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Design and Construction of a K_a-band Scatterometer

by Michael Zoll

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13. ABSTRACT *(Maximum 200 words)*

This report provides documentation of a K_a-band scatterometer designed and constructed for the Corps of Engineers Waterways Experiment Station. The system is designed to work in conjunction with a Hewlett-Packard 8510 network analyzer to provide fully polarimetric measurements of backscatter from terrain. It operates over a 2-GHz bandwidth and can be operated in a monostatic, quasi-monostatic, or bistatic configuration. The design, theory of operation, and characteristics are provided as a means to assist the operator or to provide information to others wishing to construct their own.

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1. Introduction

This report provides documentation of a 35-GHz millimeter-wave scatterometer designed and built for the Waterways Experiment Station (WES) by the U.S. Army Research Laboratory (ARL). This scatterometer will be used by WES, in conjunction with a Hewlett-Packard (HP) 8510A network analyzer system, to make radar cross-section measurements of backgrounds.

The scatterometer upconverts the modulation signal provided by the HP network analyzer system to the K_a frequency band and transmits the modulated signal through a lens antenna. The scattered signal from the measured background is received through a lens antenna, downconverted to the intermediate frequency (IF) band, and returned to the network analyzer for processing.

The network analyzer demodulates and digitizes the received signal, measuring phase and amplitude characteristics versus frequency. The data are then processed using a selection of digital signal processing (DSP) algorithms; alternatively, the data may be downloaded to a host computer system. Some available functions are numerical integration, clutter subtraction, and fast Fourier transforms to obtain a range profile of the measured background. The reduced data can then be displayed on the front panel in various formats.

The scatterometer was based on a previous design.[1] The center frequency was changed to 34 GHz, both vertical and horizontal transmit polarizations were added to make the design fully polarimetric, and circular polarization capability was added.

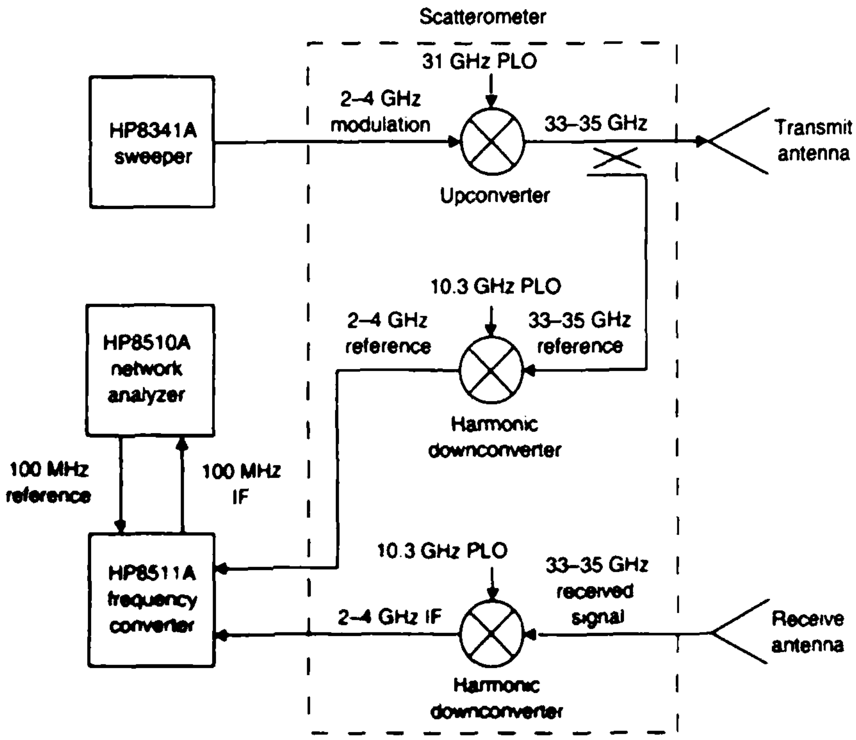
2. Configuration of Scatterometer

2.1 Basic Concept of Operation

The millimeter-wave scatterometer is designed to allow the user to make forwardscatter and backscatter measurements of objects in the 33- to 35-GHz frequency band. The scatterometer operates as the front end for the HP network analyzer system, consisting of an HP 8510A network analyzer, an HP 8341A sweeper, and an HP 8511A frequency converter. Figure 1 is a simplified drawing of the scatterometer and network analyzer system.

[1]E. [illegible], T. F. Haddock, [illegible], and M. W. [illegible], *A Millimeter-wave Network Analyzer Based Scatterometer*, IEEE Trans. on Geoscience and Remote Sensing, 26, [illegible]

Figure 1. Simplified block diagram.



The sweeper generates a 2- to 4-GHz modulation frequency that is fed to the scatterometer, which upconverts the signal to the 33- to 35-GHz millimeter-wave frequency band. This radio frequency (rf) signal is sampled and downconverted to provide a reference signal for the HP 8511A frequency converter. The fundamental rf frequency (33- to 35-GHz) is amplified and transmitted through a lens antenna.

Some of the rf energy illuminating the target is reflected back to the scatterometer. The amount of reflection is proportional to the reflection characteristics of the target. The reflected signal is received by the scatterometer, downconverted to the 2- to 4-GHz IF band, and input to the frequency converter. The frequency converter downconverts the 2- to 4-GHz IF signal to a 100-MHz IF signal. The network analyzer compares the 100-MHz IF signal with a reference signal to obtain phase and amplitude information over the 33- to 35-GHz frequency band.

2.2 Scatterometer Capabilities

The scatterometer is designed to be fully polarimetric. In the transmit section, switching is used to select either vertical or horizontal polarization. Two channels in the receive section individually process the vertical and horizontal components of the received signal and direct these to the frequency converter.

The scatterometer may be configured in either monostatic or bistatic mode of operation. In monostatic mode, the same antenna is used for both transmit and receive. When bistatic mode is configured, separate antennas are used for transmit and receive; these antennas may be separated to vary the bistatic angle.

The scatterometer normally operates with linear polarization but has been designed with an optional circular polarization capability; when a switchable polarizer is inserted in line with the transmit antenna, the transmitted linear signal is converted into left- or right-handed circular polarization. The received circular polarizations are converted to their respective linear components by a switchable polarizer inserted in line with the receive antenna.

2.3 Layout of Components

The scatterometer consists of two boxes, I and II, which may be mated together or individually positioned. The mated configuration is used for both monostatic and bistatic modes of operation. In the monostatic mode, mating is required to allow the installation of waveguide jumpers between boxes I and II. The antenna in box II is the transmit and receive antenna. In bistatic mode, box I is the transmitter and box II is the receiver. The boxes may be mated or separated to make measurements at different bistatic angles.

Figures 2 and 3 are photographs of the scatterometer in the mated configuration. The lens antennas are visible in the front view. All electrical connections between the two boxes and between the scatterometer and network analyzer are made from the connectors visible in the rear panel area. The construction drawings for the two boxes are provided in appendix A.

Box I Box II

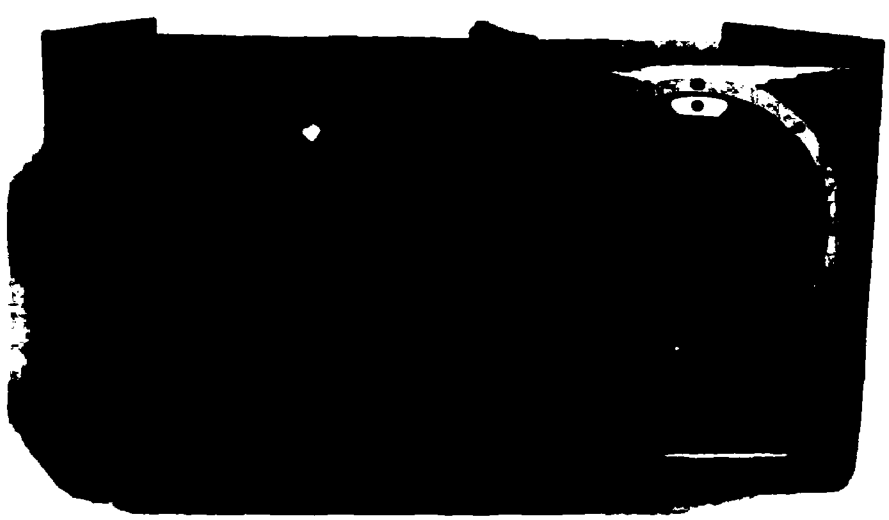
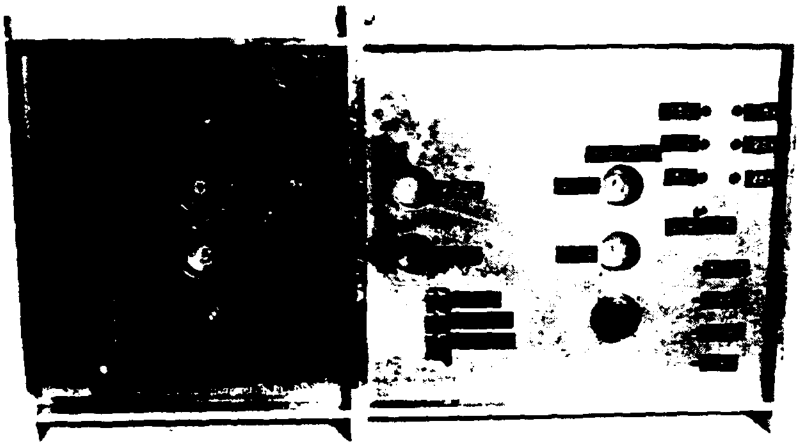


Figure 2. Scatterometer front view.

Figure 3. Scatterometer rear view.



3. Details of Operation

3.1 Transmitter Operation

The interiors of boxes I and II are shown in figures 4 to 7. The 2- to 4-GHz modulation signal provided by the HP sweeper is brought in through the connector labeled IF IN in the rear of box I, shown in figure 8. A 20-dB gain amplifier increases this signal to +17 dBm to provide the proper drive to the upconverter. A 31-GHz phase-locked oscillator (PLO) signal is mixed with the 2- to 4-GHz modulation in the upconverter to produce the frequency-swept 33- to 35-GHz rf output. A second 10.3-GHz PLO drives three harmonic mixers: a mixer to derive a 2.1- to 4.1-GHz reference when mixed with the 33- to 35-GHz rf transmitted signal, and two mixers to derive a 2.1- to 4.1-GHz IF when mixed with the vertical and horizontal components of the 33- to 35-GHz rf received signal. Isolators are used with the upconverter and harmonic mixers to prevent signal crossover interference.

The original Ulaby design included a reflection measurement made at the transmit antenna used for bistatic measurements. This concept is not incorporated in this design; however, the capability to make this reflection measurement has been included in the scatterometer. To make this measurement, a 3-dB directional coupler is used to sample the rf signal reflected back into the transmitter during bistatic operation. The sampled signal is then input to the rf port of a harmonic mixer for downconversion to the 2.1- to 4.1-GHz IF band.

An X-band phase-locked source provides the 10.3-GHz PLO signal needed by the harmonic mixers in box I. The 10.3-GHz signal from the source is split by a power splitter. Half of the local oscillator (LO) signal is routed to the LO OUT connector on the rear of box I, and

Figure 4. Box I, left front view.

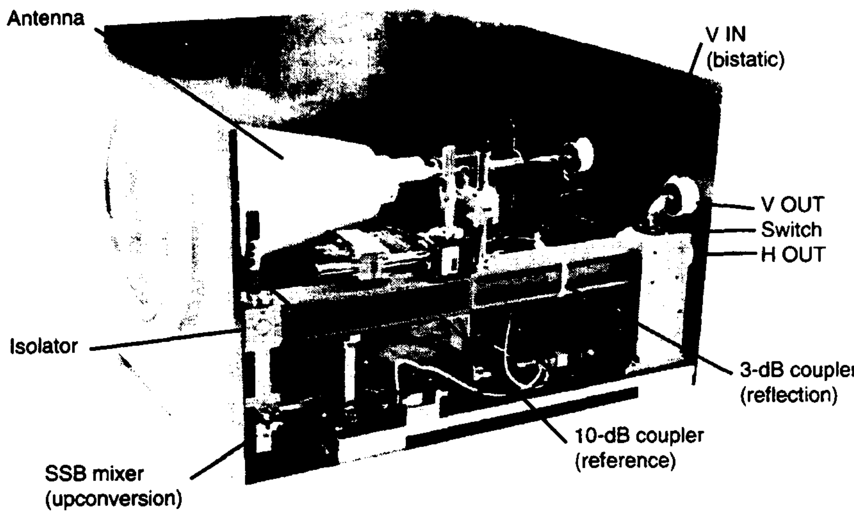


Figure 5. Box I, left rear view.

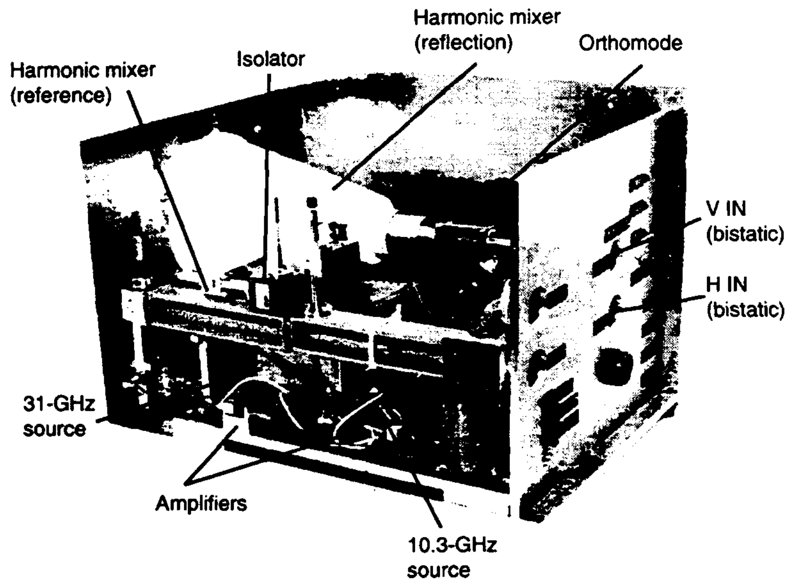


Figure 6. Box II, left front view.

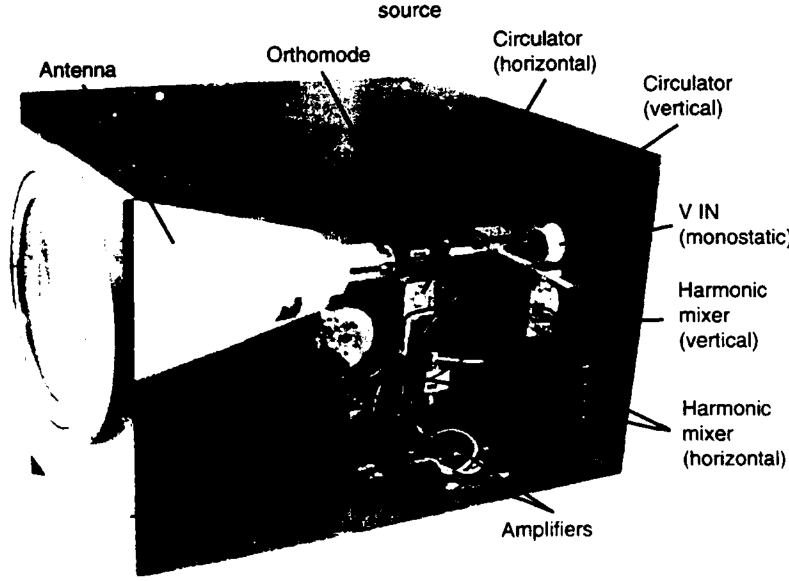
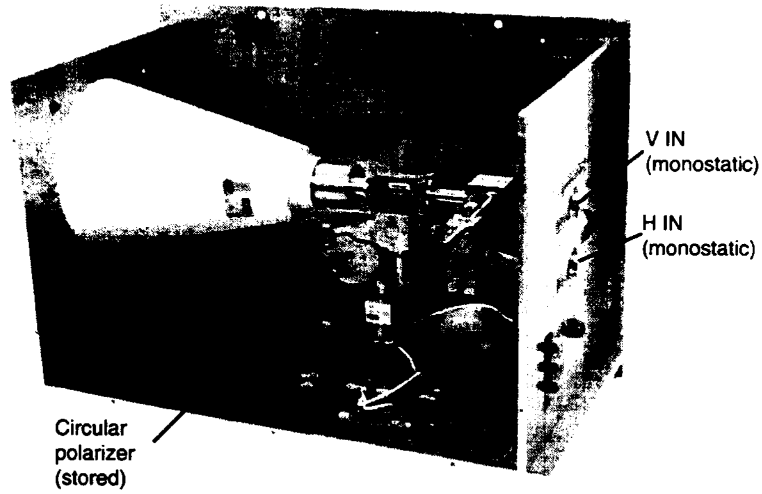


Figure 7. Box II, left rear view.



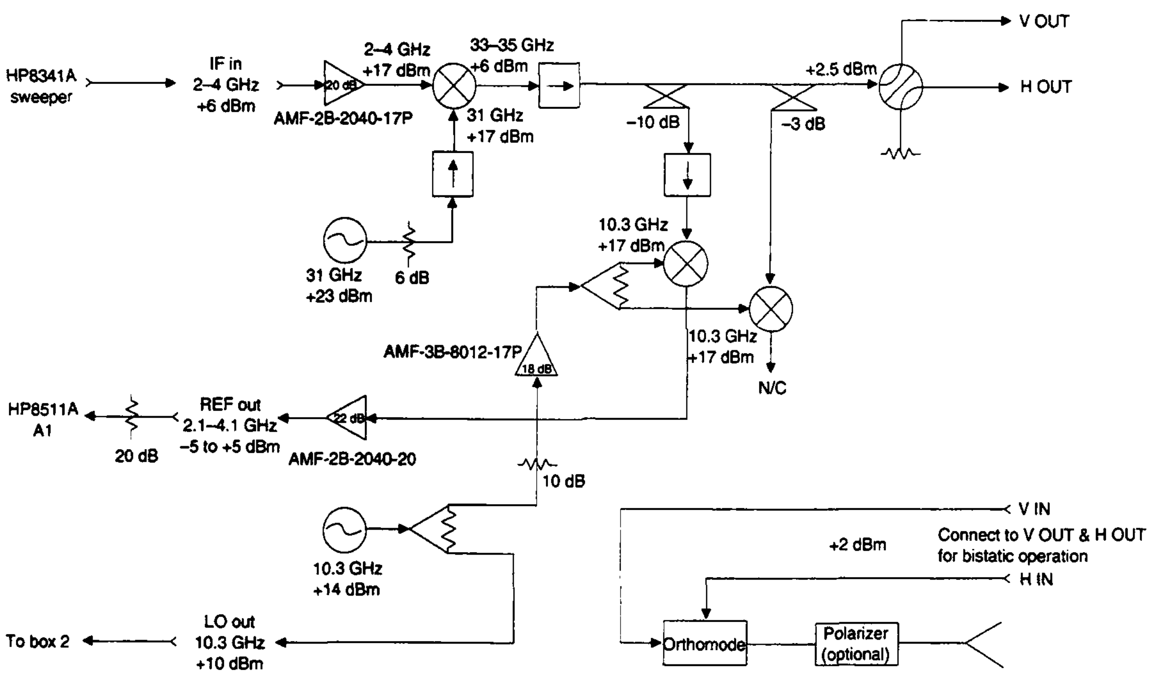


Figure 8. Box I schematic.

half is amplified for input to the two harmonic mixers. A power splitter directs the amplified LO signal to the harmonic mixer that provides the REF OUT signal.

The transmitter can be remotely controlled to provide linear vertical or horizontal polarization and can be disabled while the receiver remains on. A remote-controlled, four-position waveguide switch is used to select vertical transmit, horizontal transmit, load, or short. The vertical and horizontal transmit positions route the rf signal to the V OUT and H OUT waveguide flanges located on the rear of boxI. The load position routes the rf signal into a matched load, effectively disabling the transmitter. The short position is a function of the switch design and has no use in this system.

The V OUT and H OUT ports on the rear of box I allow the transmitter to connect to the receiver antenna for monostatic operation or to an antenna for bistatic operation. Waveguide jumpers are used to connect the V OUT and H OUT ports to the V IN and H IN ports of box II for monostatic operation (see fig. 9) or to the V IN and H IN ports of box I for bistatic operation. An orthomode transducer located in line with each antenna allows the vertically and horizontally polarized signals to be transmitted through the same antenna.

3.2 Receiver Operation

Reflections from the target are detected by the receiver through a lens antenna mounted in box II. Signals detected by the receive antenna are separated into vertical and horizontal linear components by the orthomode transducer. When receiving circularly polarized signals, a switchable polarizer should be inserted between the orthomode transducer and the receive antenna located in box II. The polarizer converts the received circularly polarized signal to a linearly polarized signal that is compatible with the receiver design.

The receiver has two channels to separately process the vertical and horizontal components of the received signal. Each channel consists of a circulator, a harmonic mixer, and an IF preamplifier. Both channels operate identically, so only one generic receive channel will be described.

The circulator isolates the transmitter from the receiver when both are connected to the same antenna in monostatic mode. Although

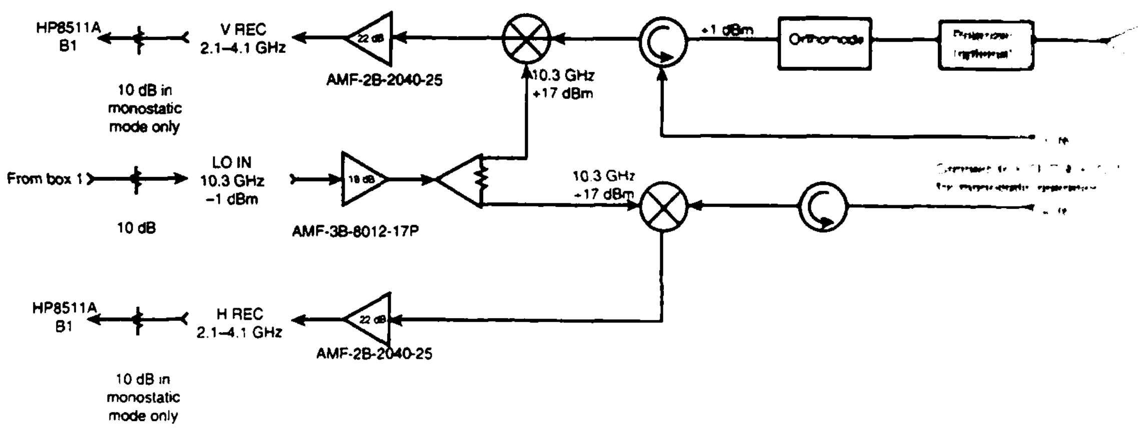


Figure 9. Box II schematic.

unnecessary when operating in bistatic mode, the circulator remains a part of the receiver to allow the operator to easily change between monostatic and bistatic modes of operation.

The received signal is input to the rf port of the harmonic mixer for downconversion to the 2.1- to 4.1-GHz IF band. The mixer operated on the third harmonic of the 10.3-GHz LO signal (30.9 GHz) and mixes with the 33- to 35-GHz received signal, resulting in the 2.1- to 4.1-GHz IF output. The IF output from the mixer is amplified using a 20-dB preamplifier and directed to a connector on the rear of box II.

The 10.3-GHz LO signal required for the harmonic mixers is generated in the transmitter section located in box I. This PLO signal is routed from the LO OUT connector on the rear of box I to the LO IN connector on the rear of box II. This signal is then amplified and split to provide the LO drive for the two harmonic mixers.

After downconversion, the IF vertical and horizontal components of the received signal are brought out of the V REC and H REC ports on the rear of box II. These signals are input to the frequency converter and downconverted to the 100-MHz IF frequency required by the HP network analyzer. The network analyzer displays the relative phase and magnitude of the vertical and horizontal channels relative to the reference signal generated in the transmitter.

4. Setup and Operation

4.1 System Setup

Figure 10 is a setup diagram illustrating the connection between the HP network analyzer and the millimeter-wave scatterometer.

The four connecting cables between the network analyzer and the scatterometer should be a semirigid coaxial cable terminated with SMA connections and rated for 10-GHz transmission. The cable should be long enough to allow separation of the two boxes during backscatter measurements in the bistatic mode.

Two waveguides jumpers are provided with the scatterometer. To prevent damage during transportation, these jumpers should be removed and the waveguide flanges covered with the plastic caps provided.

Figure 11 shows the rear panel of the millimeter-wave scatterometer. Note that the control for the waveguide switch is located on the right side of box I. This switch is operated using a small flathead screwdriver.

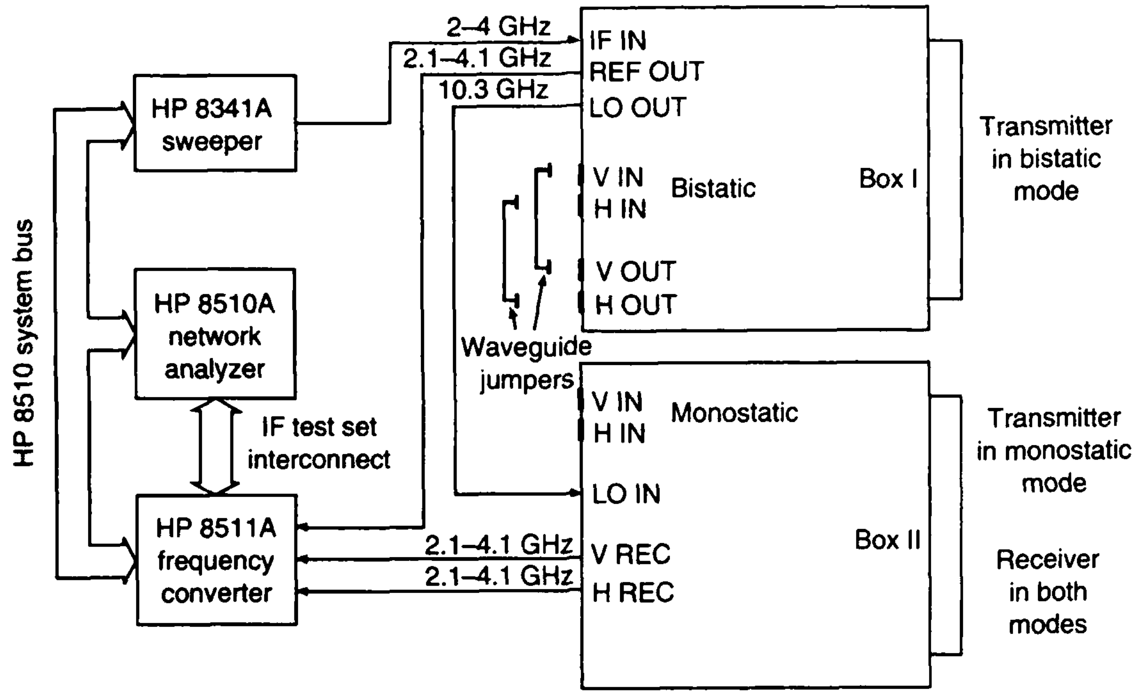


Figure 10. Scatterometer setup diagram.

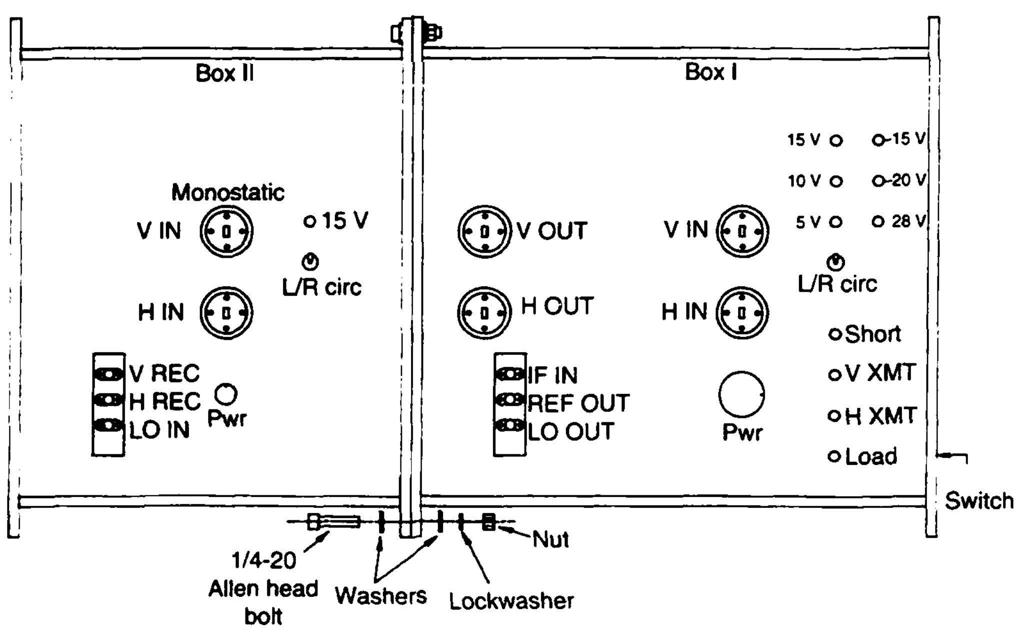


Figure 11. Scatterometer rear panel.

4.1.1 Source IF Signal Setup

This hookup connects a user-provided cable between the HP 8341A sweeper and the IF IN connection at the rear of Box I. The output power level of the HP 8341A sweeper should be set to provide –6 dBm of power at IF IN.

4.1.2 *Reference IF Signal Setup*

This hookup connects a user-provided cable between the A1 input of the HP 8511A and the REF OUT connection at the rear of box I. The power level at the REF OUT connection may be as much as +5 dBm. Attenuating pads may have to be added to bring the power level at the A1 input down below the maximum –10 dBm. This would require approximately 20-dB attenuation from the cable and pads.

4.1.3 *Receive LO Signal Setup*

This hookup connects a user-provided cable between the B1 input of the HP 8511A and V REC output of box II; it also connects the user-provided cable between the B2 input of the HP 8511A and H REC output of box II. These hookups will result in the receive vertical signal being displayed at S11 (B1 / A1) and the receive horizontal signal being displayed as S12 (B2 / A1).

During monostatic operation, an increased signal level (due to leakage) may require additional attenuation in the cables to prevent overload of the HP 8511A.

4.1.4 *LO Interconnect Signal Setup*

This setup connects a user-provided cable between the LO OUT output of box I and LO IN input of box II. The LO OUT level is +10 dBm at 10.3 GHz, but the required LO IN level should be approximately –1 dBm. The cable will have to be padded to limit the 10.3-GHz signal.

4.1.5 *Power Supply Setup*

This setup connects the larger rack-mounted power supply to the PWR connector on the rear of box I and connects the smaller power supply to the PWR connector on the rear of box II. The connectors for the two power supplies are different to prevent one from interchanging them. The box I power supply schematic diagram is provided in appendix B.

4.2 Bistatic Mode Operation

Boxes I and II may be bolted together. Washers may be inserted at the rear bolts to co-boresight the two antennas.

- Connect the two waveguide jumpers provided from the V OUT and H OUT connections at the rear of box I to the V IN and H IN connections at the rear of box I, labeled BISTATIC.

- Connect the two extra waveguide terminators, which are provided, to the V IN and H IN connections, labeled MONOSTATIC on box II.

4.3 Monostatic Mode Operation

Boxes I and II must first be bolted together to provide proper spacing for the waveguide jumpers. In this mode of operation, the antenna in box I will not be functional.

- Connect the two waveguide jumpers, which are provided, from the V OUT and H OUT connections at the rear of box I to the V IN and H IN connections, labeled MONOSTATIC at the rear of box II.

- Connect the two extra waveguide terminators provided to the V IN and H IN connectors, labeled BISTATIC on box I.

4.4 Transmit Polarization Selection

Transmit polarization is selected by means of a Hughes motor-driven waveguide switch located in box I. Four positions—SHORT, V XMT, H XMT, or LOAD—may be selected either remotely or manually. The switch position is shown with indicator lights on the rear of box I.

4.5 Circular Polarization Selection

Circular polarization is achieved by removing the two switchable polarizers from the stored position on the internal bracket and installing them between the antenna and orthomode transducer in both boxes. This operation will extend the V IN and H IN ports on both boxes so that they no longer lineup with the V IN and H IN ports. Two short, straight sections of waveguide are provided with the scatterometer to extend the V OUT and H OUT ports to match the extended locations of the respective V IN and H IN ports.

A switch labeled L / R CIRC, located on the rear of both of the boxes, is used to switch the polarizer between the left and right circular transmit polarizations. During bistatic operation, the setting of the two switches should be identical. During monostatic operation, the switch on the rear of box I has no function.

Acknowledgements

The author would like to thank those who helped in the design and construction of the WES 35-GHz scatterometer: Donny Testerman helped fabricate the enclosure. Bruce Wallace generated the initial design, and Don Bauerle provided advice on the construction of the scatterometer.

Appendix A.—Enclosure Construction

Figures A-1 and A-2 are the drawings used to construct the enclosures for the scatterometer. The enclosure is constructed using 1/4-in. aluminum, and the sides are fastened together using 4-40 allen head screws.

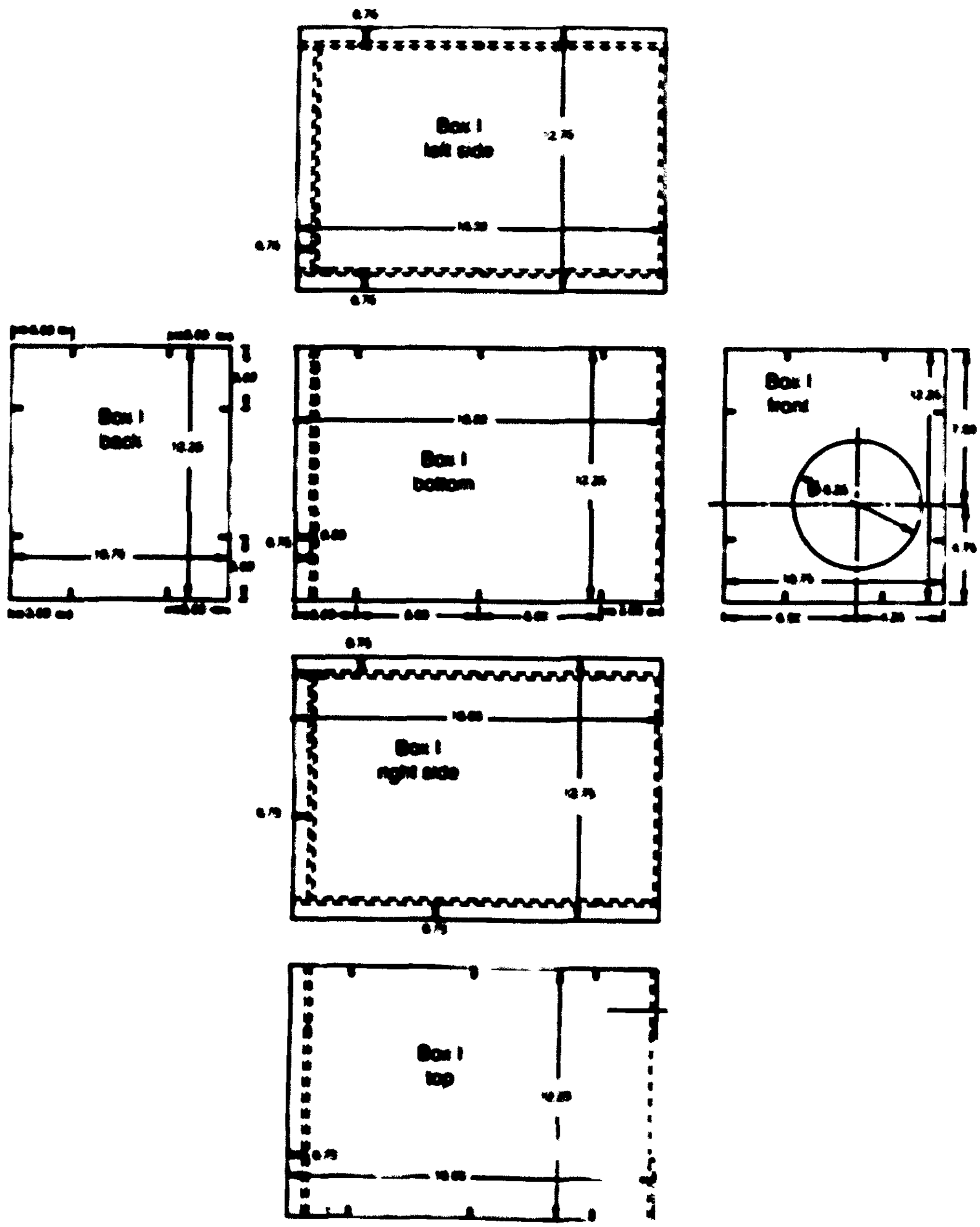


Figure A-1. Box I enclosure construction drawing.

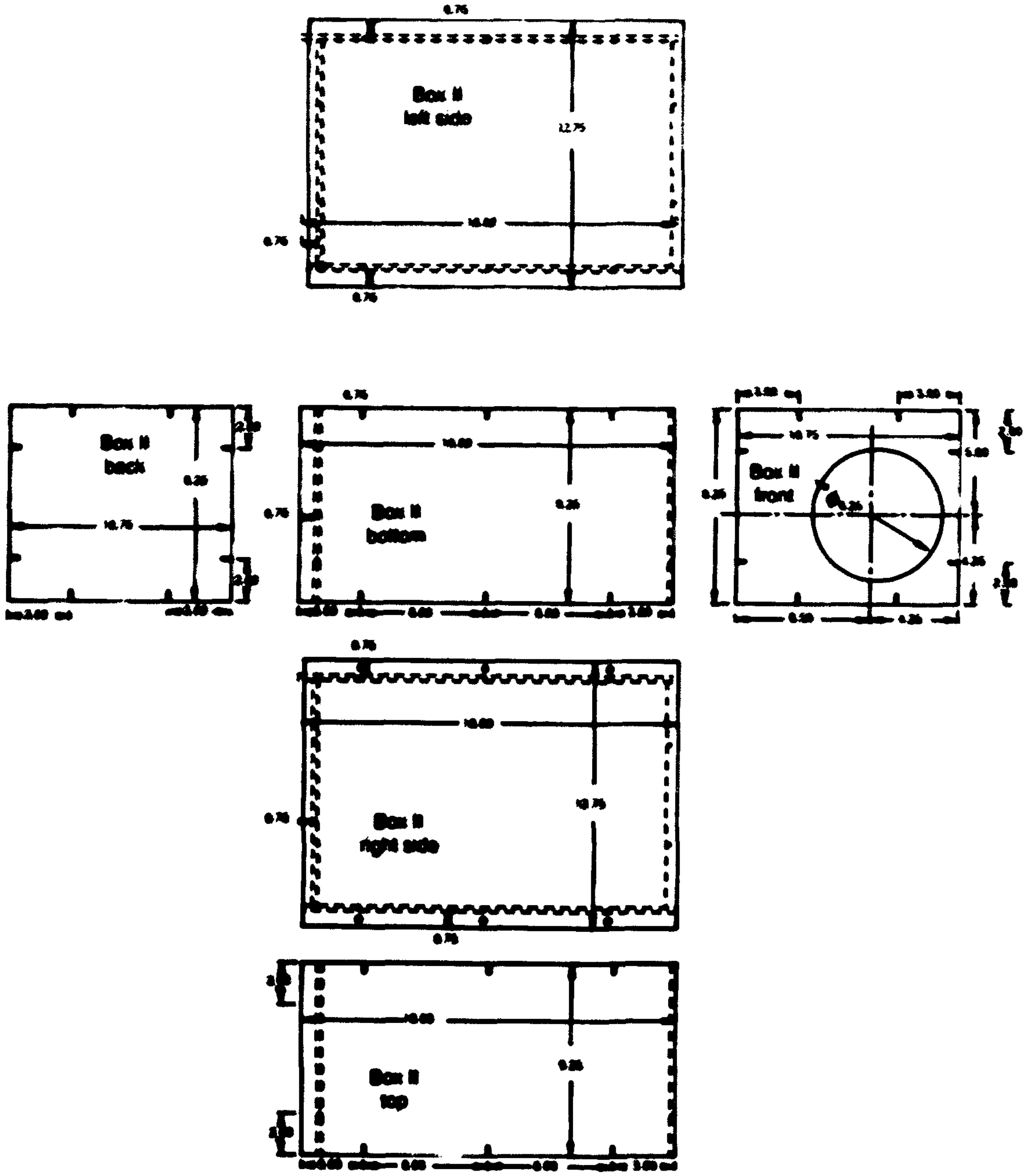


Figure A-2. Box II enclosure construction drawing.

Appendix B.—Power Supply

Figure B-1 is a schematic diagram of the power supply of box I. Note that the +10-V supply voltage is derived from the +15-V supply using a regulator located inside box I. A quick disconnect is provided at the rear of box I.

The power supply of box II, a single +15 V@1A supply, is not shown. A quick disconnect is provided at the rear of box I.

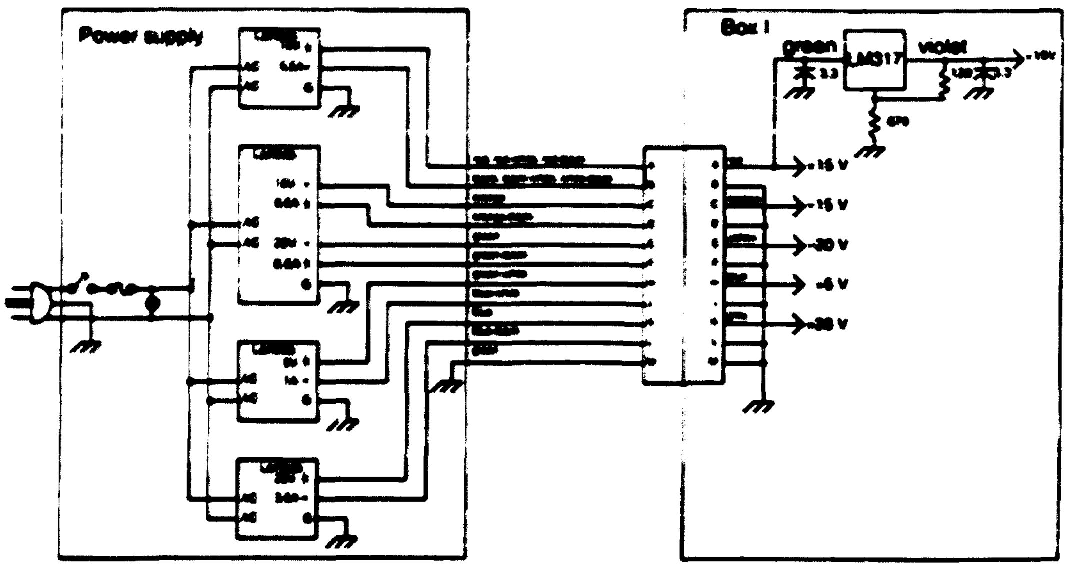


Figure B-1. Power supply schematic.

Appendix C.—rf Output Power Measurements

C-1. Introduction

Power measurements were made of the output radio frequency (rf) power versus intermediate frequency (IF) input frequency. The measurements were made using a Hewlett-Packard (HP) 8341A sweeper, a Boonton 4200 rf microwattmeter, an HP-85 instrument controller, and an HP plotter.

The sweeper is connected to the scatterometer IF IN terminal to provide the necessary modulation. The input power level is set to +6 dBm and the frequency is varied from 2 to 4 GHz. This is upconverted by the scatterometer to the 33- to 35-GHz transmitted rf signal.

The microwattmeter measures the 33- to 35-GHz rf signal at the output port of the single sideband (SSB) upconverter, just after upconversion from the 2- to 4-GHz IF frequency, or, at the input of the orthomode transducer, just before being fed into the transmit antenna.

The HP-85 controller is interfaced to the sweeper, microwattmeter, and plotter via the IEEE bus. It steps the sweeper from 2 to 4 GHz in 0.01-GHz steps, measures the rf output power using the microwattmeter, and graphs the results using the plotter.

C-2. Measurement of Bistatic Mode Power

A measurement was made of the rf power entering the orthomode through the port corresponding to vertical transmit bistatic operation located in box I (fig. C-1). The average power is observed to be about +1 dBm.

Figure C-1. RF power in bistatic mode.

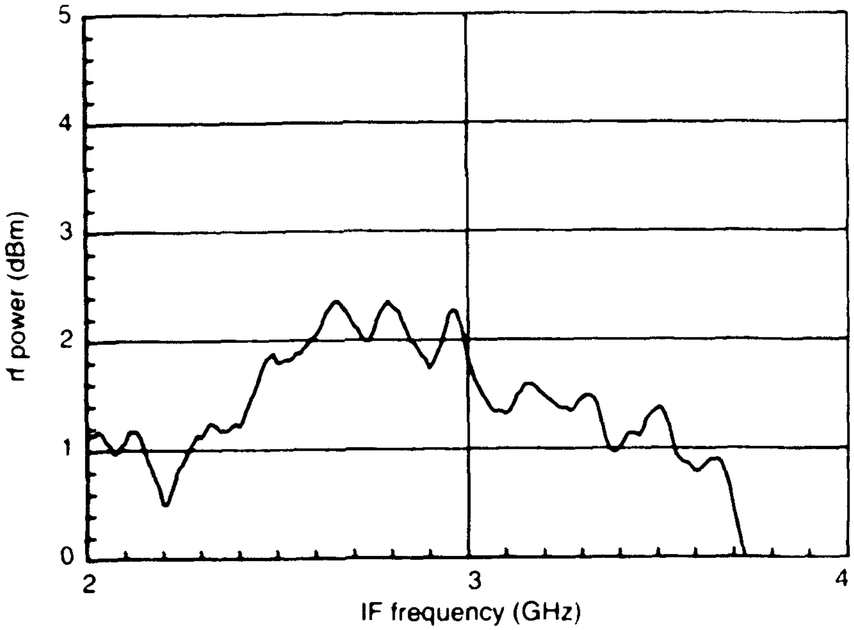
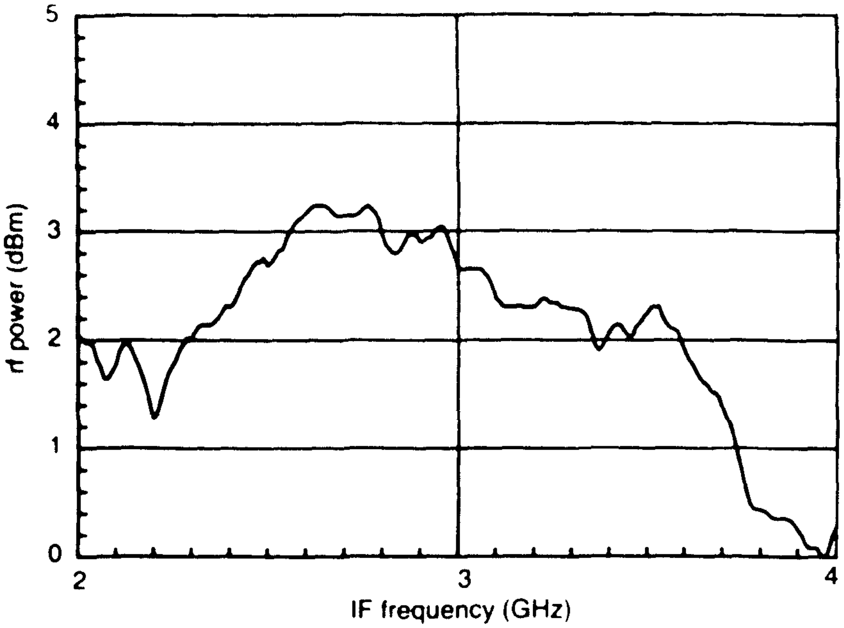


Figure C-2. RF power in monostatic mode.



Appendix D.—IF Reference Power Measurements

The intermediate frequency (IF) output REF OUT was measured to determine the performance of the harmonic mixers over the 2- to 4-GHz IF frequency range (fig. D-1). The measurement was made using a Hewlett-Packard (HP) 8341A sweeper, slowly varying the IF frequency from 2 to 4 GHz, and an HP 8566B spectrum analyzer recording the reference output. Note that the power level varies between approximately –5 and +5 dBm. The power level variation is due mostly to variations in the harmonic mixer. The contribution due to variation from the single sideband (SSB) upconverter is minimal.

This level variation is a result of the particular harmonic mixer used for downconversion. The Hughes 47431H-1002 tunable mixer used in this system is designed for a 10- to 2000-MHz IF frequency range. In this system it is operated over a 2000- to 4000-MHz IF frequency range. An improvement in frequency response flatness might be achieved by using an Alpha 924A series broadband harmonic mixer, which has an IF frequency range of DC-4 GHz.

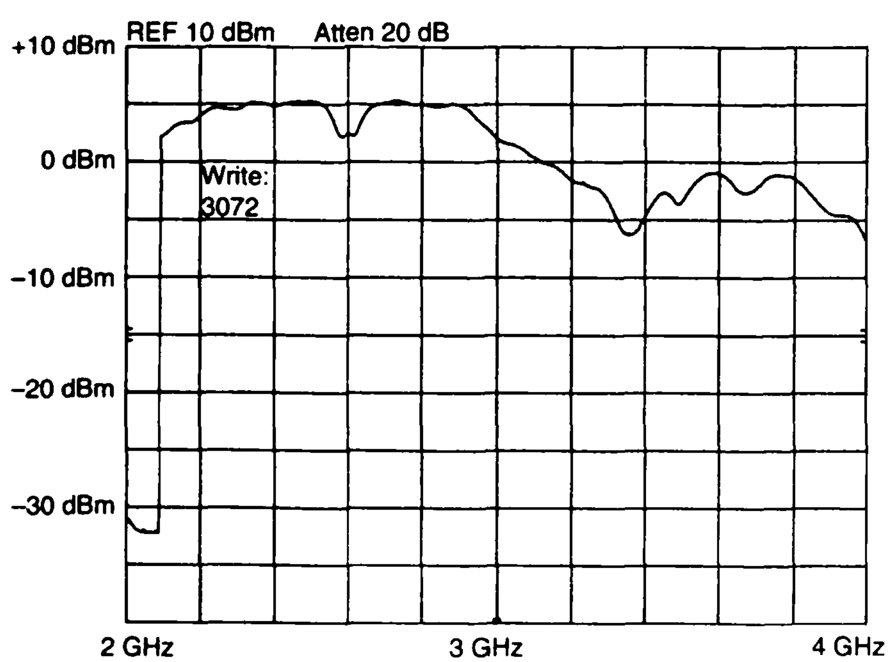


Figure D-1. REF OUT power versus frequency.

Appendix E.—Trihedral Measurements

The final test of the scatterometer was measurements made of a trihedral corner reflecter using a Hewlett-Packard (HP) 8510A network analyzer system. A +7-dBsm trihedral was setup on a tripod in an anechoic chamber 4 m from the scatterometer.

Figures E-l and E-2 show the results of parallel- and cross-polarized measurements made with the scatterometer configured for bistatic mode. The horizontal axis of the graphs corresponds to the range from the scatterometer and the vertical axis corresponds to the strength of the received signal.

Comparing the copolarized transmit vertical / receive vertical (TV / RV) and transmit horizontal / receive horizontal (TH / RH) plots with the cross-polarized (TV / RH and TH / RV) measurements, it is estimated that the copolarized return is about 15 dB greater than the cross-polarized return. Ideally, there should be no cross-polarized return but imperfections in the reflector, and limited performance of the orthomode transducer and antenna result in a finite isolation between the channels.

Figures E-3 and E-4 show the results of the measurements made with the scatterometer configured for monostatic mode. As with the bistatic case, the horizontal axis corresponds to range and the vertical axis corresponds to signal strength.

Note that there are significant signal levels near the left side of the TV / RV and TH / RH plots. This is a result of coupling of the transmitted signal into the receiver within the scatterometer via the circulator. The signal near the left side of the TV / RH and TH / RV plots is a result of the coupling within the scatterometer via the orthomode transducer and circulator.

It is estimated that the isolation between the copolarized channel and cross-polarized channel is about 15 dB.

Figure E-1. Trihedral measurement in vertical transmit bistatic mode.

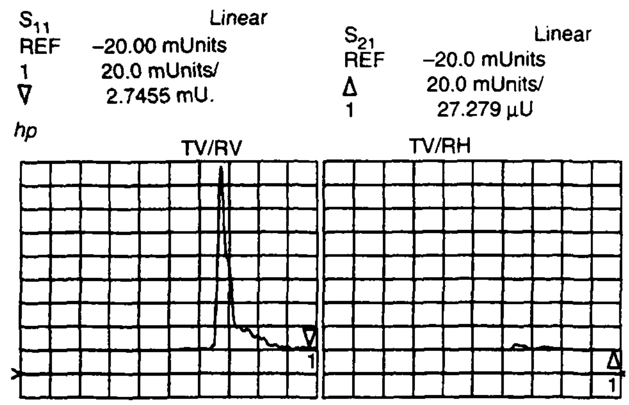


Figure E-2. Trihedral measurement in horizontal bistatic mode.

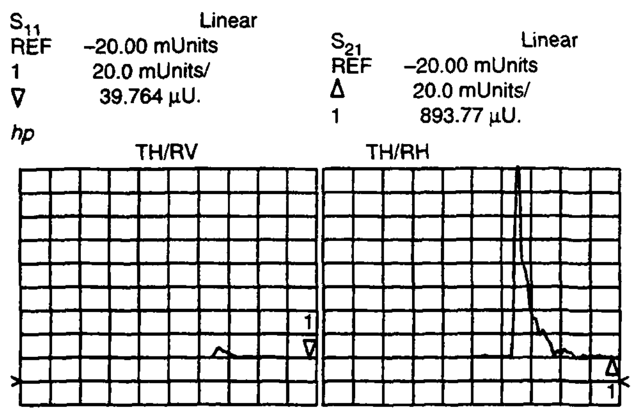


Figure E-3. Trihedral measurement in vertical transmit monostatic mode.

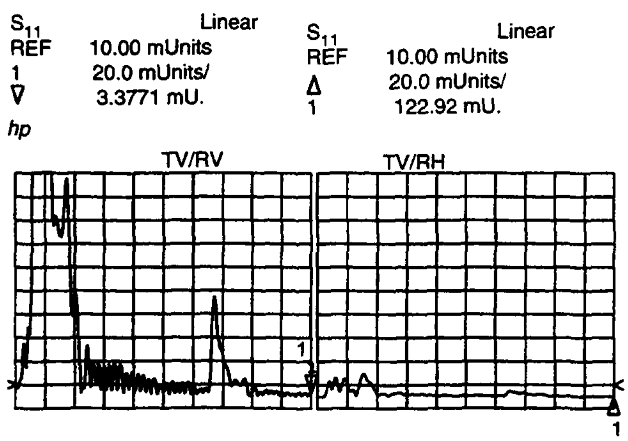
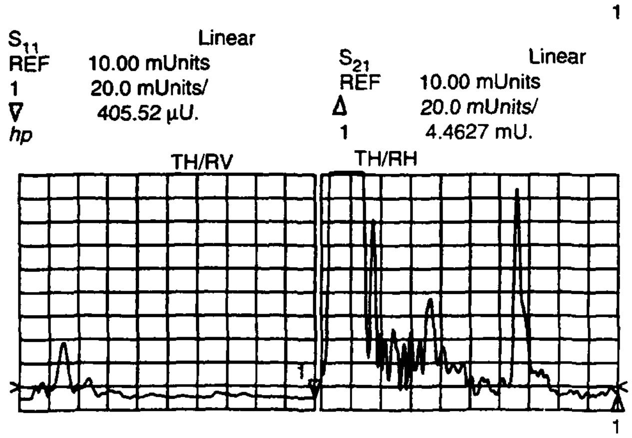


Figure E-4. Trihedral measurement in horizontal transmit monostatic mode.



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