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JOINT SOIL MOISTURE EXPERIMENT (JSME)
SCATTEROMETER SYSTEMS

Job Order 46-335

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TECHNICAL REPORT INDEX/ABSTRACT

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13. ABSTRACT

This report contains the scatterometer specifications for the 400-MHz, the 1.6-GHz, and 13.3-GHz scatterometers.

14. SUBJECT TERMS

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ABBREVIATIONS AND ACRONYMS

ADAS	Airborne Data Annotation System
CW	Continuous wave
HHFG	Horizontal-horizontal fixed date
HVFG	Horizontal-vertical fixed gate
ICW	Interrupted continuous wave
IRIG	Interrange Instrumentation Group
JSME	Joint Soil Moisture Experiment
L.O.	Local oscillator
NERDAS	Nasa Earth Resources Data Annotation System
PRF	Pulse repetition frequency
PW	Pulse width
RCVR	Receiver
R/T	Receiver/transmitter
VHFG	Vertical-horizontal fixed gate
VVFG	Vertical-vertical fixed gate
cps	Cycles per second
i.f.	intermediate frequency
preamp	Preamplifier
rf	Radio frequency

1. INTRODUCTION

This report presents the scatterometer specifications for the 400-MHz, the 1.6-MHz, and the 13.3-GHz scatterometer used in the Joint Soil Moisture Experiment (JSME).

A scatterometer is a measuring instrument designed to collect radar backscatter data which, when suitably processed, allows the determination of radar backscattering cross section per unit surface area (σ_0) as a function of incidence angle. The instruments transmit radio frequency (rf) energy from an aircraft mounted microwave antenna. The relative motion between the aircraft and the overflown terrain produces a doppler shift in the received backscattered signals. This frequency shift is proportional to the transmitted frequency, the velocity of the aircraft, and the sine of the incidence angle. By selection of narrow bands of the doppler shifted radar return, the along track spatial resolution can be made comparable to the antenna beamwidth determined crosstrack resolution. The scatterometer specifications are contained in tables I, II, and III.

TABLE I. — 400-MHz SCATTEROMETER SPECIFICATIONS

Transmit Frequency	400.85 MHz ± 1 MHz
Modulation	Interrupted continuous wave (ICW)
Pulse Width	Manual 1-5 4-20 16-40 1.35 ± .1μs 6.9 ± .2μs 29.5 ± .74μs
Pulse Repetition Frequency	42 ± .8 kHz 10.5 ± .75 kHz 4.9 ± .125 kHz
Transmit/Receiver Isolation	120 dB - during transmit
Antenna Coverage	0° to -60° along track 12° across track (two-way)
Isolation between Horizontal and Vertical Antennas	25 dB minimum
Receiver Sensitivity	-148 dBm (6 Hz bandwidth)
Dynamic Range	120 dB
Power (R/T unit)	117 Vac 400 Hz 3ϕ 160 Vac WYE connected
Weigth (R/T unit)	105 lbs.
Dimensions (R/T unit)	19in.×16in.×22in.

TABLE II. – 1.6-GHz SCATTEROMETER SPECIFICATIONS

SYSTEM CHARACTERISTICS				
Transmitter Frequency	1.6 GHz			
Transmitter Power Output	1.0 watts			
Antenna Gain	11 dB			
Antenna Beamwidth, Broadside Two-way	9°			
Antenna Beamwidth, Fore-Aft	120°			
Receive Polarization	Vertical, horizontal and crossed			
Resolution	Dependent upon altitude and data processing (75 ft. broadside at 500 ft. altitude)			
Dynamic Range of σ_o	65 dB			
Input Power, 400 cps-115 V	65 watts – R/T Unit 500 watts – Thermal Oven			
PHYSICAL CHARACTERISTICS				
	Size (inches)			Weight (pounds)
	H ×	W ×	D	
Control/Monitor Unit	10½	19	13½	34
Microwave Receiver	4	7	14	8
Antenna Array (2 req'd)	6	38	17	33
				75

TABLE III. – 13.3-GHz SCATTEROMETER SPECIFICATIONS

Transmit Frequency	13.3 GHz ± 100 MHz
Transmitted Power	1 watt
Modulation	Continuous wave (CW)
Receiver Noise Figure	20 dB @ 10 kHz
Transmit/Receiver Isolation	52 dB
Polarization	Vertical
Antenna Coverage (two-way)	+60° to -60° along track 2.5° crosstrack
Antenna Gain (two-way)	38 dB
Dynamic Range	65 dB
Operational Altitude	1,000 to 3,000 feet
Power	117 Vac 60 Hz 1φ 135 watts
Weight	75 lbs
Dimensions:	
(Control Panel) (Power Supply)	19in.×16in.×10-1/2in. 19in.×16in.×5-1/2in.

2. 400-MHz SCATTEROMETER PRINCIPLES OF OPERATION

2.1 GENERAL OPERATION

The 400-MHz scatterometer transmits a 400-MHz signal alternately from two antennas. One antenna radiates a horizontally polarized wave and the other radiates a vertically polarized wave (E vector along line of flight). The reflected wave is received by both antennas and is processed by individual receivers for each transmitted polarization.

The antenna patterns are shaped to illuminate all terrain within the area bounded by a 12° angle crosstrack and 0° to -60° along track.

Multiple receivers in combination with switches automatically separate the backscatter signals into the following data channels:

1. Horizontally polarized return when transmitting a horizontally polarized wave using a fixed receiver gate (HHFG).
2. Vertically polarized return when transmitting a vertically polarized wave using a fixed receiver gate (VVFG).
3. Vertically polarized return when transmitting a horizontally polarized wave using a fixed receiver gate (HVFG).
4. Horizontally polarized return when transmitting a vertically polarized wave using a fixed receiver gate (VHFG).

Continuous calibration of the backscatter signals is obtained by injecting a calibration signal into each channel and continously monitoring the transmitter power using a calibration channel. The ratio of power return-to-power transmitted is obtained by measuring the ratio of power returned-to-calibrate signal in the channel of interest and the ratio of transmitted power-to-calibrate power in the calibrate channel. The ratio of calibrate signal in the data channel-to-calibrate signal in the calibrate channel is a predetermined system constant. The backscatter-to-transmitted power ratio is transformed into backscatter per unit area versus incidence angle by a computer program incorporating antenna gains, terrain area, altitude, velocity, and other aircraft parameters.

2.2 BLOCK DIAGRAM ANALYSIS

The block diagram of the scatterometer is shown in figure 2-1. The transmitted signal is an interrupted CW (ICW) signal whose width and duty cycle are controlled by the synchronizer. The frequency of the transmitted signal is determined by a crystal controlled oscillator in the transmitter/modulator. In addition to providing the 20-watt peak 400.85-MHz ICW output signal, the transmitter/modulator provides a 400.85-MHz CW signal to the first local oscillator (L.O.) source and a transmit sample (approximately 50 dB down) to the calibrate receiver (see figure 2-2).

The first L.O. source uses the 400.85-MHz transmit CW signal and the 5-MHz and 55-MHz signals from the low frequency source to develop the 340.85-MHz first L.O. signal (see figure 2-3). In addition to providing the first L.O. source with 5 MHz and 55 MHz, the low frequency source also provides the 55-MHz second L.O. and the 4.9995-MHz third L.O. to the five receivers and a 5.0005-MHz signal to the calibrate source (see figure 2-4).

The calibrate source uses the 340.85-first L.O., the 55-MHz second L.O. and the 5.0005-MHz signal from the low frequency source to develop the 400.8505-MHz calibrate signals (see figure 2-5).

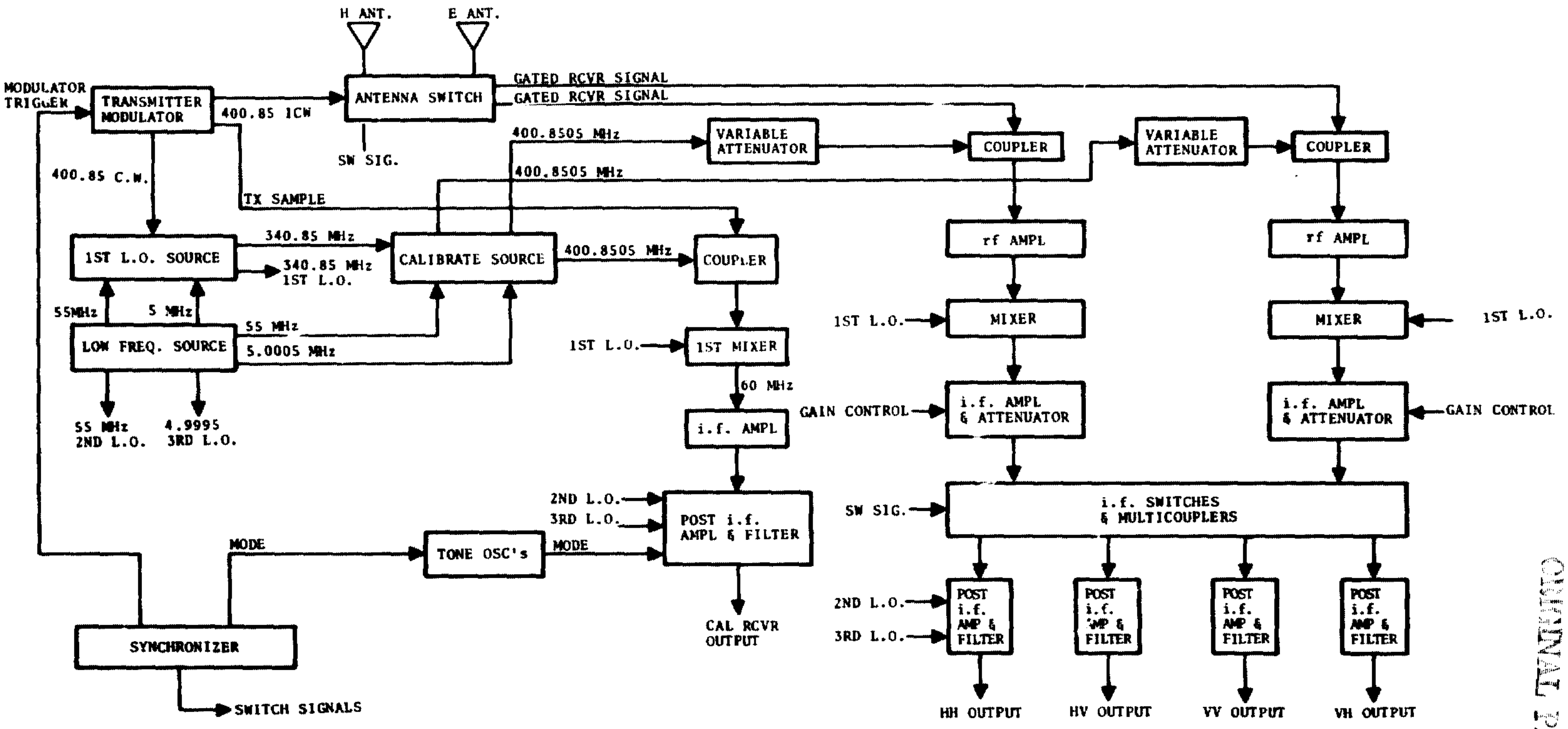

Figure 2-1. – Block diagram 400 MHz scatterometer.

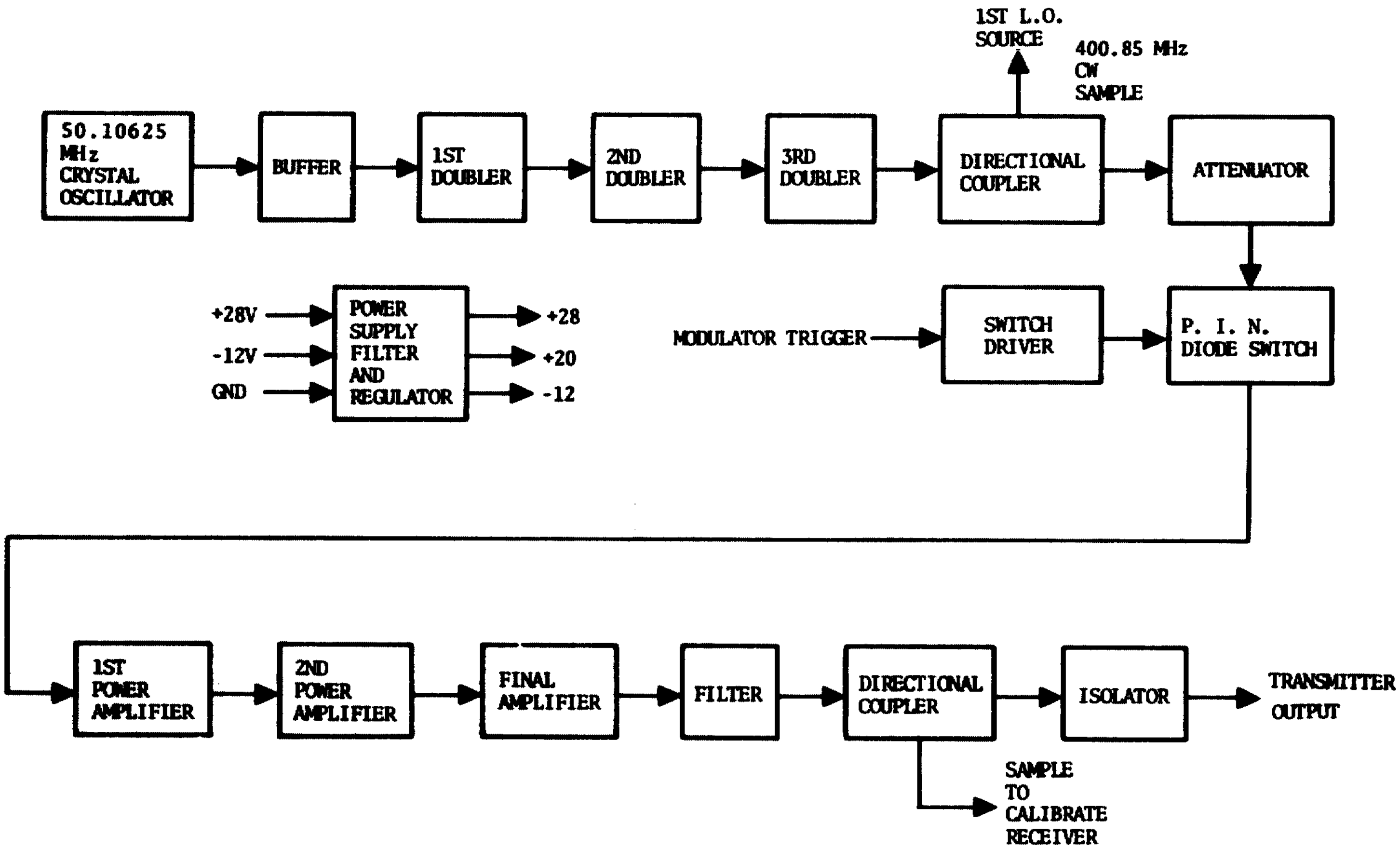

Figure 2-2. — Block diagram transmitter and modulator.

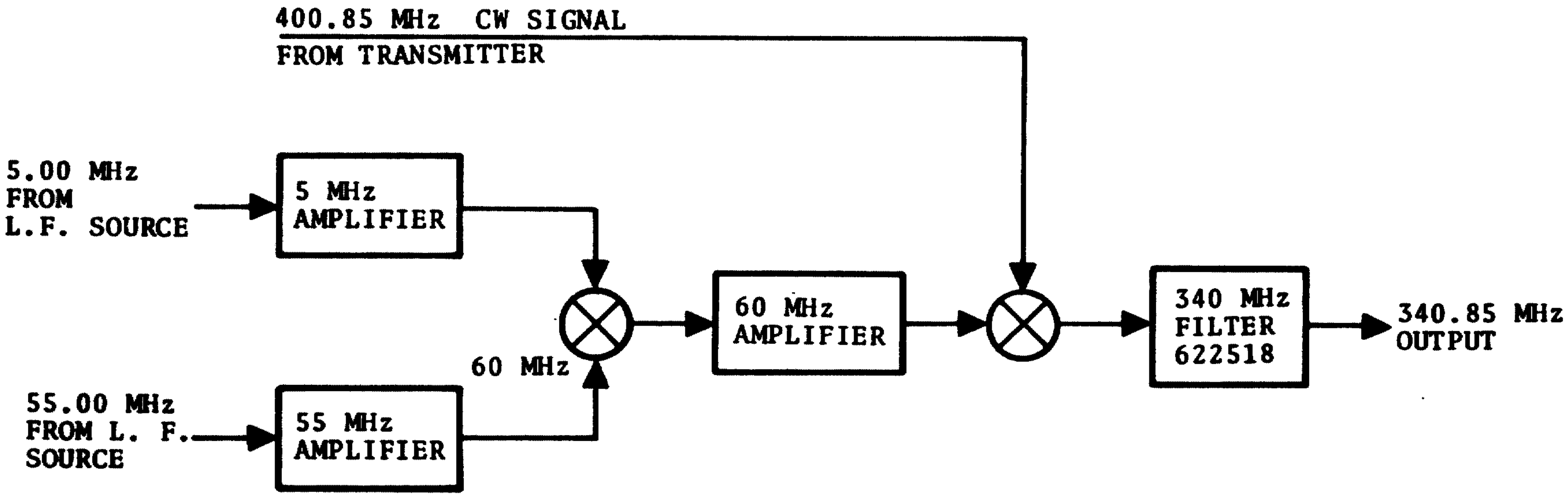

Figure 2-3. — Block diagram first L. O. source.

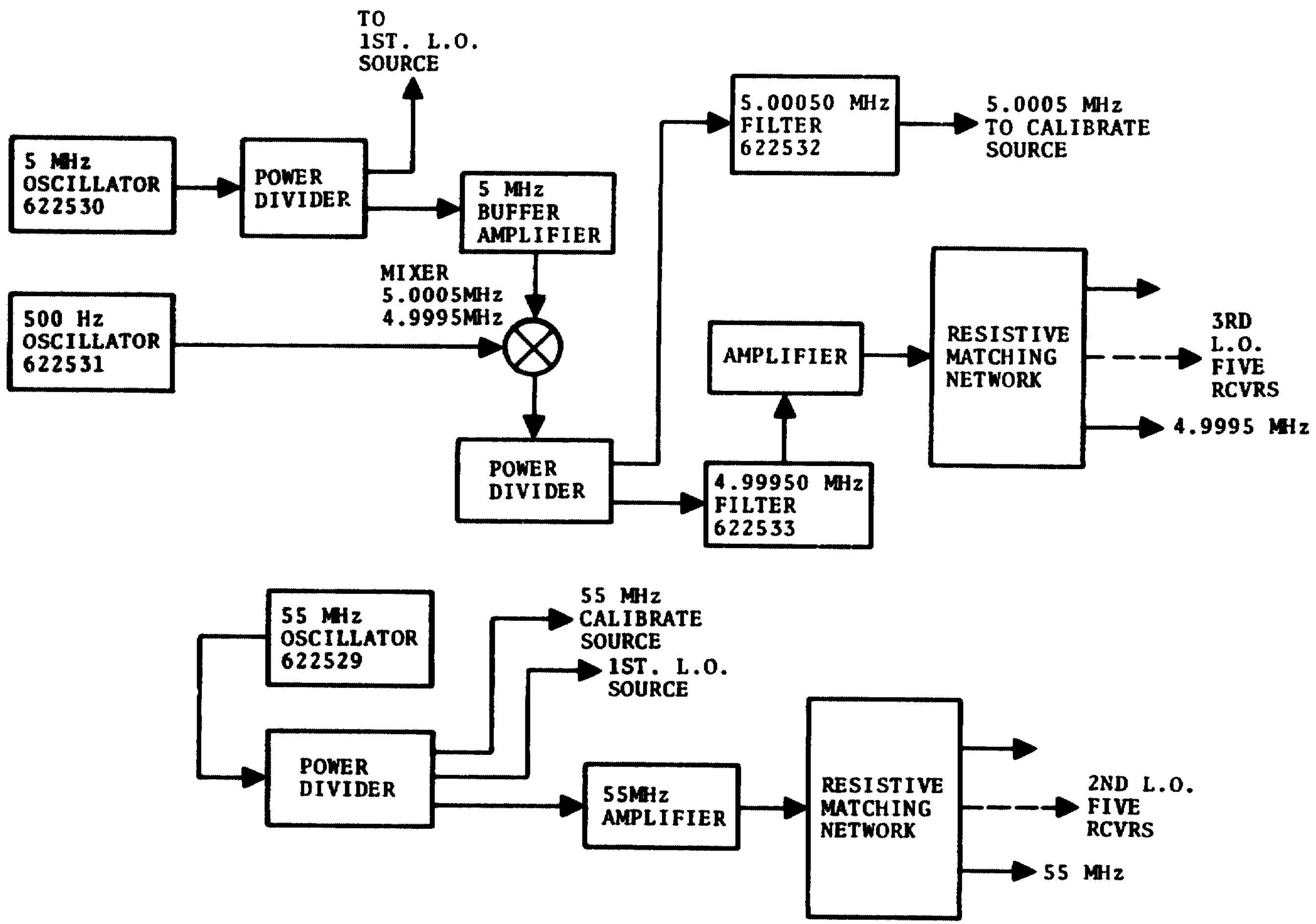

Figure 2-4. – Block diagram low frequency source.

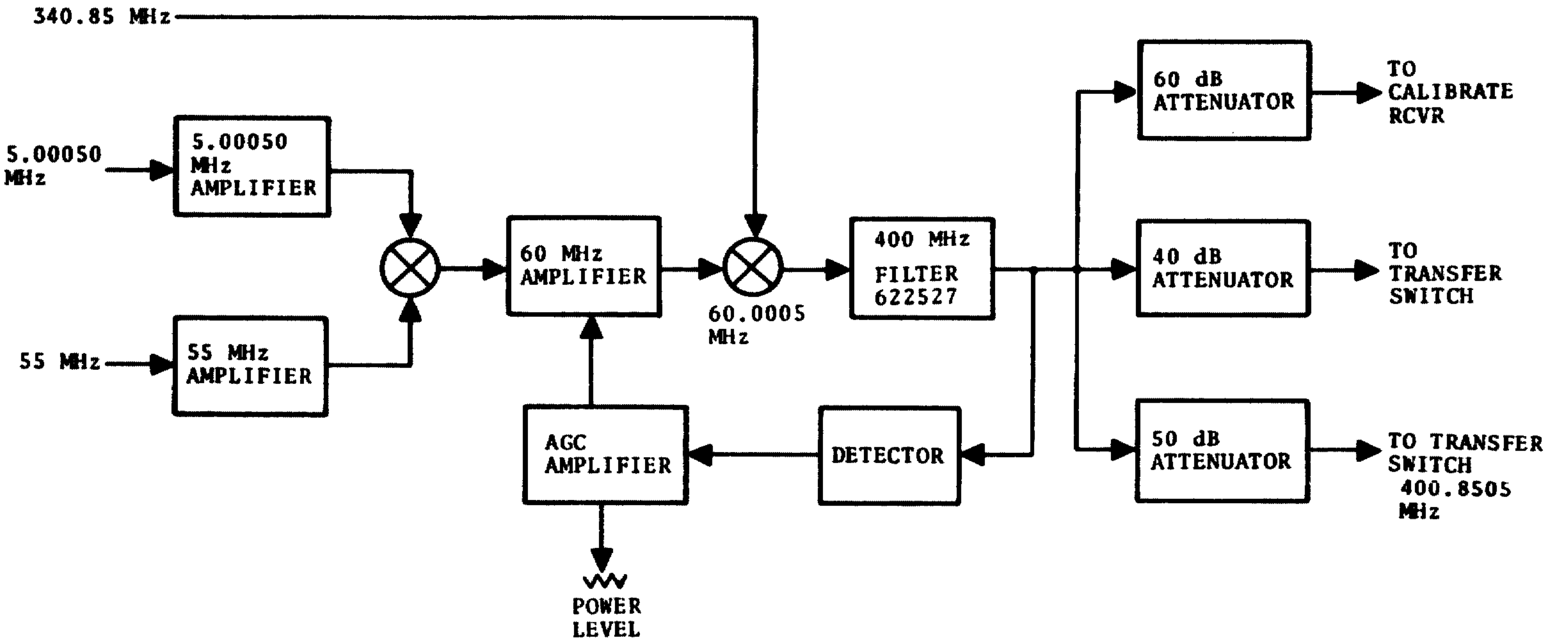

Figure 2-5. — Block diagram calibrate source.

The timing signals are generated by the synchronizer. These include the modulator trigger supplied to the transmitter/modulator and the switching signals to the rf and intermediate frequency (i.f.) switches. The pulse width (PW) and pulse repetition frequency (PRF) are determined by the mode selected by the operator. In the manual mode, the PW and PRF are fixed by the range of altitude selected and are given in table I. The system timing diagram is shown in figure 2-6. The transmitter/modulator is turned on by the modulator trigger pulse and has a fixed 0.2μs delay with respect to the trigger pulse. The rf energy from the transmitter/modulator is alternately switched between the horizontally polarized antenna and the vertically polarized antenna by the antenna switch toggle waveform. Both receiving channels are coupled to their respective antennas by the antenna switch waveform. An inherent delay is built into this waveform to insure that the transmitter is turned off before the antennas are switched to their receivers. The first L.O. switching waveform controls the L.O. input to the first receiver mixers. The first L.O. excitation is removed during transmission to provide additional transmitter/receiver isolation. Further isolation is accomplished in the i.f. switches where receiver gating is done.

The scatterometer has two identical receiver channels. One is designated horizontal and the other vertical. During the receive part of a system cycle the signals that appear at the two antennas are fed to their respective receivers. The detailed discussion of a single channel that follows is applicable to the other channel as well.

The received signals from the antenna are gated by the antenna switch and applied to a directional coupler which provides a means of injecting the calibrate signal. The gated receive signal is attenuated very little by the coupler (the insertion

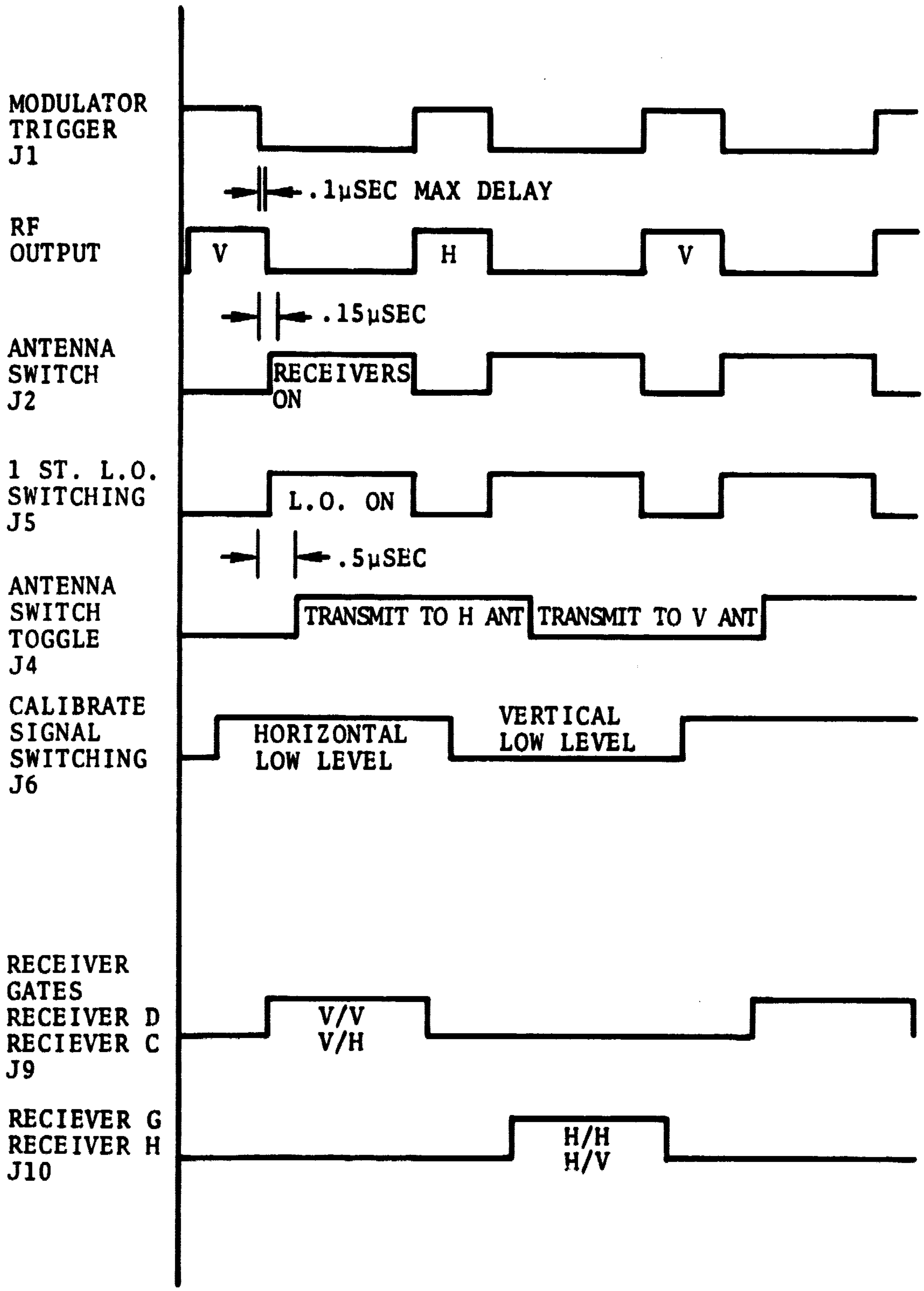

Figure 2-6. — Scatterometer timing waveforms.

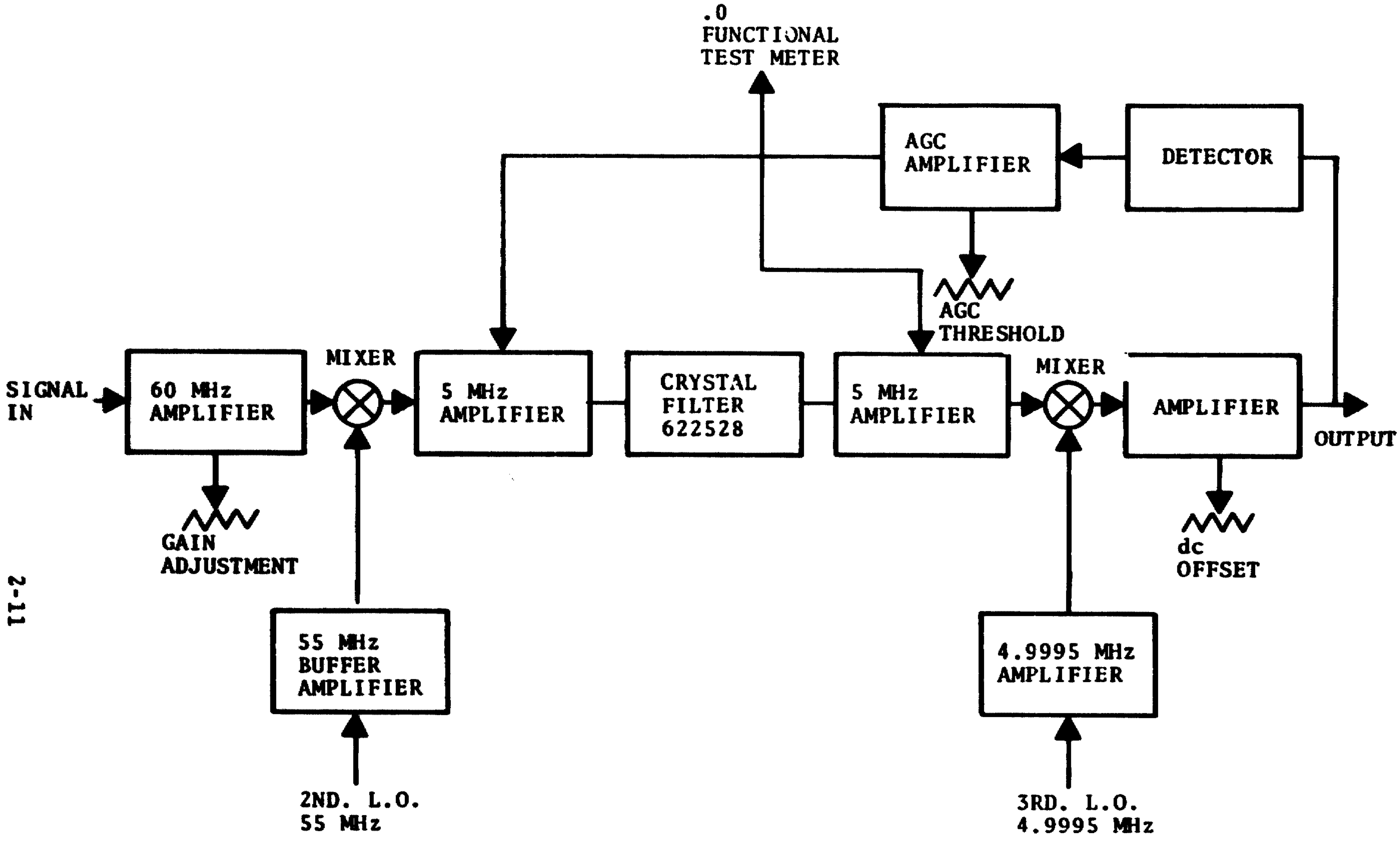

Figure 2-7. — Block diagram post i.f. amplifier.

the 400.8505-MHz calibrate signal and the 400.85-MHz transmitter sample. The mixer down converts these signals to 60.0005 MHz and 60 MHz. The post i.f. amplifier further down converts these signals to the audio range (1 kHz and 500 Hz).

Subcarrier oscillator tones are combined with the calibrate receiver output to indicate mode and gain settings within the scatterometer system. Table IV provides a listing of the frequencies indicative of various conditions.

The power supply provides the seven dc voltages used in the R/T unit. A block diagram is shown in figure 2-8. The primary input to the supply is 115-Vac 3-phase 400-Hz prime ac power. Fuses which are on the front panel of the R/T unit are used as protective devices. The power supply provides +28, +24, +12 +4.4, -12, -20, and -45 volts using conventional series regulators with Zener control.

The antenna is a 10-foot by 4-1/2-foot dipole array. The 17 E-plane dipoles are interleaved with 16 H-plane dipoles and each array is fed with a -27 dB Tchebyscheff crosstrack taper. The crosstrack 3-dB beamwidth (two-way) is 12° and the along-track pattern has a cosecant squared form.

TABLE IV. – SUBCARRIER OSCILLATOR FREQUENCIES

Position		Frequency
CHANNEL 1.	(Mode Switch)	
Auto	(1-5)	370
Auto	(4-20)	382
Auto	(16-40)	394
Manual	(1-5)	406
Manual	(4-20)	418
Manual	(16-40)	430
CHANNEL 2.	(Horizontal Gain)	
Position 1		518
Position 2		533
Position 3		548
Position 4		572
Position 5		587
Position 6		602
CHANNEL 3.	(Vertical Gain)	
Position 1		675
Position 2		697
Position 3		719
Position 4		741
Position 5		763
Position 6		785

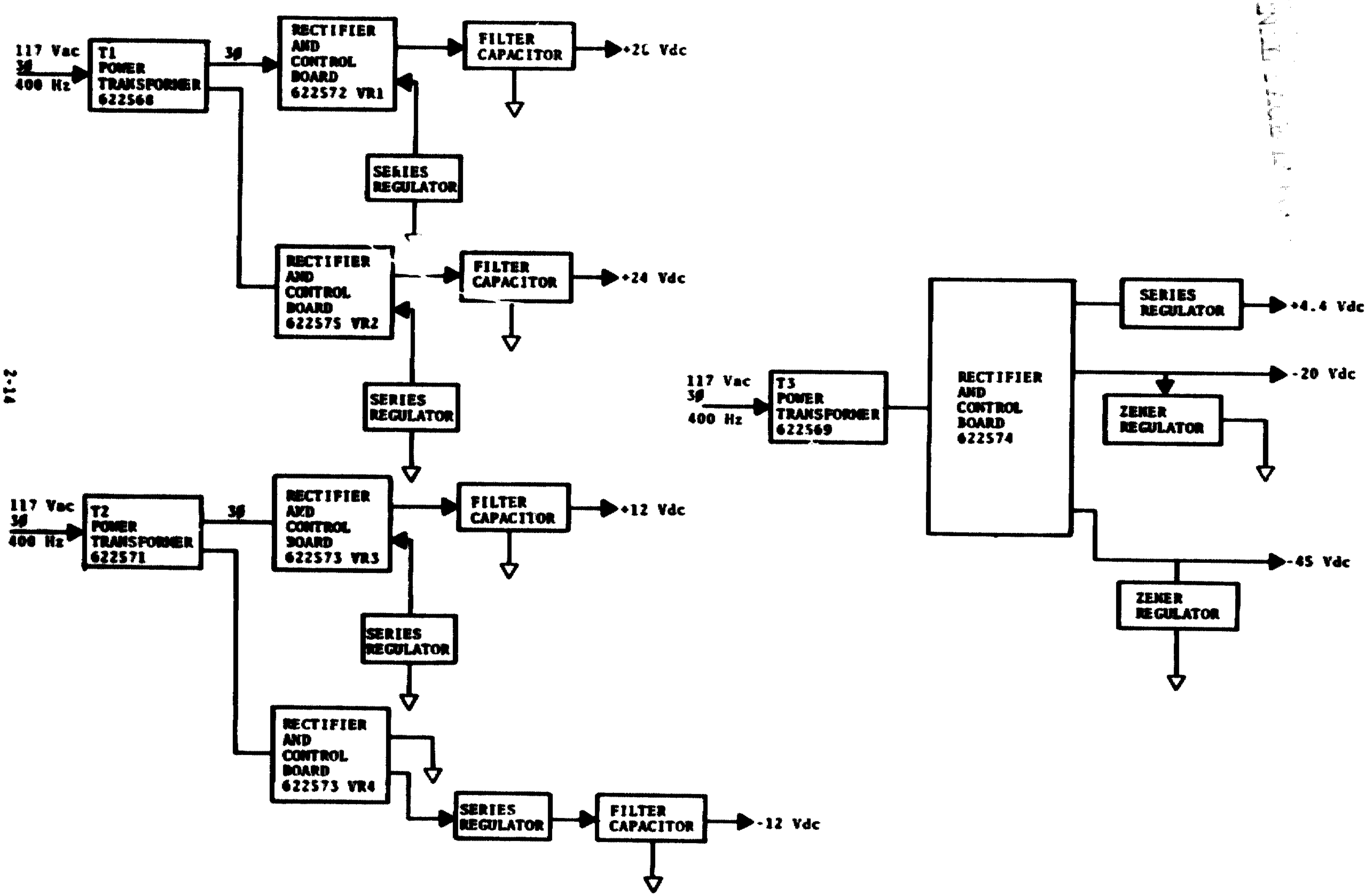

Figure 2-8. — Block diagram power supply.

3. 1.6-GHz SCATTEROMETER PRINCIPLES OF OPERATION

3.1 GENERAL OPERATION

Radio frequency energy at 1.6 GHz is transmitted by one of two dipole arrays to generate vertically or horizontally polarized fan-shaped beams. The radiated energy has a wide beamwidth (±60°) along track and a narrow beamwidth (±5°) crosstrack. Both linear and cross-polarized returns are received and processed for each transient polarization.

As the aircraft is flown, data is received from all angles of incidence simultaneously. The folding of the fore and aft signals in a zero i.f. system results from the mixing of the received signal with a small portion of the transmitted signal. The output data, therefore, consists of four audio signals: 2 linear polarized channels in phase quadrature with each other and 2 cross-polarized channels in phase quadrature. The separation of the fore and aft Doppler signals is accomplished by the insertion of phase quadrature signals and summation during data reduction.

A calibration reference signal is provided by employing a PIN diode modulator to inject an absolute rf level reference into the receiver mixer for comparison to the received signals during data reduction.

From a knowledge of the received signal amplitude, the radar system parameters, and the aircraft flight parameters, the backscattering cross section per unit surface area (σ_0) as a function of incidence angle can then be determined.

3.2 FUNCTIONAL DESCRIPTION

The scatterometer consists of an antenna, transmitter/receiver, and control/monitor. A block diagram of the system is shown in figure 3-1.

3.2.1 ANTENNA

The scatterometer transmitting antennas are dipole arrays that alternately generate vertically and horizontally polarized, fan-shaped beams. The radiation patterns have nominal beamwidths of 12° crosstrack and 120° along track. The nominal antenna gain is 11 dB.

A diode switch located on the transmitter/receiver is used to switch the rf energy to the vertically or horizontally polarized array. The switch can be operated automatically at 0.5-Hz rate, or manually fixed for either vertical or horizontal transmit polarization.

The receiving antennas are dipole arrays identical to the transmitting antennas. Radio frequency energy is received by the vertically and horizontally polarized arrays to provide linear and cross-polarized information. A bandpass filtering network is incorporated in the antenna assembly to reduce radio frequency interference.

3.2.2 TRANSMITTER/RECEIVER

The transmitter is a fix-tuned solid-state device with a CW power output of 1 watt at 1.6 GHz. The rf energy is coupled through a stripline microwave section, through an isolator, and to the diode switch for transmission to either the vertically or horizontally polarized antenna. A portion of the transmitted signal is coupled into the stripline for mixing with the received signals.

The stripline microwave section contains the receiver-mixer diodes, the calibration reference PIN diode modulator, and power leveler and power monitor circuits. Single-ended mixers are utilized to convert the received signals from the vertically and horizontally polarized receiver antennas into two quadrature pairs at a zero i.f. frequency. A power leveler circuit maintains a constant L.O. level to the mixers.

A calibration reference signal (1.9 kHz) from the control/monitor is used to modulate two PIN diodes within the stripline section. An absolute rf calibration source is thereby provided at the receiver input for each quadrature pair.

Included in the stripline is a detector-to-monitor transmitter power at the control/monitor. The circuit produces 250 μA for 1 watt of rf energy.

The two quadrature pairs at the mixer output are coupled to four preamplifiers (preamps). The preamps are designed to give a linear gain of approximately 60 dB over the Doppler spectrum.

3.2.3 CONTROL/MONITOR

The control/monitor unit conditions and codes the data, and allows the operator to perform various system operational functions. The switching functions provided are: land/sea operation; vertical, horizontal, or time-share transmit polarization; calibration/coding signal on-off; gain control switching for all four channels; and signal monitoring selection.

The data signals from the four preamplifiers on the transmitter/receiver are first coupled to the linear/cross-polarized switching circuits. These circuits maintain the proper signal order

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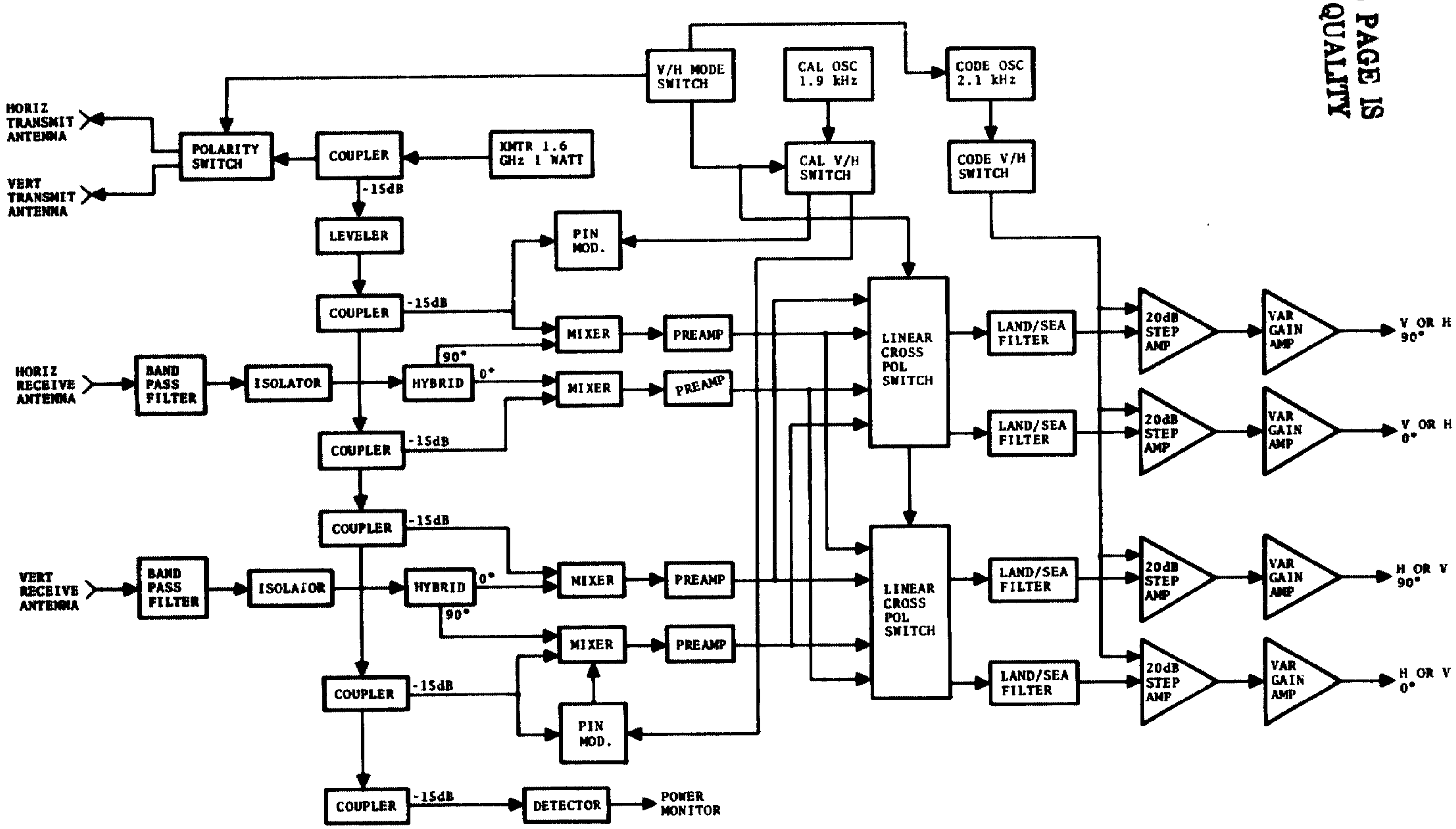

Figure 3-1. — Block diagram 1.6 GHz scatterometer.

at the receiver output for the corresponding transmit polarization. The signal is then passed through a filter that adjusts the roll-off characteristics of the low-frequency Doppler signals for land or sea operation.

Finally, the signal is passed through two gain adjustable amplifiers. The first amplifier provides amplification from 0 to 20 dB in 5-dB steps. The second amplifier provides continuously variable gain adjustment from 0 to 10 dB.

Two oscillators are employed for signal calibration and channel identification. The calibration oscillator (1.9 kHz) modulates the L.O. in the transmitter/receiver to provide an absolute rf reference level at the receiver-mixer input. The coding oscillator (2.1 kHz) identifies which polarization is being transmitted and which quadrature pair is linear or cross-polarized. The level of the oscillator in the cross-polarized pair is set 15 dB below that of the linear. The coding oscillator is injected into the first gain controlled step amplifier.

4. 13.3-GHz SCATTEROMETER PRINCIPLES OF OPERATION

4.1 GENERAL OPERATION

The instrument transmits a 13.3-GHz CW signal via a vertically polarized leaky waveguide antenna. The reflected energy is received by an identical antenna after which it is converted to a zero baseband audio signal.

The relative motion between the aircraft and the terrain produces a Doppler shift in the frequency of the backscattered signal. This shift is proportional to the velocity of the aircraft and the sine of the incidence angle.

Both positive and negative Doppler shifts occur representing fore and aft directions. The spectrums are folded in the audio output of the zero i.f. mixer. In order to provide a means for separation of fore and aft returns, quadrature signals are developed at rf prior to zero i.f. conversion. During the data reduction process, quadrature carrier insertion and summation restablishes the fore/aft spectrum about the inserted carrier.

A calibration signal proportional to transmitted power is inserted prior to conversion, thus, providing a means for correction of transmitter power output and receiver gain changes.

4.2 BLOCK DIAGRAM ANALYSIS

The block diagram of the scatterometer is shown in figure 4-1. The klystron transmitter provides the 1.5-watt 13.3-GHz CW signal to a waveguide assembly which contains two 36-dB L.O. directional couplers, a receive short-slot coupler, and a power monitor directional coupler. The output from the waveguide assembly is applied to the transmit antenna which radiates the rf electromagnetic wave in a fore-aft fan beam.

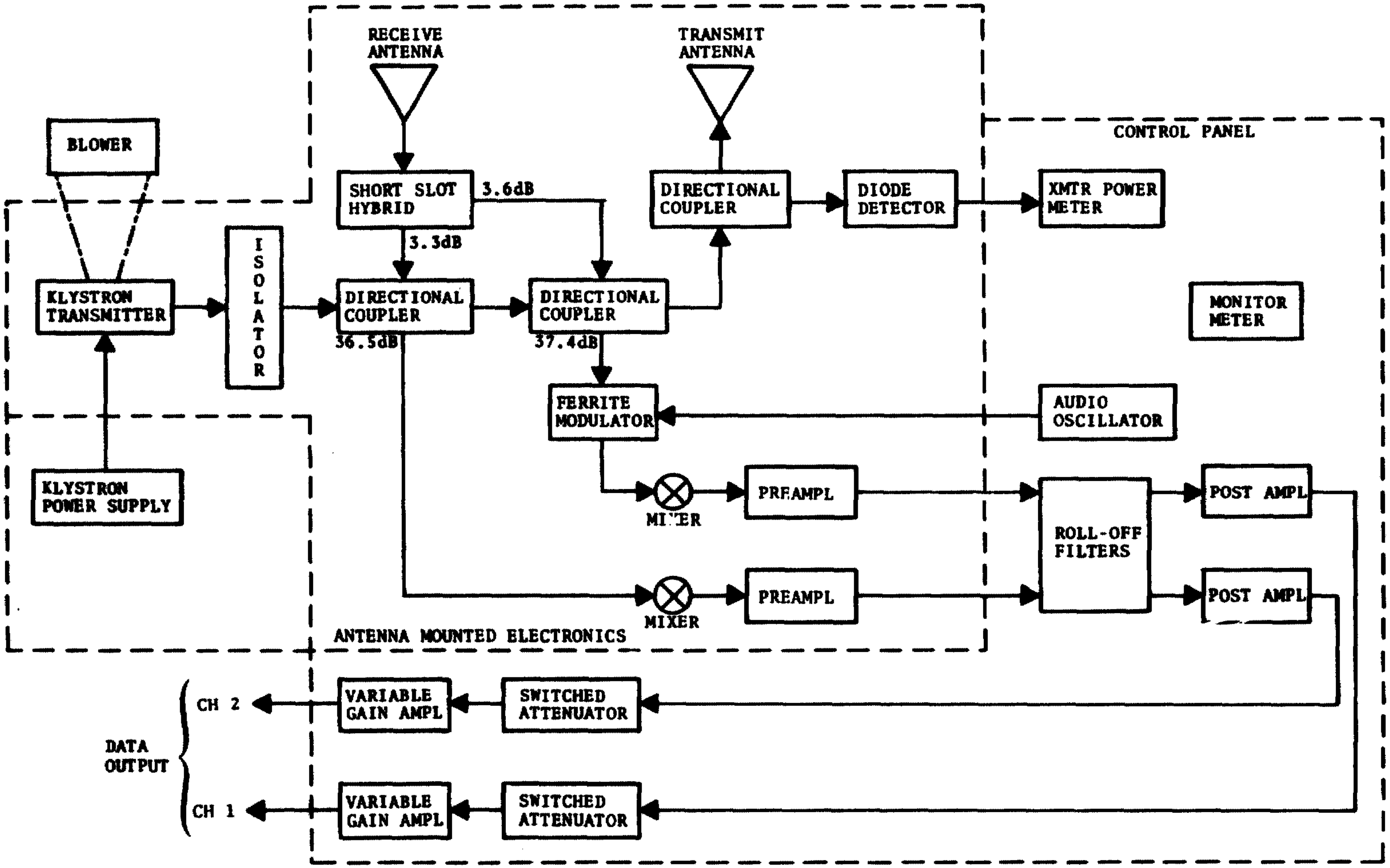

Figure 4-1. – Block diagram 13.3 GHz scatterometer.

The backscattered energy from the overflown terrain is received by an identical receive antenna. The antenna output is applied to the waveguide assembly where a 90°-phase lag is provided to the channel 1 signal. Both receive channel signals are combined with the samples of the transmitter signal and applied to the rf to audio conversion mixers. The audio range mixer output signals are applied to low noise preamplifiers where they are amplified by 40 dB.

A waveguide Ferrite modulator is used to insert the 12-kHz reference signal into the channel-1 L.O. signal. A stable audio oscillator provides the modulation input to the Fenite modulator.

After preamplification, high pass filters are used to provide for roll-off of the low-frequency Doppler returns. The filter used (land or water roll-off) is operator selected dependent upon the expected backscatter characteristics. The land filter provides a 6-dB per octave roll-off with a low frequency corner at about 500 Hz. The water filter provides a 6 dB per octave roll-off with a low frequency curve at about 5 kHz.

After filtering, the signals are amplified by 20 dB gain post-amplifiers. A switched attenuator (0/-20 dB) is provided to decrease the signals applied to the variable gain amplifiers. The variable gain amplifiers provide 20 to 40 dB of gain in four steps (20 dB - X1, 26 dB - X2, 34 dB - X5, 40 dB - X10).

5. SCATTEROMETER SYSTEMS DATA RECORDING

The scatterometer analog data outputs will be recorded on the aircraft Mincom 110 14-channel system. The two 13.3 data channels will be 108 kc carrier frequency modulation (FM) on adjacent channels of the same head. The four 1.6 data channels will be 108 kc carrier FM on adjacent channels of the same head. The four 400 data channels and one reference channel will be 108 kc carrier FM. Interrange Instrumentation Group (IRIG)-A will be provided on a direct channel. Airborne Data Annotation System (ADAS) or NASA Earth Resources Data Annotation System (NERDAS) aircraft parameter information will be provided 225 kHz carrier FM or direct, dependent on whichever formatting system is available on the aircraft in March 1976. The 14th track will be the control track with a 50-kHz reference. The recording speed will be 30 inches per second (ips).