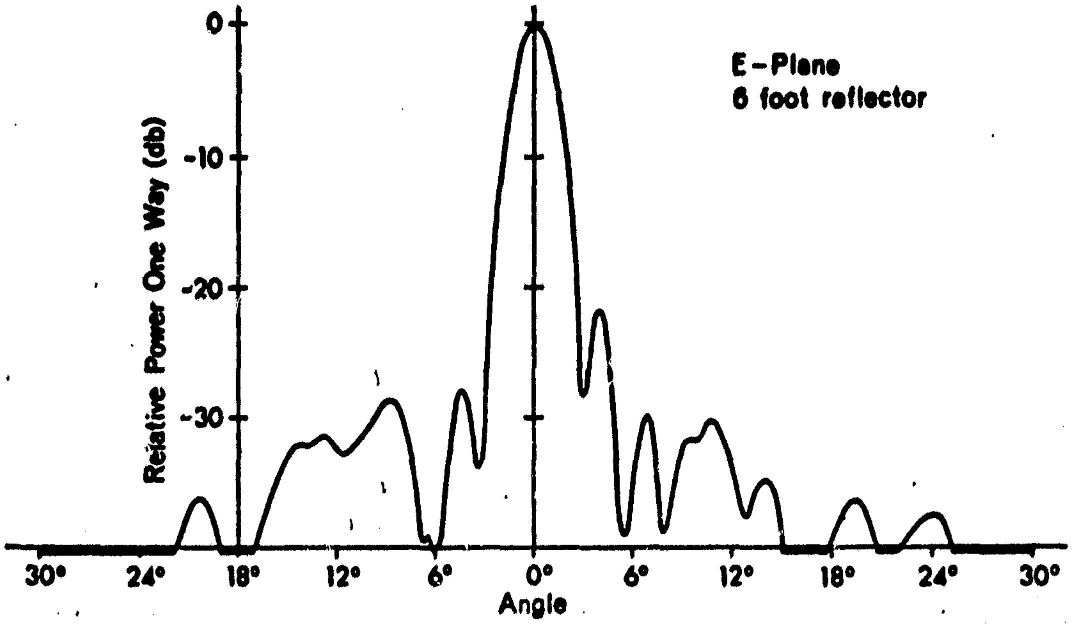


(a) Frequency 4 GHz.

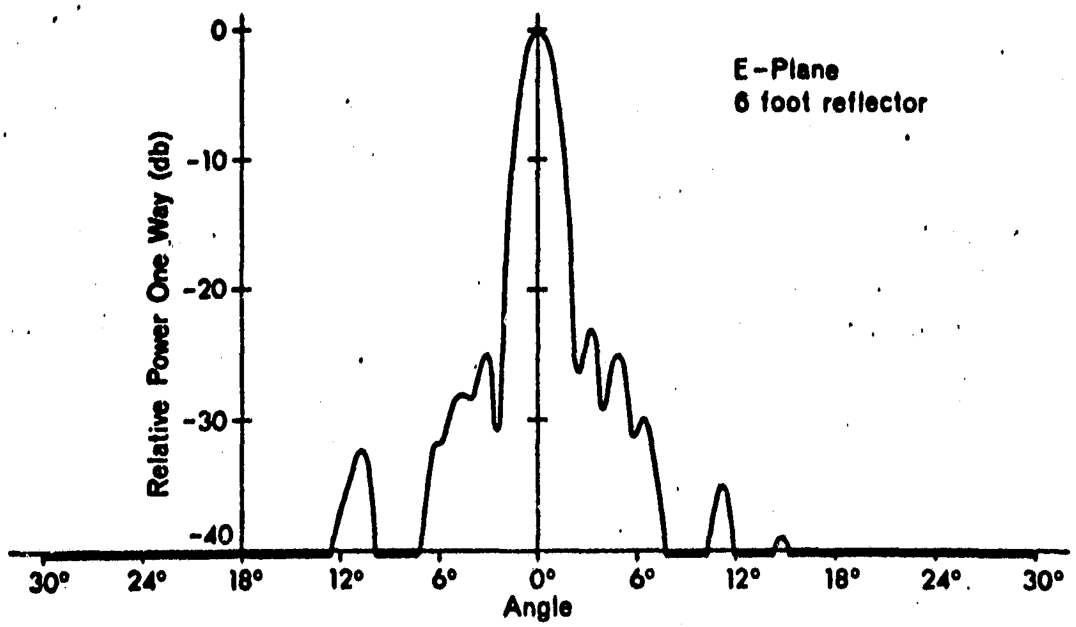


(b) Frequency 8 GHz

Figure 2. E-plane patterns for 3-foot reflector (ref. 1).

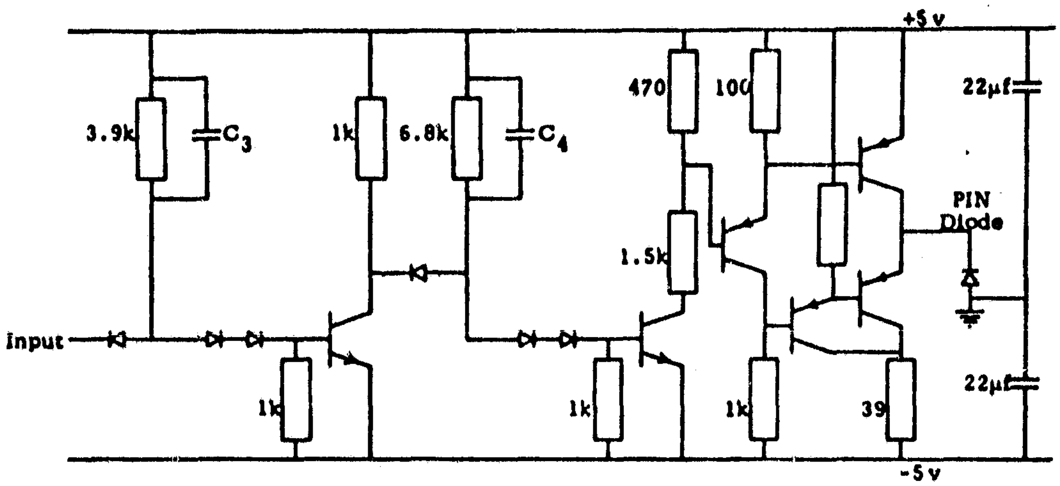


(c) Frequency 4 GHz.



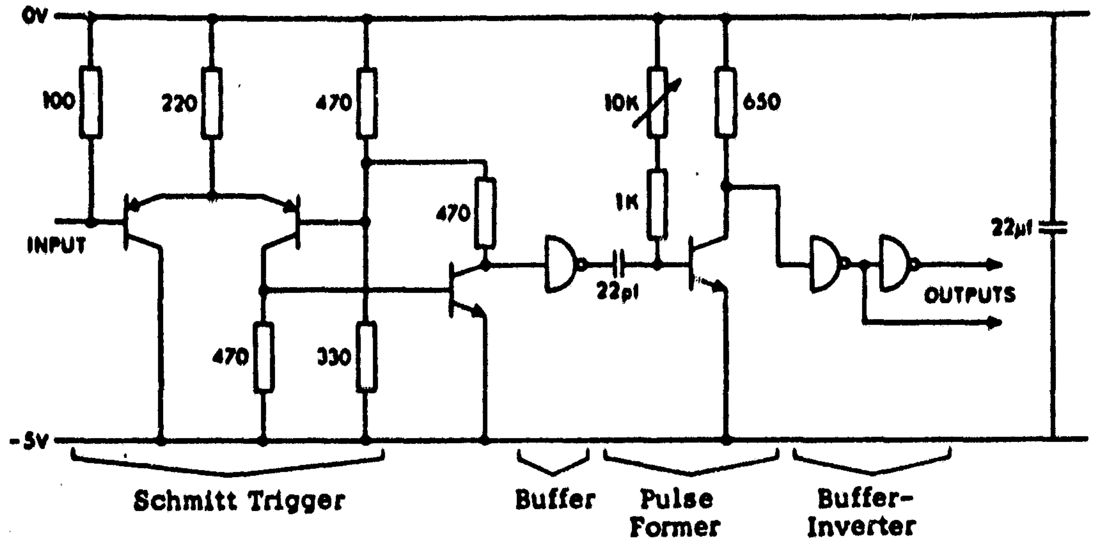
(d) Frequency 8 GHz.

Figure 2 (continued). E-plane patterns for 6-foot reflector (ref. 1).



All resistances in ohms
Diodes: 1N4009 Transistors: NPN 2N4420; PNP 2N4423
C_3 and C_4 selected for required delay
Input: -5 volts: switch ON to RF
0 volts: switch OFF to RF

Figure 3. Driver circuit for grounded anode microwave PIN diode switch (ref. 1).



V_{on} = -3 volts

V_{off} = -2 volts

All resistances in ohms
Transistors: NPN 2N4420, PNP 2N4423
Gates: Texas Instruments SN7410N

Figure 4. Circuit diagram of pulse forming network (ref. 1).

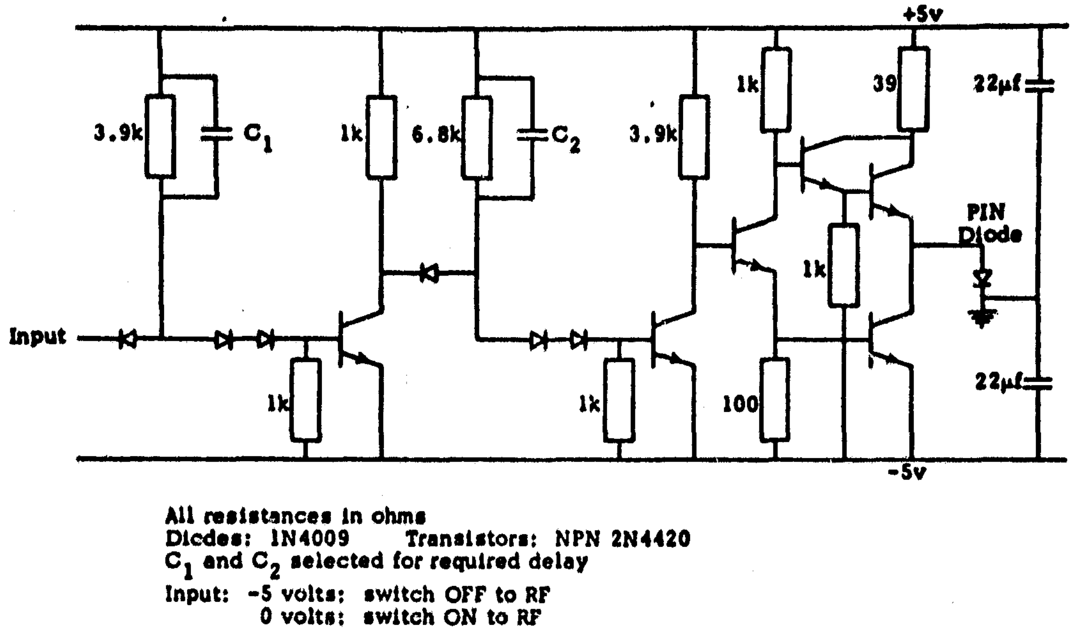


Figure 5. Driver circuit for grounded cathode microwave PIN diode switch (ref. 1).

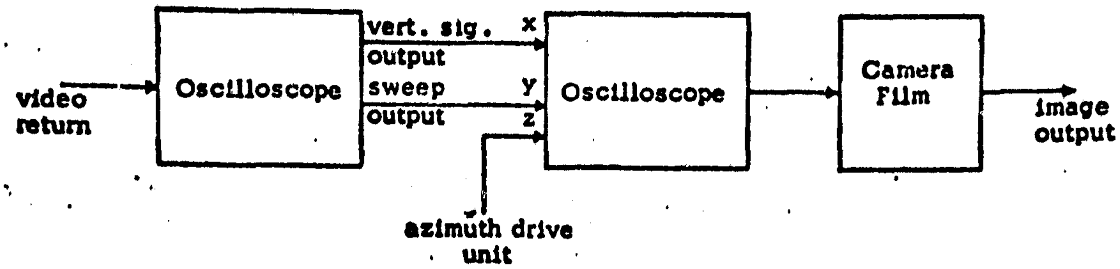


Figure 6. Component arrangement for imagery operation (ref. 1).

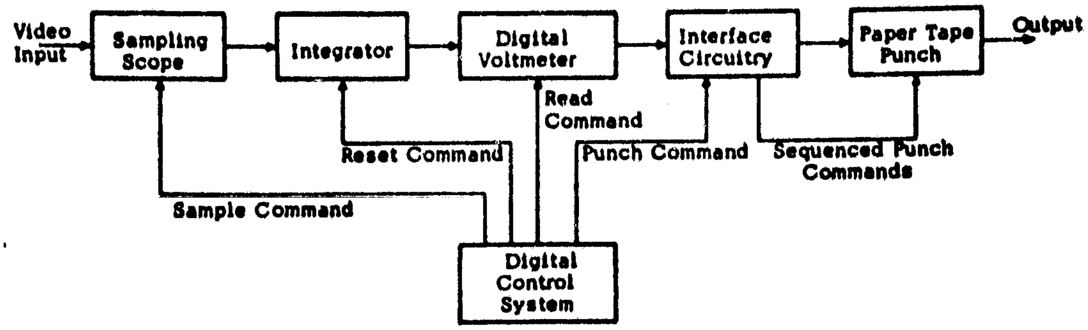


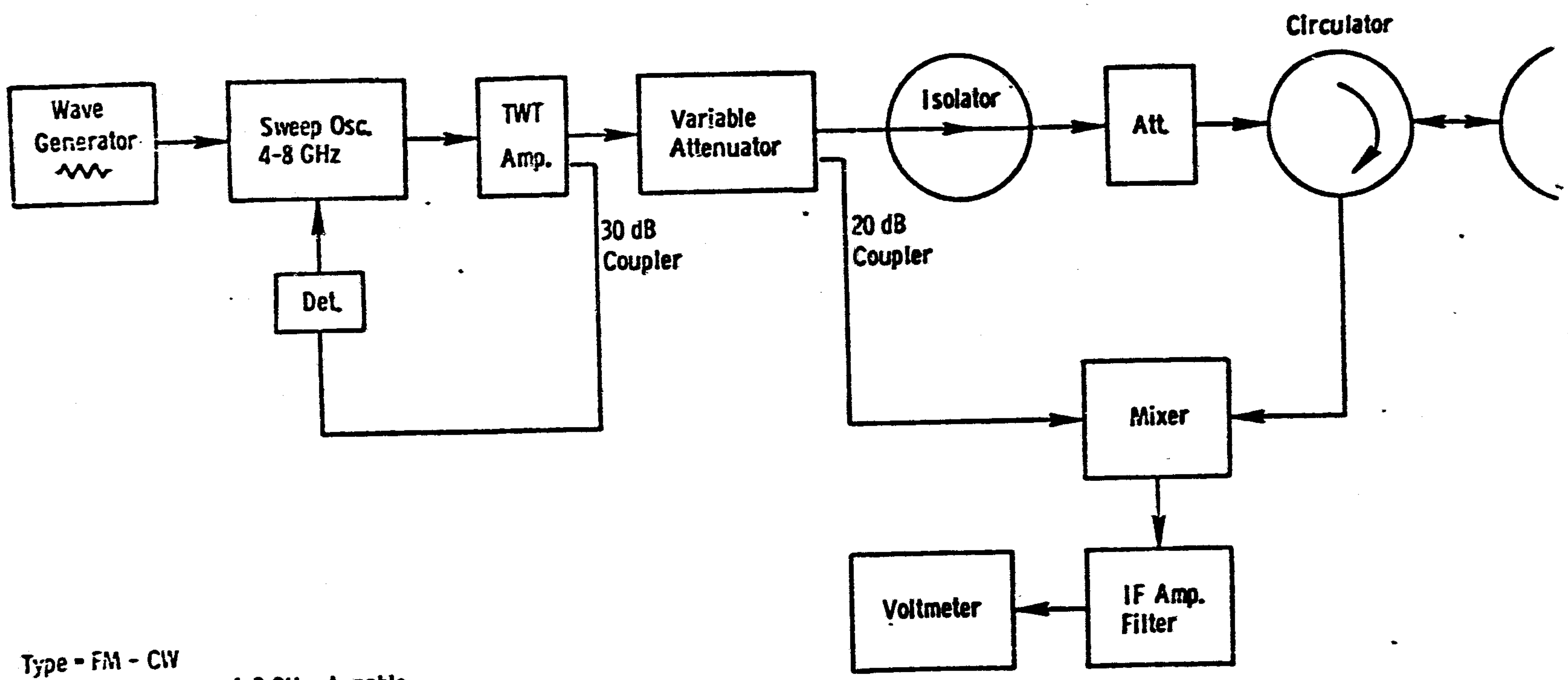
Figure 7. Block diagram of scattering coefficient signal processor (ref. 1).

3.2 4 - 8 GHz MICROWAVE ACTIVE SPECTROMETER

The original pulse system (Figure 1) was converted to an FM-CW system during 1970/1971. After more "refinements and improvements", this original CW system was completed during the summer of 1972 (ref. 4). This initial system covered the 4 - 8 GHz frequency range. A block diagram of the system as in its 1971 configuration is given in Figure 8 (ref. 2). This configuration used a single antenna for both transmitting and receiving. A circulator provided isolation between the transmitter and receiver sections of the radar. The published system specifications for this 1971 system configuration are given in Figure 8 (ref. 2).

As mentioned in references 2, 4, and 5, many more modifications to the 4 - 8 GHz scatterometer were made. As of 1972, the modified system specifications were as given in Table 2 (ref. 5).

The block diagram of the 4 - 8 GHz MAS system corresponding to these specifications is given in Figure 9 (refs. 2, 4). When comparing figures 8 and 9, it is noticed that in one block diagram, there is one antenna and circulator (Figure 8) as compared to two antennae and a delay line (Figure 9). The configuration utilizing the circulator was replaced with the dual antenna system because no circulators were available at that time that had sufficient isolation to keep received data from being obscured from oscillator noise (ref. 6). The corresponding system specifications for Figure 9 are given in Table 3 (ref. 4) and were measured in early 1973. It should be noted that in Figure 9, a 4 - 8 GHz radiometer section is part of the Microwave Active and Passive Spectrometer System (MAPS). The radiometer section is not discussed in this report. Considering the transmitter section, the sweep oscillator is located in the van and the TWT amplifier is located on the boom with 100 feet of cable separating the two. In Figure 10, Sweep Oscillator Output, cable losses,



Type - FM - CW
Center Frequency - 4-8 GHz, tunable.
Modulation Bandwidth - 400 MHz
IF Frequency - 37 KHz
Antenna - 3' diameter dish

Figure 8. Block diagram of original 4 - 8 GHz FM-CW radar system (ref. 2).

TABLE 2. 4 - 8 GHz SCATTEROMETER SYSTEM SPECIFICATIONS (Ref. 5, 1972)

OVERALL SYSTEM

Antenna's Height: 75 feet

Transmitting Antenna: 2.5-foot parabolic dish

Receiving Antenna (both radar and radiometer): 3-foot dish

Approximate Size of Illuminated Cell at Nadir: 1.7 m^2

Look Angle: 0^{o} to 85^{o}

RADAR SECTION

Type: FM-CW

Modulating Wave Form: Triangular

Frequency: 4 - 8 GHz

FM Sweep: 400 MHz

IF Frequency: Channel 1 - 87 KHz, 5 KHz Bandwidth
Channel 2 - 100 KHz, 1.2 KHz Bandwidth

Transmitter Power: 5 watts

Noise Figure: 18 dB

Polarizations: HH, VV, VH, and HV

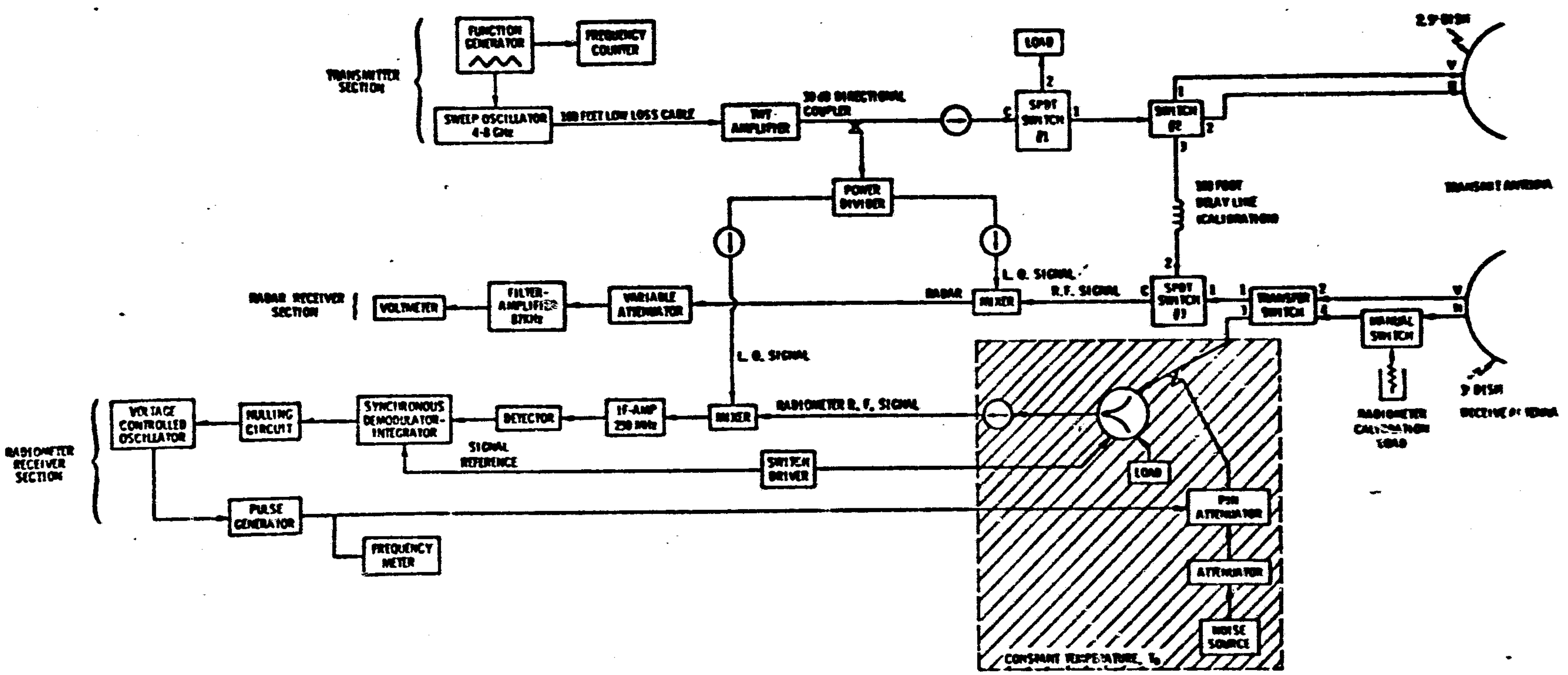


Figure 9. 4-8 GHz Microwave Active and Passive Spectrometer (MAPS) System

TABLE 3. MODIFIED MAPS RADAR SECTION SPECIFICATION (Ref. 4)

Type:	FM-CW
Modulating Wave Form:	Triangular
Frequency:	4 - 8 GHz
FM Sweep: ΔF	400 MHz
Transmitter Power:	5 watts
Noise Figure:	18 dB
IF Frequency: F_{IF}	87 KHz
IF Bandwidth: ΔF_{IF}	5 KHz
Antennae:	
Height above ground:	67 feet
Transmitting antenna diameter	2.5 feet
Receiving antenna diameter	3.0 feet
Feeds	ridged waveguide, dual polarized

TABLE 3. Continued

	Measured Antenna Gain		Effective Beamwidths of Product Patterns*	
Frequency	2.5-foot (Tra[illegible]t)	3-foot (Receive)	Azimuth	Elevation
4 GHz	28.8 dB	27.8 dB	3.8°	4.0°
6 GHz	32.2 dB	33.2 dB	2.7°	3.2°
8 GHz	29.1 dB	27.8 dB	2.8°	3.0°

*$G_{Transmit} \cdot G_{Receive}$

TWT input and TWT output are shown as a function of frequency (ref. 4). In the receiver section (Figure 9), the received signal is fed through a variable 50 attenuator to a 40 dB amplifier. It has been reported that the attenuator is set to 20 dB for data gathered at incidence angles varying from 0° to 40° and reset to 0 dB for larger incidence angles (ref. 4). Following the 40 dB amplifier is a bandpass filter having a center frequency of 87 KHz and a 5 KHz bandwidth. An RMS voltmeter measures the filter output.

The switches (Numbers 1, 2, 3) have better than 80 dB isolation between the common port and the isolated port. At this stage of MAS system development (1972/1973), the measured dynamic range exceeded 80 dB, and a noise figure (calculated from ± tangential sensitivity) measurements, was 16 dB to 18 dB (ref. 4). Both of these quantities were across the 4 - 8 GHz band. Table 4 summarizes the MAS block diagram data as published in reference 4.

A rigid dual polarized waveguide feed is used to connect to the two antennae.

In ref. 7, it was mentioned that the antennae were mounted atop a 23 meter boom. Compare this with data given in Tables 2 and 3. Also, the reported illuminated area is $.8m^2$ at nadir and $7.1m^2$ at 70° incidence angle. In ref. 8, the antennae are reported to be atop a 20m boom. It was reported in ref. 8 that data taken at 7.8 GHz was not used at that time due to system performance problems. What were the problems and what solutions were used? This was never reported. As reported in ref. 6, the MAS low frequency system (4 - 8 GHz) has been extended to cover 2 - 8 GHz. These "new" system specifications are listed in Table 5. It should be noted that the antenna diameter, sweep frequency, modulation rate, IF frequency, IF bandwidth, and transmit power have been changed when comparing Tables 5 (ref. 6) and Table 3 (ref. 4). Antenna data, delay time, bandpass filter, and RMS/DC

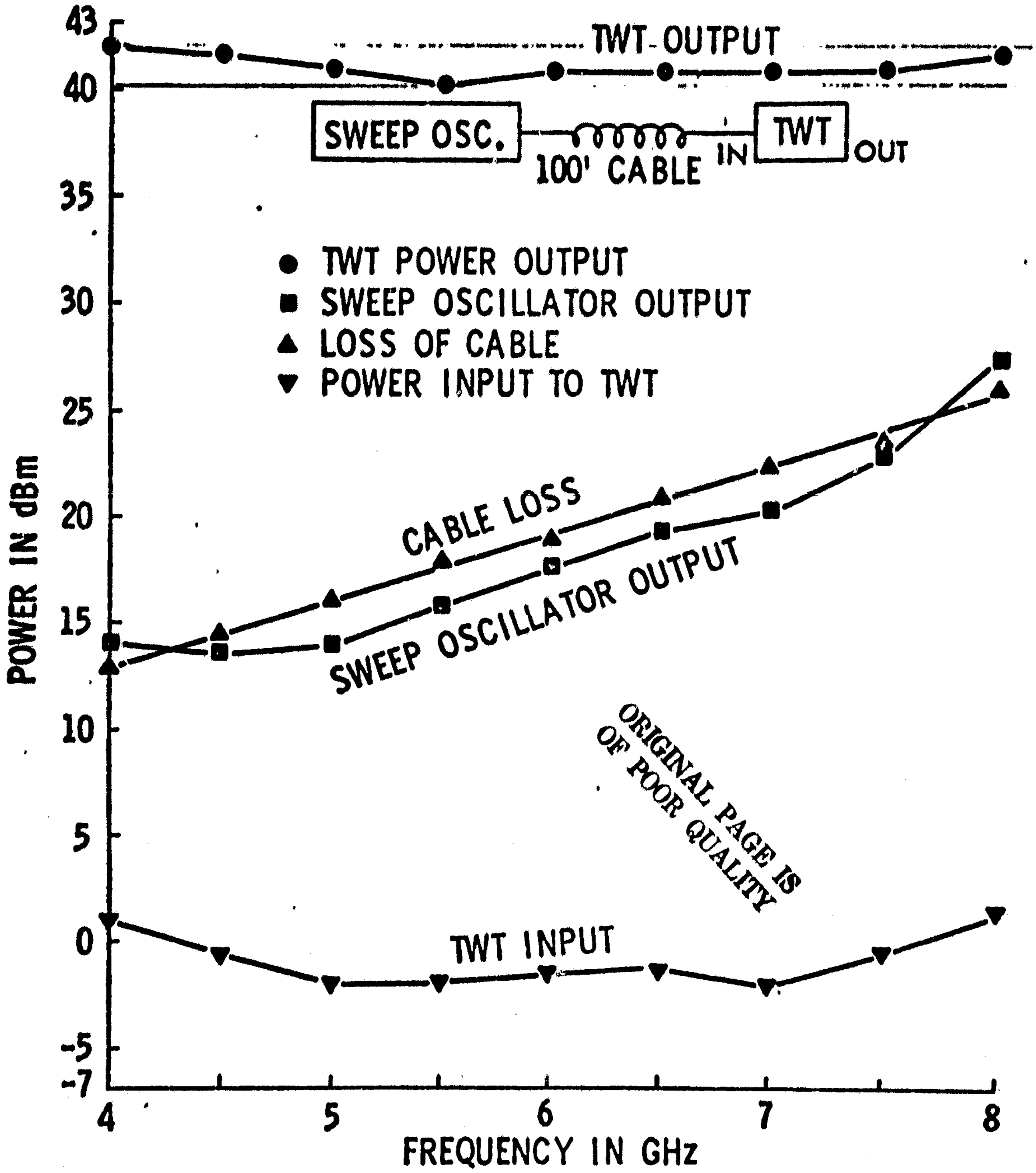


Figure 10. Power variation with frequency monitored at the sweep oscillator output, at the end of the 100-foot cable, and the TWT output (ref. 4).

TABLE 4. MAS SYSTEM BLOCK DIAGRAM COMPONENT SPECIFICATION (Ref. 4, April 1973)

1. Transmit Antenna: 2-foot 5-inch dish antenna

   @ 4 GHz: G_T = 28.8 dB; G_T G_R = 3.8° Azimuth,* 4.0° Elevation*

   @ 6 GHz: G_T = 32.2 dB; G_T G_R = 2.7° Azimuth,* 3.2° Elevation*

   @ 8 GHz: G_T = 29.1 dB; G_T G_R = 2.8° Azimuth,* 3.0° Elevation*

2. Receive Antenna: 3-foot dish

   @ 4 GHz: G_R = 27.8 dB

   @ 6 GHz: G_R = 33.2 dB

   @ 8 GHz: G_R = 27.8 dB

3. Manual Switch**

4. Transfer Switch, > 80 dB isolation

5. SPDT Switch, > 80 dB isolation

6. Switch, > 80 dB isolation

7. Load**

8. SPDT Switch, > 80 dB isolation

9. TWT Amplifier, gain = approximately 40 dB over 4 - 8 GHz

10. 4 - 8 GHz Sweep Oscillator, power out = 15 dBm to 25 dBm over 4 - 8 GHz

11. Function Generator**

12. Frequency Counter**

TABLE 4. Concluded

13.	Power Divider**
14.	Mixer**
15.	Variable Attenuator, 0 dB to 50 dB attenuation
16.	Filter/Amplifier, filter center frequency = 87 KHz, filter bandwidth = 5 KHz, amplifier gain = 40 dB (nominal), variable
17.	RMS Voltmeter**
18.	Directional Coupler, nominally 30 dB over 4 - 8 GHz
19.	Low Loss Cable, 13 dB to 25 dB loss over 4 - 8 GHz

*Effective Beamwidth of Products Patterns
**Denotes no data available

TABLE 5. MAS 2 - 8 GHz SYSTEM SPECIFICATION (ref. 6).

Platform Height:	20 meters
Antennae:	1-meter parabolic dishes with f/D = .42
Feeds	2 - 8 GHz log-periodic; single linear polarization
Incidence Angle Capability	0 - 70° in 10° increments
Radar:	
Operation Mode	FM-CW
Center Frequency	2.25-7.75 GHz in .5 GHz steps
Frequency Sweep	450 MHz
Modulation Type	Triangle-wave
Modulation Rate	100-500 Hz
IF Frequency	57 KHz
IF Bandwidth	10 KHz
Detection Type	RMS
Transmit Power	10 dBm (10 mW) minimum
Dynamic Range	80 dB minimum
Polarization	VV, VH, HH

converter linearity characteristics are given in Figures 11-16 (ref. 6). In ref. 9, it was reported that there was a possible antenna misalignment (June 28, 1975), replacement of RMS to DC converter (July 7, 1975), positioner cables were fixed (July 1, 1975, July 2, 1975, July 13, 1975), parts of the 40^{o} data were below noise level (July 17, 1975), new fixed gain amplifier was built and utilized (July 10, 1975). As reported in ref. 10, the MAS 2-8 GHz system showed different characteristics as given here in Table 6. Ref. 11 stated that the low frequency 2-8 GHz MAS system was "upgraded" to a 1-8 GHz system. Ref. 12 stated different 1-8 GHz MAS system characteristics as given in Table 7. On September 19, 1976, data was deleted due to system problems (ref. 12). What was the problem? Why was there a problem? How were they corrected?

It was reported in ref. 13 that during the autumn of 1974, the MAS 1-8 GHz system experienced hardware difficulties and data was not collected. Corresponding system data is given in Table 8. What were the difficulties and how were they corrected? Table 9 gives different MAS 1-8 GHz system characteristics as of June 1976 (ref. 14). Table 9 gives another set of system data (ref. 14). In Table 10, the apparent latest system specifications (1-8 GHz MAS) are given (ref. 15), yet the reference refers to a 2-8 GHz system. Has the system been downgraded? This concludes this section. Obviously, the low frequency MAS system has undergone many changes and supporting documentation. As reported here, this is the extent of the published information.

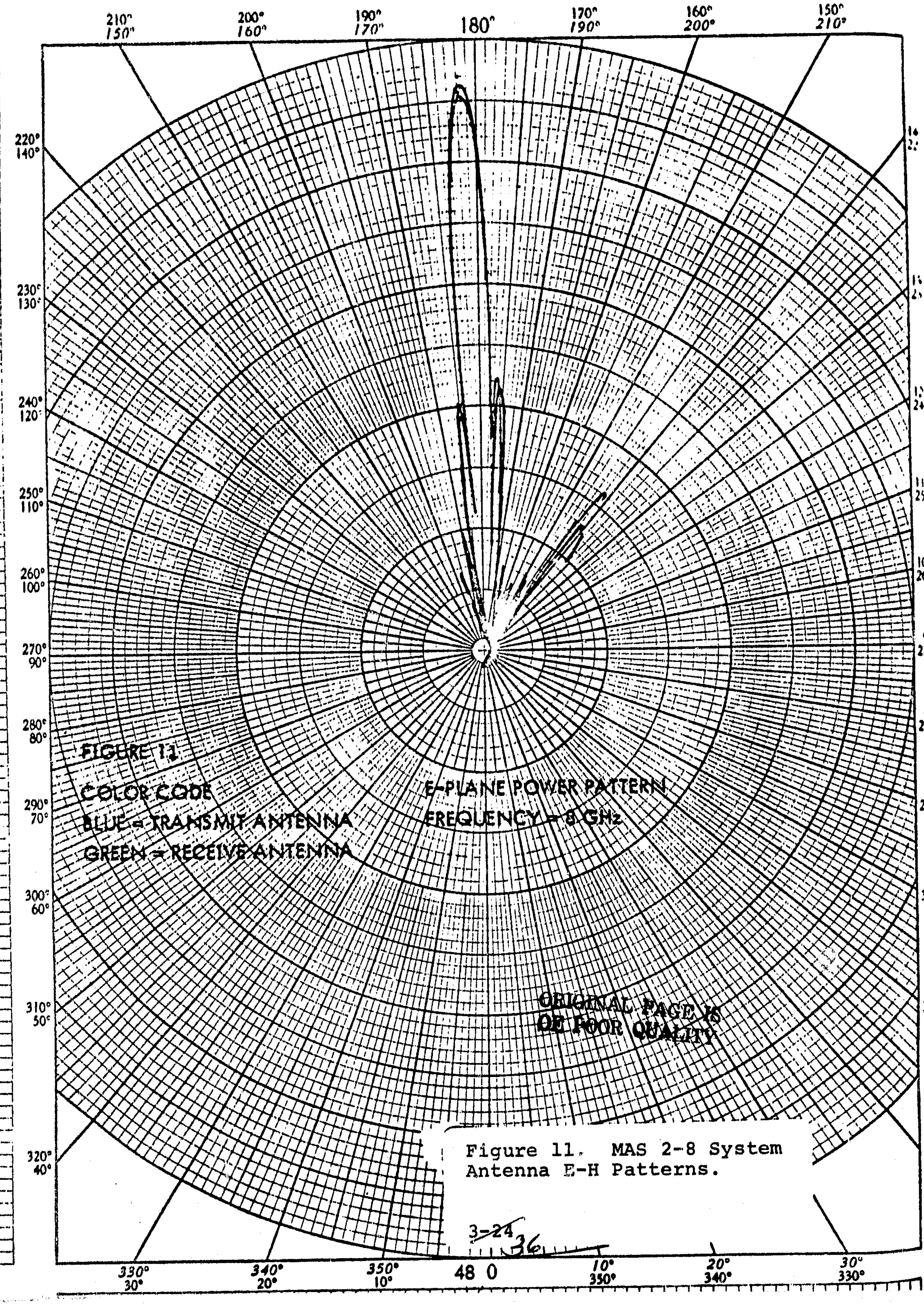


Figure 11. MAS 2-8 System Antenna E-H Patterns.

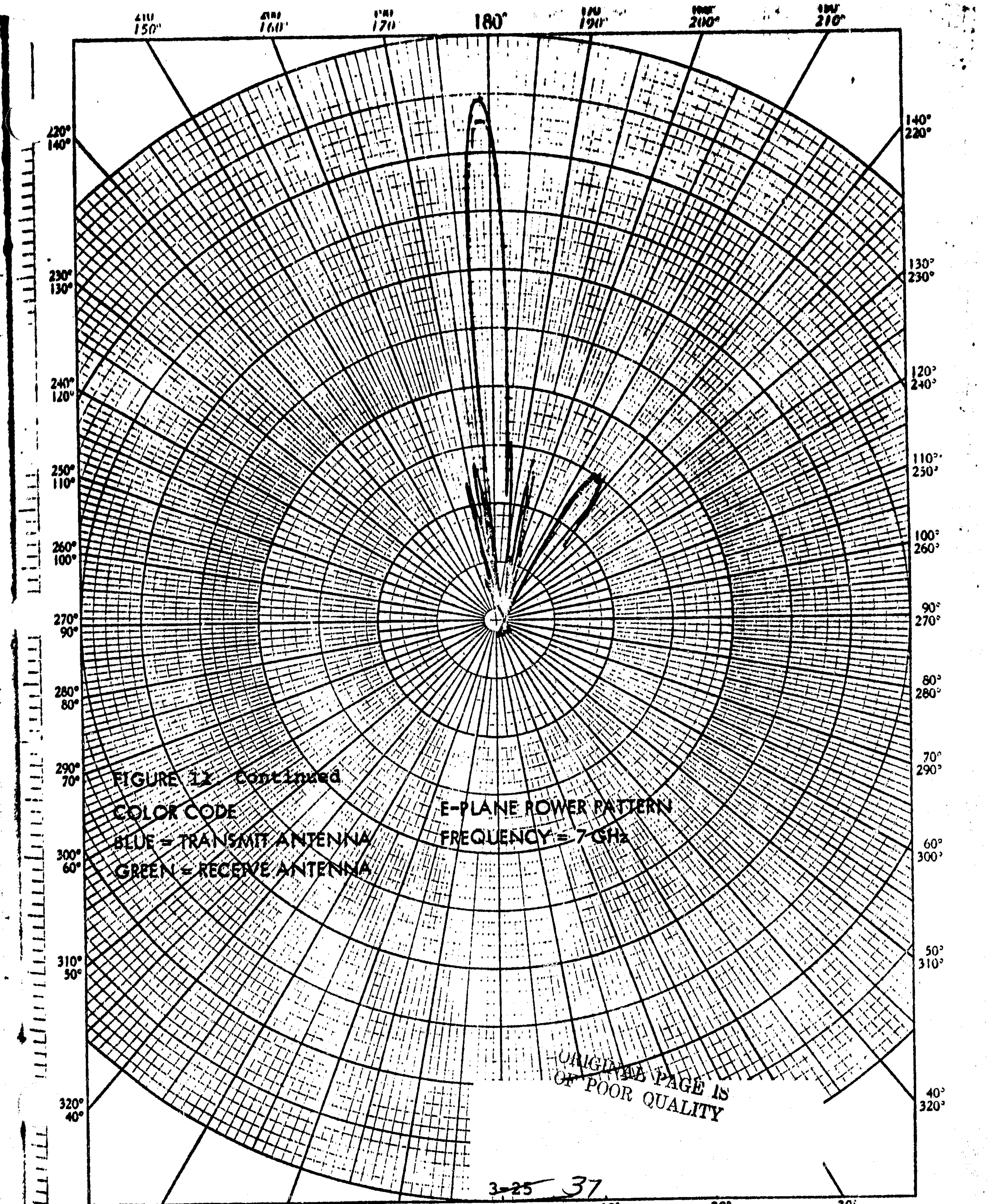


FIGURE 12 Continued

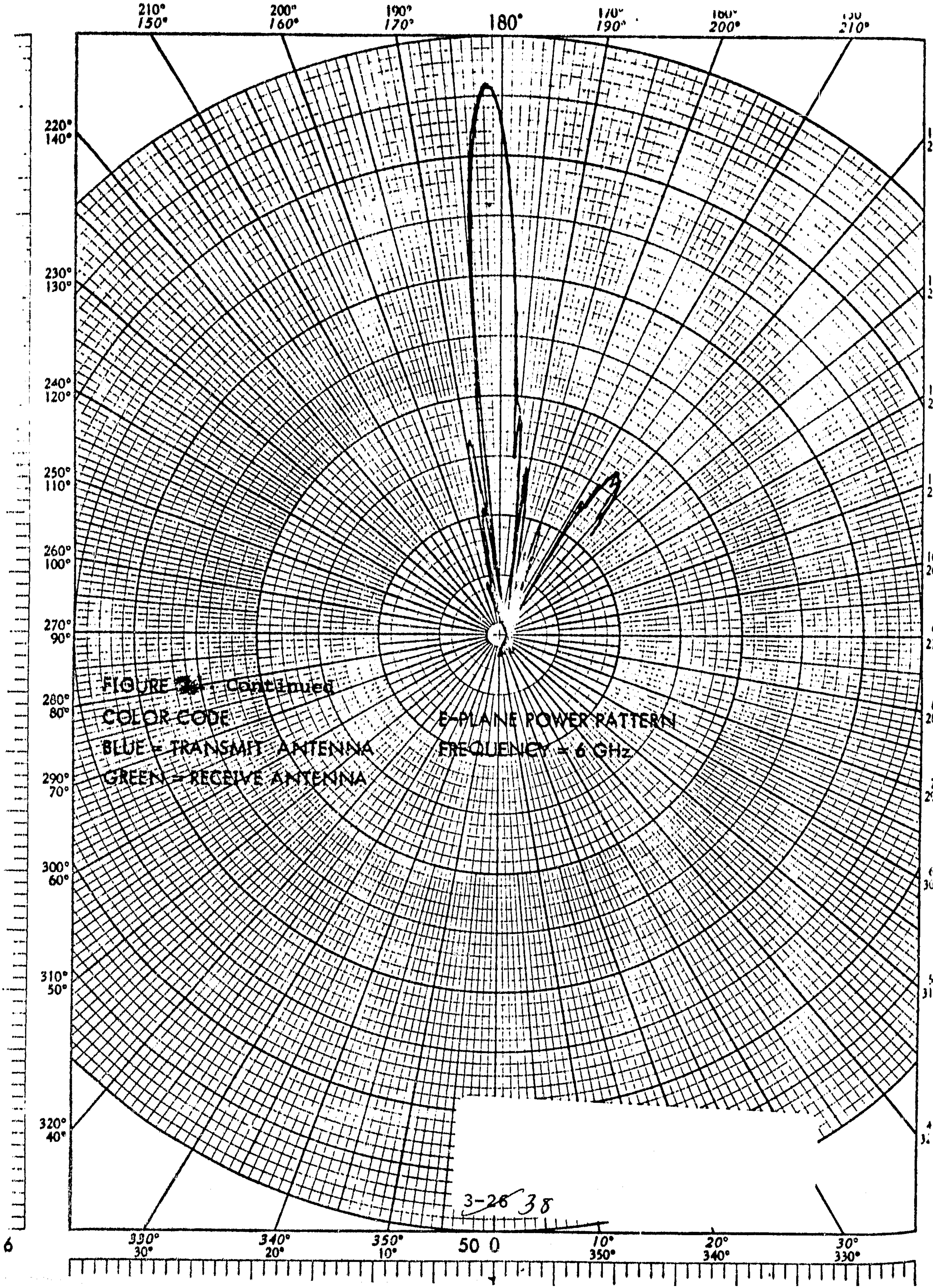


FIGURE [illegible] : Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
E-PLANE POWER PATTERN
FREQUENCY = 6 GHz
180°
3-26

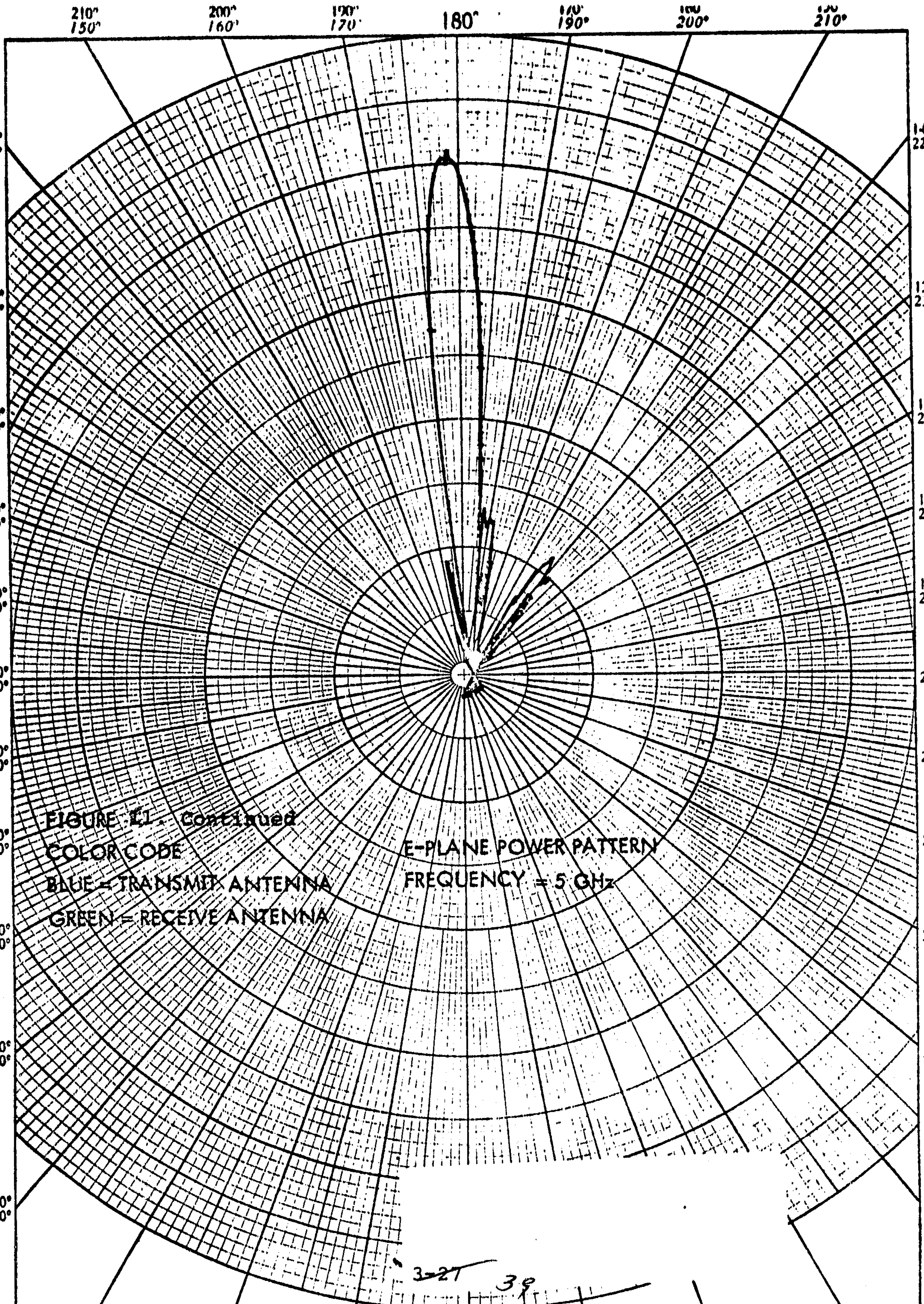
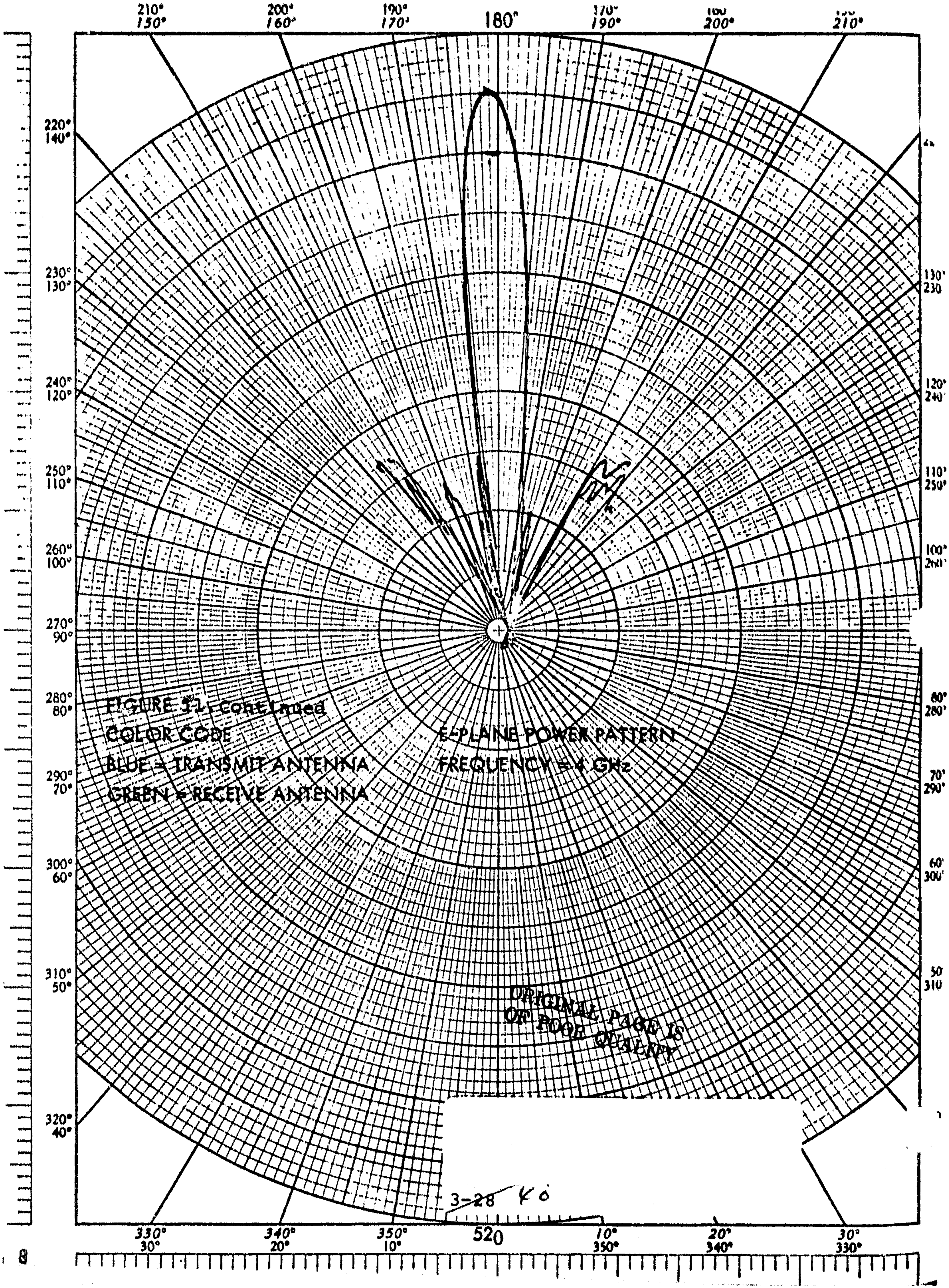


FIGURE E1 - Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA



180°
FIGURE 31. Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
E-PLANE POWER PATTERN
FREQUENCY = 4 GHz
ORIGINAL PAGE IS OF POOR QUALITY
3-28

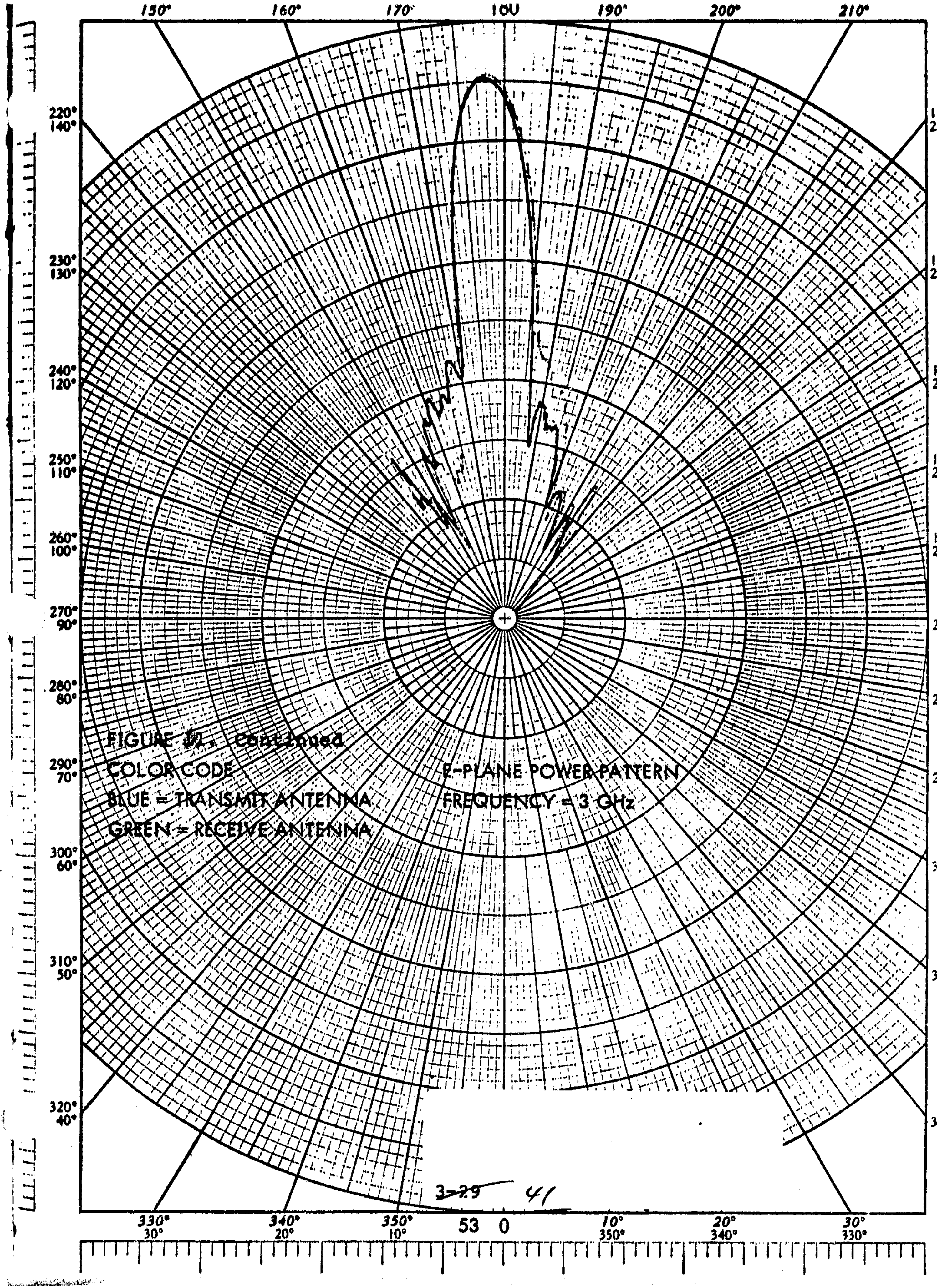
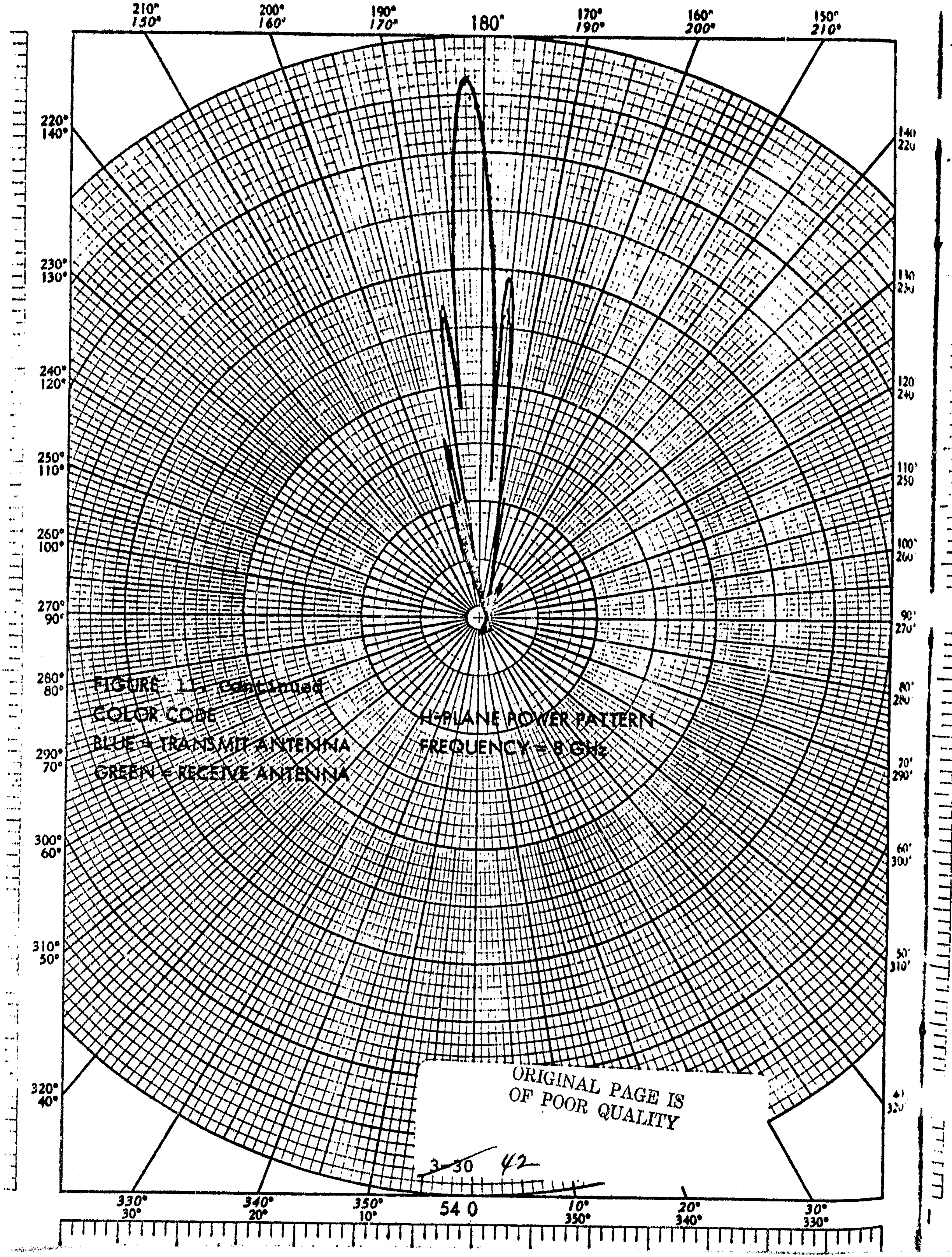


FIGURE 11. Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
E-PLANE POWER PATTERN
FREQUENCY = 3 GHz

3-29 41



180°
FIGURE 1 - Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
H-PLANE POWER PATTERN
FREQUENCY = 8 GHz

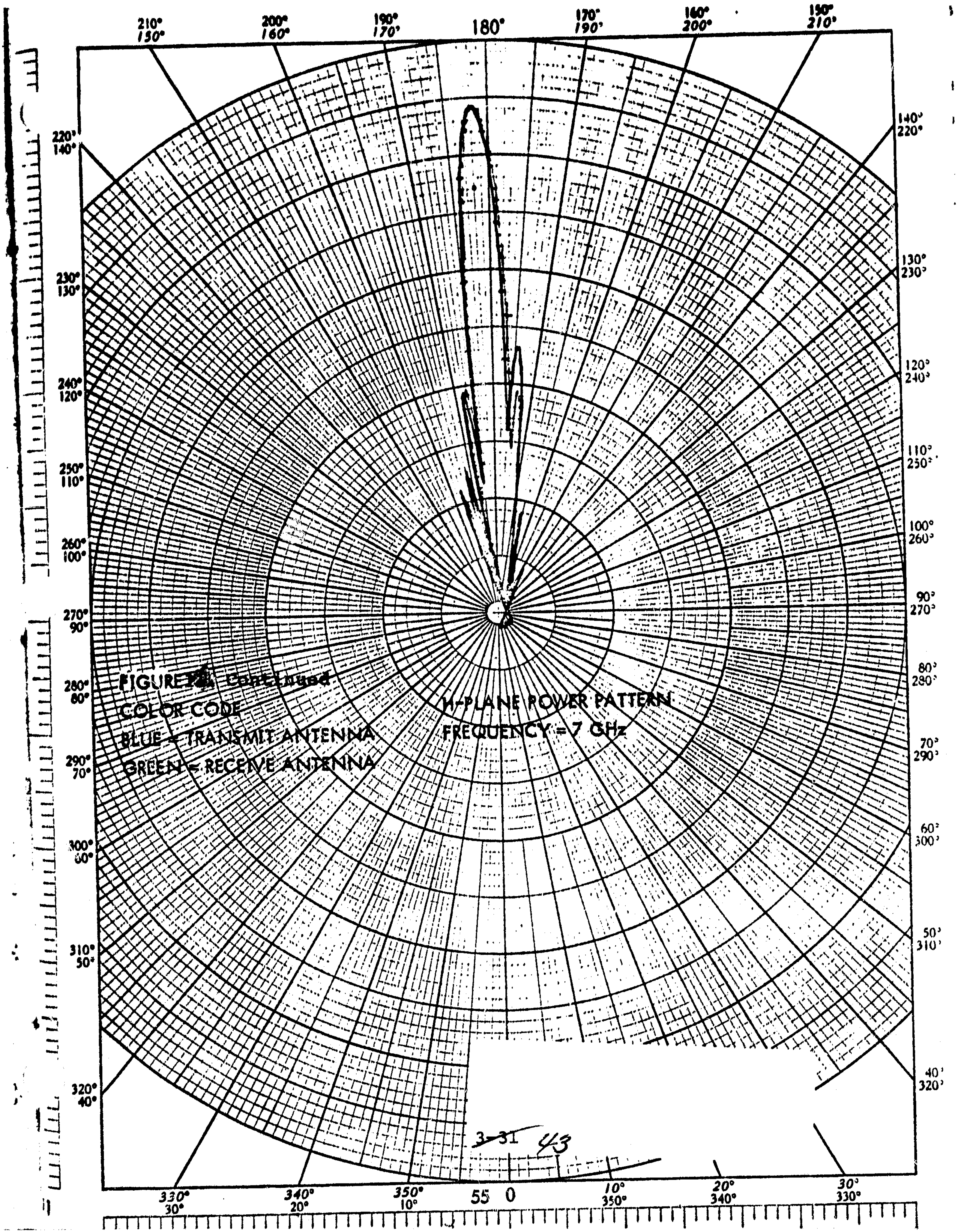
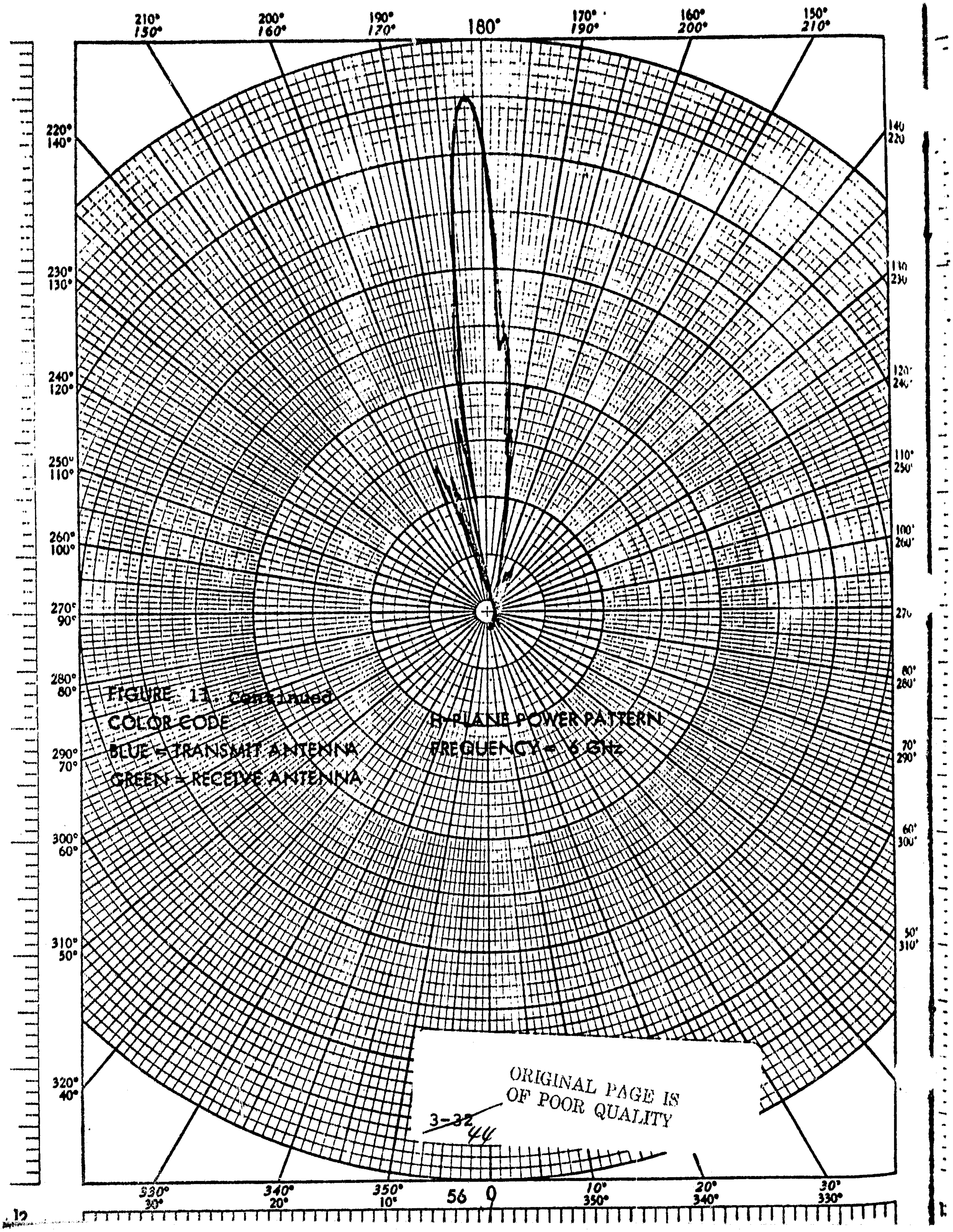


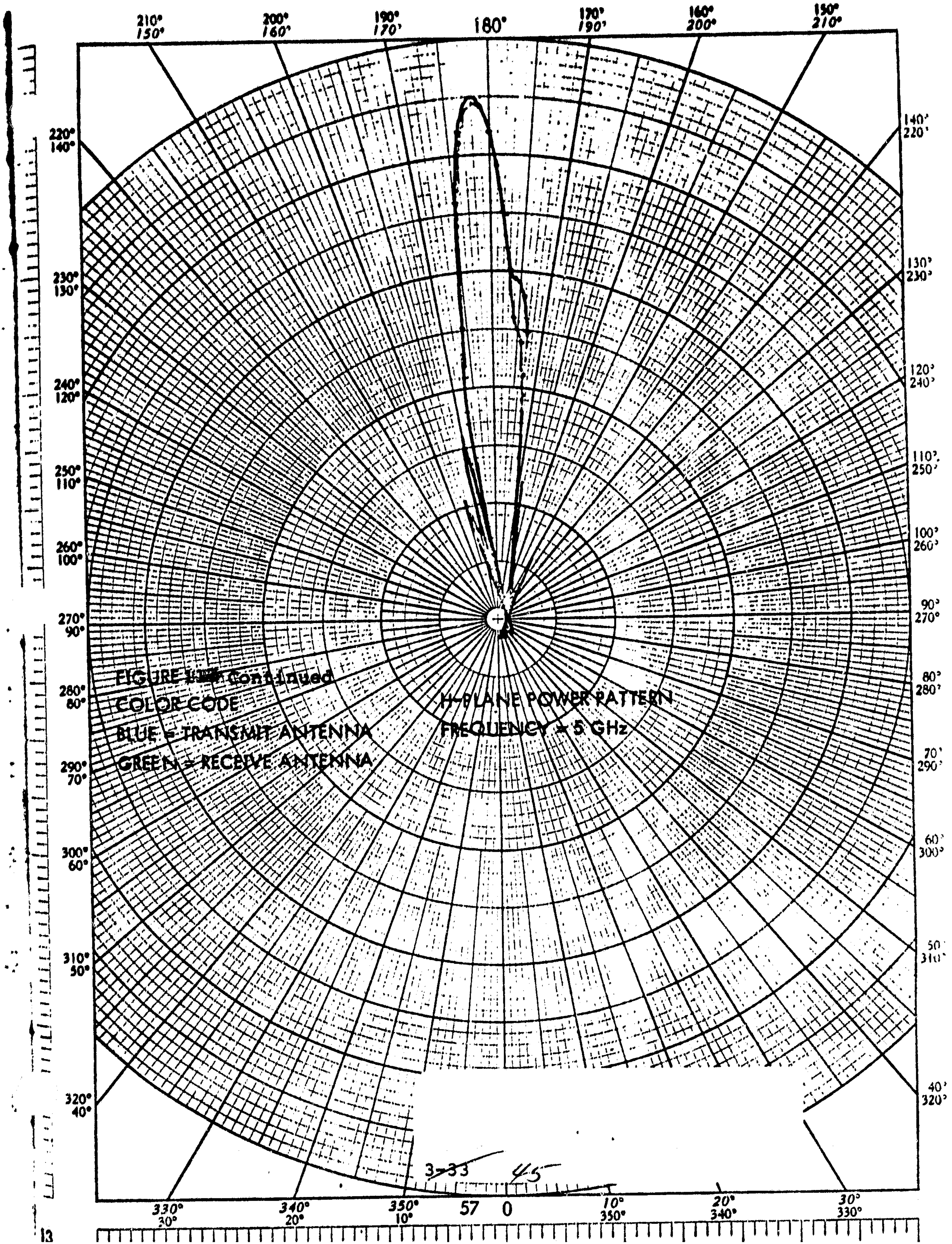
FIGURE Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
H-PLANE POWER PATTERN
FREQUENCY = 7 GHz
180°
0

55



180°
FIGURE 11. Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
H-PLANE POWER PATTERN
FREQUENCY = 6 GHz

3-32 44



180°
FIGURE Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
H-PLANE POWER PATTERN
FREQUENCY = 5 GHz

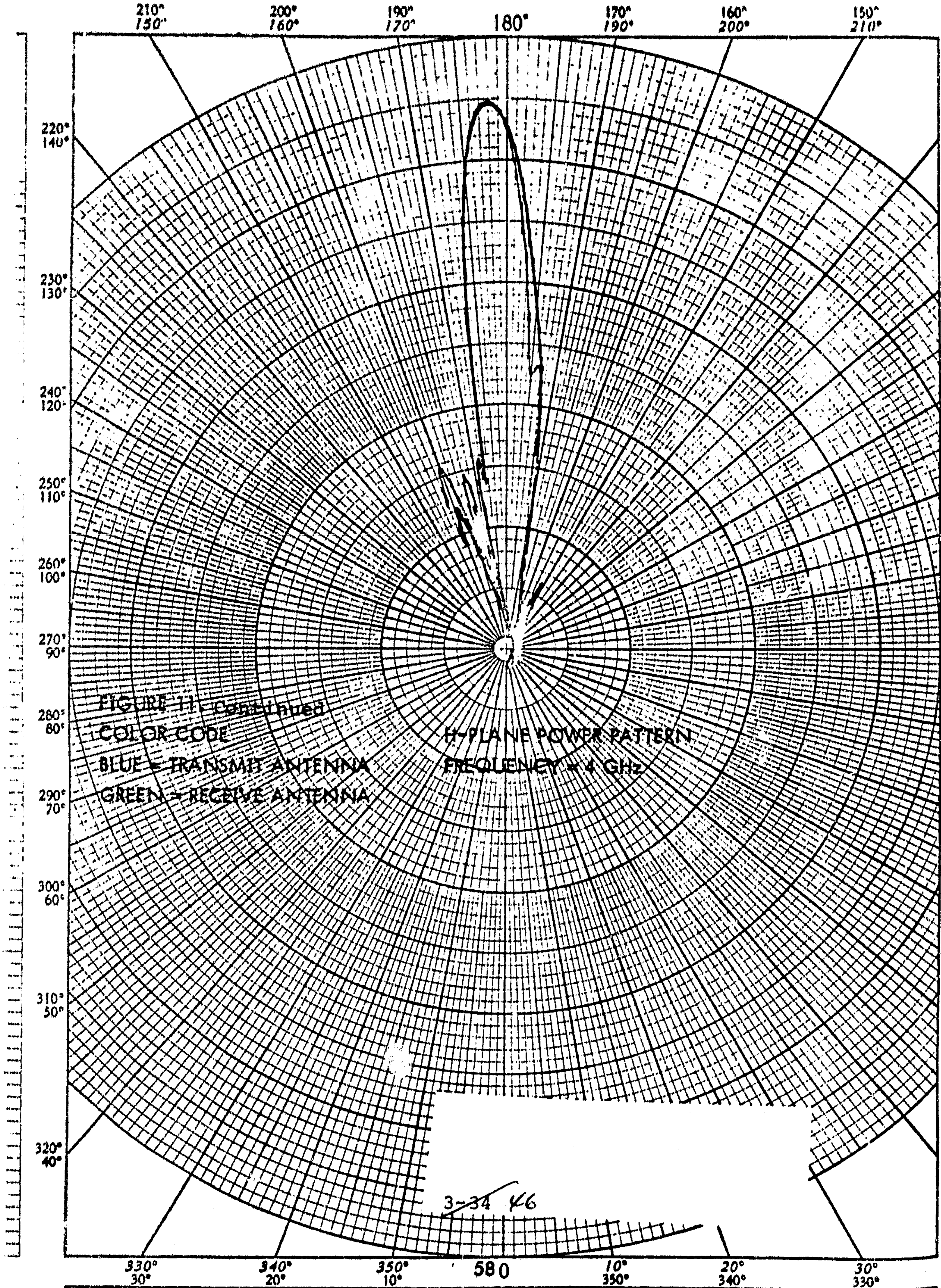
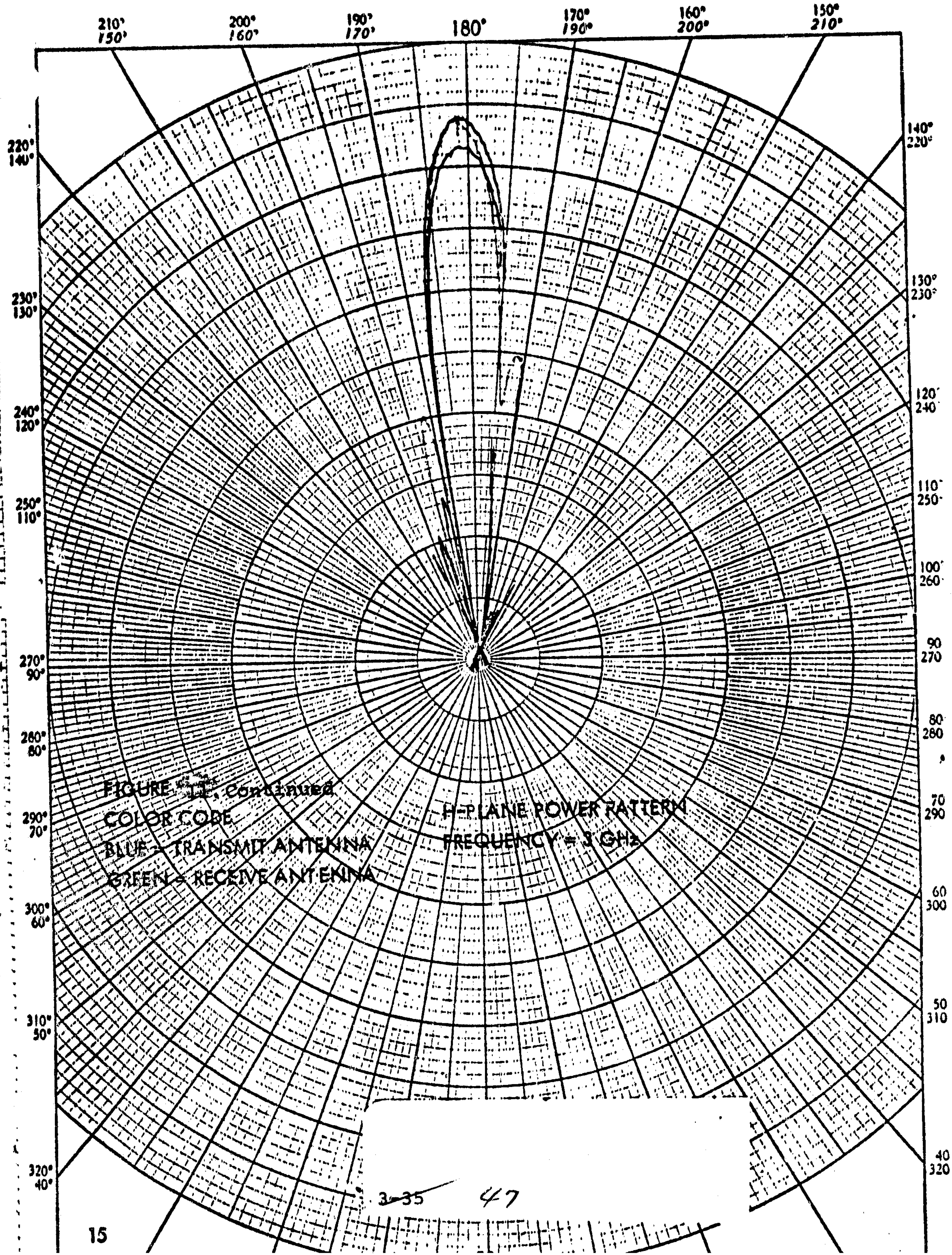


FIGURE 11. Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
H-PLANE POWER PATTERN
FREQUENCY = 4 GHz
180°
3-34 46



210° 150°
200° 160°
190° 170°
180°
170° 190°
160° 200°
150° 210°
220° 140°
140° 220°
230° 130°
130° 230°
240° 120°
120 240
250° 110°
110 250
100 260
270° 90°
90 270
280° 80°
80 280
290° 70°
70 290
300° 60°
60 300
310° 50°
50 310
320° 40°
40 320
FIGURE , Continued
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
H-PLANE POWER PATTERN
FREQUENCY = 3 GHz

~~3-35~~ 47

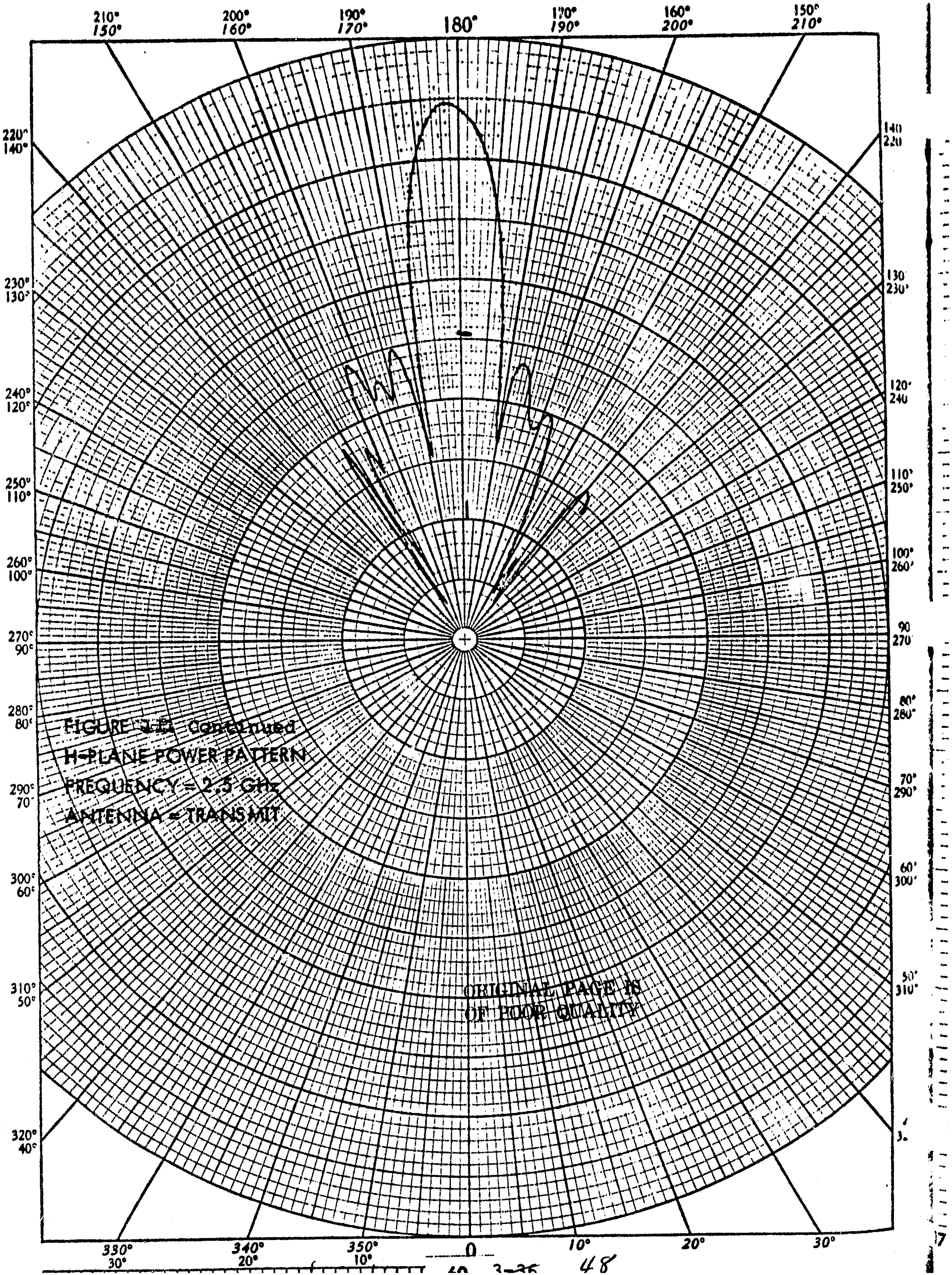


FIGURE [illegible] continued
H-PLANE POWER PATTERN
FREQUENCY = 2.5 GHz
ANTENNA = TRANSMIT

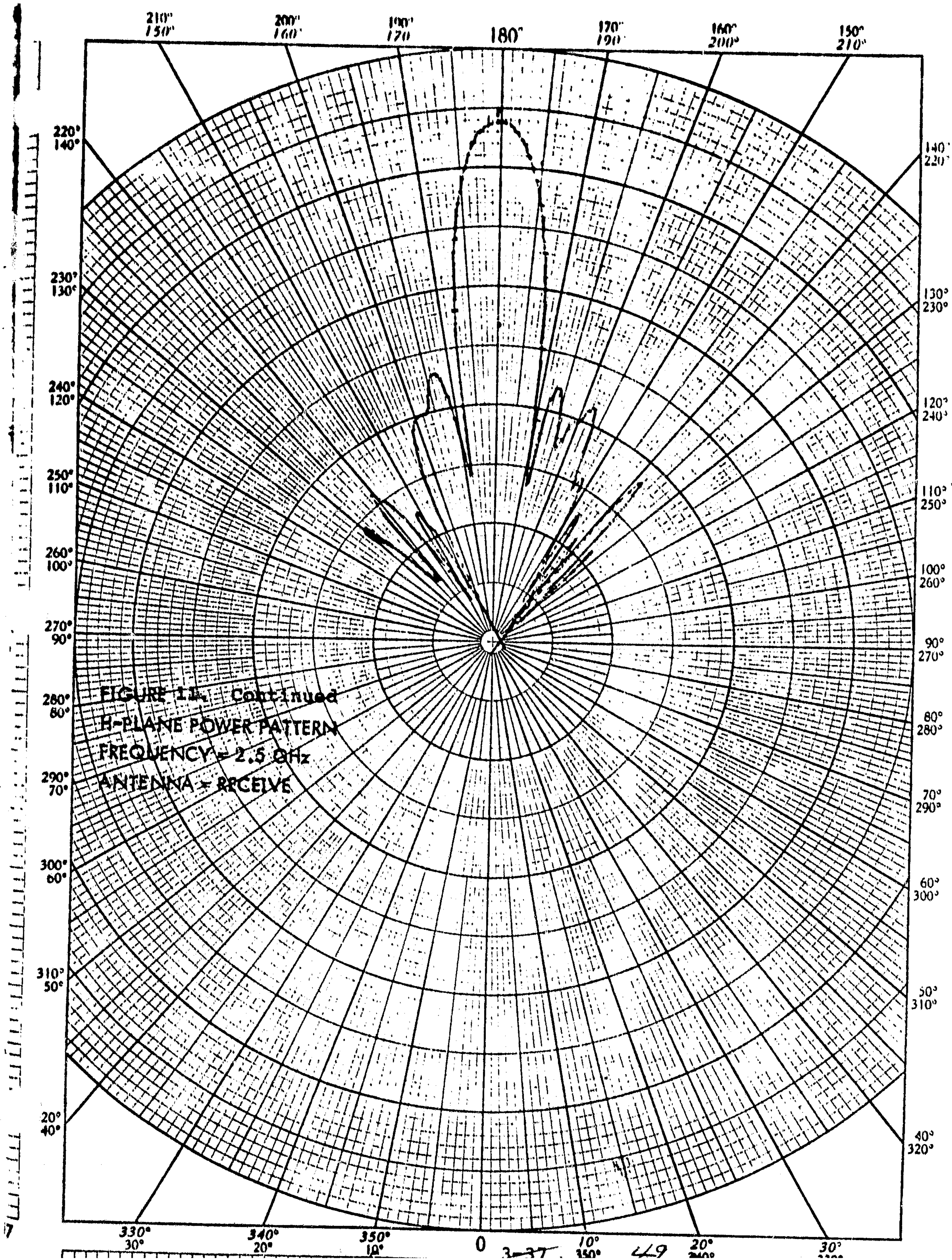


FIGURE 11. Continued
H-PLANE POWER PATTERN
FREQUENCY = 2.5 GHz
ANTENNA = RECEIVE

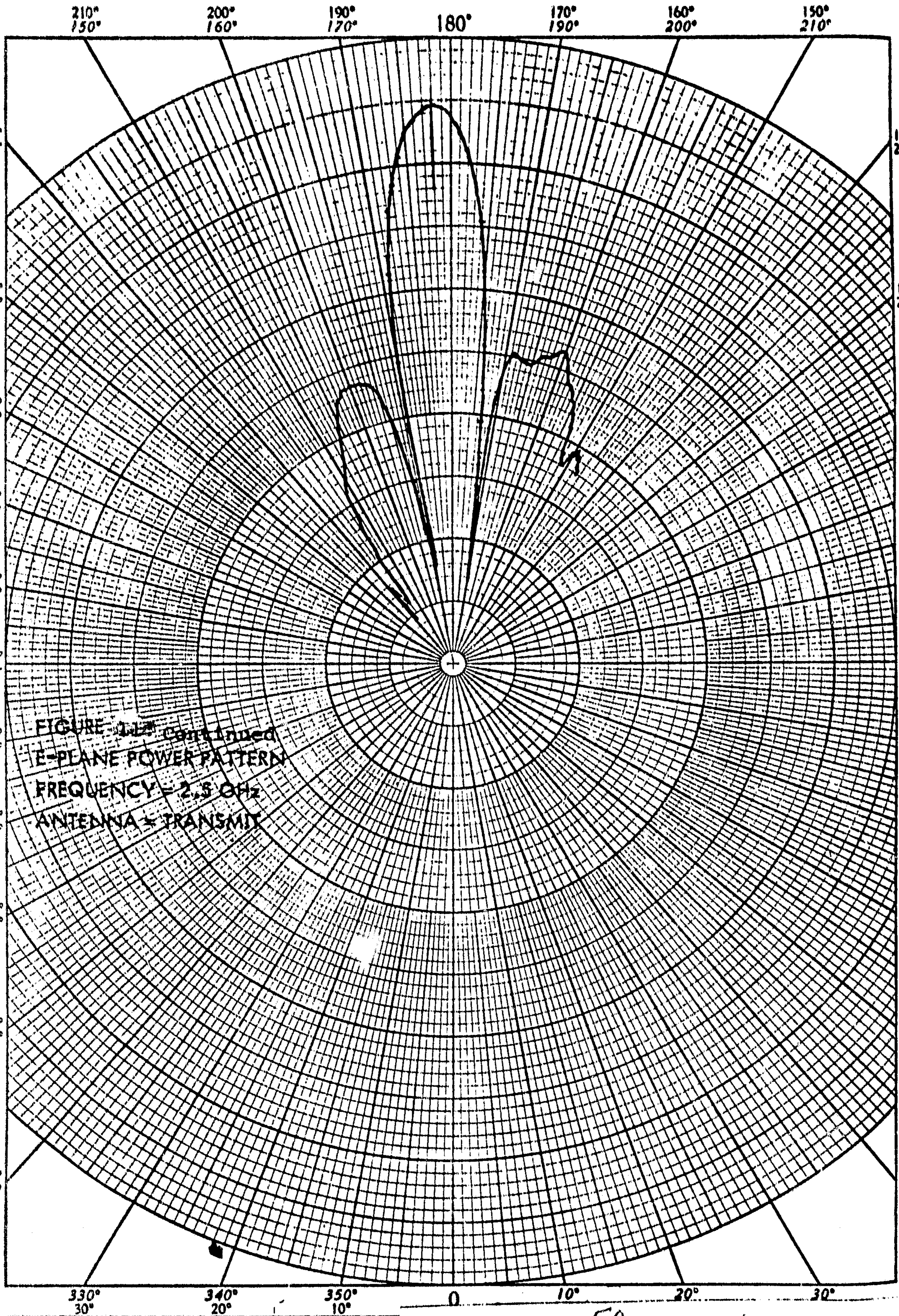


FIGURE 1.1[illegible] continued
E-PLANE POWER PATTERN
FREQUENCY = 2.5 GHz
ANTENNA = TRANSMIT

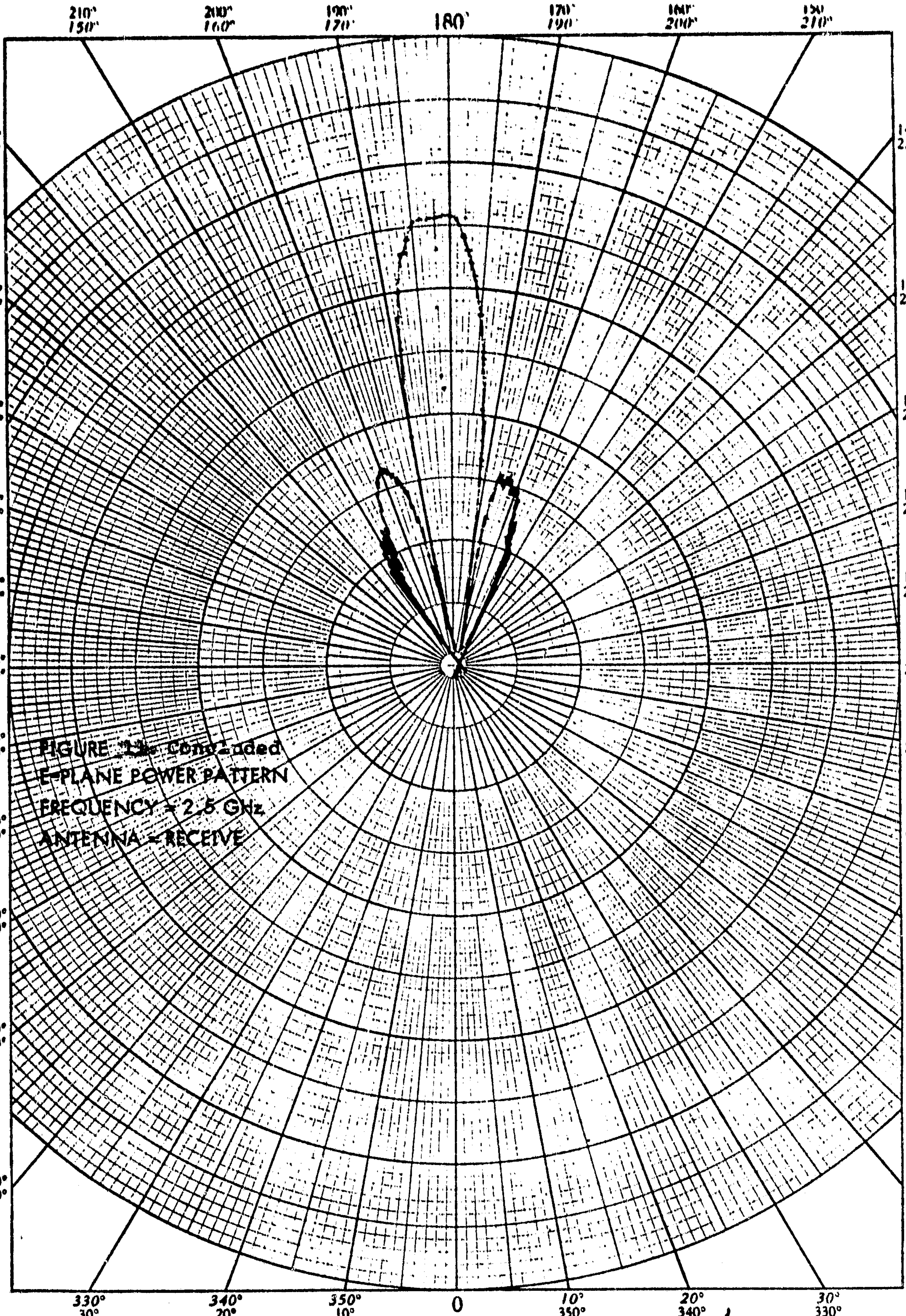
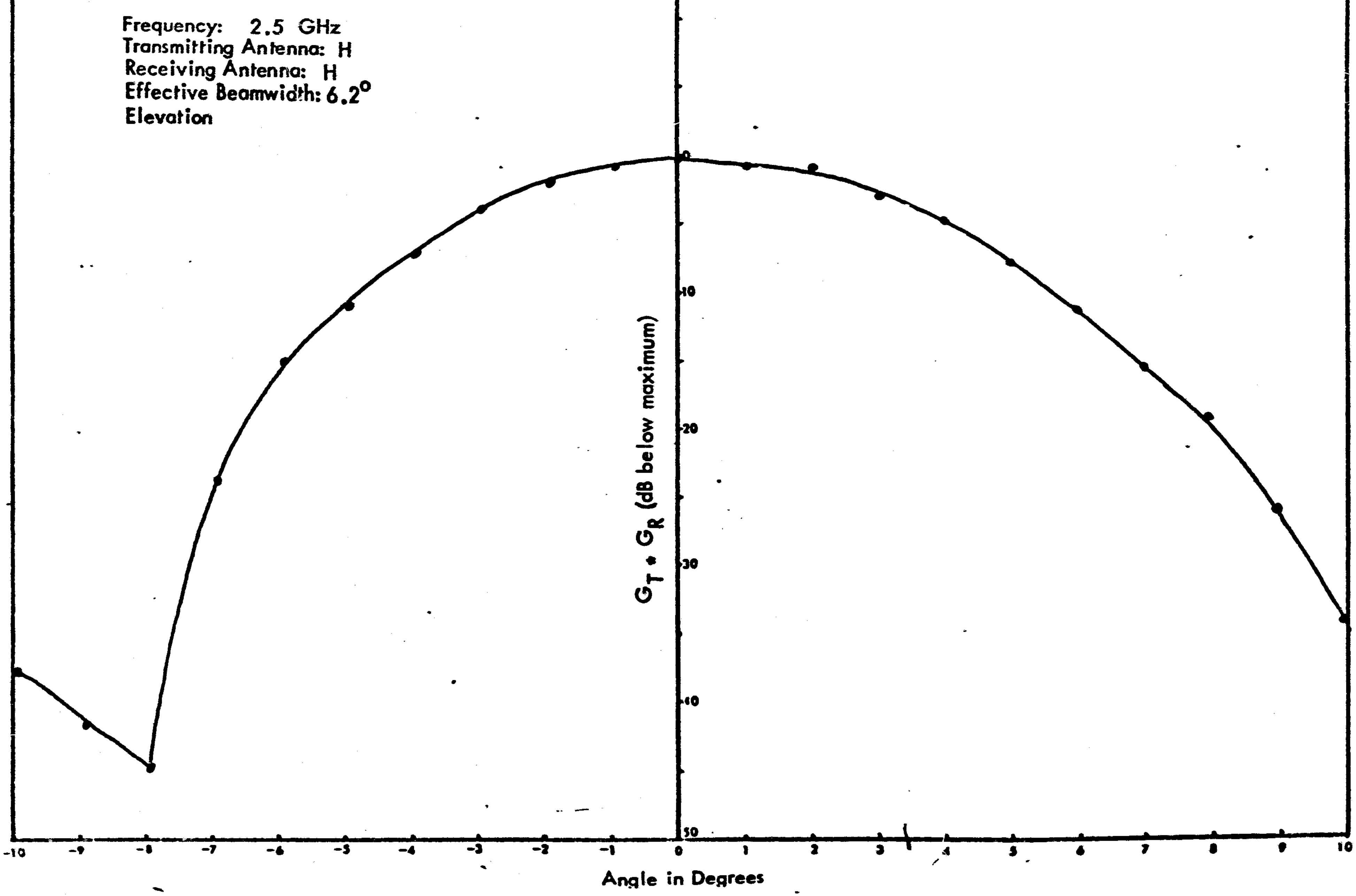


FIGURE [illegible] Concluded
E-PLANE POWER PATTERN
FREQUENCY = 2.5 GHz
ANTENNA = RECEIVE

Figure 12. - MAS 2-8 effective principal plane power pattern (ref. 6).



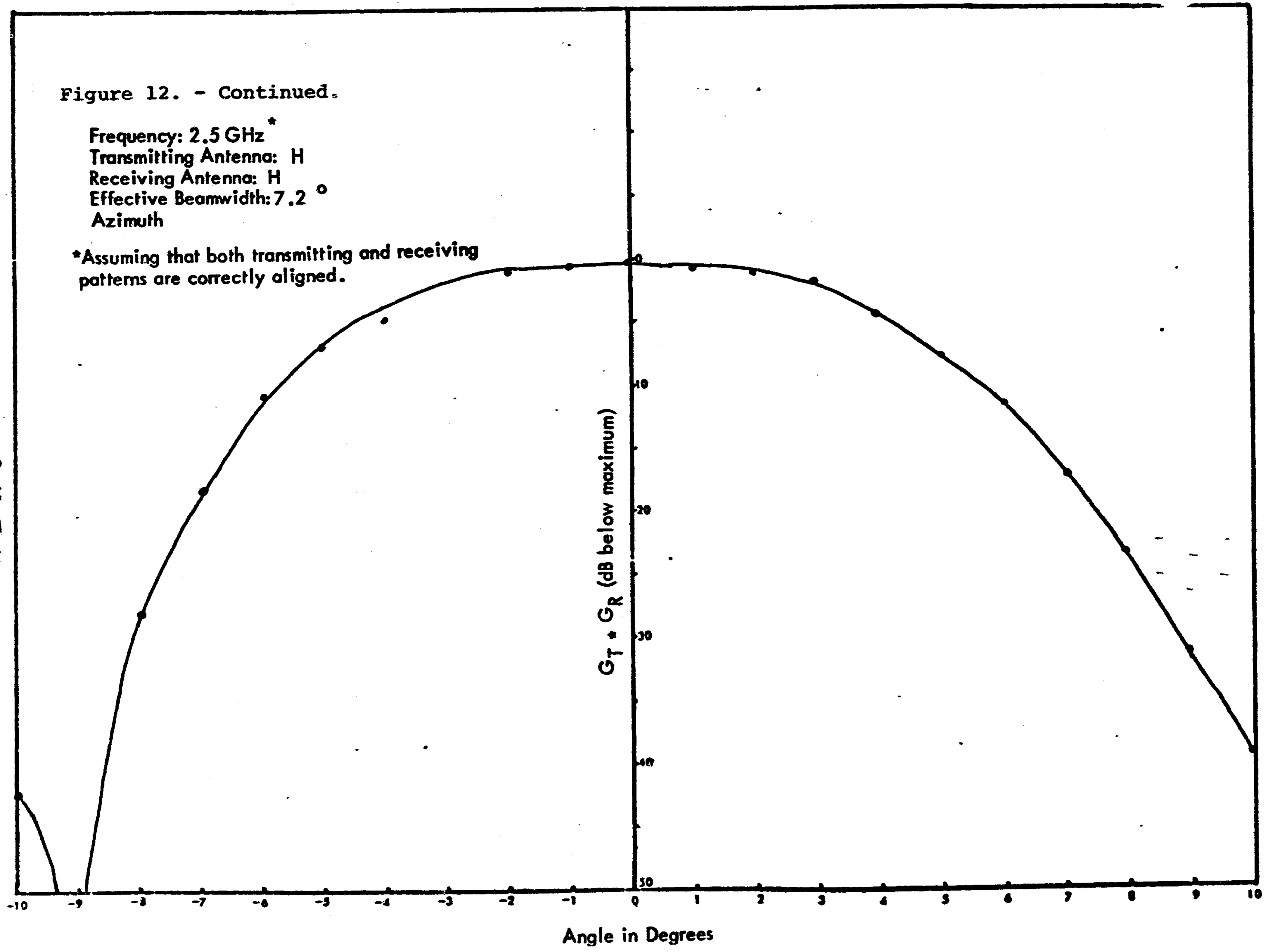


Figure 12. - Continued.

Frequency: 2.5 GHz*
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 7.2 °
Azimuth

*Assuming that both transmitting and receiving patterns are correctly aligned.

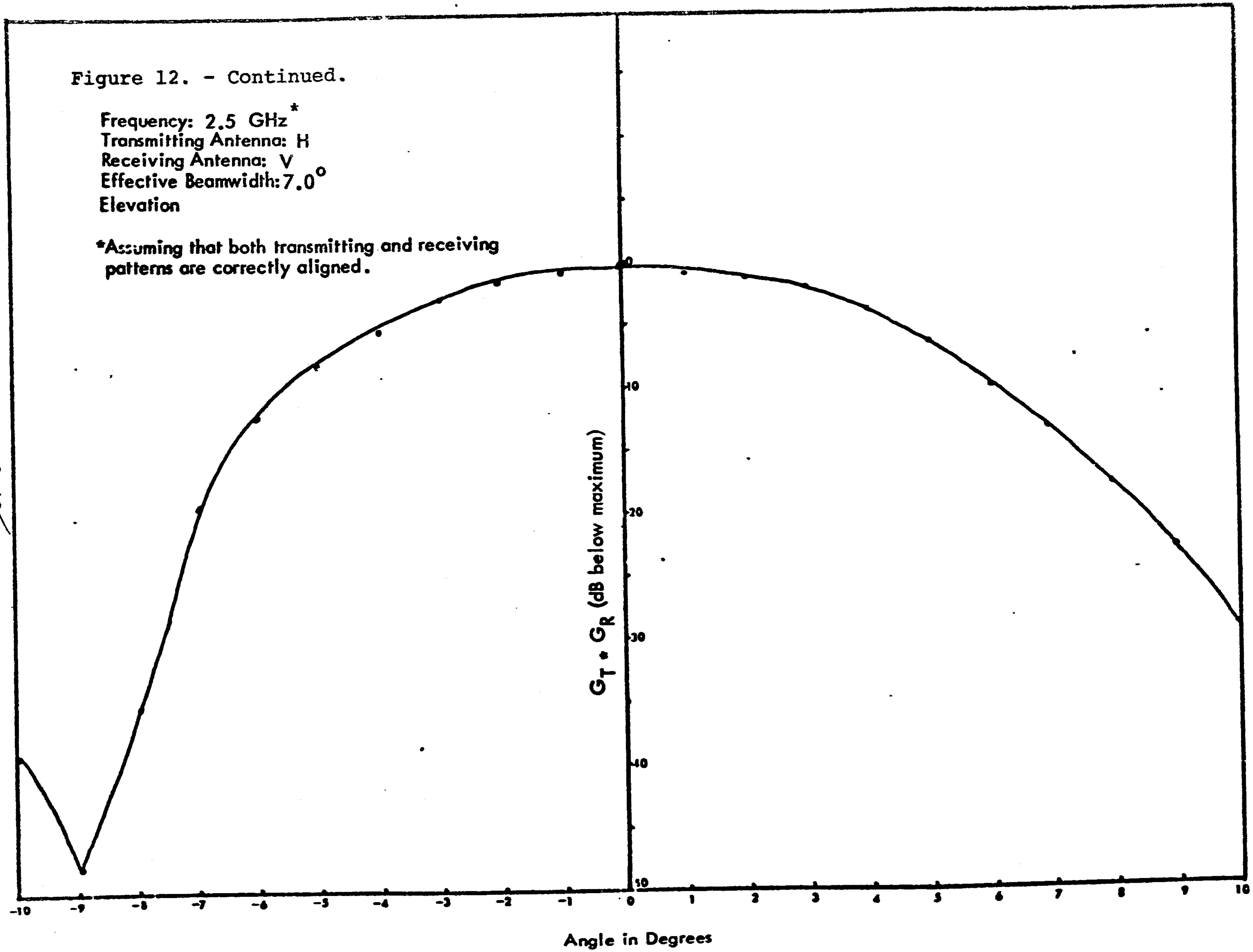


Figure 12. - Continued.

Frequency: 2.5 GHz*
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 7.0°
Elevation

*Assuming that both transmitting and receiving patterns are correctly aligned.

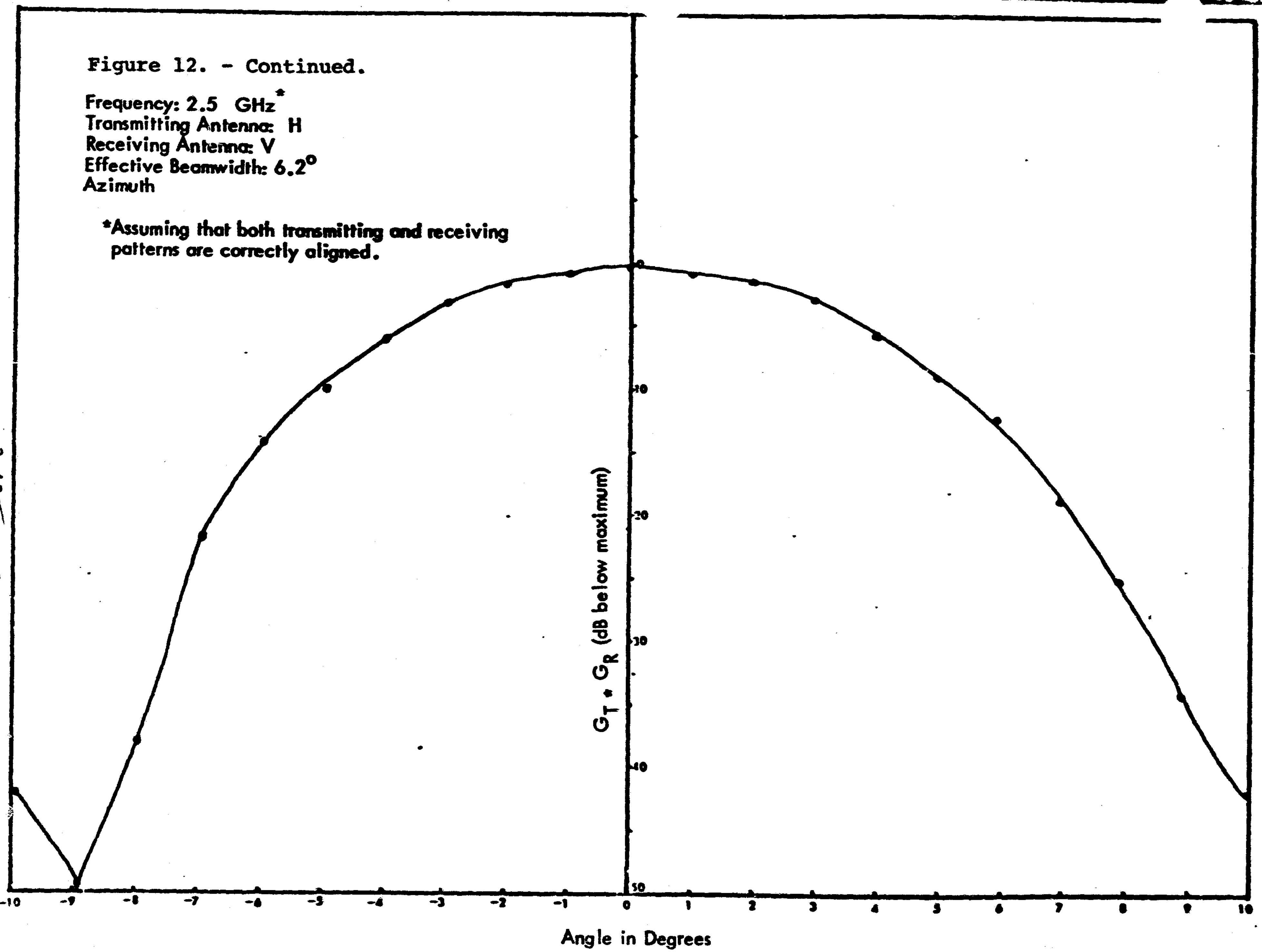


Figure 12. - Continued.

Frequency: 2.5 GHz*
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 6.2°
Azimuth

*Assuming that both transmitting and receiving patterns are correctly aligned.

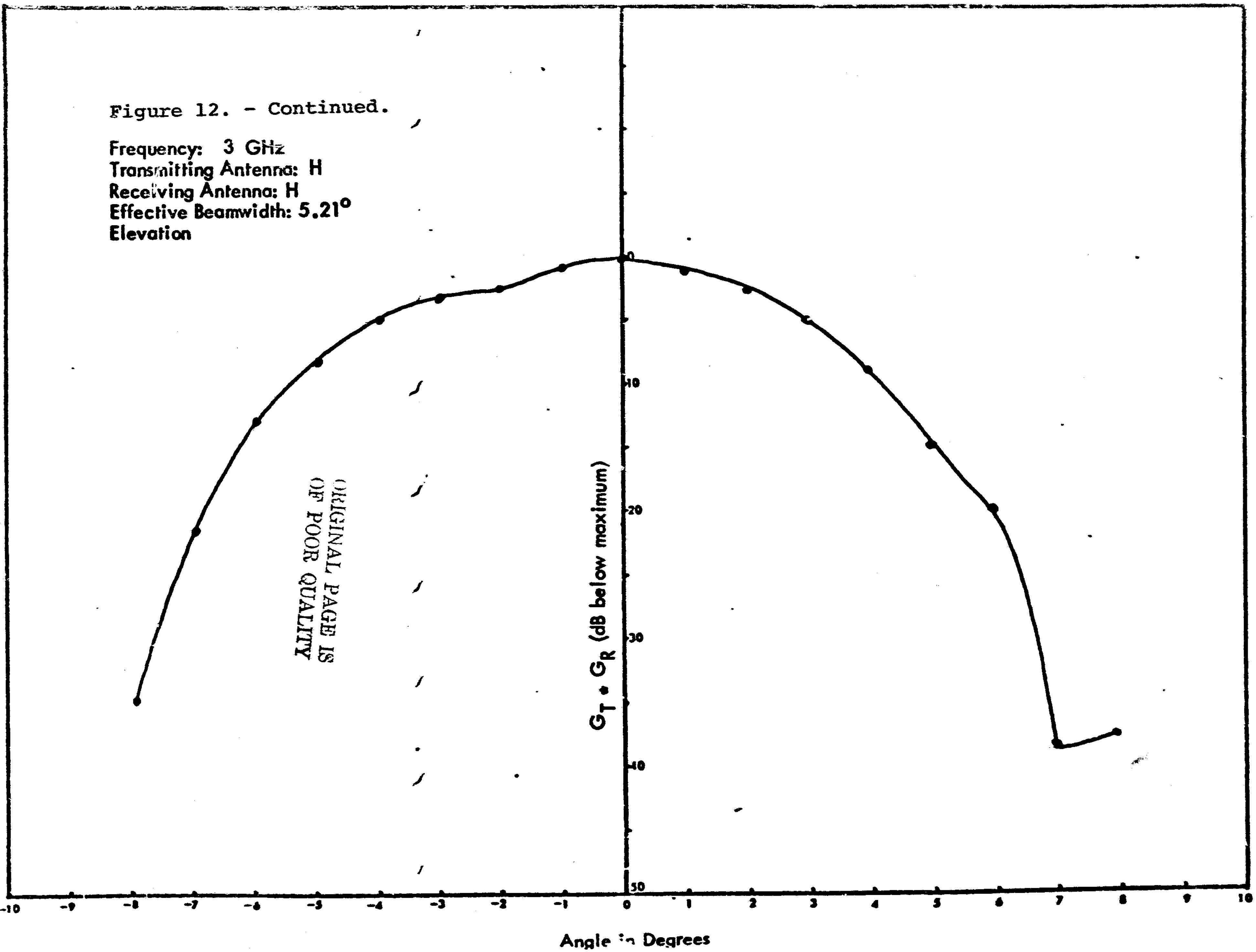


Figure 12. - Continued.

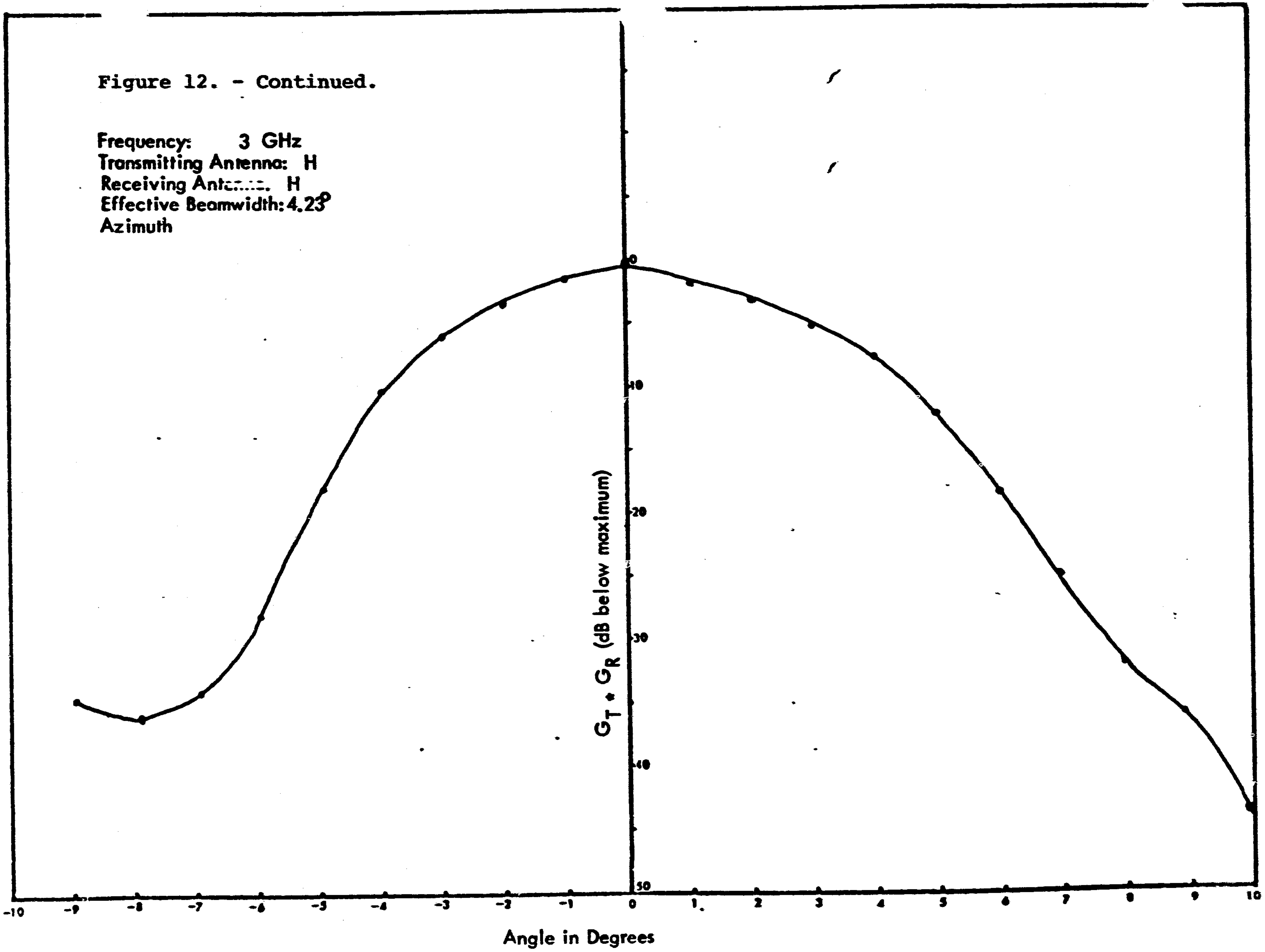
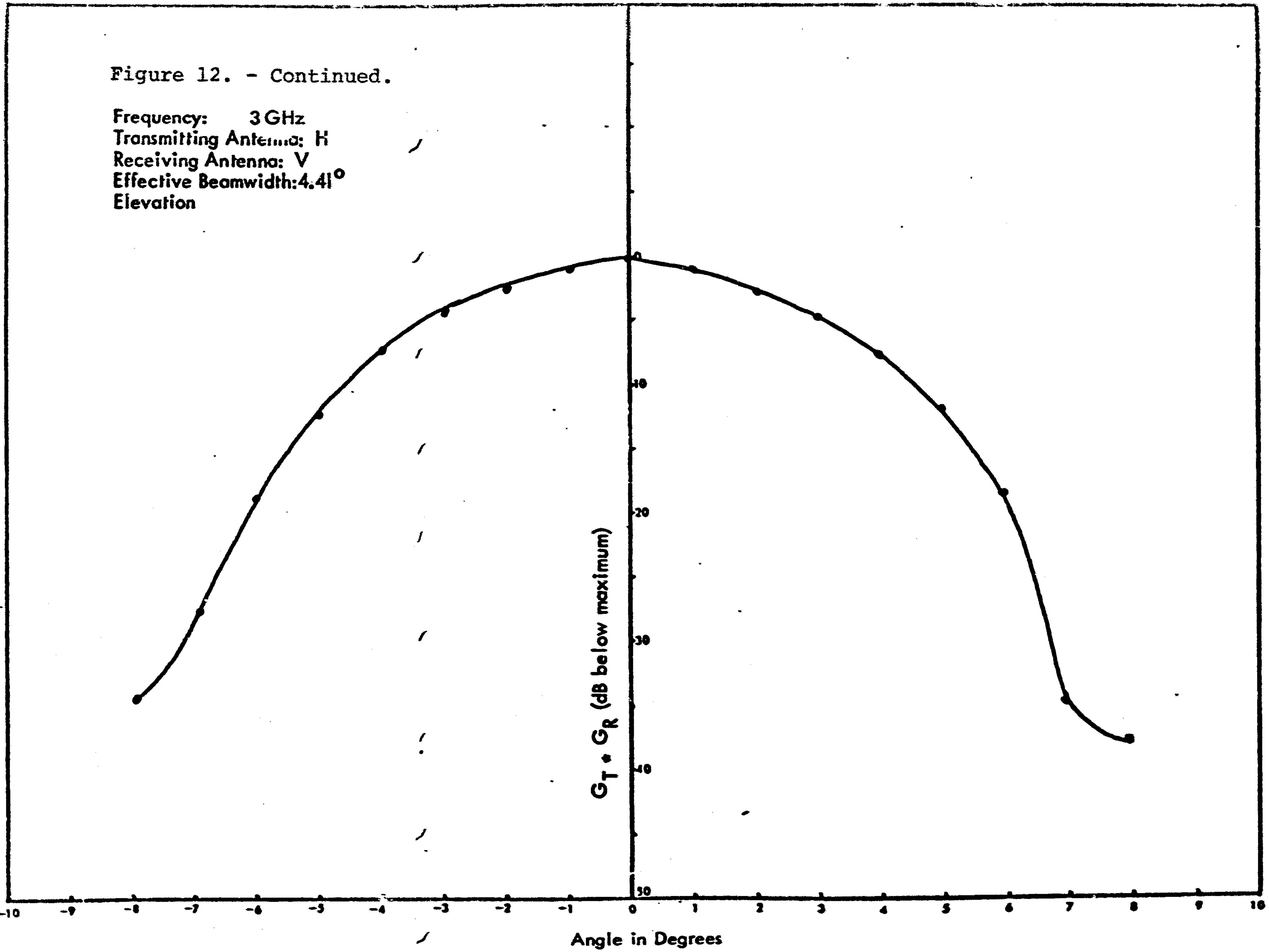


Figure 12. - Continued.

Figure 12. - Continued.

Frequency: 3 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 4.41°
Elevation



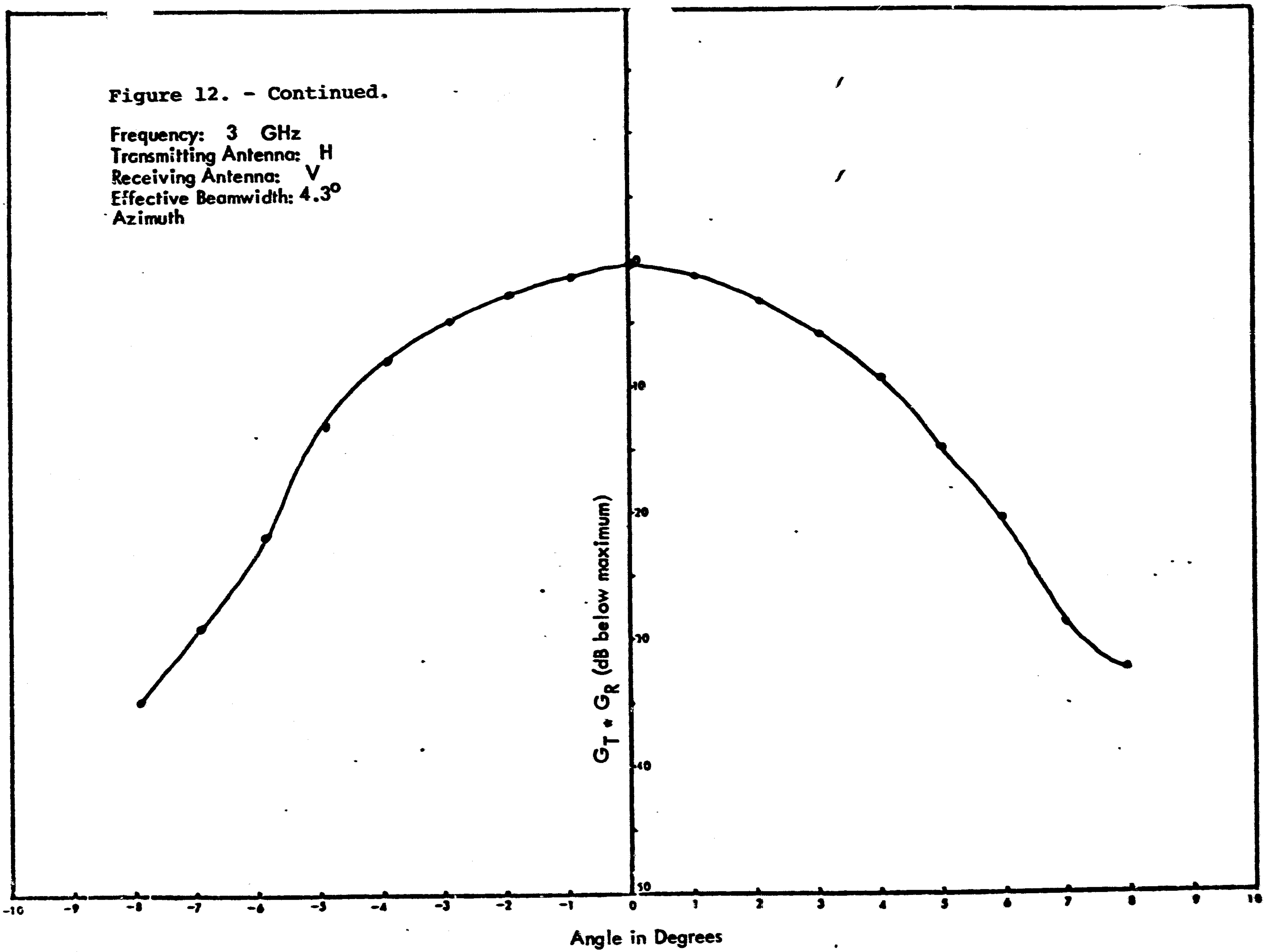


Figure 12. - Continued.
Frequency: 3 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 4.3°
Azimuth
0
10
20
30
40
50
$G_T * G_R$ (dB below maximum)
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Angle in Degrees

Figure 12. - Continued.

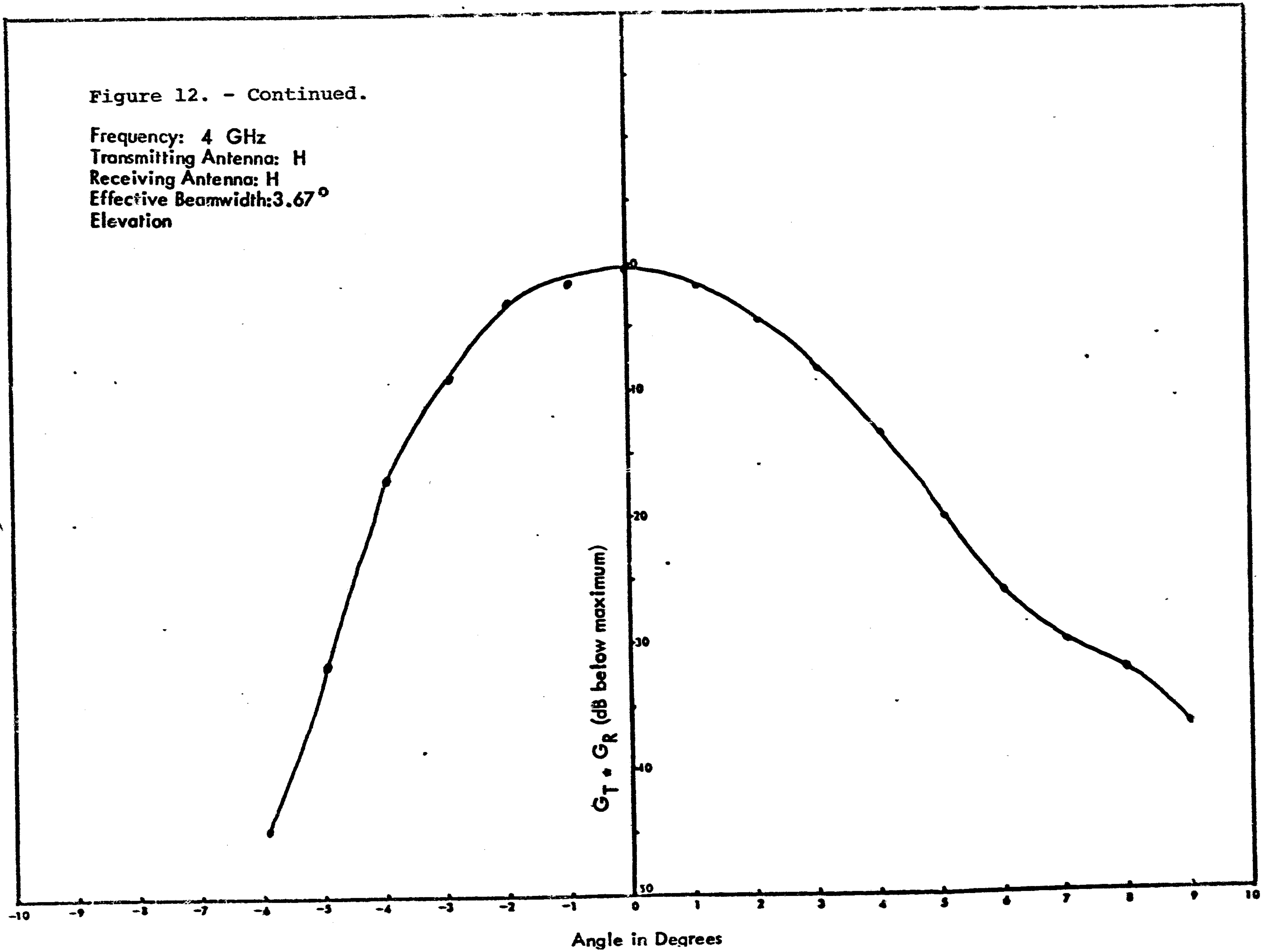
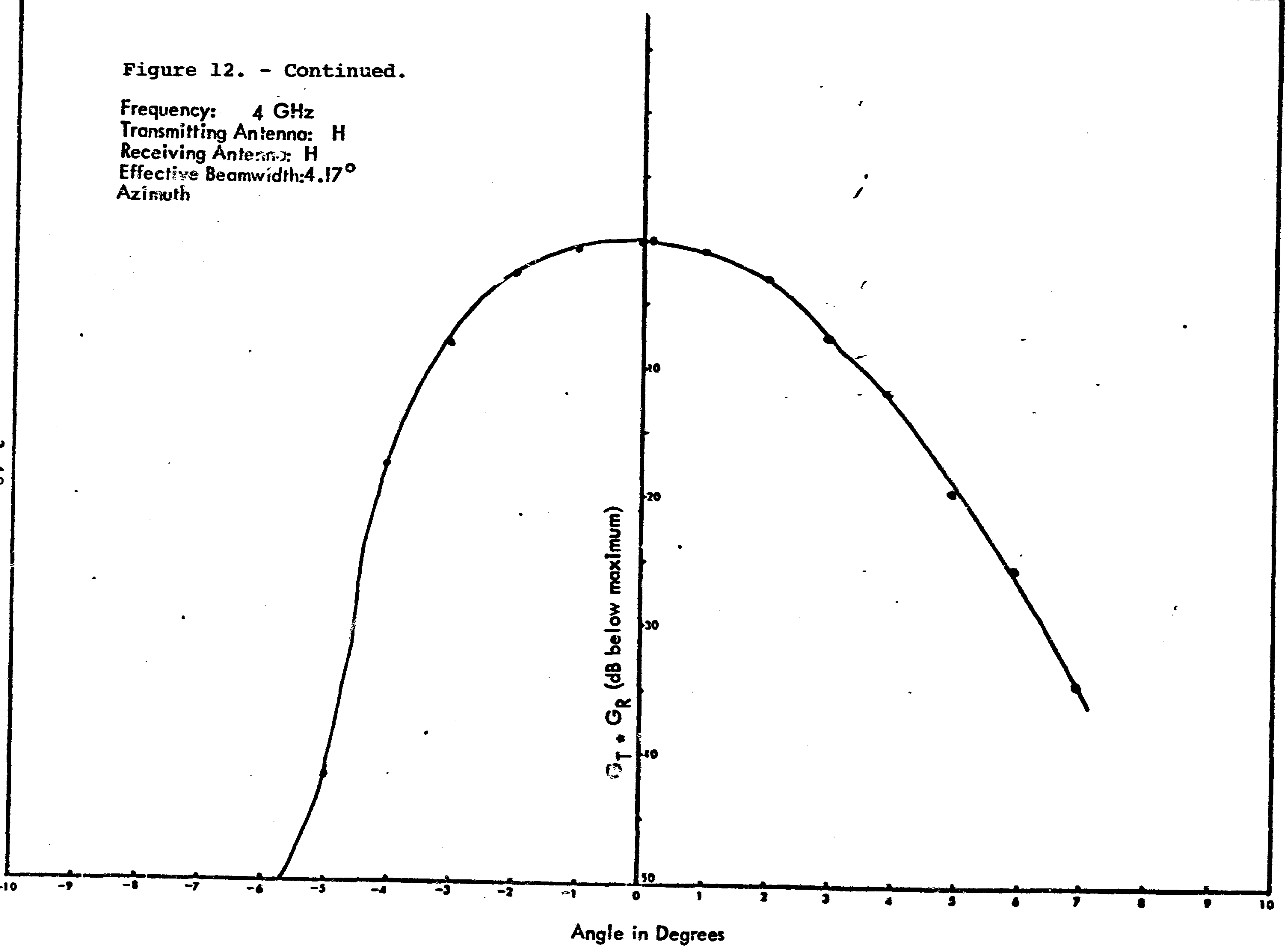


Figure 12. - Continued.

Frequency: 4 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 4.17°
Azimuth



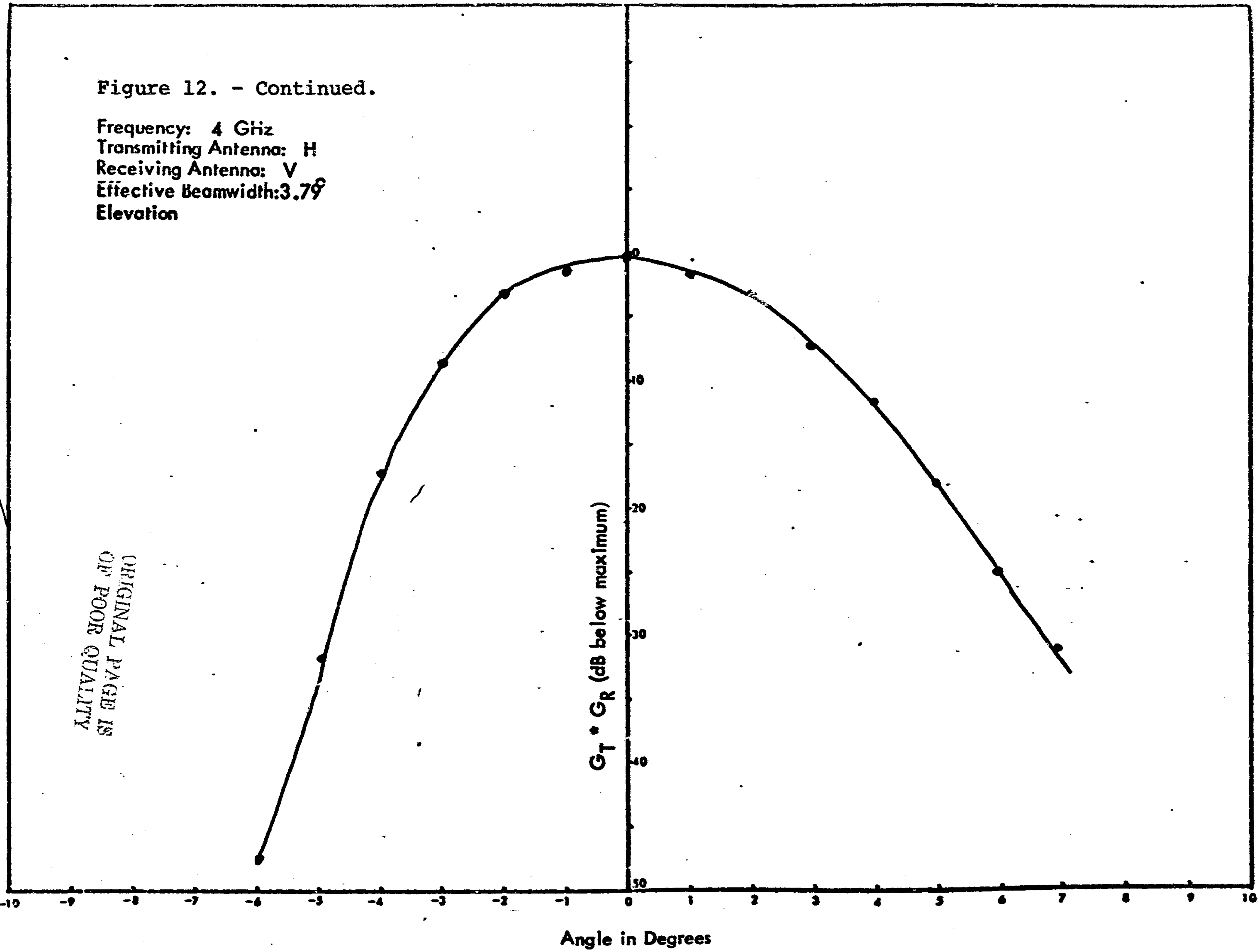


Figure 12. - Continued.

Frequency: 4 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 3.79°
Elevation

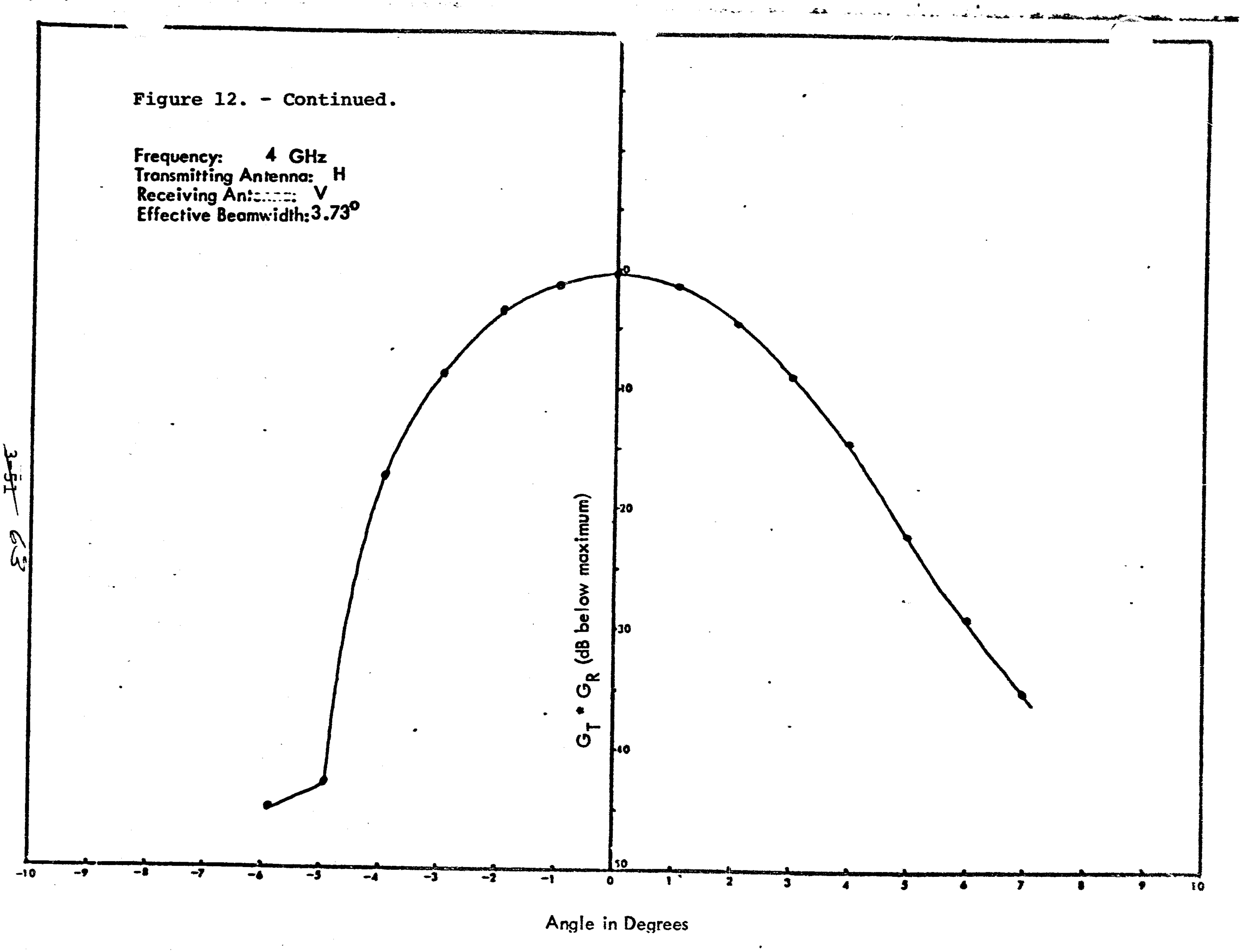


Figure 12. - Continued.

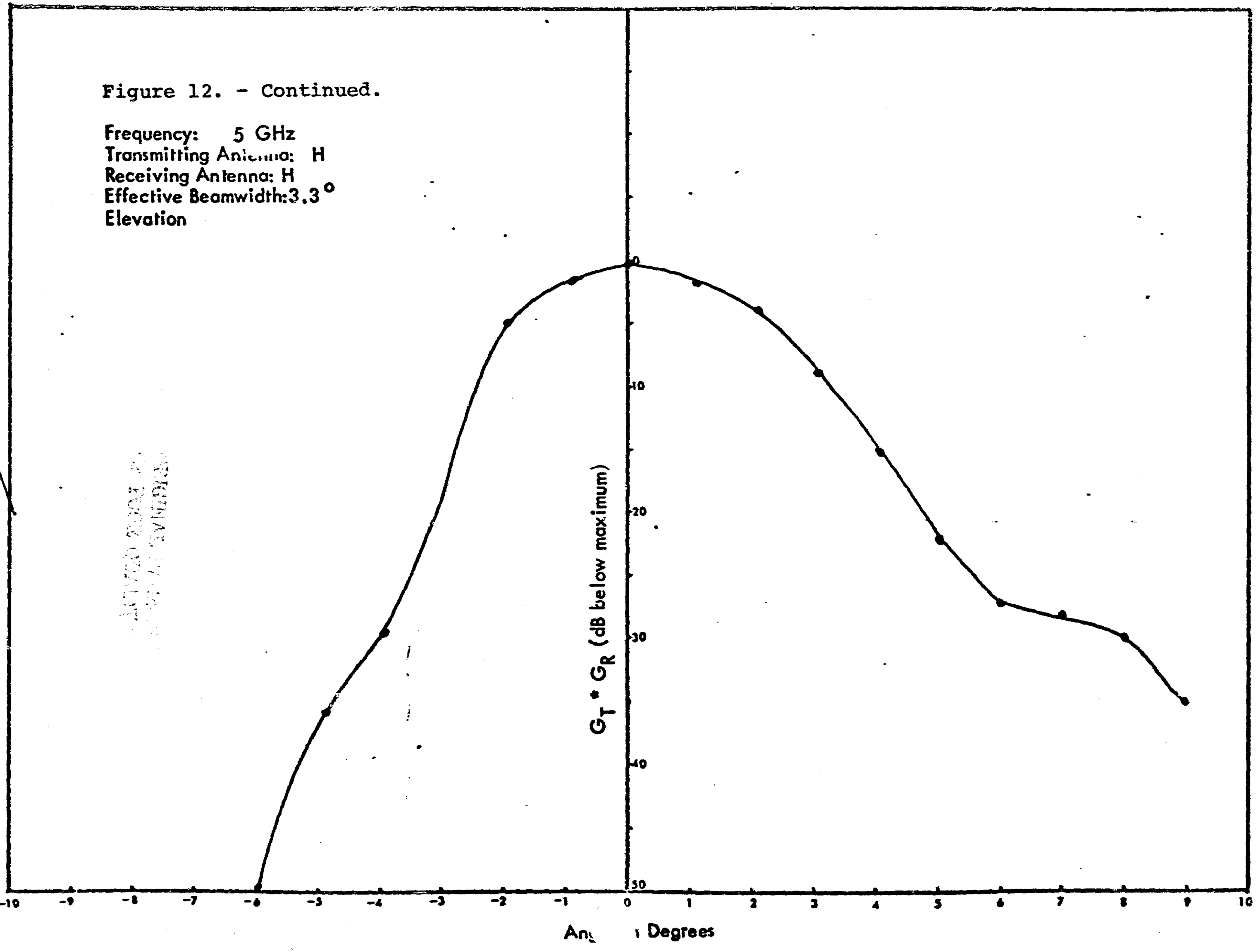


Figure 12. - Continued.

Frequency: 5 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 3.3°
Elevation

Figure 12. - Continued.

Frequency: 5 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 3.44°
Azimuth

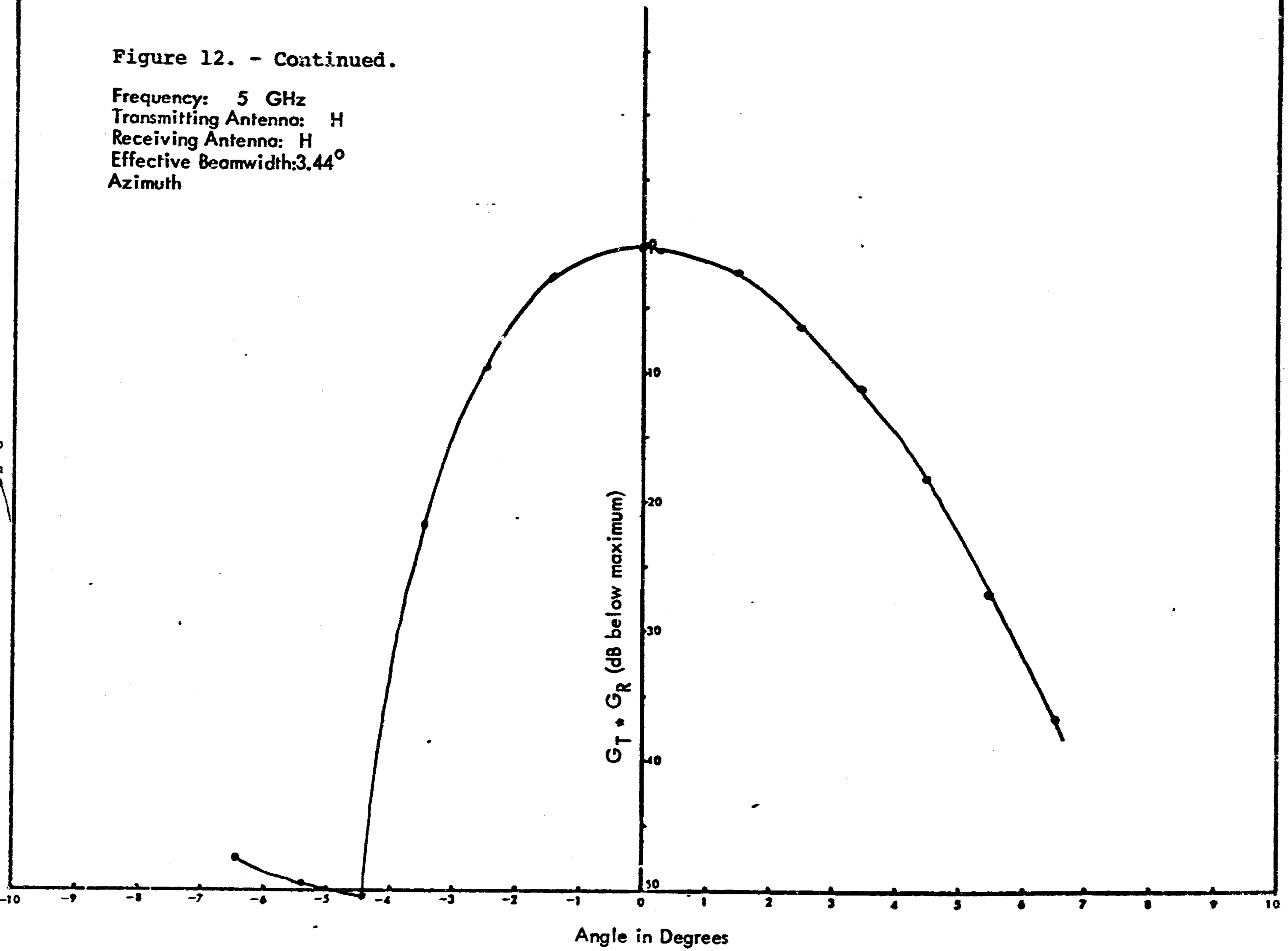
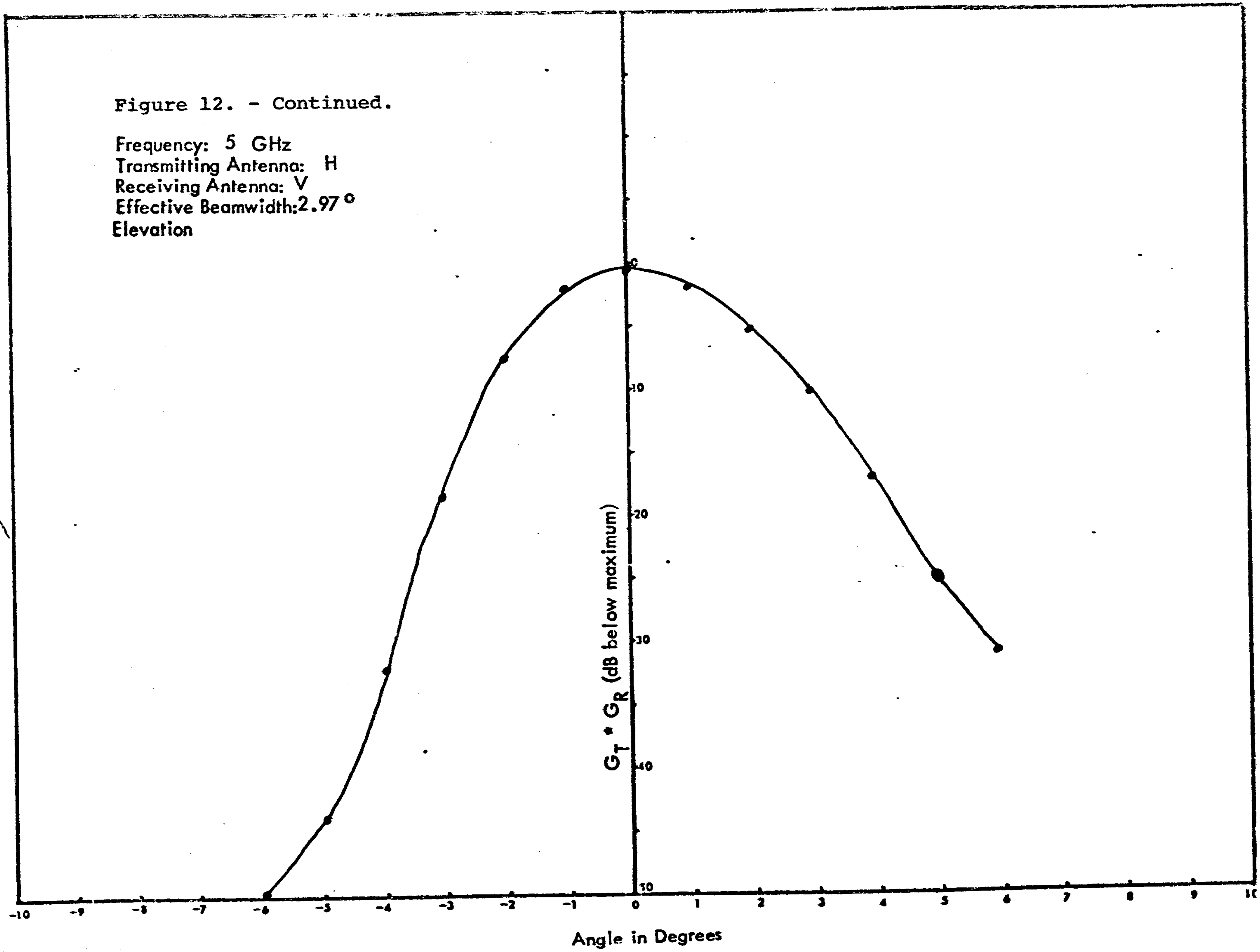


Figure 12. - Continued.

Frequency: 5 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.97°
Elevation



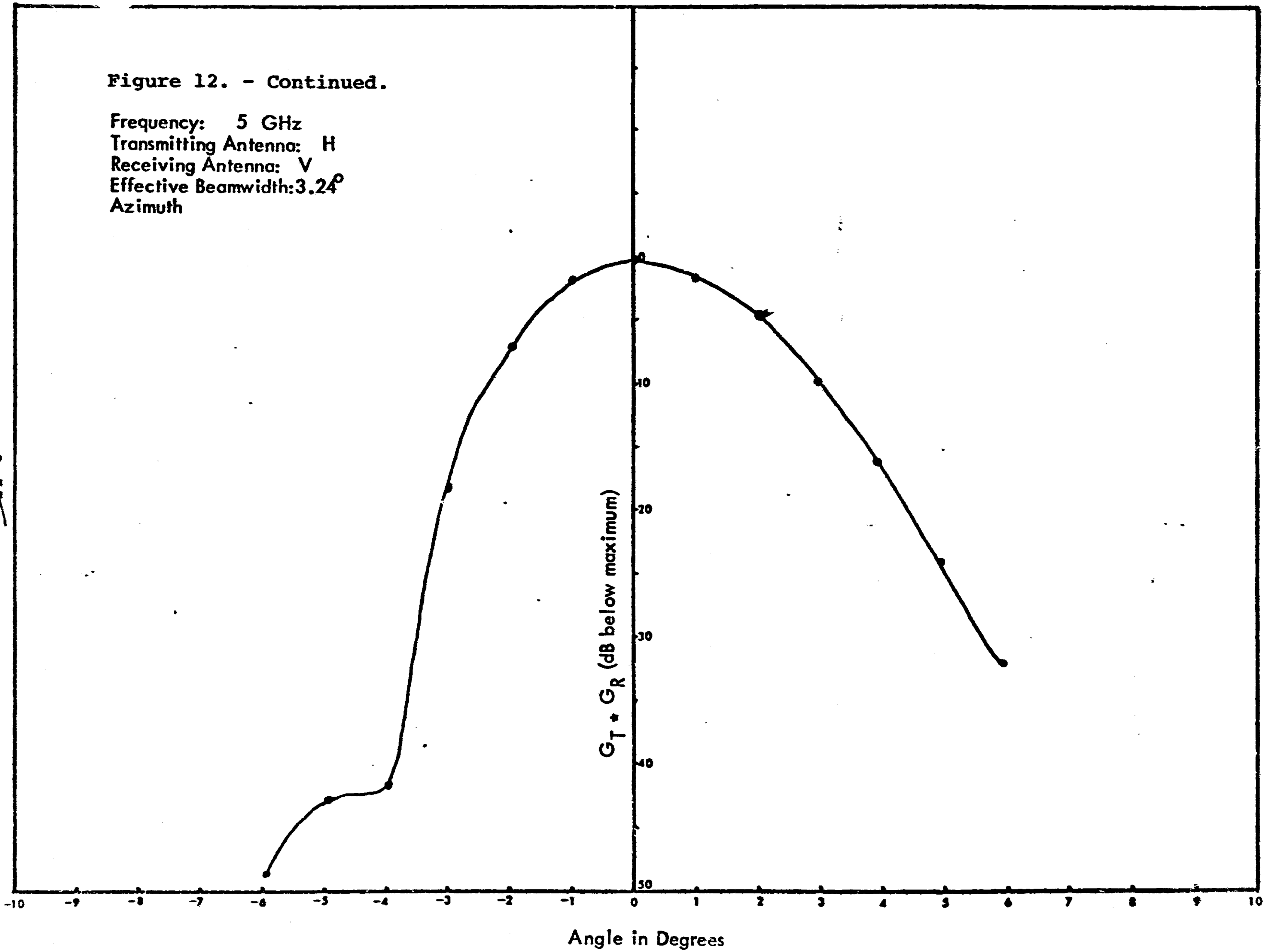


Figure 12. - Continued.
Frequency: 5 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 3.24°
Azimuth
$G_T * G_R$ (dB below maximum)
0
10
20
30
40
50
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Angle in Degrees

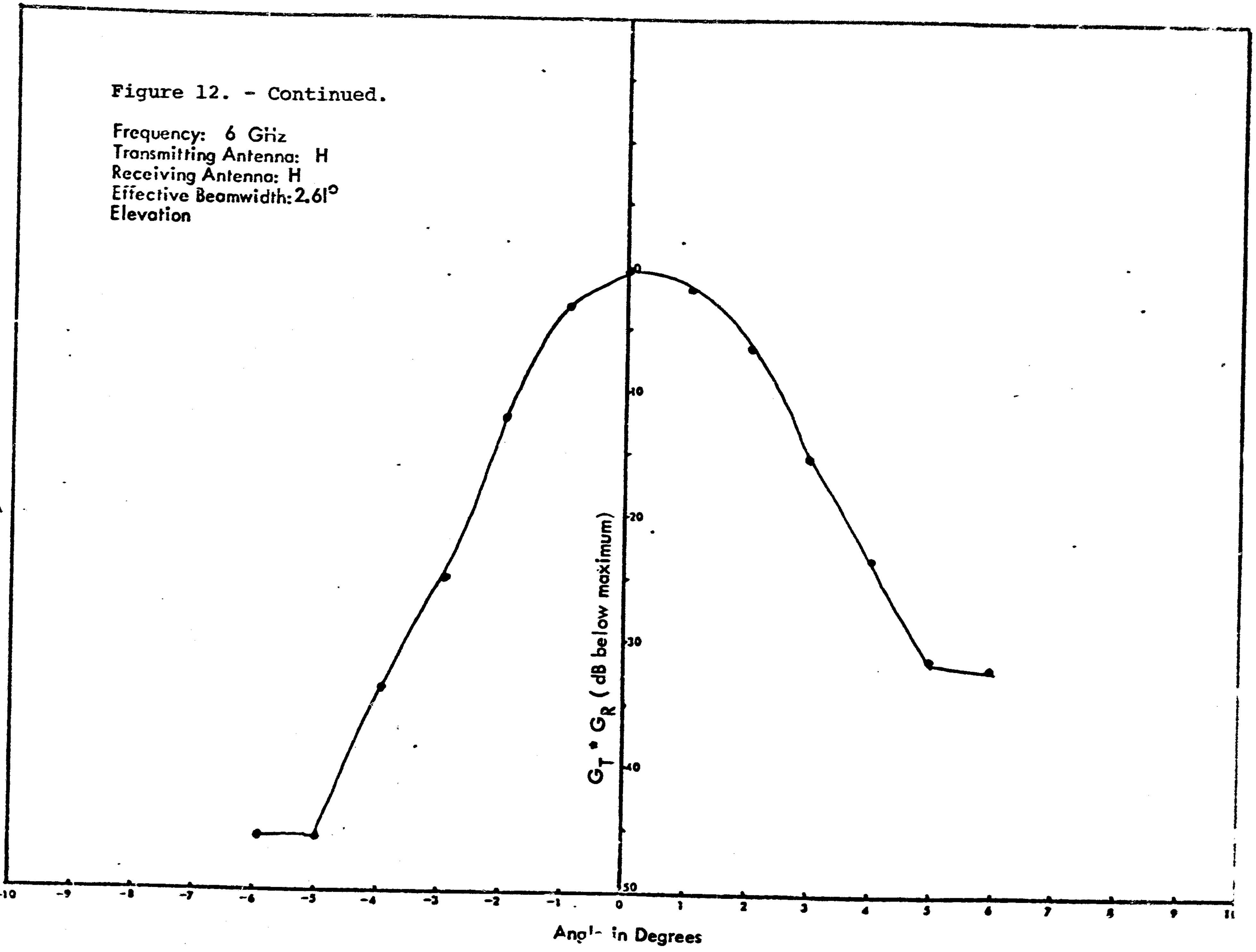


Figure 12. - Continued.

Frequency: 6 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.61°
Elevation

Figure 12. - Continued.

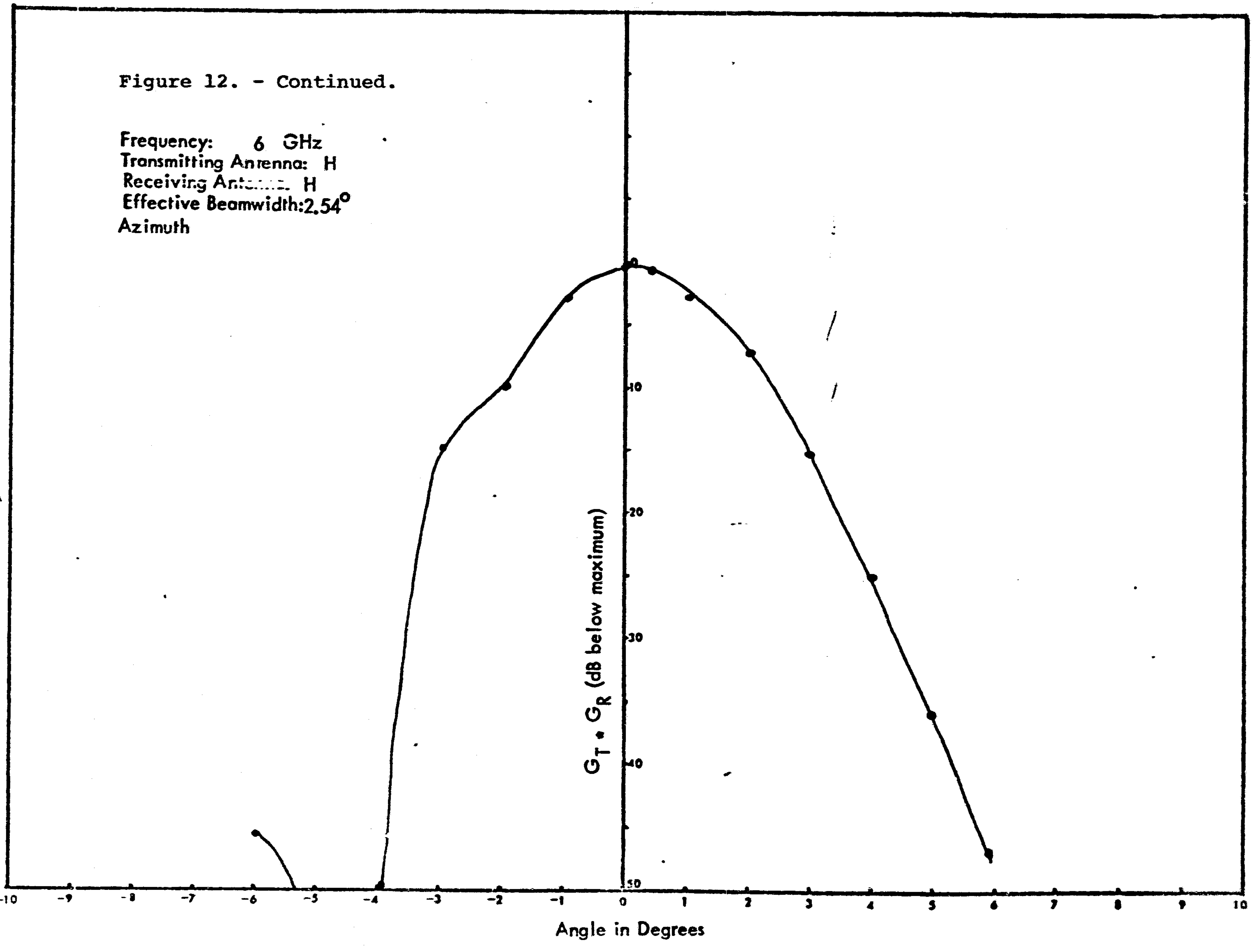


Figure 12. - Continued.

Frequency: 6 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.51°
Elevation

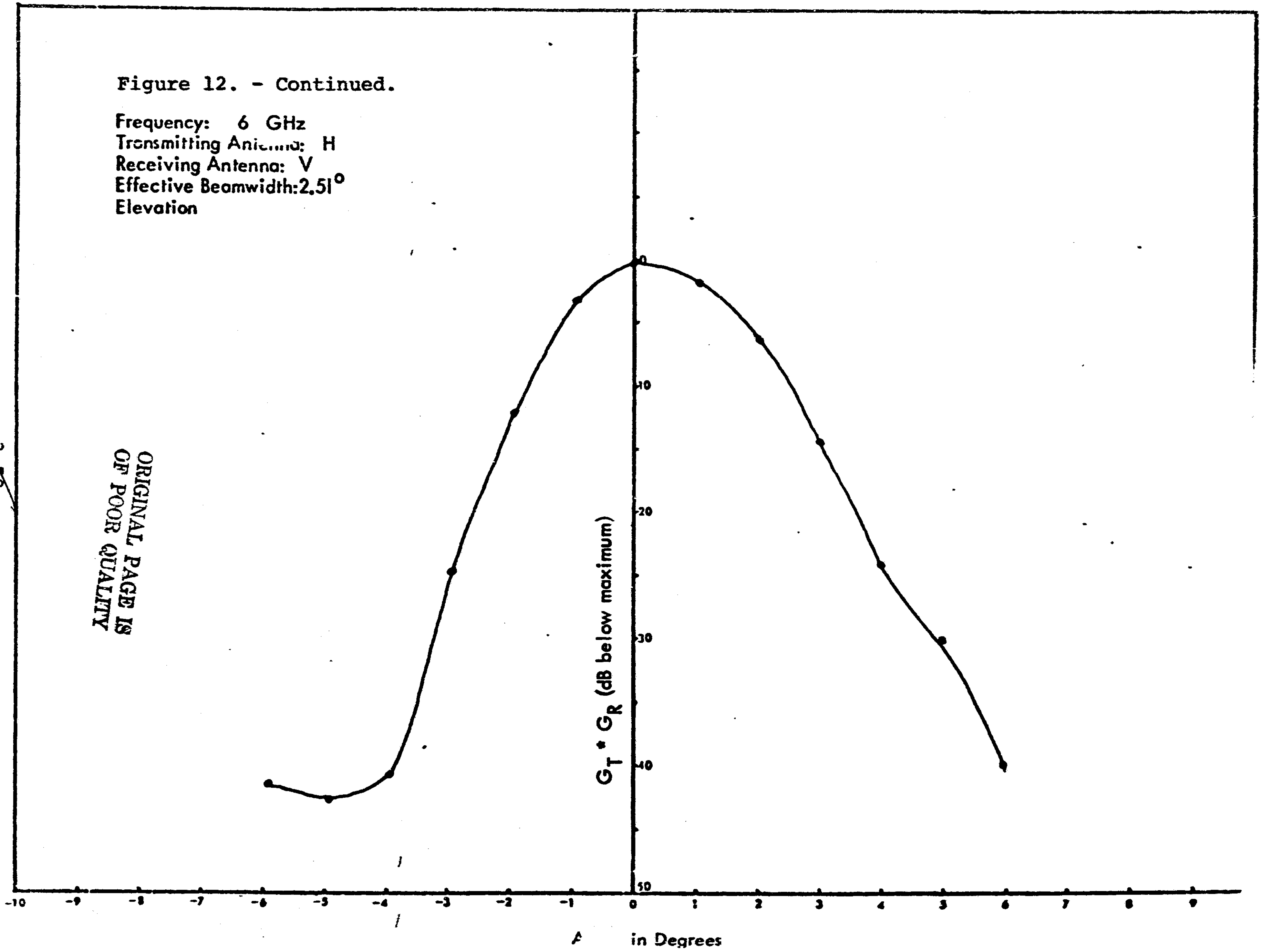
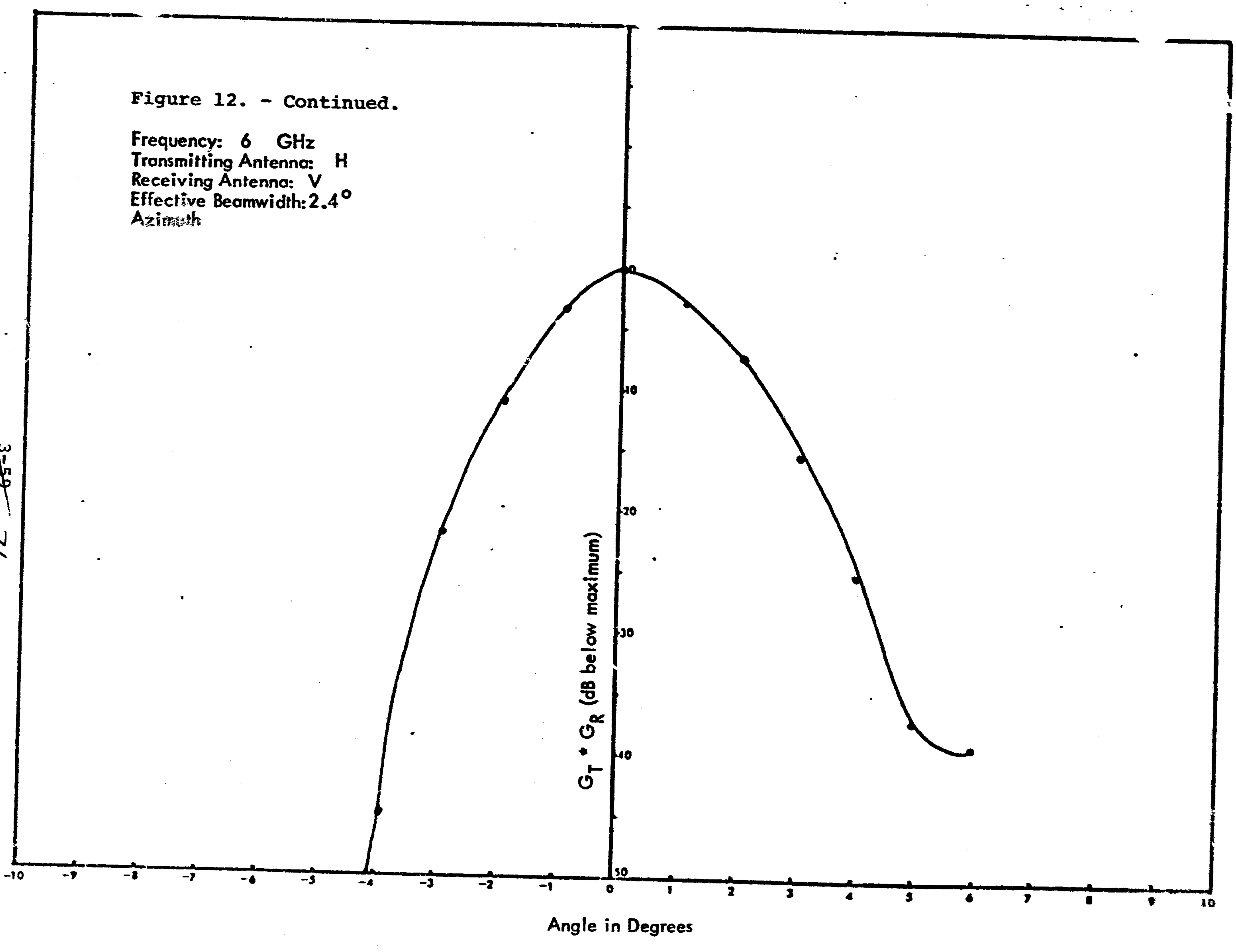


Figure 12. - Continued.

Frequency: 6 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.4°
Azimuth



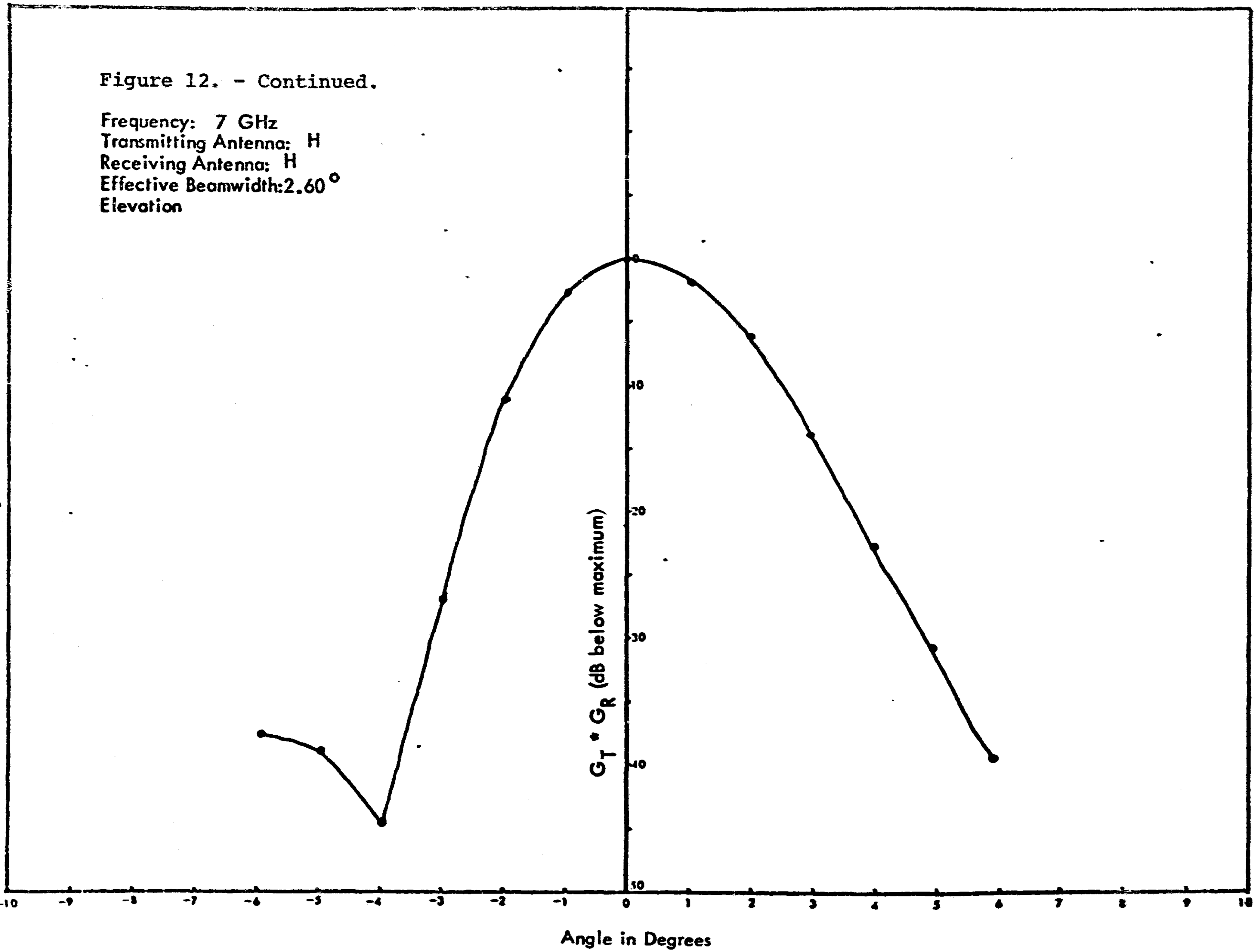
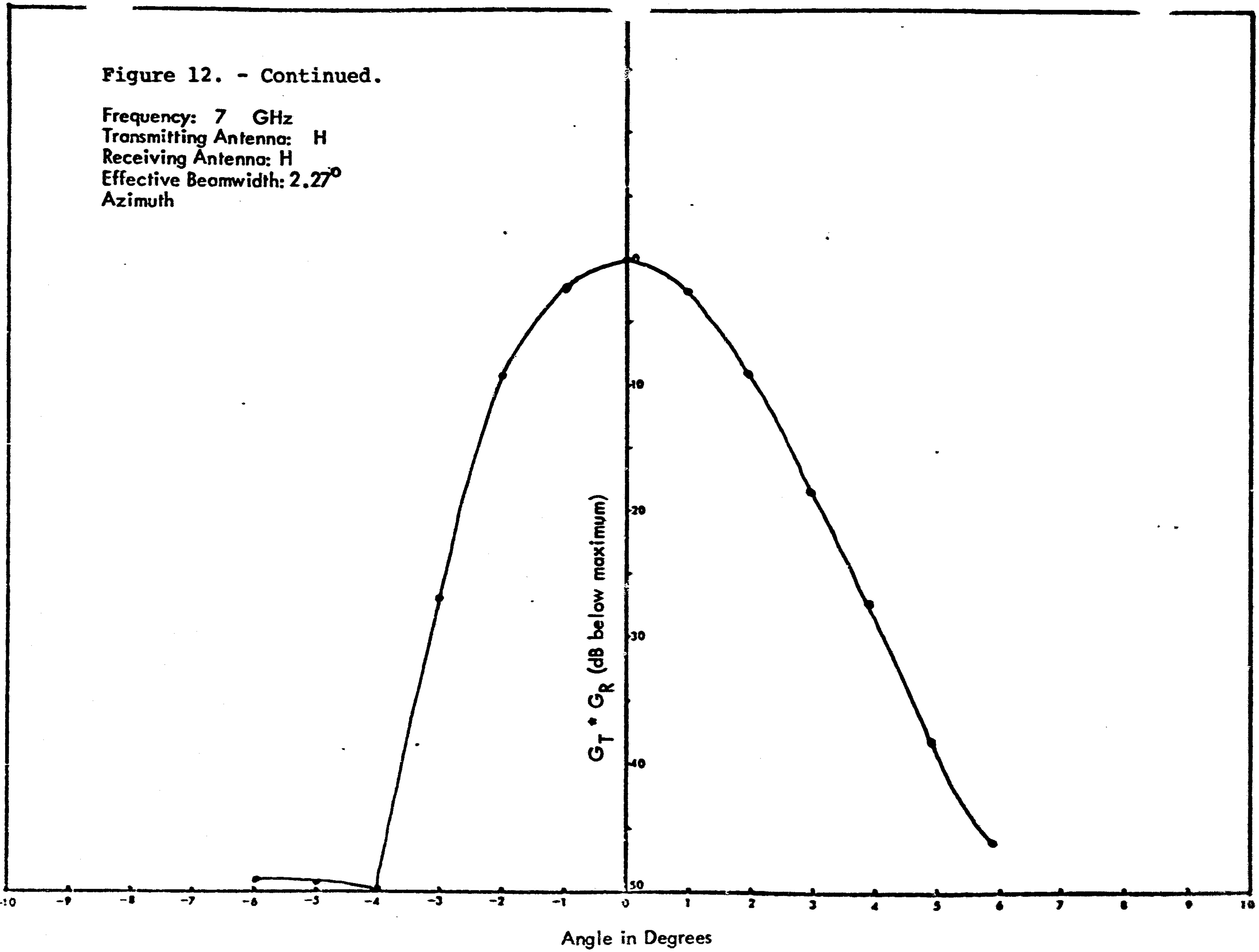


Figure 12. - Continued.

Frequency: 7 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.60°
Elevation

Figure 12. - Continued.

Frequency: 7 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.27°
Azimuth



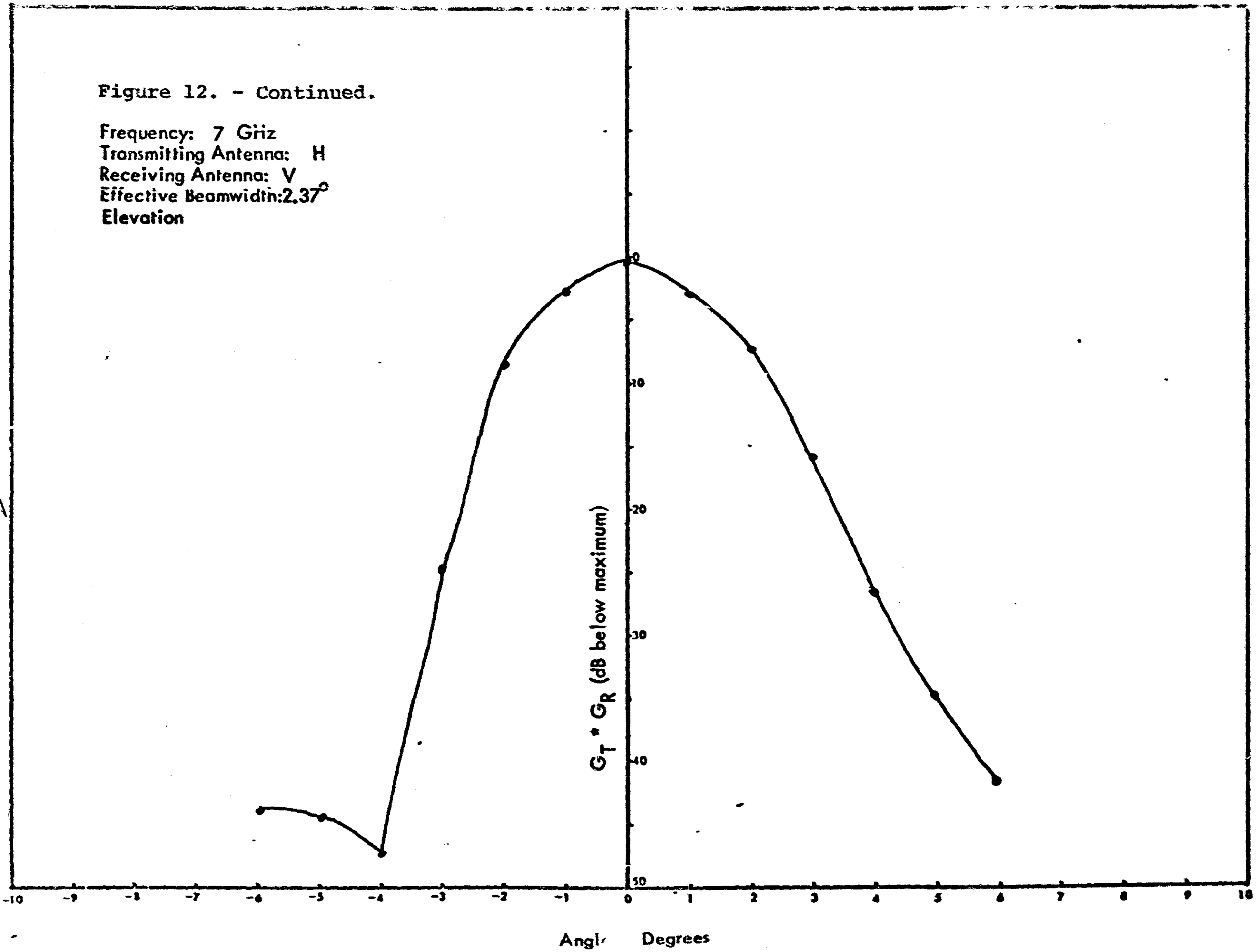


Figure 12. - Continued.

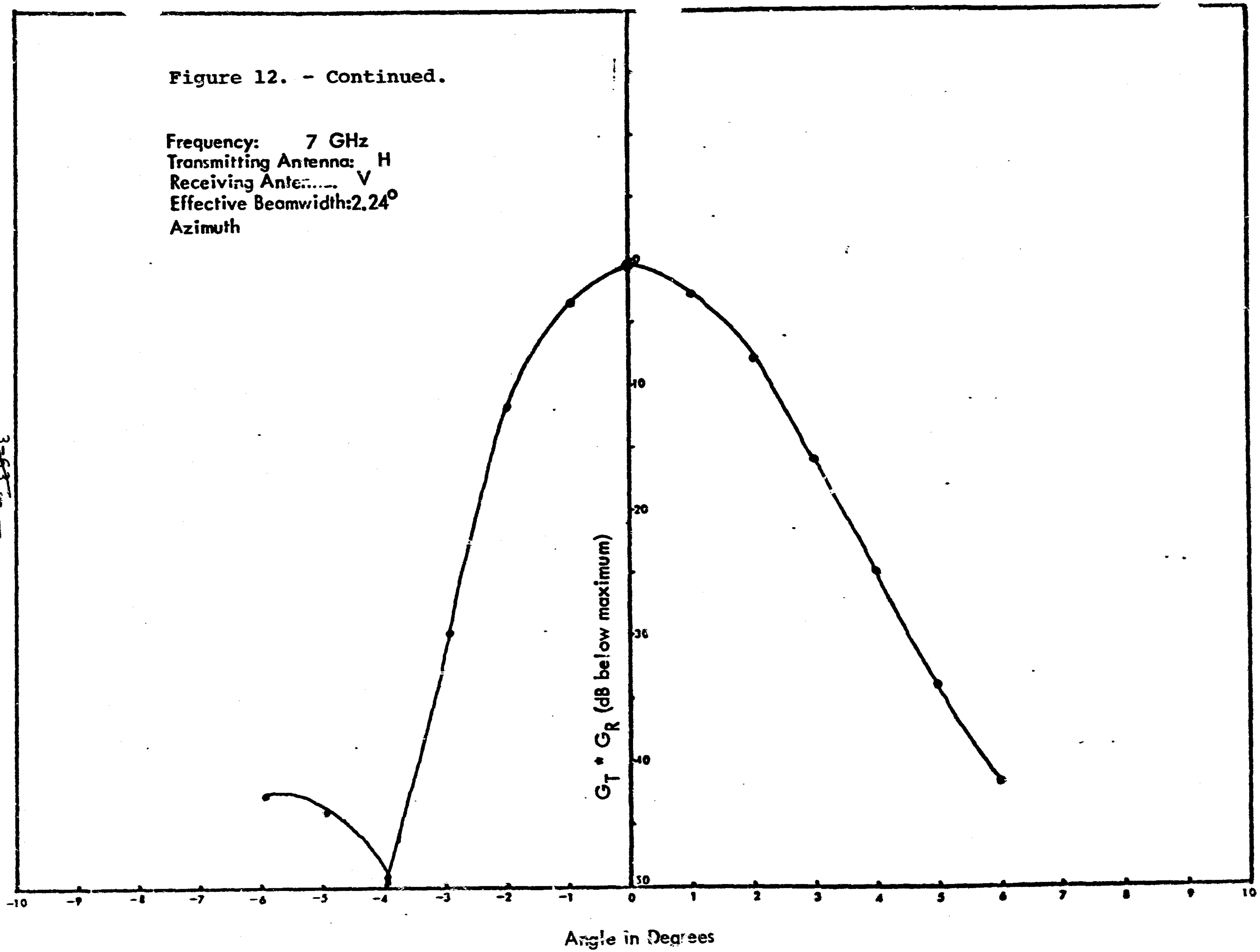


Figure 12. - Continued.

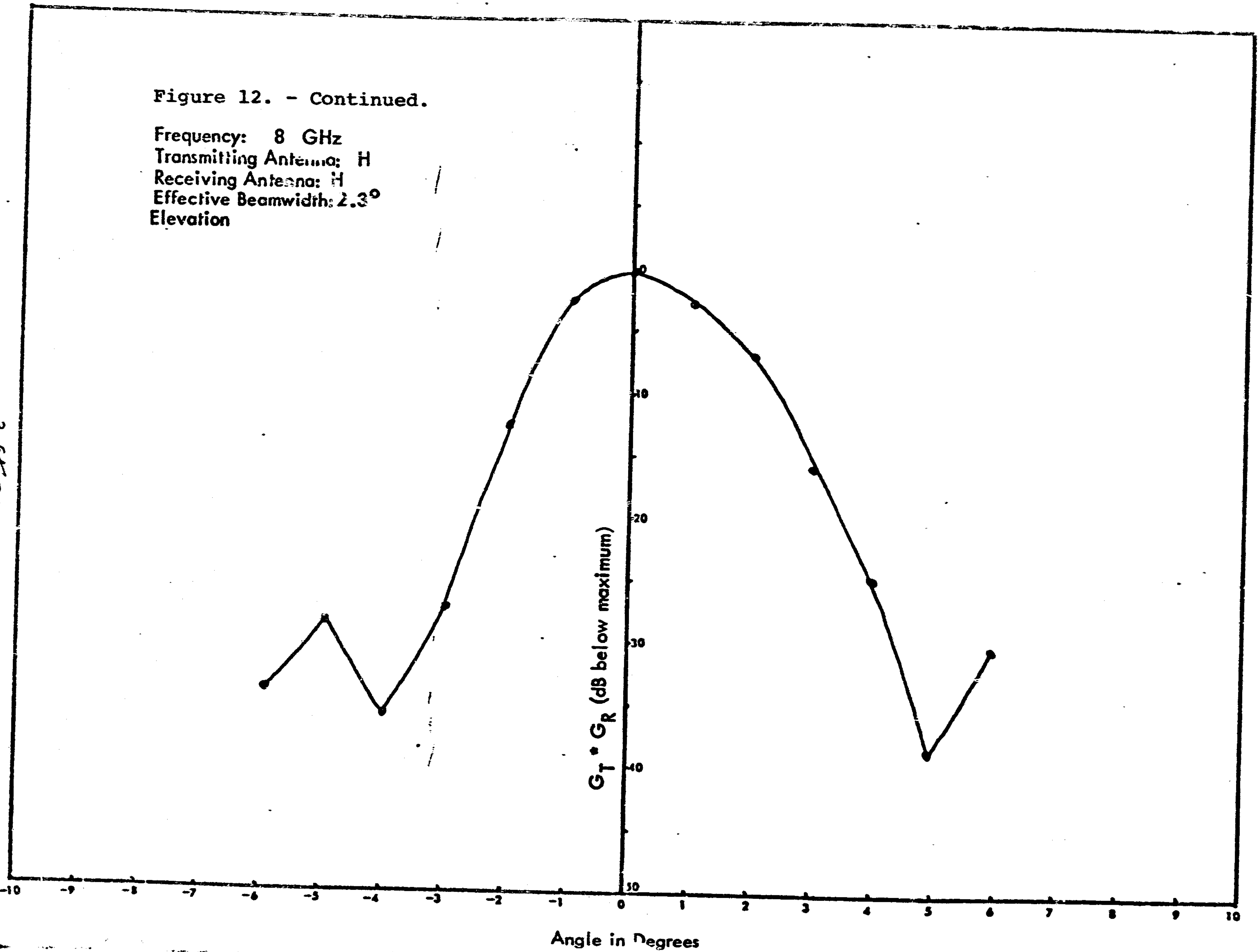


Figure 12. - Continued.

Frequency: 8 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.3°
Elevation

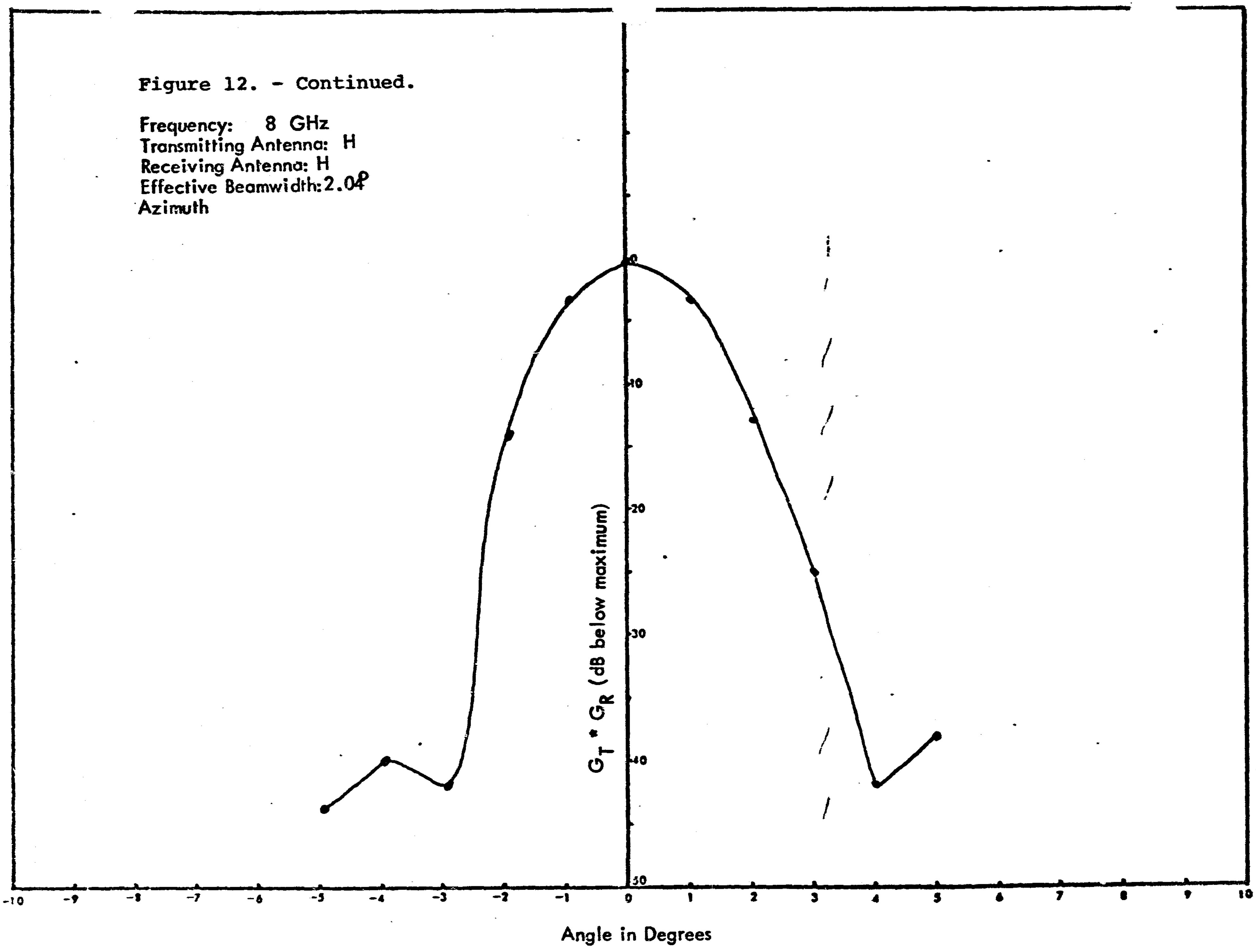
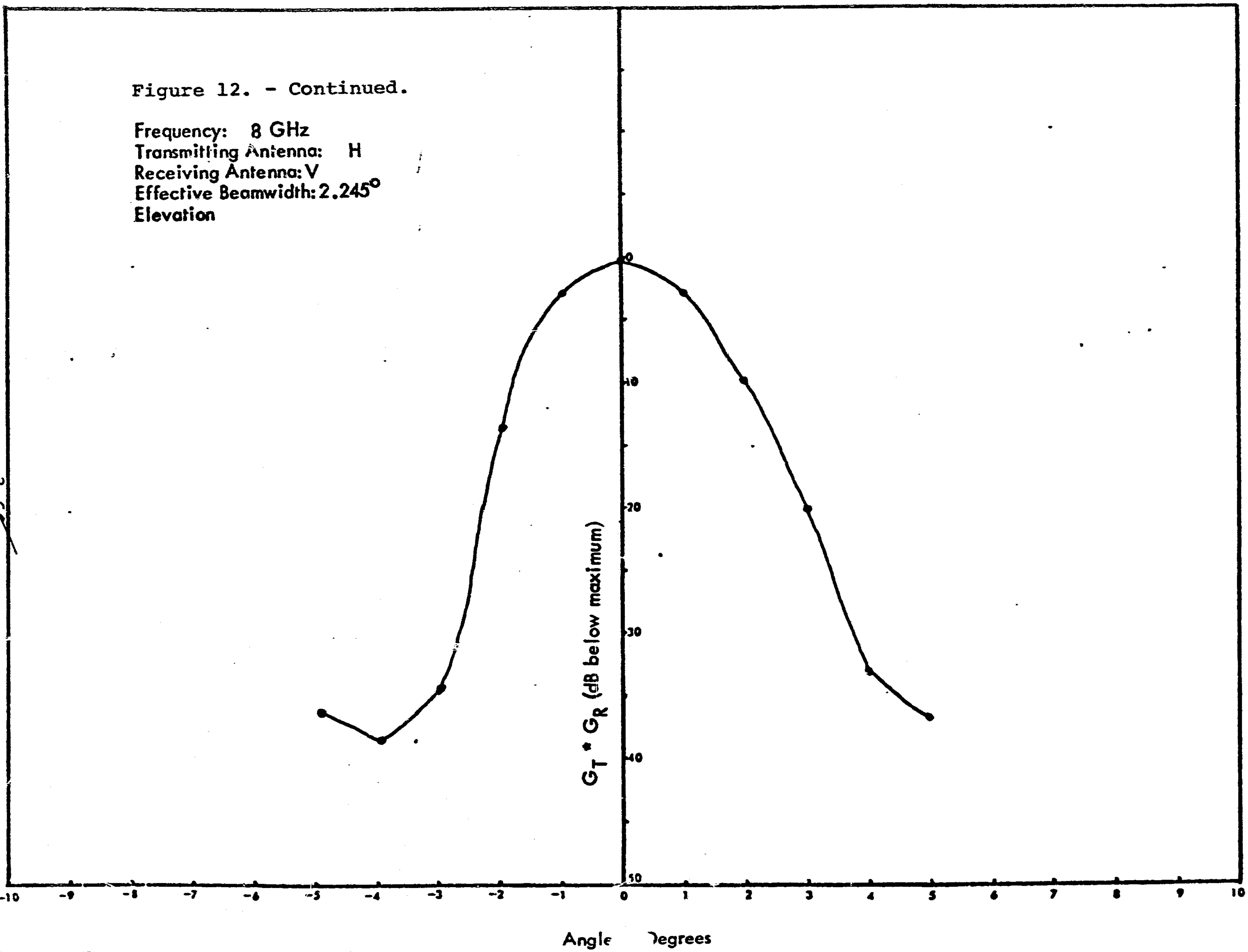


Figure 12. - Continued.

Figure 12. - Continued.

Frequency: 8 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.245°
Elevation



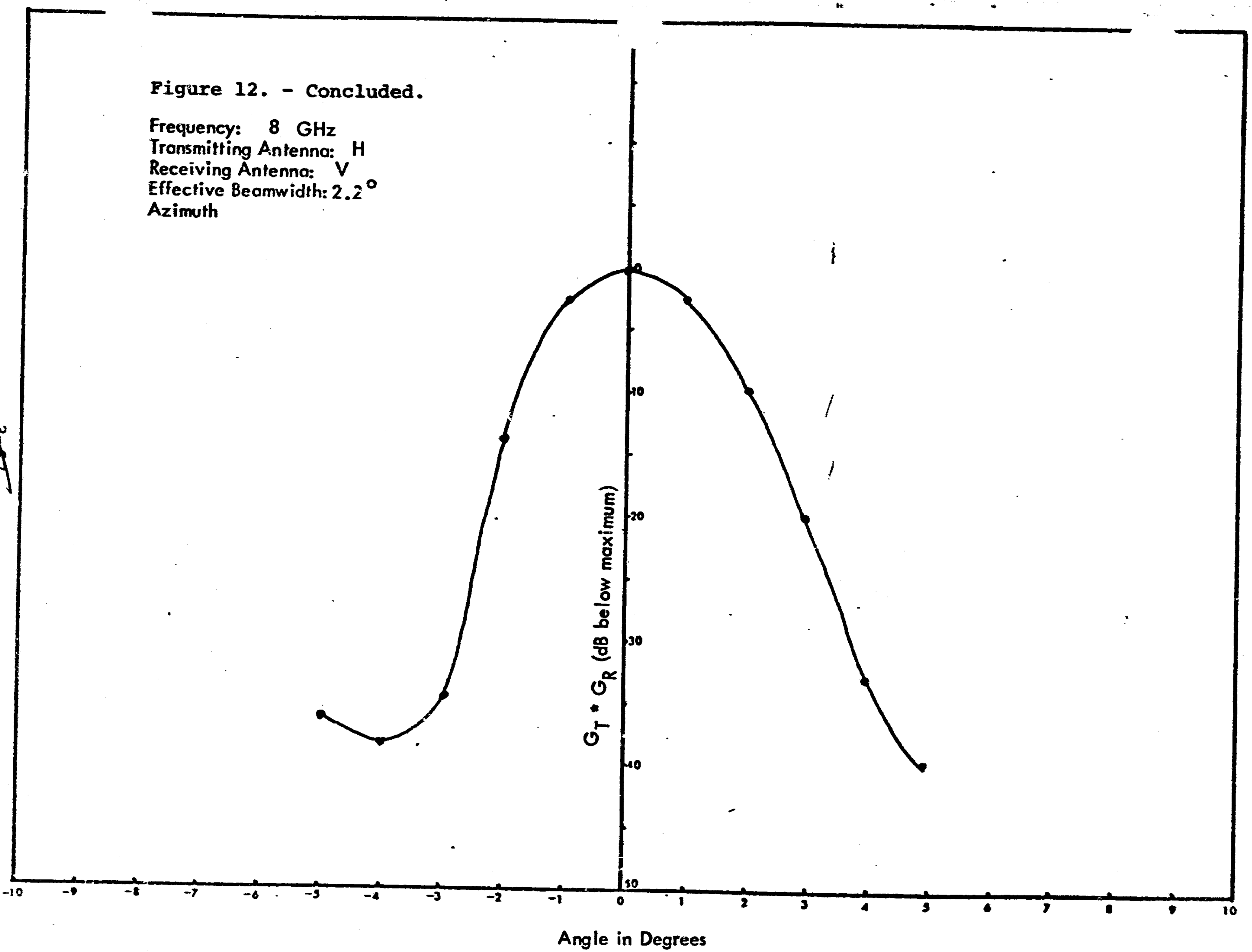


Figure 12. - Concluded.

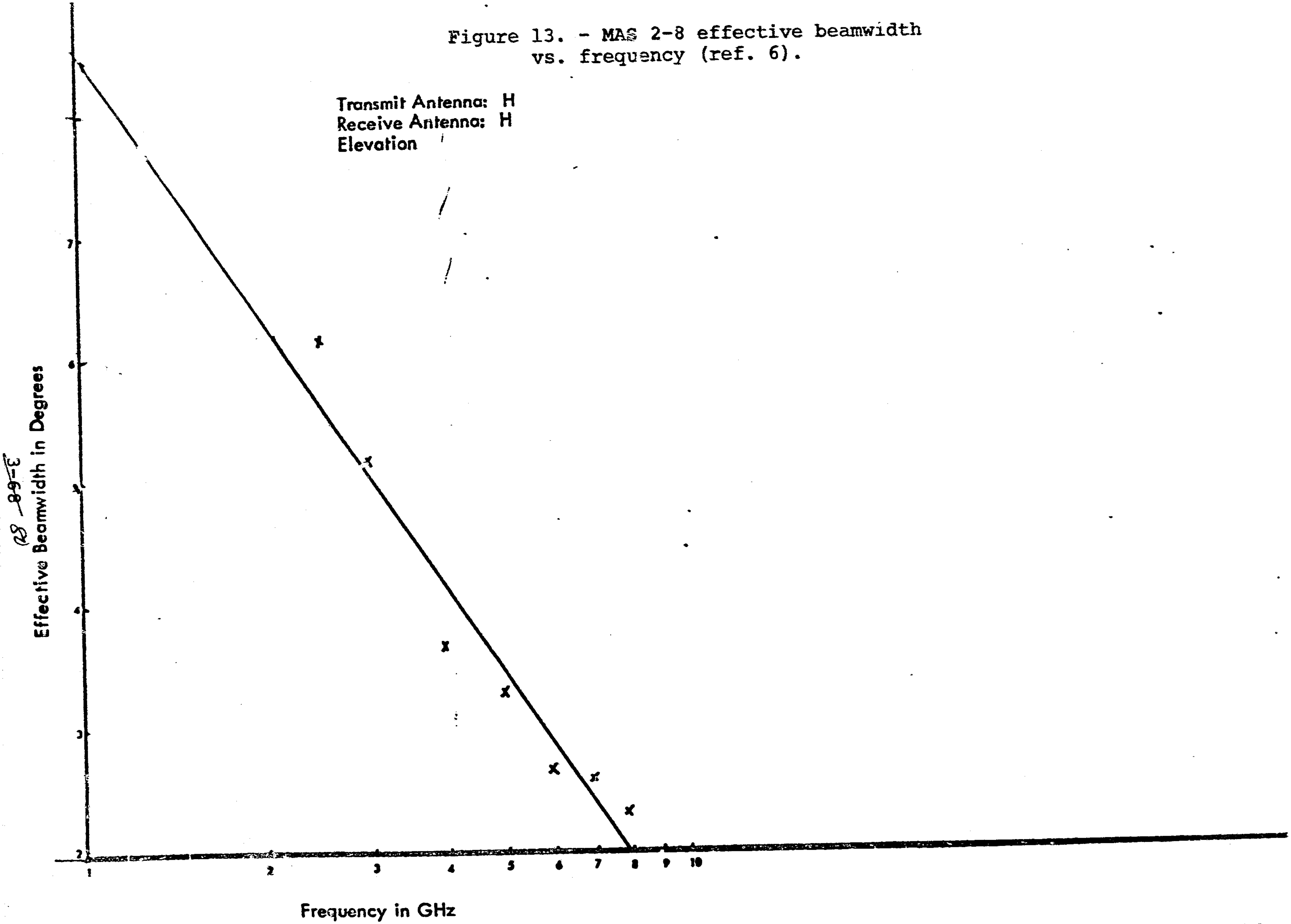


Figure 13. - MAS 2-8 effective beamwidth vs. frequency (ref. 6).

3-68 80

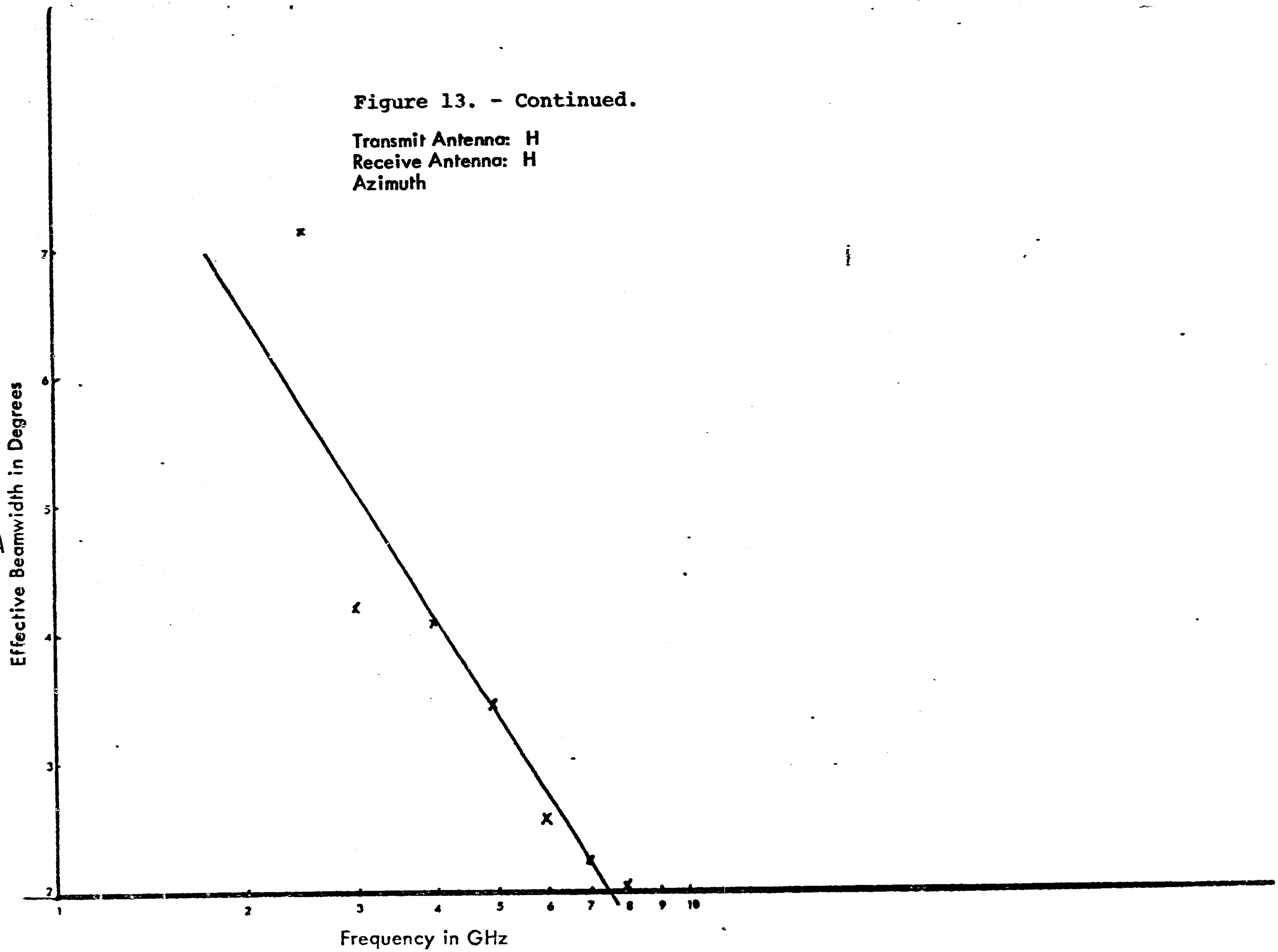
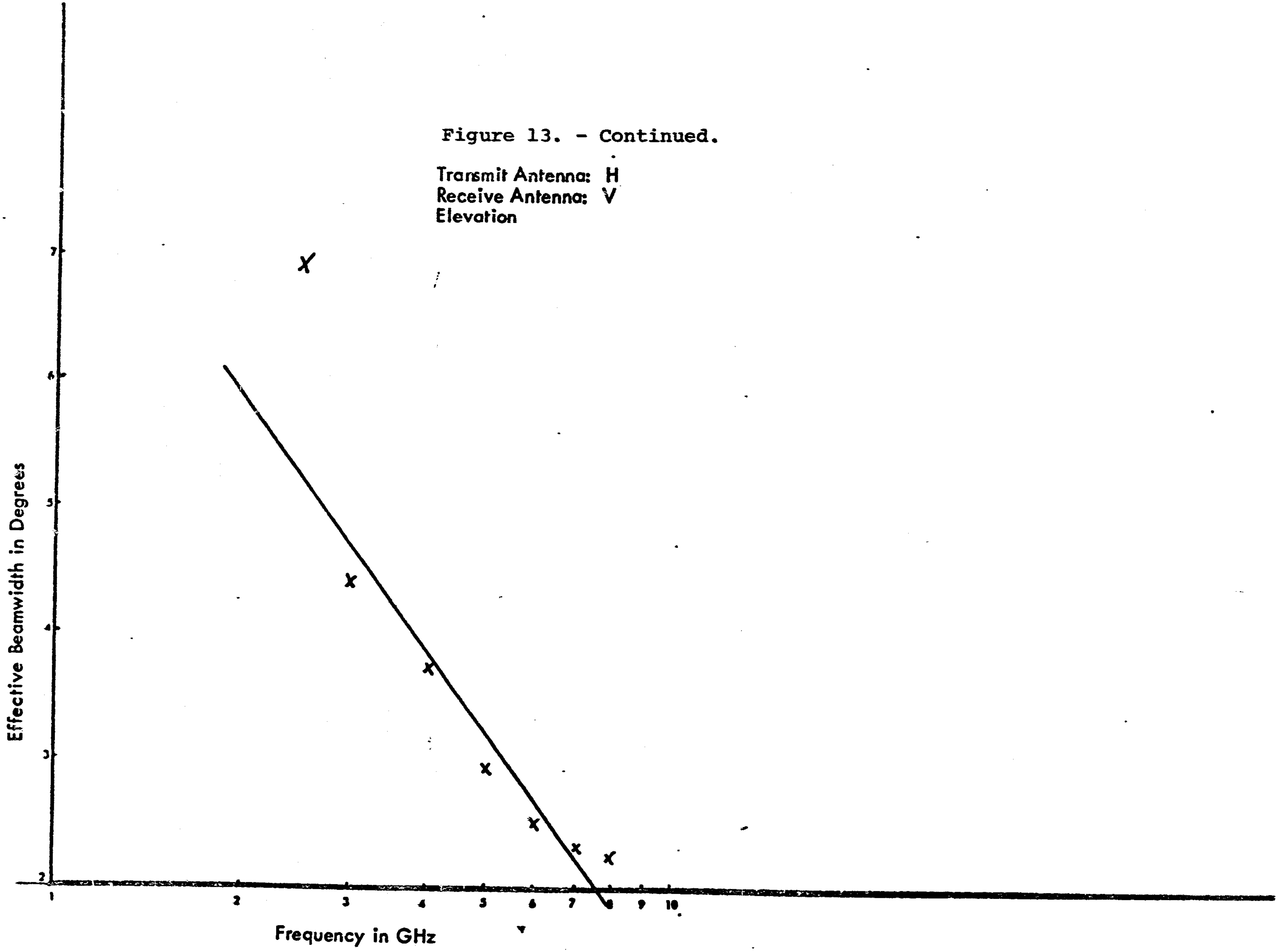


Figure 13. - Continued.

3-69-E
18

Figure 13. - Continued.



3-70 82

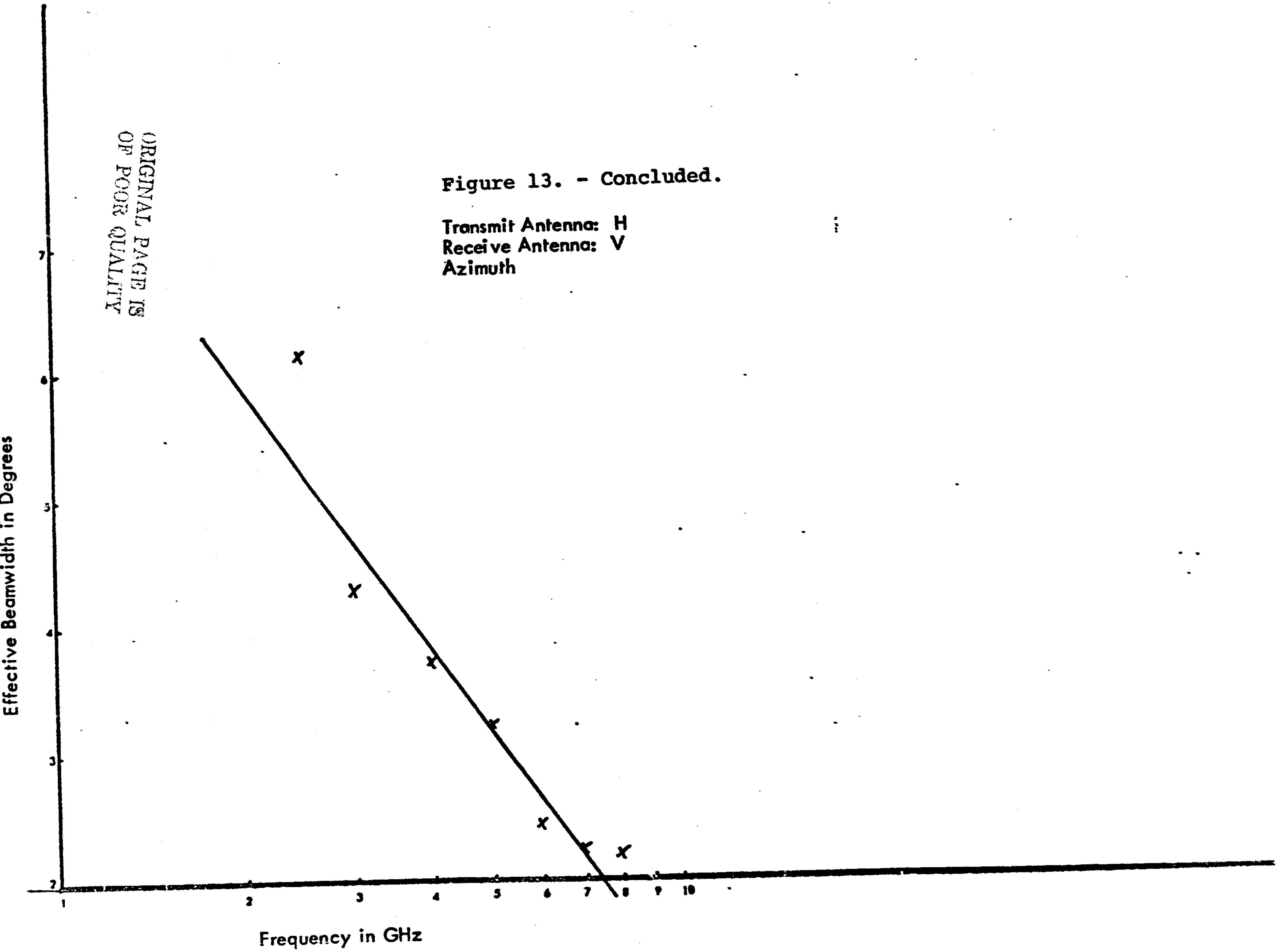


Figure 13. - Concluded.

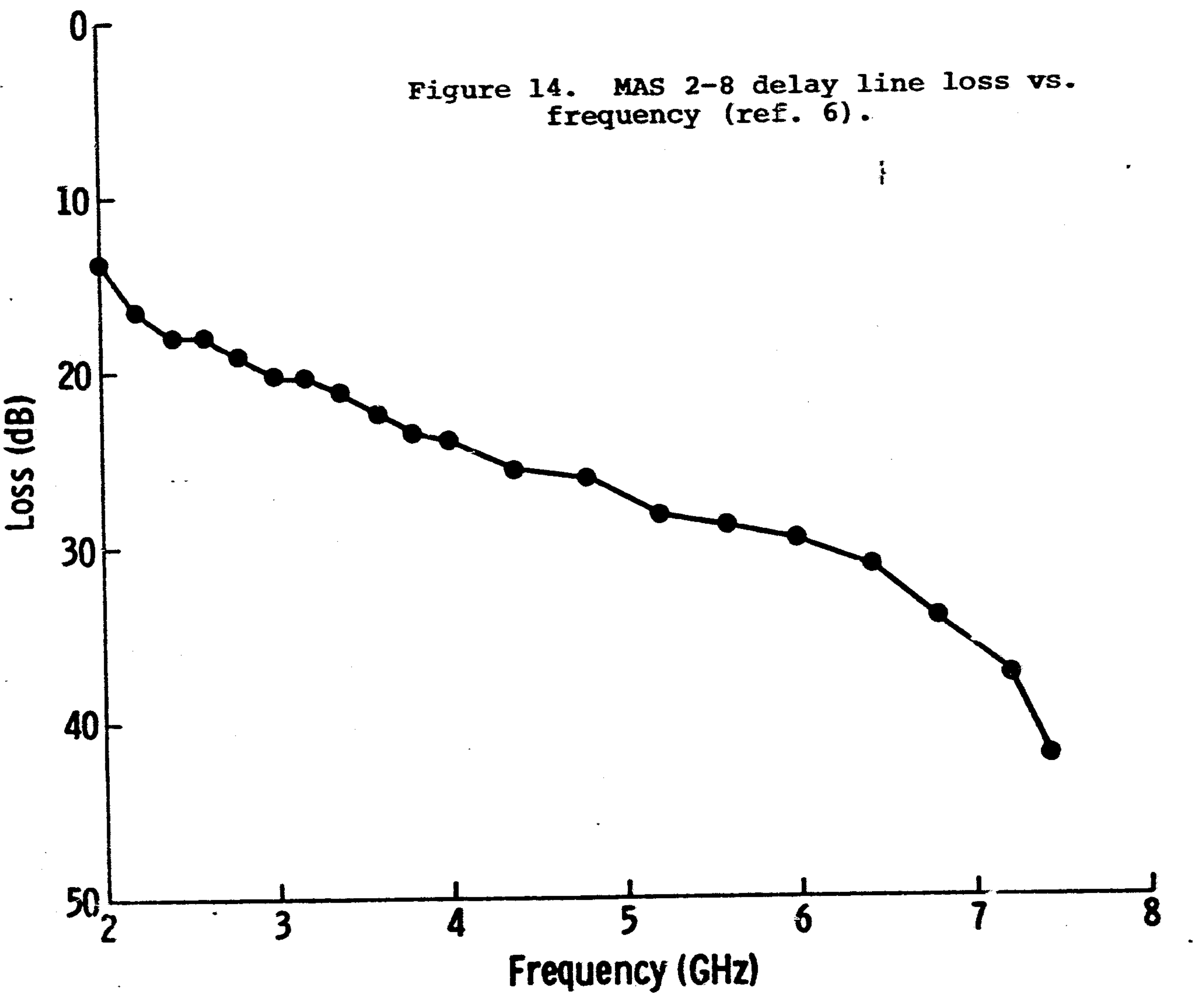


Figure 14. MAS 2-8 delay line loss vs. frequency (ref. 6).

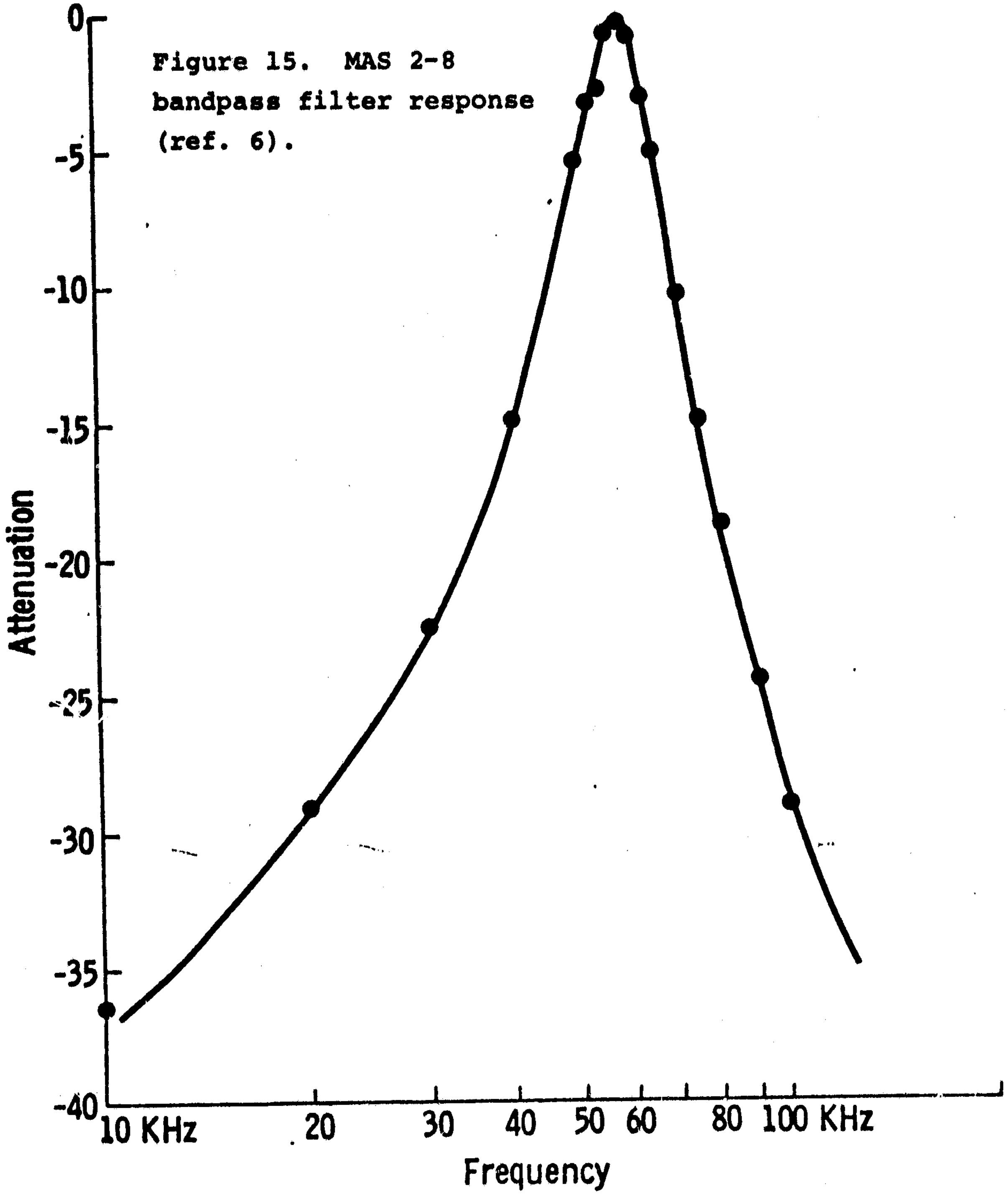


Figure 15. MAS 2-8
bandpass filter response
(ref. 6).
0
-5
-10
-15
-20
-25
-30
-35
-40
Attenuation
10 KHz
20
30
40
50
60
80
100 KHz
Frequency

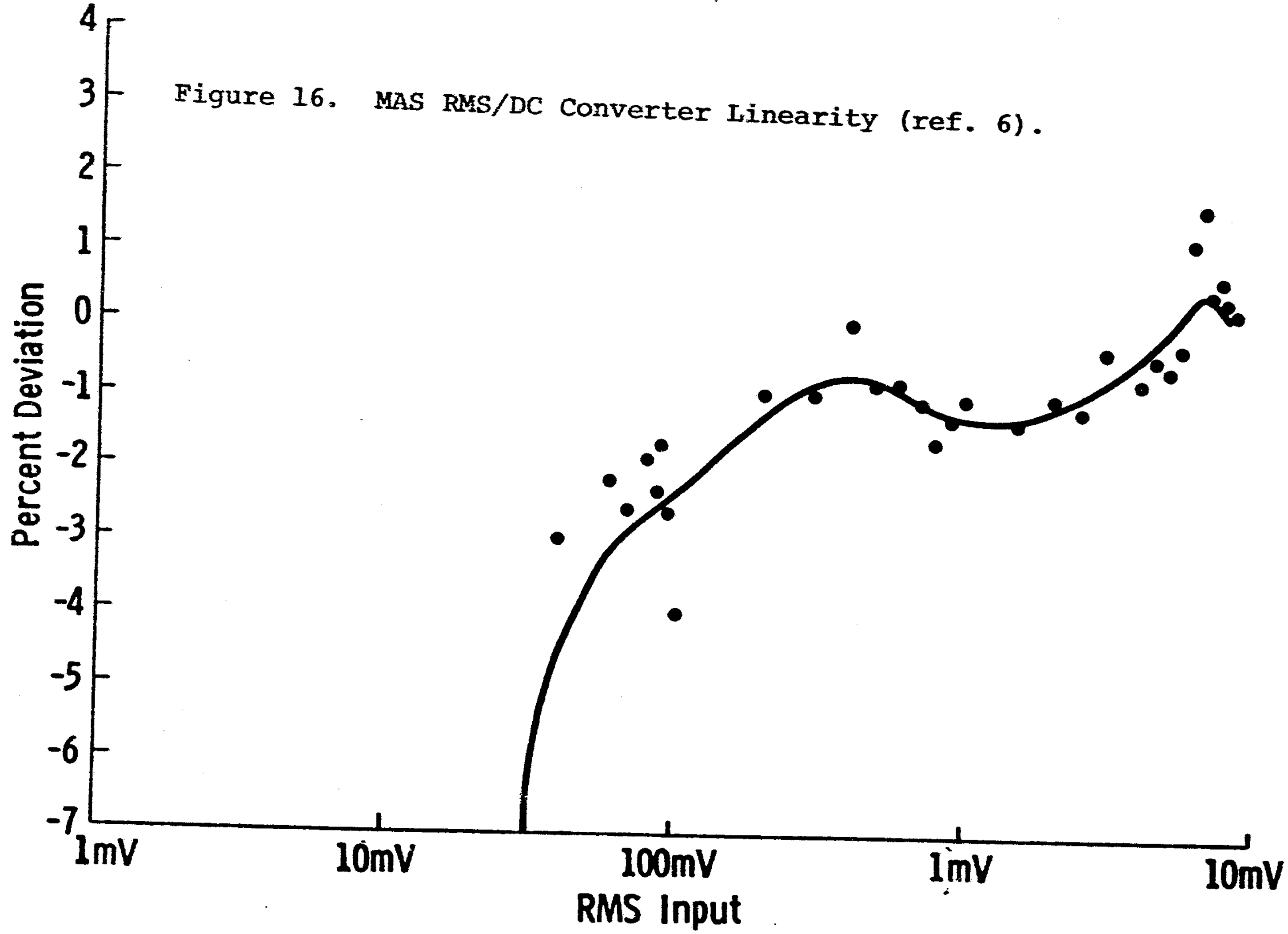


Figure 16. MAS RMS/DC Converter Linearity (ref. 6).

TABLE 6. MAS 2-8 SYSTEM SPECIFICATIONS (Ref. 10)

Type:	FM-CW
Modulating Waveform:	Triangular
Center Frequencies:	2.75, 3.25, 4.75, 5.25, 5.75, 6.25, 6.75, 7.25 GHz
FM Sweep: ΔF	450 MHz
Transmitter Power:	40 mW
IF Frequency: F_{IF}	50 KHz
IF Bandwidth: ΔF_{IF}	.6 KHz
Antennae:	
Height above ground:	20 m
Transmitting antenna diameter:	91.5 cm
Receiving antenna diameter:	91.5 cm
Feeds:	Log periodic
Incidence angle range:	0° (nadir) -80°
Polarization:	Horizontal transmit-Horizontal receive (HH) Vertical transmit-Vertical receive (VV)
Calibration:	
Internal	Delay line
External	Luneberg lens

TABLE 7. MAS 1-8 SYSTEM PARAMETERS (Ref. 12).

Platform Height:	20 meters
Antennae:	4-foot parabolic dishes
Feeds:	Dual polarized 1-8 GHz log periodic
Incident Angle Capability:	0 - 80°
Radar:	
Center frequency	1.1, 1.5, 2.25, 3.25, 4.25, 5.25, 6.25, and 7.25 GHz
Frequency sweep	400 MHz
IF frequency and band-width:	49.5 KHz, 11.5 KHz
Transmit power:	20 dBm
Dynamic range:	100 dB
Polarization	HH, HV, VV

TABLE 8. MAS 1-8 AND NOMINAL SYSTEM SPECIFICATIONS (Ref. 13).

Type:	FM-CW
Modulating Waveform:	Triangular
Frequency Range:	1-8 GHz
FM Sweep: Δf	400 MHz
Transmitter Power:	10 dBm
Intermediate Frequency	50 KHz
IF Bandwidth:	10 KHz
Antennae:	
Height of ground	20 m
Reflector diameter	122 cm
Feeds	Crossed Log-periodic
Incidence Angle Range	0^{o} (nadir)-80^{o}
Calibration:	
Internal	Signal Injection (delay line)
External	Luneberg lens reflector

TABLE 9. MODIFIED MAS 1-8 SYSTEM SPECIFICATIONS (Ref. 14).

Type:	FM-CW
Modulating Waveform:	Triangular
Center Frequencies:	1.2, 1.6, 2.25, 3.25, 4.25, 5.25, 6.25, 7.25 GHz
FM Sweep: ΔF	400 MHz
Transmit Power:	100 mW
IF: F_{IF}	49.5 KHz
IF Bandwidth: ΔF_{IF}	11.5 KHz
Antennae:	
Height above ground:	19 m
Transmit antenna diameter:	1.22 m
Receive antenna diameter:	1.22 m
Feeds:	Dual polarized switchable 1-12 GHz log periodics
Effective system beam-width:	12° at 1.2 GHz to 2° at 7.25 GHz
Incidence angle range:	0° (nadir)-80°
Polarization:	Horizontal transmit-horizonal receive (HH); horizontal transmit-vertical receive (HV); vertical transmit-vertical receive (VV)
Calibration:	
Internal:	Coaxial delay line
External:	Luneberg lens

TABLE 10. LATEST MAS 2-8 SYSTEM SPECIFICATIONS (Ref. 15).

Type:	FM-CW
Modulating Waveform:	Triangular
Center Frequencies:	2.75, 3.25, 4.75, 5.25, 6.25, 6.75, 7.25 GHz
FM Sweep: ΔF	450 MHz
Transmitter Power:	40 mW
IF Frequency: ΔF_{IF}	50 KHz
IF Bandwidth: F_{IF}	6 KHz
Antennae:	
Height above ground:	20 m
Transmitting antenna diameter:	91.5 cm
Receiving antenna diameter:	91.5 cm
Feeds:	log periodic
Effective two-way beamwidth:	5.4° at 2.75 GHz/2.2° at 7.25 GHz
Incidence Angle Range:	0° (nadir)-80°
Polarization:	Horizontal transmit-Horizonal receive (HH), Vertical transmit-Vertical receive (VV)
Calibration:	
Internal	Delay line
External	Luneberg lens

3.3 8-18 GHz MICROWAVE ACTIVE SPECTROMETER

In 1972/1973, personnel at the University of Kansas Remote Sensing Laboratory designed, built, and tested an 8-18 GHz scatterometer which is referred to as the 8-18 GHz Microwave Active Spectrometer (8-18 GHz MAS, ref. 3). A basic block diagram of the 8-18 GHz MAS system is given in Figure 17 (ref. 3). A description of the initial 8-18 GHz MAS system corresponding to Figure 17 is given in Table 11 and below.

The IF filter response is given in Figure 18 (ref. 3). The unleveled sweep oscillator power spectrum is shown in Figure 19 (ref. 3) and the leveled power spectrum is shown in Figure 20 (ref. 3). Figure 21 shows the receiver tangential sensitivity and Figure 22 shows both the sweep oscillators AM noise spectrum output for various modulating frequencies (ref. 3). Figure 23 shows tabulated antenna characteristics for both antennae (ref. 3) and Figures 24a, b, c, and d show antenna 3 dB beamwidth, antenna feed VSWR, antenna feed gain, and antenna feed cross polarization data (ref. 3). Ref. 3 reports the measured dynamic range of the receiver as greater than 82 dB.

As reported in both refs. 3 and 16, the basic 8-18 GHz MAS system specifications are listed in Table 12.

In ref. 17, it was reported that minor modifications were made to the 8-18 GHz MAS system. These changes included: (a) minor antenna changes, (b) IF filtering improvement, and (c) use of isolators for reflection reduction. The effects of these changes were not sufficiently described in the above reference, however the new IF and IF bandwidth were defined and are given in Table 13.

Finally, Table 14 as reported in ref. 13, gives the 8-18 MAS nominal system specifications as of June 1976. (Note antenna reflector diameter and feeds have been altered.)

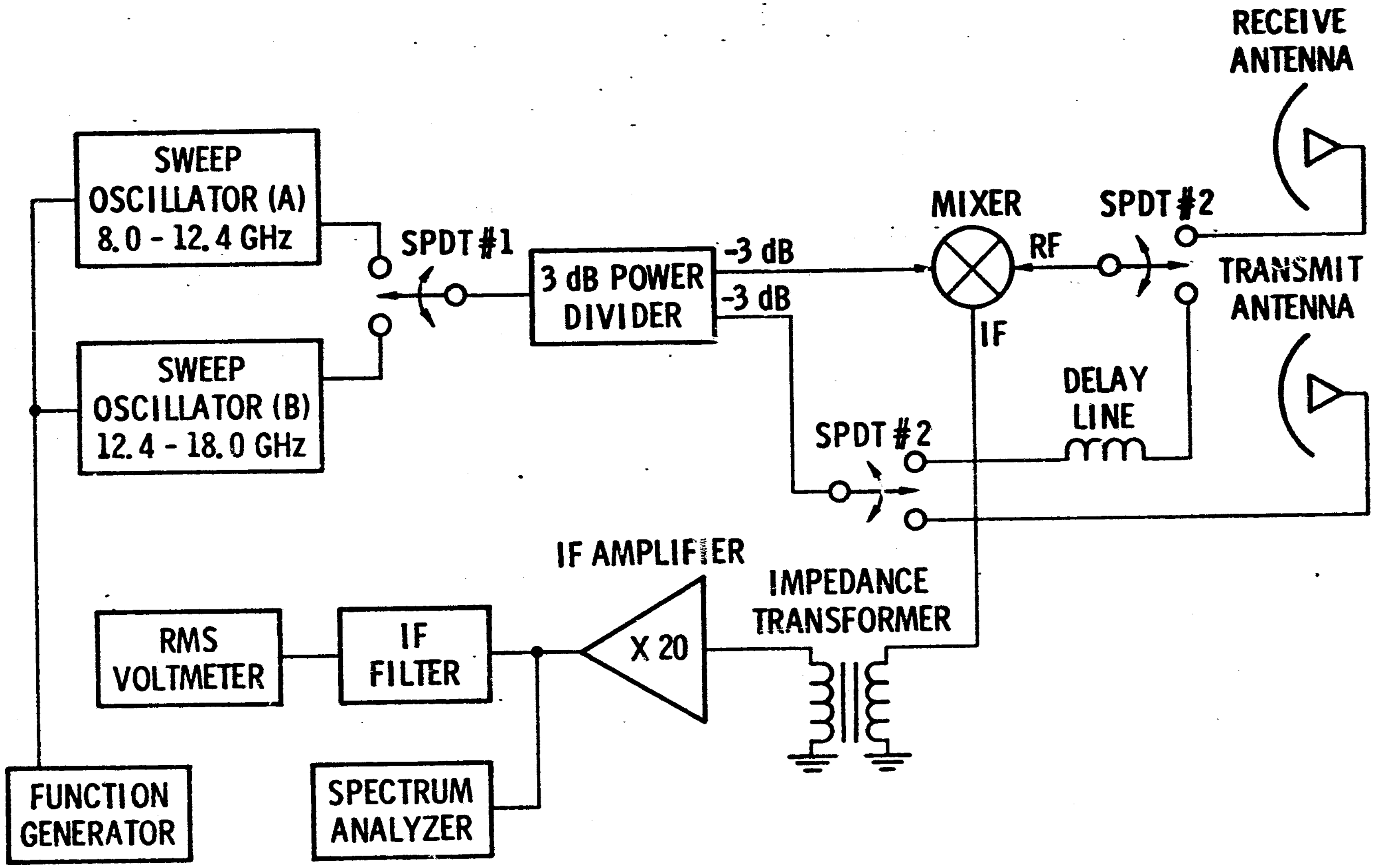


Figure 17. Basic block diagram of the 8-18 GHz radar spectrometer (ref. 3).

TABLE 11. 8-18 MAS BLOCK DIAGRAM DESCRIPTION (Ref. 3). (Unavailable information is denoted by as asterisk.)

---

1. Receive Antenna: 61 cm dish, cavity backed log periodic feed. Model not given.

2. Transmit Antenna: 61 cm dish, cavity backed log periodic feed. Model not given.

3.* Single Pole Double Throw Switch: #2.

4. Mixer: Manufactured by RHG Electronics Laboratory, Inc., +76+10 dBm L. Power required, NF = 9.5 dB for 8-18 GHz. L.O. - RF isolation > 20 dB for 8-18 GHz. No model number given.

5.* 3 dB Power Divider:

6.* Single Pole Double Throw Switch: #1.

7. Sweep Oscillator: (8-17.4 GHz), HP 8690 main frame.

8. Sweep Oscillator: (12.4-18 GHz), HP 8690 main frame.

9.* Single Pole Double Throw Switch: #3.

10. Impedance Transformer: 10:1 turns ratio, type not known.

11. IF Amplifier: Single ended, low noise, 10 mΩ input impedance, flat frequency response from 1 Hz to 1 mHz, variable gain settings from 0 to 30 dB, 26 dB gain setting is optimum for system performance, with the impedance transformer the noise figure (NF) is 8 dB.

12. IF Filter: IF = 60 KHz, IF bandwidth = 3.58 KHz, see Figure 12 for IF filter curves. Type unknown.

13.* Spectrum Analyzer:

14.* RMS Voltmeter:

15.* Function Generator:

16. Delay Line: 72 feet of RG 142 B.

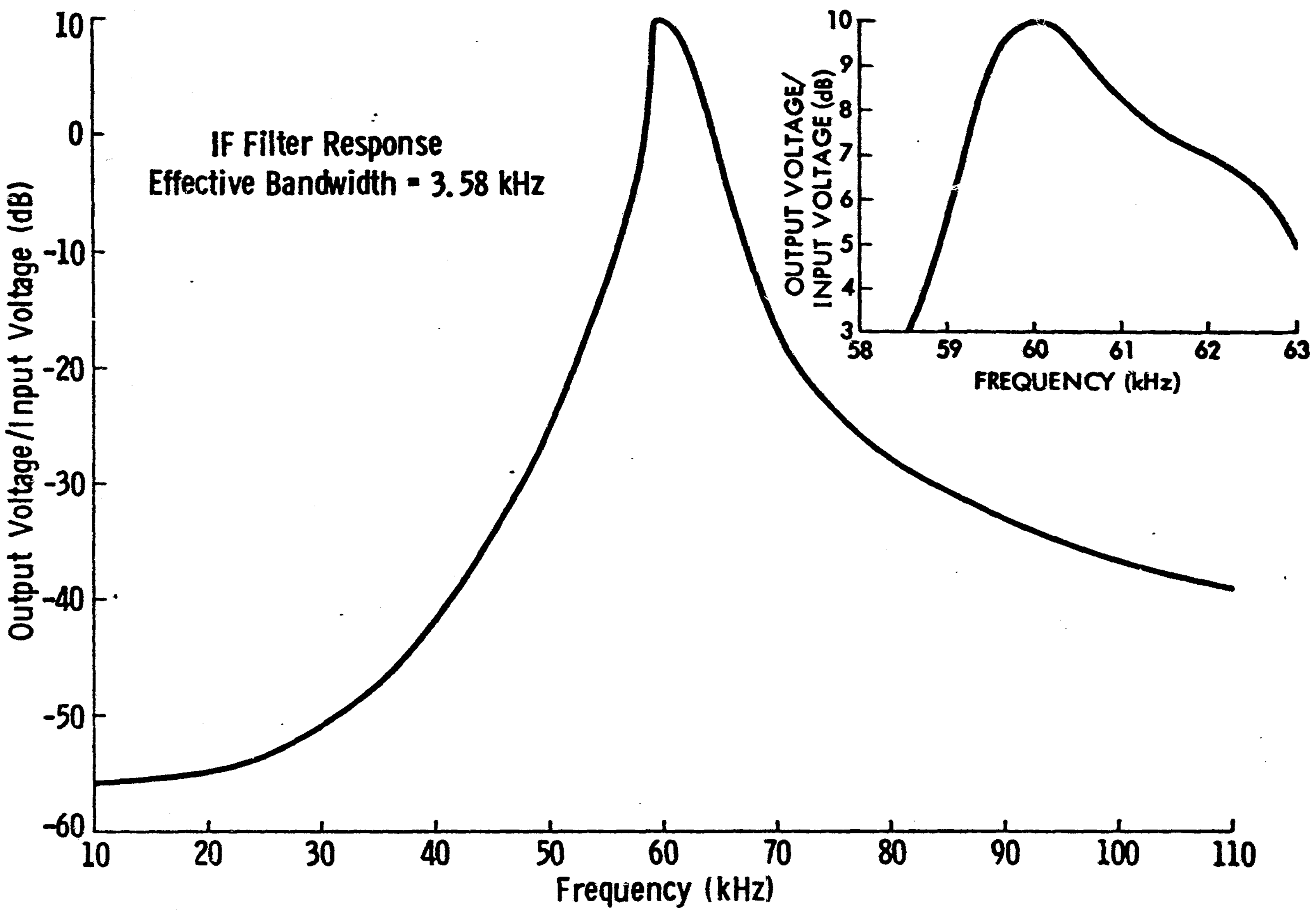


Figure 18. 8-18 MAS IF filter response characteristics (ref. 3).

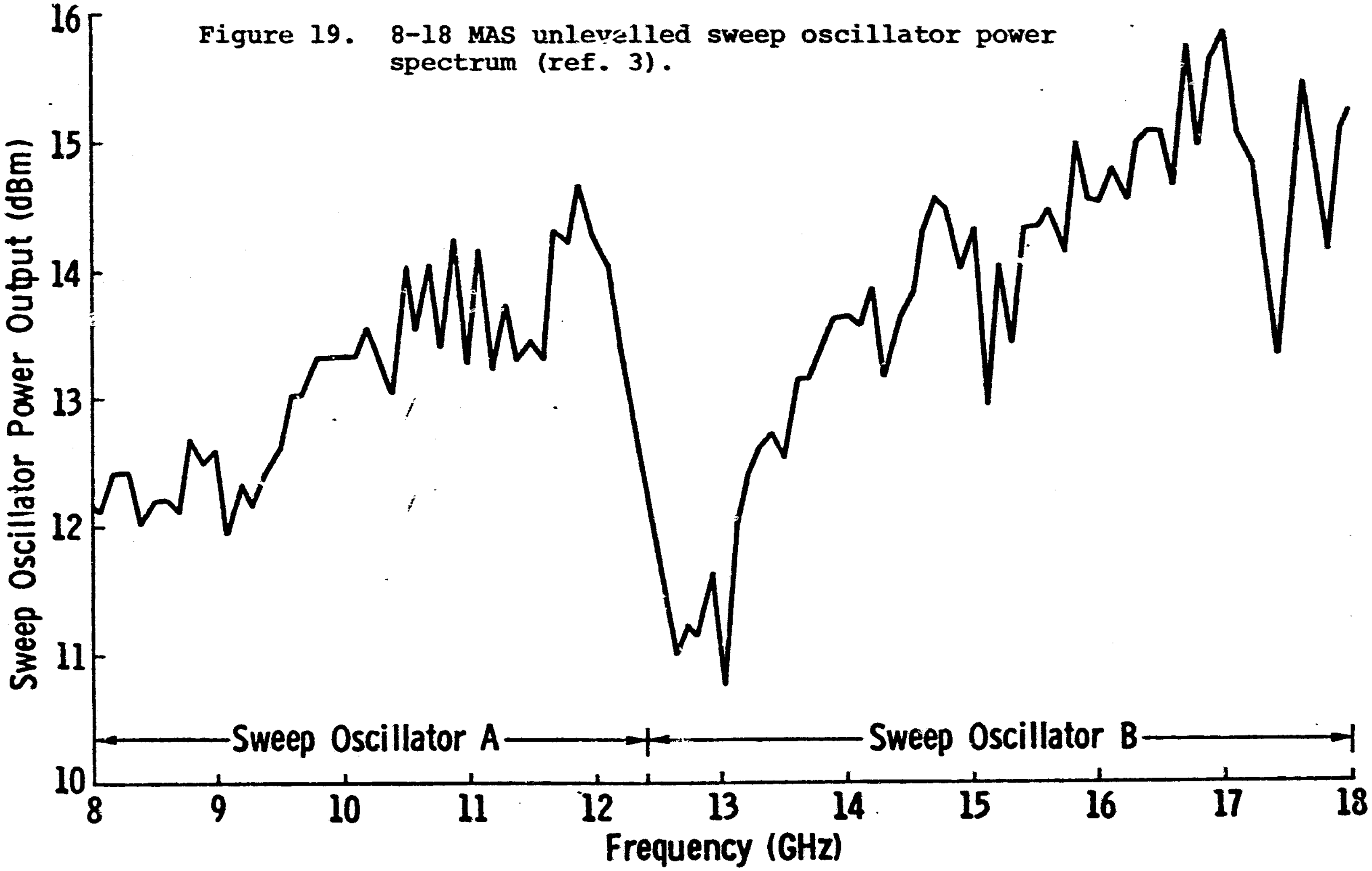
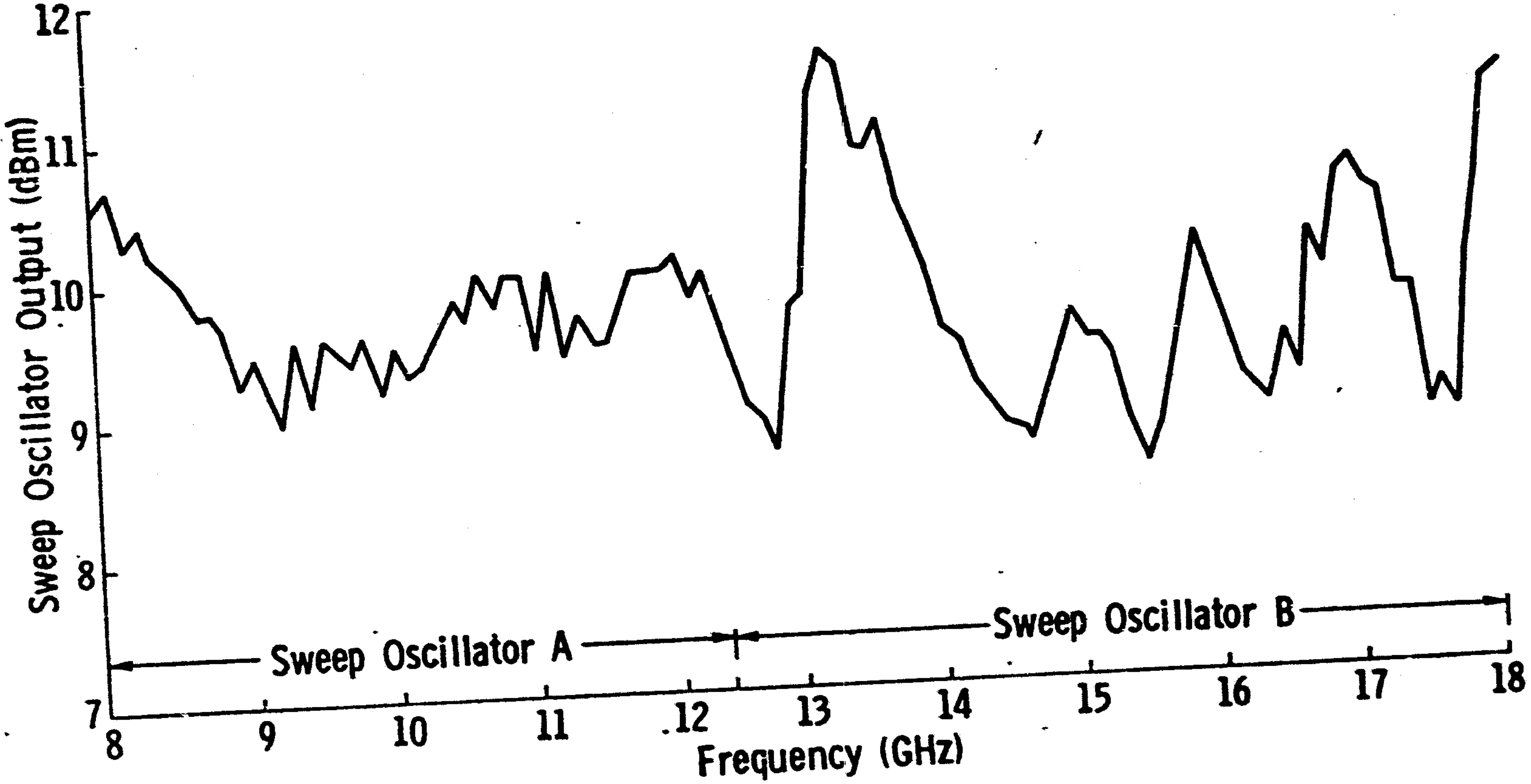


Figure 19. 8-18 MAS unlevelled sweep oscillator power spectrum (ref. 3).

Figure 20. 8-18 MAS levelled sweep oscillator power spectrum (ref. 3).



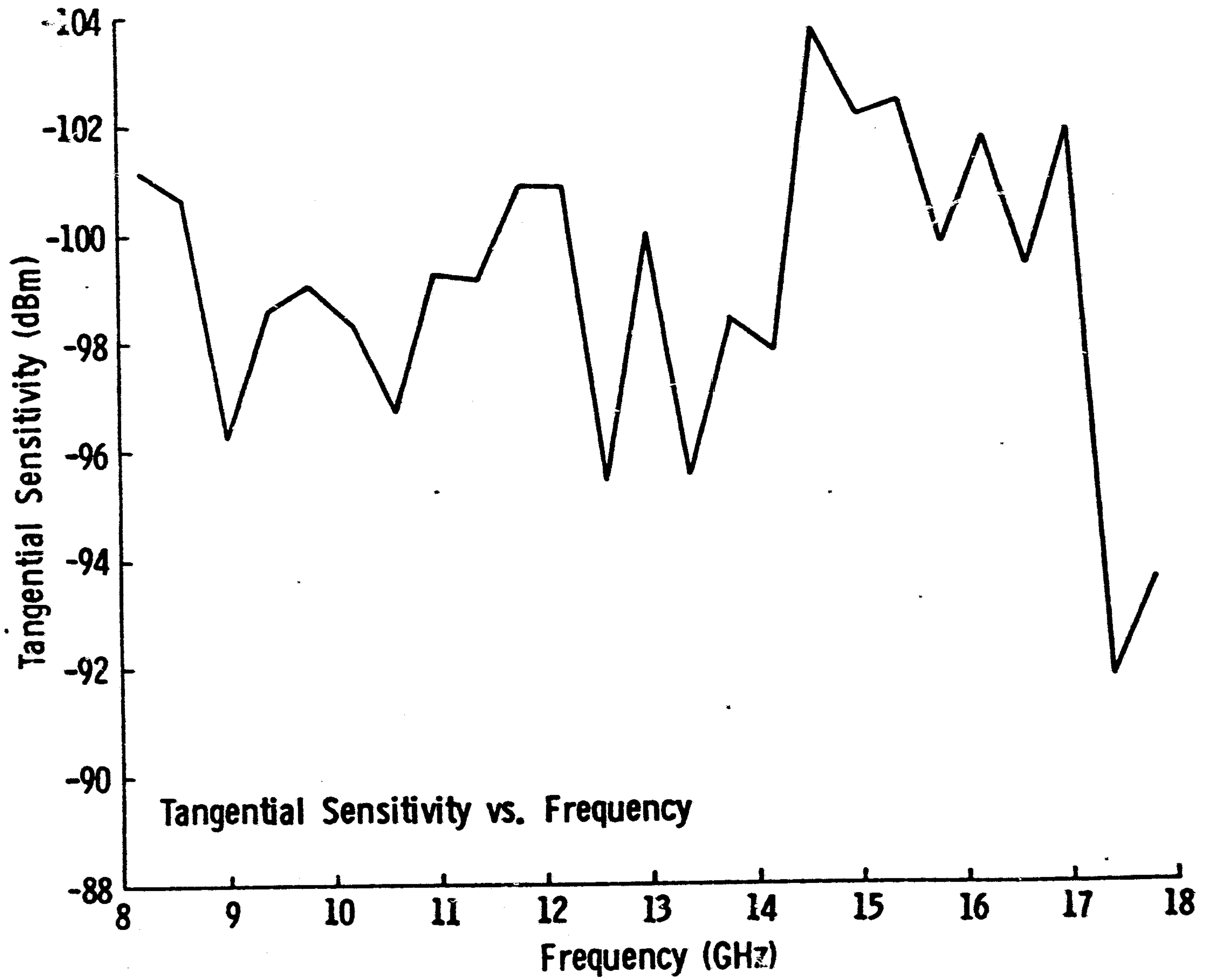


Figure 21. 8-18 MAS receiver tangential sensitivity curve (ref. 3).

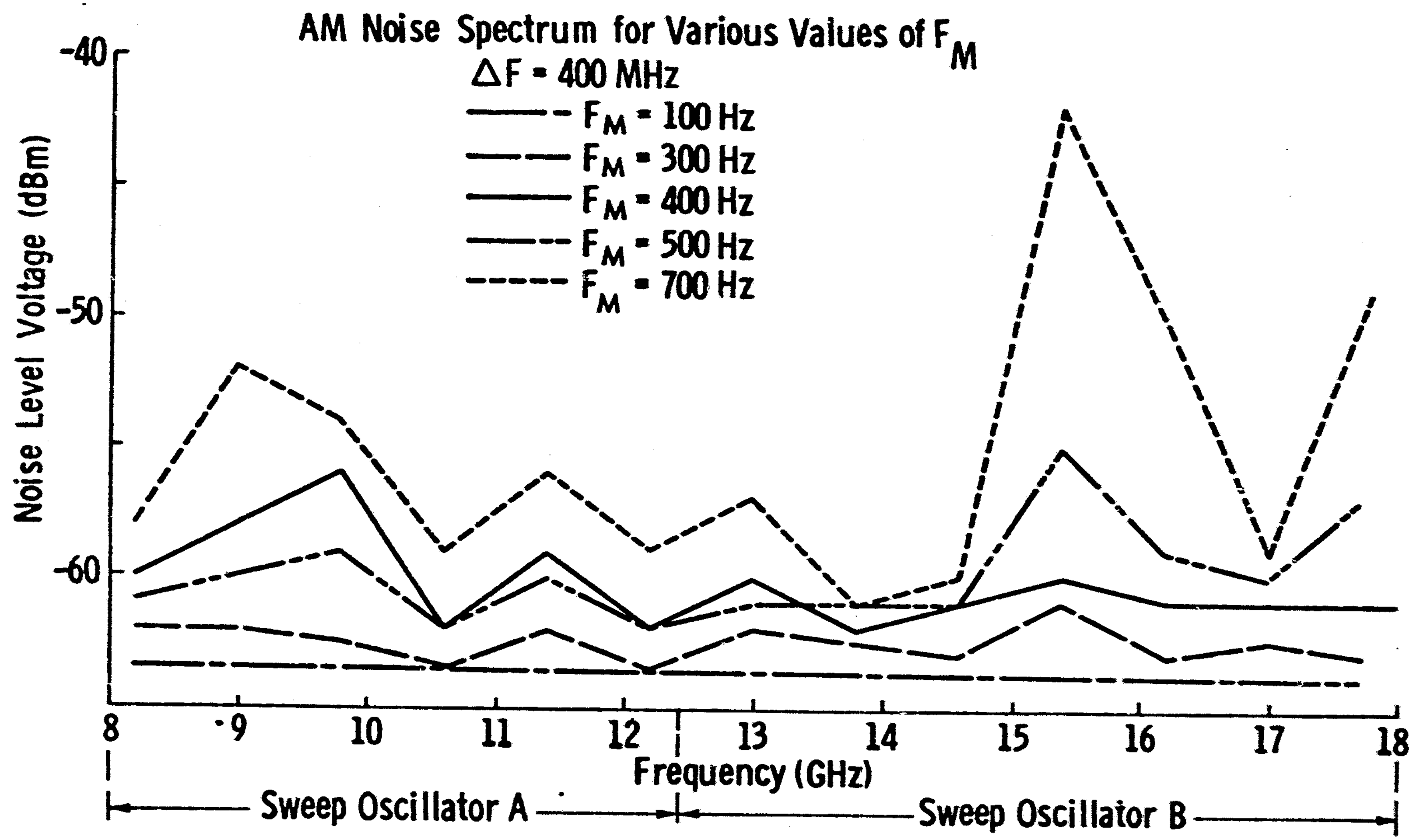


Figure 22. 8-18 MAS AM noise spectrum for various values of modulating frequency F_M. Note the trend of increasing noise with increasing values of F_M (ref. 3).

3-87
99

Frequency (GHz)	Calculated Antenna Gain (dB)	Effective Beamwidths of Product Patterns (Degrees)	
		Azimuth	Elevation
8	31.2	2.94	3.43
10	33.0	3.07	3.24
12	34.6	2.42	2.38
14	35.9	2.35	2.34
16	37.1	1.65	1.46
18	38.1	2.02	3.20

Figure 23. 8-18 MAS tabulated antenna characteristics for both antennae (ref. 3).

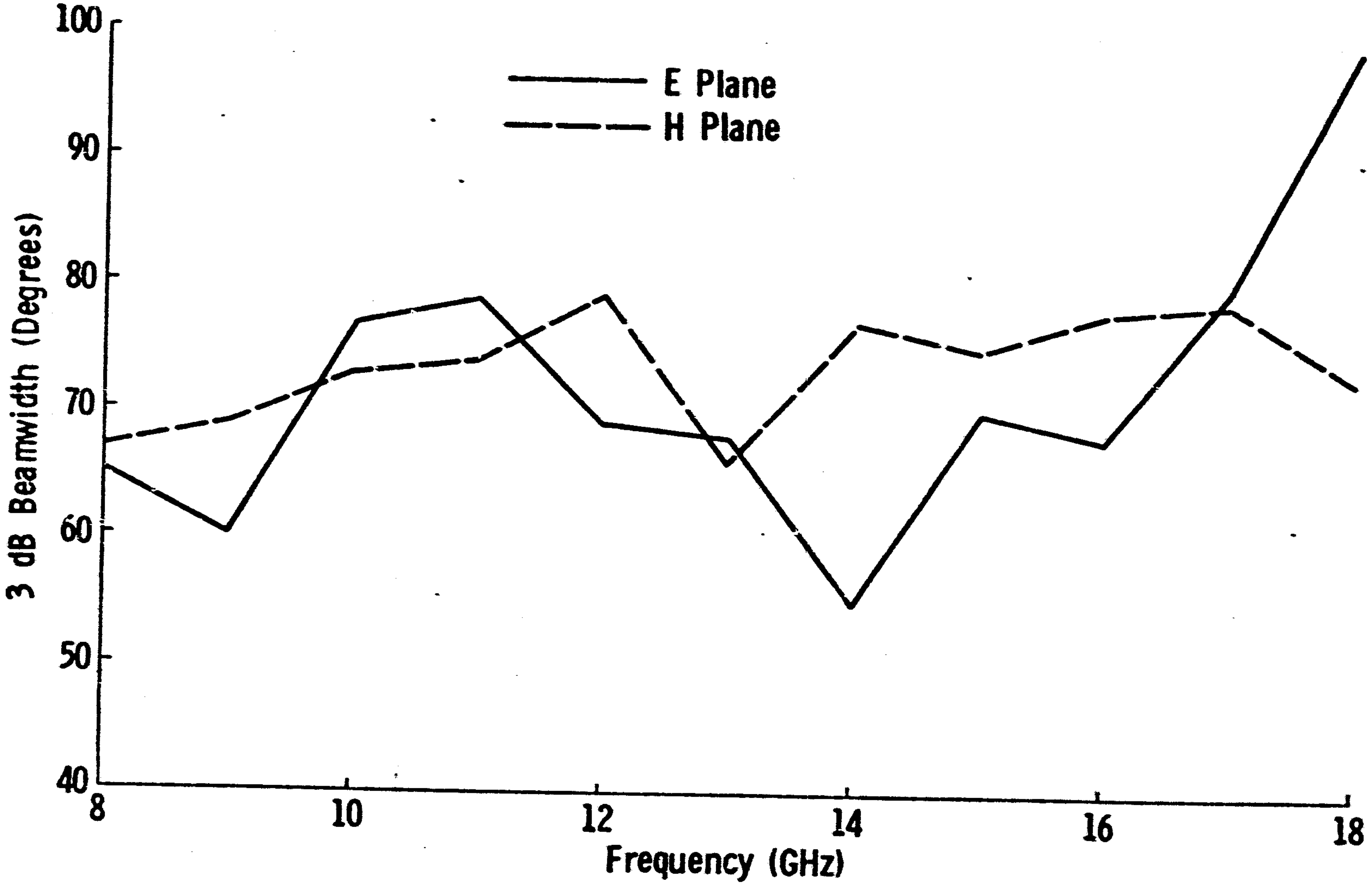
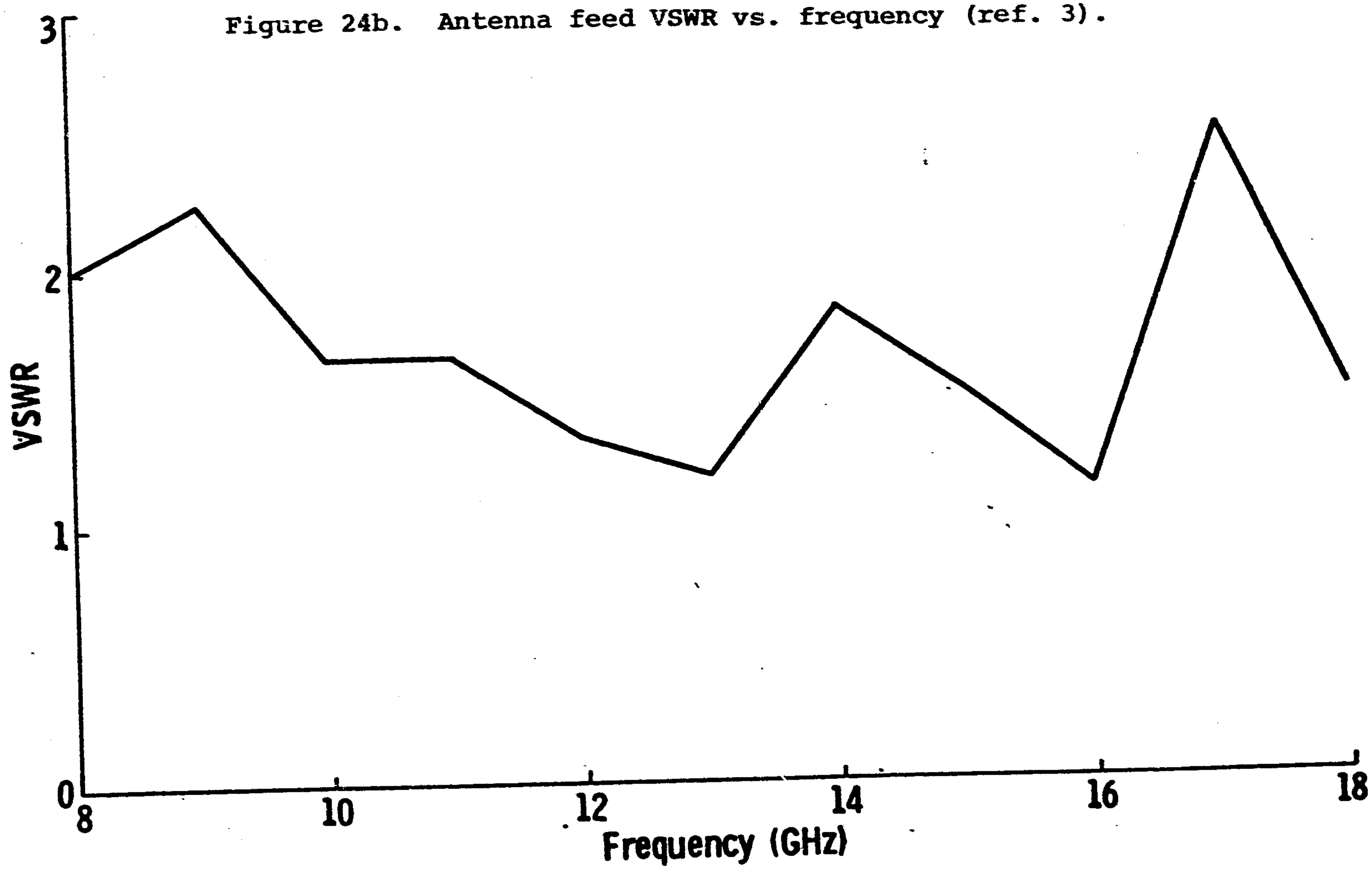


Figure 24a. 8-18 MAS antenna feed data. Antenna feed 3 dB beamwidth vs. frequency (ref. 3).

Figure 24b. Antenna feed VSWR vs. frequency (ref. 3).



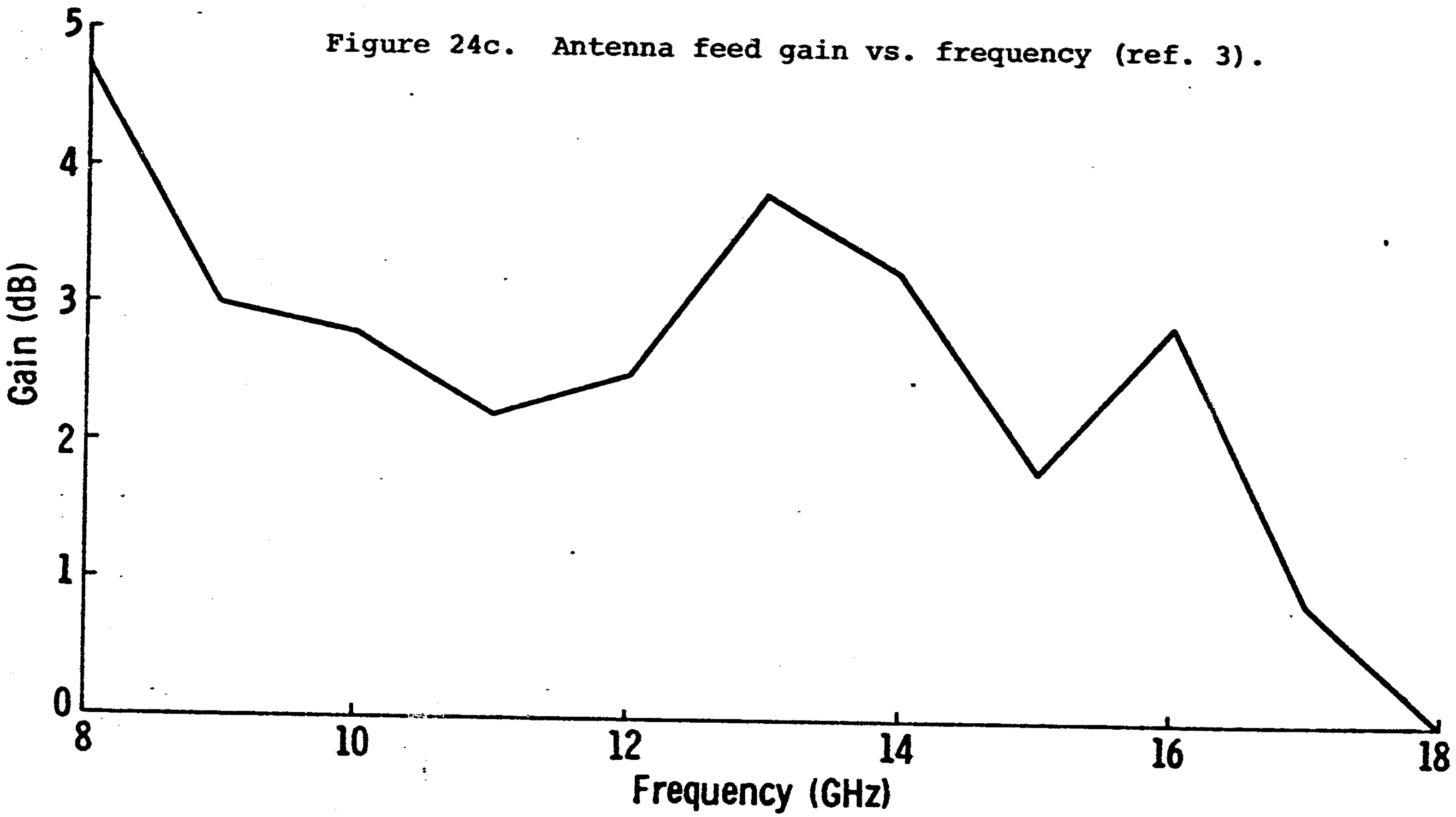


Figure 24c. Antenna feed gain vs. frequency (ref. 3).

Figure 24d. Antenna feed cross polarization isolation vs. frequency (ref. 3).

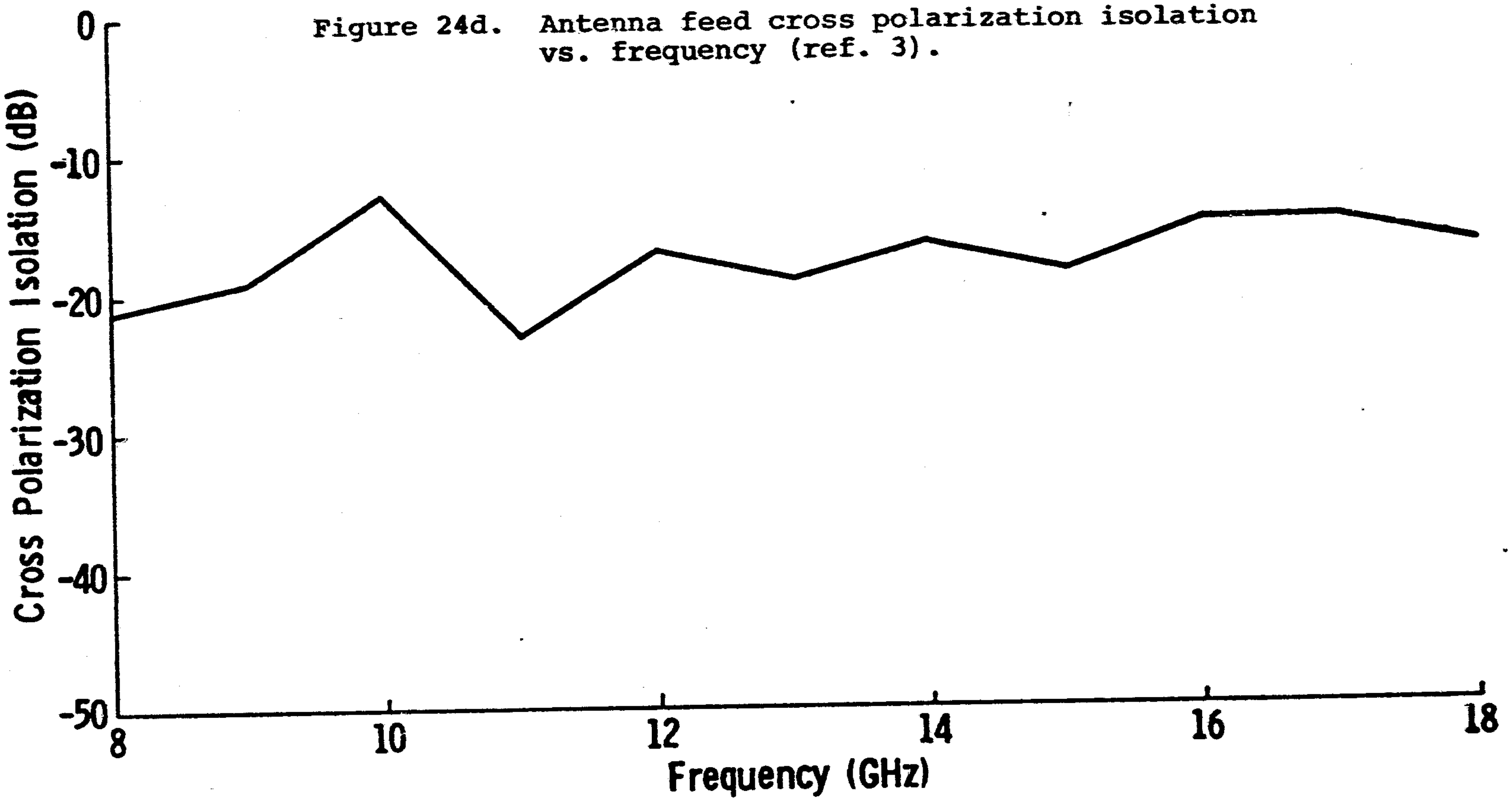


TABLE 12. 8-18 MAS BASIC SPECIFICATIONS

Type:	FM-CW
Modulating Waveform:	Triangular
Frequency:	8-18 GHz
FM Sweep: ΔF	400 MHz
Transmitter Power:	10 dBm (10 mW)
Intermediate Frequency:	50 KHz
IF Bandwidth:	3.58 KHz
Antennae:	
Height above ground:	26 m
Reflector diameter:	61 cm
Feeds:	Cavity backed, log periodic

Frequency (GHz)	Calculated Antenna Gain (dB)	Effective Beamwidths of Product Patterns (degrees)	
		Azimuth	Elevation
9	31.2	2.94	3.43

TABLE 13. 8-18 MAS SYSTEM SPECIFICATIONS (Ref. 17).

Type:	FM-CW
Modulating Waveform:	Triangular
Frequency Range:	8-18 GHz
FM Sweep: ΔF	800 MHz
Transmitter Power:	10 dBm (10 mW)
Intermediate Frequency:	50 KHz
IF Bandwidth:	10.0 KHz
Antennae:	
Height above ground:	26 m
Reflector diameter:	61 cm
Feeds:	Cavity backed, log periodic
Polarization:	Horizontal transmit-Horizontal receive (HH), Vertical transmit-Vertical receive (VV)
Incidence Angle Range:	0° (nadir)-80°
Calibration:	
Internal:	Delay line
External:	Luneberg lens

TABLE 14. 8-18 MAS NOMINAL SYSTEM SPECIFICATIONS (Ref. 13)
June 1976

Type:	FM-CW
Modulating Waveform:	Triangular
Frequency Range:	8-18 GHz
FM Sweep: ΔF	800 MHz
Transmitter Power:	10 dBm
Intermediate Frequency:	50 KHz
IF Bandwidth:	10 KHz
Antennae:	
Height above ground:	25 m
Reflector diameter:	46 cm
Feeds:	Quad-ridged horn
Incidence Angle Range:	0° (nadir)-80°
Calibration:	
Internal:	Signal injection (delay line)
External:	Luneberg lens reflector

4. ALGORITHMS FOR THE MICROWAVE ACTIVE SPECTROMETER SYSTEMS

Scattering coefficient algorithms for each of the microwave active spectrometer systems are presented here in order to indicate what measurements and calculations are needed to compute σ^o.

4.1 1-8 GHz MAS SYSTEM SCATTERING COEFFICIENT ALGORITHM

From ref. 4, σ^o is computed from equation 1.

$$\sigma^o = \left(\frac{P_R}{P_L}\right)\left(\frac{\sigma_L}{A_T}\right)\left(\frac{R_T}{R_L}\right)^4 \quad (1)$$

Where,

σ^o = average scattering coefficient over the area A

P_R = received power from the target

P_L = received power from the calibration target Luneberg Lens

σ_L = scattering cross section of the Luneburg Lens

A_T = scattering area of the target

R_T = range between antennas and target

R_L = range between antennas and calibration target and Luneberg Lens.

Equation 1 is arrived at as follows:

From the well documented radar equation:

$$P_R = \frac{P_T G_T G_R \lambda^2 \sigma^o A_T}{(4\pi)^3 \; R_T^4} \quad (2)$$

where,

P_T = transmitted power

G_T = gain of transmitting antenna

G_R = gain of receiving antenna

λ = wavelength of transmitted signal

For the calibration case where the Luneberg Lens is the target,

$$P_L = \frac{P_T G_T G_R \lambda^2 \sigma_L}{(4\pi)^3 R_L^4} \quad (3)$$

Dividing equation 2 by 3

$$\frac{P_R}{P_L} = \frac{P_T G_T G_R \lambda^2 \sigma^o A_T / (4\pi)^3 R_T^4}{P_T G_T G_R \lambda^2 \sigma_L / (4\pi)^3 R_L^4} \quad (4)$$

$$\frac{P_R}{P_L} = \frac{\sigma^o R_L^4 A_T}{\sigma_L \; R_T^4} \quad (5)$$

which gives

$$\sigma^0 = \left(\frac{P_R}{P_L}\right)\left(\frac{R_T}{R_L}\right)^4\left(\frac{\sigma_L}{A_T}\right) \quad (6)$$

The RMS voltmeter measures a receiver output voltage which is proportional to the received power. Hence,

$$\sigma^0 = \left(\frac{V_R}{V_L}\right)\left(\frac{R_T}{R_L}\right)^4\left(\frac{\sigma_L}{A_T}\right) \quad (7)$$

It was reported that the voltmeter dB scales are used when recording σ^0 measurements. As for equation (7), σ_L is a measured quantity, A_T is a computed quantity depending on the antenna footprint and look angle, and R_T/R_L is determined from the following equation.

$$R = \frac{C\ F_{IF}}{4\Delta F_{IF}\cdot f_m} \quad (8)$$

where,

- R = range to target or Luneberg Lens
- F_{IF} = IF frequency, a preset quantity
- ΔF_{IF} = FM bandwidth, a preset quantity
- f_m = modulation frequency, a measured quantity
- C = velocity of propagation of the transmitted signal

Also σ_L can be calculated from equation (9).

$$\sigma_L = \frac{4\pi^3 r^4}{\lambda^2} \quad (9)$$

where,

- r = Luneberg Lens radius
- λ = wavelength of incident energy upon the Lens

According to equations (7) and (8), the accuracy of the σ^0 measurement is determined by the accuracy for which V_R, V_L, R_T, σ_L are measured and A_T is formulated and computed. The accuracy of σ^0 computation with respect to the problem of fading and number of independent samples when taking measurements is not addressed here (ref. 18).

4.2 8-18 GHz MAS SYSTEM SCATTERING COEFFICIENT ALGORITHM

The algorithm given in equation (10) is used to compute σ^0 (ref. 4).

$$\sigma^0 = \frac{V_T V_{d1L} R_T^4 \sigma_L}{V_L V_{d1T} R_L^4 A} \qquad (10)$$

where,

V_T = receiver output voltage after square law detection

V_{d1L} = receiver output voltage with the delay line inserted while taking Luneberg Lens measurements

V_L = receiver output voltage while calibrating with Luneberg Lens

V_{d1T} = receiver output voltage with the delay line inserted while taking data

R_T = range distance to target

R_L = range distance to Luneberg Lens

A = illuminated area

σ_L = radar cross section of Luneberg lens

This equation was arrived at as follows (ref. 4).

The received power (P_R) times a constant K (K = cable loss, mixer conversion loss, etc.) equals the receiver voltage output (V), see Figure 17.

Hence,
$$V = KP_R \qquad (11)$$

The transmitted power (P) times K times the delay line loss (L) equals receiver voltage output.

Hence,
$$V_{d1} = KP_T L \qquad (12)$$

With these ideas, when a Luneberg Lens calibration is being made then the output voltage is V_L.

$$V_L = K_1 P_{RL} \qquad (13)$$

If during this calibration time the delay line is inserted into the system (via the switch) and K_1 does not vary then the output voltage is V_{d1L}.

$$V_{d1L} = K_1 P_T L \qquad (14)$$

While data is being taken the output voltage is V_t.

$$V_t = K_2 P_R \tag{15}$$

During data taking, if the delay line is inserted into the system (via the switch), the output voltage is

$$V_{d1T} = K_2 P_T L \tag{16}$$

Then,

$$\frac{V_T}{V_L} = \frac{K_2 P_R}{K_1 P_{RL}} \tag{17}$$

and,

$$\frac{V_{d1T}}{V_{d1L}} = \frac{K_2 P_T L}{K_1 P_T L} = \frac{K_2}{K_1} \tag{18}$$

thus,

$$\frac{V_T}{V_L} = \frac{V_{d1T}}{V_{d1L}} \cdot \frac{P_R}{P_{RL}} \tag{19}$$

where,

$$P_R = \frac{P_T G_T G_R \lambda^2 \sigma^o A}{(4\pi)^3 R_T^4} \tag{20}$$

and,

$$P_{RL} = \frac{P_T G_T G_R \lambda^2 \sigma_L}{(4\pi)^3 R_L^4} \tag{21}$$

thus,

$$\sigma^o = \frac{V_T V_{d1L} R_T^4 \sigma_L}{V_L V_{d1T} R_L^4 A} \tag{22}$$

5. RECOMMENDATIONS AND CONCLUSIONS

5.1 INTRODUCTION

In the following two sections (5.2, and 5.3) recommendations and conclusions are given concerning the two MAS systems. Section 5.2 discusses recommendations on what MAS system data should be provided by the University of Kansas in order to develop different levels of MAS system description and analysis. Recommendations concerning future related work as a result of information on the MAS systems provided by the University of Kansas are given in section 5.2. Conclusions are given in section 5.3.

5.2 RECOMMENDATIONS CONCERNING NEEDED INFORMATION REGARDING THE TWO MAS SYSTEMS

In section 3.2, Table 10, the latest published 1-8 GHz MAS system information, is given. Table 14 in section 3.3 presents the latest published 8-18 GHz MAS system specifications. The information given in these two tables along with the accompanying discussion allows for most of two levels of documentation as discussed in section 2.1 and 2.2, i.e., a system description and system specification. The published information to date is insufficient for the following reasons. Existing system data will not permit a (1) system analysis and corresponding system effects on the data quality, (2) reproduction of a duplicate system, or (3) give sufficient information to have a new independent group operate, maintain, calibrate, or redesign the system if need be in a reasonable period of time.

NASA/JSC management should decide what tasks are to be performed in respect to the MAS systems at JSC. Also, the decision by NASA management of what information is needed to establish what confidence level in the backscatter data supplied by Kansas

University will imply a level of documentation needed on the MAS systems. This required documentation should then be requested of the University of Kansas.

To help assess MAS backscatter data quality, and have information available detailing the MAS system (operation, maintenance, calibration, storage) the following recommendations are made.

1. Kansas University should be asked to supply information to the levels desired by JSC management on the current MAS systems configuration.

2. Kansas University should be asked to report in detail any changes in configuration. These change notices could take an easily prepared form such as xeroxed copies of engineering laboratory notes with simple explanations as opposed to formal reports.

3. Where a question exists, Kansas University should be asked to tell JSC what system configuration was used for each data set that has been gathered along with different data reduction constants that may have been used on different data sets.

4. Kansas University should be asked to provide the complete algorithms used in reducing data for each system configuration along with all data reduction constants and how these constants are incorporated.

5. Kansas University should be asked to provide copies of any reports, memorandums, or other publications which deal with the MAS systems, associated algorithms, and reported data which are not presently on hand at JSC.

Three reports have been written that explicitly discuss only the MAS systems. They are, "4-8 GHz Microwave Active and Passive Spectrometer (MAPS)", (Ref. 4); "MAS 2-8 Radar and Digital Control

Unit" (ref. 6); and "8-18 GHz Radar Spectrometer" (ref. 3). However, modifications to the MAS systems have been continually made.

It is recommended that an updated report to replace TR 177-34 (ref. 4), TR 177-37 (ref. 6), and TR 177-43 (ref. 3) be generated. This report would include any and all system modifications and improvements that have been made since the previous reports were published. Included in this updating of the system specifications would be material contained in engineering notebooks that show design analysis and criteria, components, subsystems, and system test results. It is recommended that models of the two MAS systems be generated and be of the comprehensive nature like that presented in the CRES technical reports TR 177-1, TR 177-2, and TR177-22 by Bradley (ref. 19, 20, 21). This report should include modifications to data processing and analysis. It is recommended that an error budget for the MAS systems, including such things as area calculation, data processing, etc., be generated. In Figure 18 of reference 3, cables are shown to exist in front of the MAS 8-18 GHz system antennas. It is recommended that any effects that these cables might have on the scatterometer data be ascertained and documented.

It is recommended that support contractors at JSC do the following tasks.

1. Prepare a list of all documents pertinent to the MAS systems associated algorithms and theories, and data taken using the MAS systems and note which documents are presently available and which are not available.

2. Complete and maintain a library of reports and other publications which relate to the MAS systems, associated algorithms and theory, and data gathered by the MAS systems.

3. Review new material supplied by Kansas University on the MAS systems for completeness and consistency.

4. Develop target models for soil and agricultural targets of interest.

5. Develop sensor models for the MAS systems.

6. Develop a means of assessing the MAS systems scatterometer data quality.

7. Initiate an effort on the Microwave Signature Acquisition System (MSAS) similar to the one just completed on the MAS systems.

5.3 CONCLUSIONS

The efforts involved in this report and a previous report by Lockheed Electronics Company prepared by W. A. Rosenkranz (ref. 22) confirm that:

1. Considerable effort will be required of the University of Kansas to bring the documentation of the system up to date.

2. Specifications and requirements for future sensor systems and modifications should be written to minimize bias errors in the final output data in order to make comparison with other sensors and other configurations of the same sensor simpler and more conclusive.

3. The sensor system should be viewed as a whole rather than an assemblage of parts. This viewpoint may bring about changes in the overall project management as well as the data acquisition and processing.

4. Care should be taken to assure a balanced, integrated approach to the experiments. Emphasis must be placed equally on gathering information for definitive target descriptions; hardware adequate for data acquisition, storage and processing; algorithms for data reduction; verification of data processing algorithms and software; establishment of precision and accuracy limits; and analysis of the data.

5. Sustained interest in the project by NASA/JSC management and support contractor personnel will probably enhance the results achieved.

6. REFERENCES

1 Holtzman, J., Radar Studies Related to the Earth Resources Program Interim Technical Progress Report, CRES TR177-13, University of Kansas, NASA Contract NAS 9-10261, March 1971.

2 Holtzman, J., Radar Studies Related to the Earth Resources Program, CRES TR 177-26, University of Kansas, NASA Contract NAS 9-10261, March 1972.

3 Bush, T. F., Ulaby, F. T., 8-18 GHz Radar Spectrometer, CRES TR177-43, University of Kansas, NASA Contract NAS 9-10261, September 1973.

4 Ulaby, F. T., 4-8 GHz Microwave Active and Passive Spectrometer (MAPS) Volume 1: Radar Section, CRES TR177-34, University of Kansas, NASA Contract NAS 9-10261, April 1973.

5 Moore, R. K., Holtzman, J., et. al.,: Radar Studies Related to the Earth Resources Program, Progress Report; CRES177-33, University of Kansas, NASA Contract NAS 9-10261, November 1972.

6 Oberg, J. M., Ulaby, F. T.,: MAS 2-8 Radar and Digital Control Unit, CRES 177-37, University of Kansas, NASA Contract NAS 9-10261, October 1974.

7 Ulaby, F. T., Moore, R. K.,: Radar Spectral Measurements of Vegetation, CRES 177-40, University of Kansas, NASA Contract NAS 9-10261, August 1973.

8 Ulaby, F. T.,: Radar Response to Vegetation, CRES 177-42, University of Kansas, NASA Contract NAS 9-10261, September 1973.

9 Batlivala, P. P., Ahlar, J.,: Joint Soil Moisture Experiment (TEXAS): Documentation of Radar Backscatter and Ground Truth, CRES 264-1, University of Kansas, NASA Contract NAS 9-14052, April 1975.

10 Ulaby, F. T., Batlivala, P. P., Measurements of Radar Backscatter From a Hybred of Sorghum, CRES 264-2, University of Kansas, NASA Contract NAS 9-14052, May 1975.

11 Lubben, M. MAS Computer Interface, CRES 177-54, University of Kansas, NASA Contract NAS 9-10261, December 1975.

12 Batlivala, P. P., Dobson, C., Soil Moisture Experiment (Kansas): Documentation of Radar Backscatter and Ground Truth Return, CRES TR264-7, University of Kansas, NASA Contract NAS 9-14052, March 1976.

13 Ulaby, F. T., Bush, T. F., Metzler, T., Stites, H., Seasonal Variations of the Microwave Scattering Properties of the Deciduous Trees as Measured in the 1-18 GHz Spectral Range, CRES, 177-60; University of Kansas, NASA Contract NAS9-10261, June 1976.

14 Stiles, H., Ulaby, F., Hanson, B., Dellwig, L., Snow Backscatter In the 1-8 GHz Region, CRES TR 177-61, University of Kansas, NASA Contract NAS9-10261, June 1976.

15 Batlivala, P. P., Ulaby, F. T., Feasibility of Monitoring Soil Moisture Using Active Microwave Remote Sensing, CRES 264-12, University of Kansas, NASA Contract NAS9-14052, January 1977.

16 Bush, T. F., Ulaby, F. T.,Fading Characteristics of Panchromatic Radar Backscatter From Selected Agricultural Targets, CRES TR 177-48, University of Kansas, NASA Contract NAS9-10261, December 1973.

17 Bush, T. F.,Ulaby, F. T., Remotely Sensing Wheat Maturation with Radar, CRES TR 177-55, University of Kansas, NASA Contract NAS9-10261, May 1975.

18 Bush, T. F., Ulaby, F. T.,Fading Characteristics of Panchromatic Radar Backscatter from Selected Agricultural Targets, CRES TR 177-48, NASA Contract NAS9-10261, December 1973.

19 Bradley, G. A., An Analysis of Methods for Calibrating the 13.3 GHz Scatterometer, CRES TR 177-1, University of Kansas Center for Research, Inc., Lawrence, Kansas, November 1969, NASA Contract NAS9-10261.

20 Bradley, G. A., Signal Analysis of the Single-Polarized 13.3 GHz Scatterometer, CRES TR 177-2, University of Kansas Center for Research, Inc., Lawrence, Kansas, May 1970, NASA Contract NAS9-10261.

21 Bradley, G. A., Remote Sensing of Ocean Winds Using a Radar Scatterometer, CRES TR 177-22, University of Kansas Center for Research, Inc., Lawrence, Kansas, September 1971, NASA Contract NAS9-10261.

22 Rosenkranz, W. A., Recommendations and Comments Concerning the Microwave Agriculture Field Measurements, Lockheed Electronics Company, Inc., LEC-10108, NASA Contract NAS9-15200, February 1977.