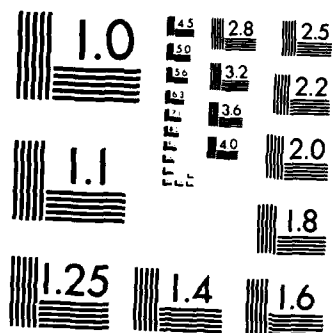


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A Multi-Channel Radar Receiver

ALEXANDER W. BISHOP
JAMES I. METCALF



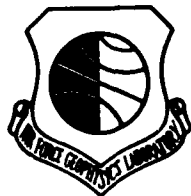
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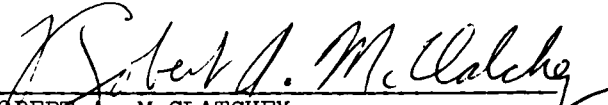
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"This technical report has been reviewed and is approved for publication"

FOR THE COMMANDER


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A radar receiver design is presented that yields logarithmic and coherent signals of two orthogonal polarizations derived from each of two S-band transmitted frequencies. The radar is to be used for measuring Doppler velocity and polarization parameters of meteorological backscatter. The receiver design goals include phase and amplitude balance of 5 degrees and 0.5 dB between signals of opposite polarization. The logarithmic amplifiers are specified to have linearity of ± 0.5 dB over a dynamic range of 90 dB. High-power ferrite switching devices are to be used to alternate the polarization of transmitted signals between orthogonal states on a pulse-to-pulse basis and to permit reception of co-polarized and cross-polarized signal components. <i>Kennedy, J. M.</i>				
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A Multi-Channel Radar Receiver

1. INTRODUCTION

The 10-cm Doppler weather radar at AFGL is being modified to enable polarization diversity backscatter measurements. The goal of this development is to deduce dynamical and microphysical characteristics of clouds and precipitation from the radar measurements. Recent research has shown that, in some circumstances, measurements with linear and circular polarization base-vectors yield complementary rather than redundant results.¹ While one or the other may be preferable for a particular application, a comparison of results derived from signals of the two polarization states is desirable.² Both linear and circular polarizations involve ambiguities in the interpretation of the received signals that can be resolved only by simultaneous or near simultaneous measurements with alternating orthogonal transmitted polarizations. Hence, the radar is intended to operate with pulse-to-pulse switching of the transmitted signal between

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1. Jameson, A. R. (1983) Microphysical interpretation of multi-parameter radar measurements in rain. Part I: Interpretation of polarization measurements and estimation of raindrop shapes, J. Atmos. Sci. 40:1792-1802.
2. Atlas, D. (1984) Highlights of the Symposium on the Multiple-Parameter Radar Measurements of Precipitation: Personal reflections, Radio Sci. 19:238-242.

either horizontal and vertical or right and left circular polarizations.

The radar was originally built to operate with two carrier frequencies, 2710 and 2760 MHz. Depending on the particular measurement objective and analysis technique, polarization-related parameters are to be derived from one or the other of the two frequencies. Furthermore, measurements may require either the complex signal output of a linear receiver, or the wide dynamic range of a logarithmic receiver, or both. Hence, both logarithmic and coherent linear output are to be provided for each polarization at each of the two carrier frequencies.

We do not intend to describe possible experiments in detail here. However, because one may justifiably ask why so many outputs are to be available, we offer some examples of parameters derived from them. Although some of our measurements will be conducted at a single frequency, we anticipate dual-frequency operations, as heretofore, using 2710 MHz for Doppler velocity parameters and 2760 MHz for reflectivity. In dual polarization measurements, we shall want to derive the autocovariance functions and the cross-covariance function from the 2710 MHz signals in the two polarization channels. The power in each polarization channel from the 2760 MHz signal will be used to derive reflectivity, differential reflectivity, and linear or circular depolarization ratio, as appropriate. The coherent 2710 MHz output, being gain-controlled, cannot be used to derive power or power ratios; it does provide the complex cross-correlation $R_{12}(0)/(R_1(0)R_2(0))^{1/2}$. Derivation of the cross-covariance amplitude ratio from the cross-correlation requires that the depolarization ratio be available from the 2710 MHz signal, that is, from a logarithmic receiver. We then can compute (for circular polarization):

$$CCAR = R_{12}(0)/R_2(0) = (\text{cross-correlation}) \times (CDR)^{1/2}$$

Thus, we use the logarithmic outputs at each frequency and polarization and the coherent outputs at 2710 MHz for a variety of experimental objectives. Comparisons of the coherent outputs from the two frequencies will be useful in evaluating certain characteristics of the radar system, since differences in backscatter between the two frequencies will generally be negligible. Finally, the unamplified intermediate frequency (IF) outputs are to be available for precise comparison with similar outputs from other radars operating in different frequency bands.

The design of the receiver that makes all of these outputs available has the advantage that all four signal components (two polarizations and two frequencies) are handled identically, that is, filters, power dividers, switches, amplifiers, and other components are identical in all four lines. Objectives of the receiver design are a high degree of isolation among channels, sufficient sensitivity for the detection of weak meteorological backscatter, wide dynamic range, and minimal channel-to-channel differences of phase tracking and amplitude response.

Previous reports described the radar,³ the design of the polarization diversity modification,⁴ the preliminary design of the data processor,⁵ and the implementation of the antenna modification.⁶

The following sections describe the radio-frequency (RF) section of the receiver, including the high-power microwave switches, and the intermediate-frequency (IF) sections.

2. RADIO-FREQUENCY (RF) SECTION

Figure 1 illustrates the radio-frequency (RF) section of the four-channel, dual-frequency polarimetric receiver with associated high-power RF switches and polarizer. Located directly behind the 24-ft-diameter Cassegrain antenna are the sloped septum polarizer and associated waveguide switches which select either horizontal, vertical, or circular polarization. A more detailed description of the polarizer is included in the system design report.⁴

2.1 High Power Switching

Three high-power ferrite switching devices (manufactured by Raytheon Co.) direct the energy from the dual frequency radar transmitters to the appropriate port of the polarizer and also direct received signals into the proper receiver channels. These devices are shown schematically as circulators in Figure 2. In relation to the transmitted signal, each device comprises a magic T as the input element, a dual phase shifter, and a 3 dB hybrid coupler as the output element. Isolation between the output ports of a single switching device is about 20-25 dB. By using three devices in a cascading configuration, we can achieve 40 dB of isolation between output ports 2 and 3 on transmission and also between receive ports Rx1 and Rx2 on reception. Detailed specifications for the combined switching devices are presented in the Appendix.

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3. Bishop, A. W., and Armstrong, G. M. (1982) A 10-cm Dual Frequency Doppler Weather Radar, Part I: The Radar System, AFGL-TR-82-0321 (I).
 4. Ussailis, J. S., Leiker, L. A., Goodman, R. M. IV, and Metcalf, J. I. (1982) Analysis of a Polarization Diversity Weather Radar Design, AFGL-TR-82-0234, AD A12166.
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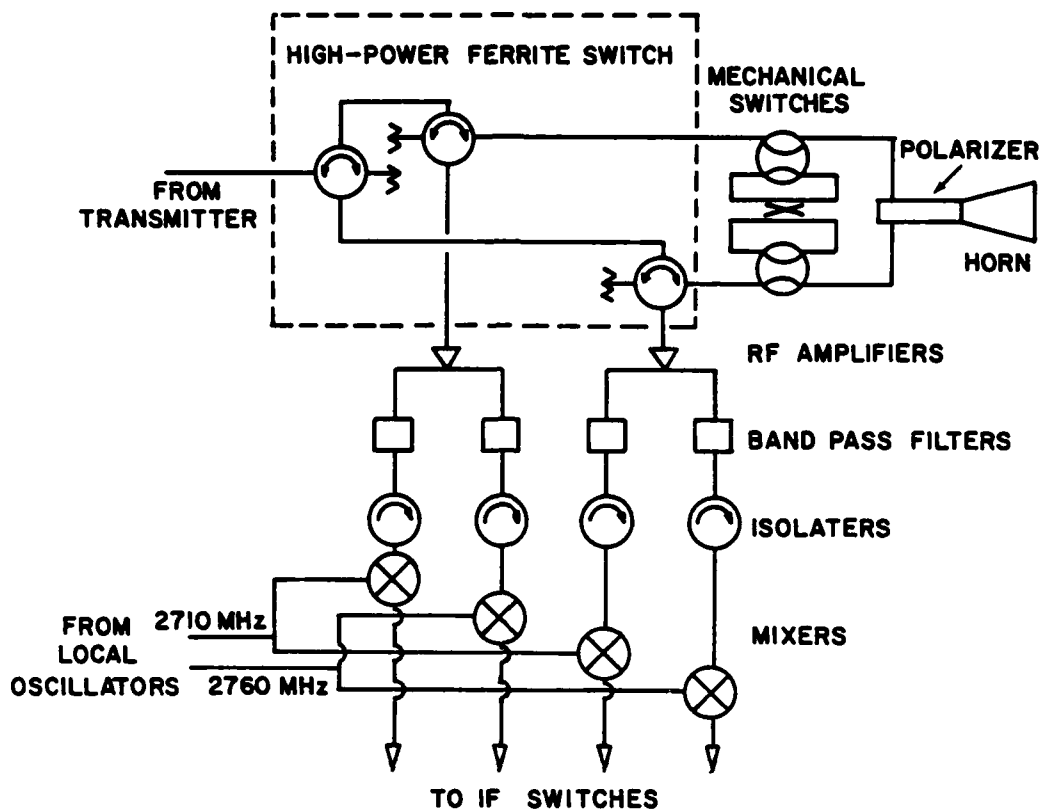


Figure 1. Radio-Frequency (RF) Section of Dual-Frequency, Dual-Polarization Radar Receiver. Waveguide switches permit operation with either linear or circular polarization. Two of the three fast-switching circulators serve as transmit/receive duplexers. Components are described in Section 2

Energy from the dual frequency transmitter enters at port 1 and is directed to either output port 2 or 3, depending upon the settings of the phase shifters. The settings of the circulators depicted in Figure 2 correspond to the transmission of horizontal or right circular polarization (depending on the setting of the polarizer switches). When the high-power transmitted pulse passes through the phase shifters, the phase shift varies, and the effective output isolation varies correspondingly. Hence, it is necessary to reset circulators B and C between transmission and reception to maintain low loss in the receiver path. The timing logic for switching the circulators is shown in Figure 3. Because the transmitted signal is being alternated between horizontal and vertical (or between right and left circular) and because the horizontally polarized received signal always enters

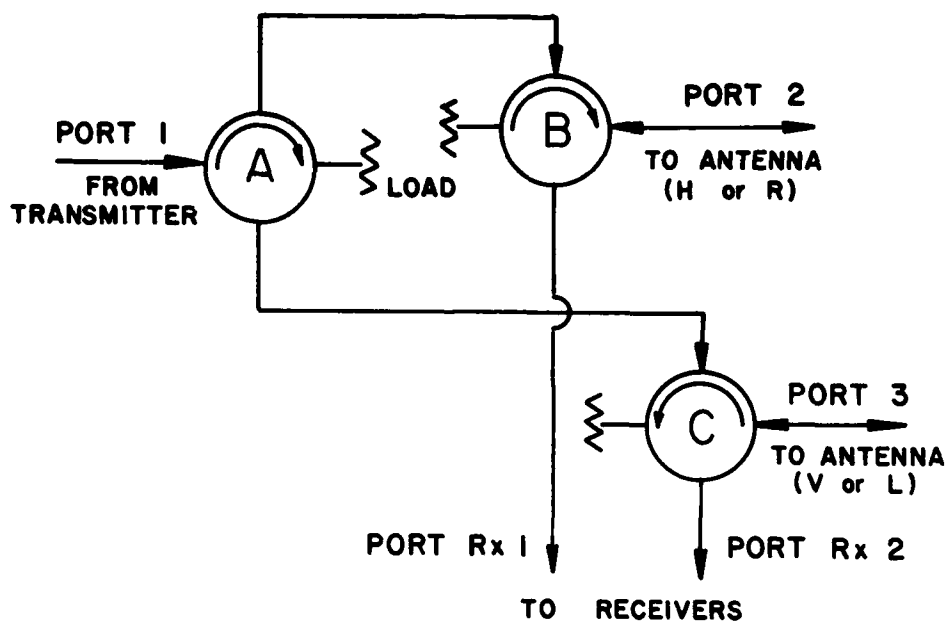


Figure 2. Schematic Diagram of High-Power Microwave Switch. Three switchable circulators (A, B, C) enable alternating transmission through ports 2 and 3, and reception of two orthogonal polarizations through receiver ports Rx1 and Rx2. Setting of circulators shown corresponds to transmission of horizontal or right circular polarization

circulator B while the vertically polarized signal always enters circulator C, the co-polarized and cross-polarized received signals alternate with each other in the two outputs to the receivers. This problem of alternating polarization is handled in the receiver channels and is discussed in Section 3. A different timing sequence is required if the two carrier frequencies are pulsed at different rates.

2.2 Signal Separation

Signals received from both transmitted frequencies are first amplified in two low-noise RF amplifiers, one for each polarization component. (These components alternate as co-polarized and cross-polarized if the transmitted polarization is being alternated). The RF amplifier (Micromega Model 70149) is extremely stable, has level protection, exhibits a noise figure of 1.2 dB over the 2700-2900 MHz frequency band, and has a gain of 20 dB, an input and output VSWR of 1.5:1, and a maximum output power of +10 dBm for a 1 dB compression. After this amplification at RF, each of the signals is equally power divided into two channels, which are filtered to separate the two frequency components.

The RF filters, centered at 2710 MHz and 2760 MHz, reduce the spurious signal levels from the adjacent channel by more than 50 dB and exhibit a phase

change of less than 2° over an 8 MHz bandwidth. On each of the resulting four channels, a series of three circulators with carefully matched loads provides 90 dB of additional isolation. The combination of the bandpass filters, the power dividers, and the isolators serves to isolate the mixers from one another by more than 160 dB at both RF and IF, preventing generation of unwanted sidebands in the mixers. The signals are amplitude balanced and phase balanced before entering the mixers.

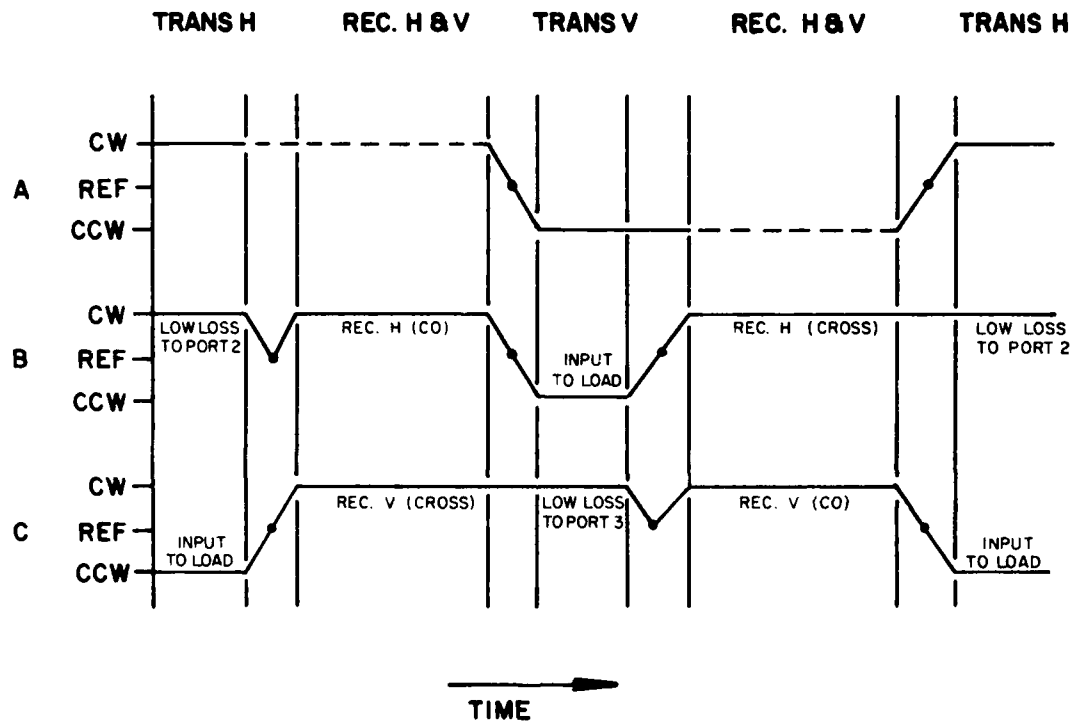


Figure 3. Switching Sequence for Switchable Circulators Shown in Figure 2. Transmission time is 1 μ sec; receiving interval is variable, but typically 1-10 msec. Transition time between clockwise and counterclockwise circulator settings, or vice versa, or to reset after transmission is less than 10 μ sec. The low-loss path through the switch during transmission corresponds to the "on" antenna port for that pulse

The mixers (RIIG Model IRD2.7C14HB) are of the image rejection quiet type and can accept input signals as high as +5 dBm. The two mixers for each frequency are phase balanced to within $\pm 5^\circ$ and amplitude balanced to within ± 0.5 dB.

Local oscillator frequencies for the mixers are derived from phase locked oscillators that are referenced to the radar master oscillator. The outputs of the phase locked oscillators are bandpass filtered, isolated, phase balanced, and amplitude balanced before being injected into the mixers.

3. INTERMEDIATE-FREQUENCY (IF) SECTION

3.1 Selection of Co-Polar and Cross-Polar Signals

The received signal in each mixer alternates between co-polarized and cross-polarized, as discussed in Section 2. Effective operation of the automatic gain-controls for the linear receivers requires that this alternation be compensated, so that the input to each linear receiver is always either co-polarized or cross-polarized. The required switching can take place at either RF or IF, but IF is the simpler and less costly option. Figure 4 illustrates switching at IF using a network of single-pole double-throw switches exhibiting typically 90 dB isolation, 1.1:1 VSWR, and 1.3 dB insertion loss.

3.2 IF Signal Flow

The receiver configuration for a single channel after IF switching is shown in Figure 5. Each signal is amplified, first in a low noise amplifier and then in a high performance amplifier, to achieve the proper signal level for the linear and logarithmic amplifiers. The signals are level set, bandpass filtered, amplitude balanced, and phase balanced.

We intend that the phase change introduced by the bandpass filters not vary by more than 2° across the information bandwidth. Factors affecting the IF filter specifications were discussed in the system design report.⁴ Final specifications of these filters will be prepared after one receiver channel has been assembled and evaluated for intermodulation products in the mixer outputs. After balancing, each signal is divided into three components of equal power. Two of the outputs are for the amplifiers, and the third is for general use. The linear amplifiers derive their reference frequency (30 MHz) from the 5 MHz master oscillator signal multiplied by a factor of 6, thus preserving system phase coherence. The automatic gain controls for the linear amplifiers are derived from the pulse-pair processor and control each range cell to provide a linear response over an 80 dB dynamic range. The logarithmic amplifiers are designed to provide a uniform response of ± 0.5 dB over a 90 dB dynamic range.

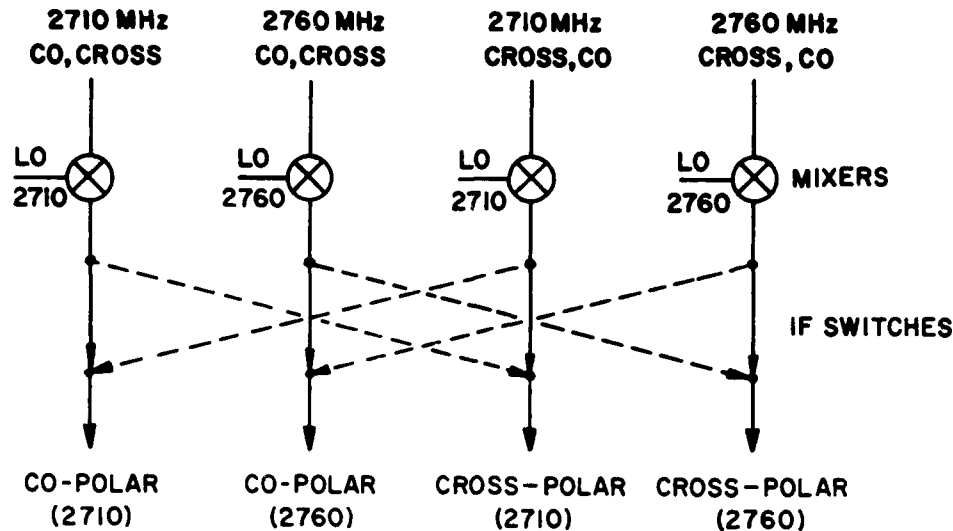


Figure 4. Intermediate-Frequency (IF) Switches for Selection of Co-Polarized and Cross-Polarized Signals. The solid lines show the signal flow for one pulse. The dashed lines show the flow for the following pulse, yielding co-polar only in the two left channels, and cross-polar only in the two right channels.

1. SUMMARY

The radar receiver we have described is designed for flexible dual-polarization operations with two radio frequencies. Phase and amplitude balance is to be maintained between signals of opposite polarization derived from each of the carrier frequencies. Toward this end, each pair of mixers is specified to track phase within $\pm 5^\circ$ and amplitude within ± 0.5 dB. Other components are specified to higher accuracies, where possible. Logarithmic amplifiers are specified to have a linearity of ± 0.5 dB over a dynamic range of 90 dB. Receiver outputs for each polarization and from each carrier frequency (2710 and 2760 MHz) include in-phase and quadrature components from a coherent receiver with automatic gain control, the logarithm of received power, and the unamplified IF signal. Future reports are planned to describe the performance of the data processor and of the completed radar system.

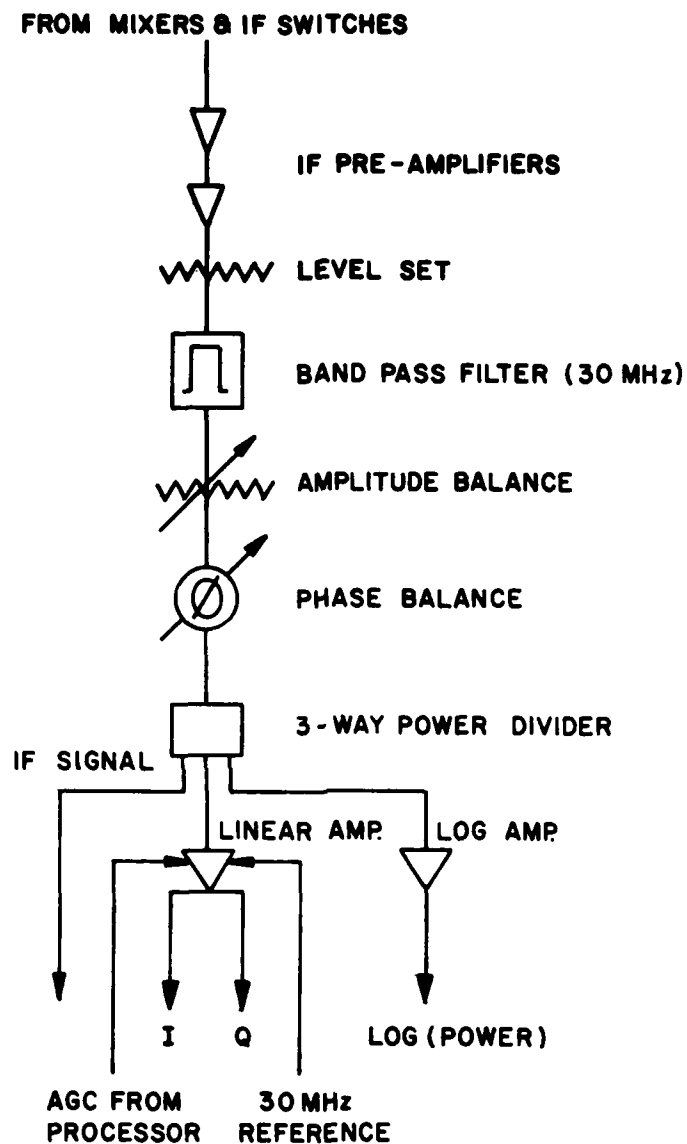


Figure 5. Schematic Intermediate-Frequency (IF) Signal Flow for One Polarization Component Derived from One Carrier Frequency. Outputs are the logarithm of received power, the in-phase (I) and quadrature (Q) components, and the unamplified IF signal

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2. Atlas, D. (1984) Highlights of the Symposium on the Multiple-Parameter Radar Measurements of Precipitation: Personal reflections, Radio Sci. 19:238-242.
3. Bishop, A.W., and Armstrong, G.M. (1982) A 10-cm Dual Frequency Doppler Weather Radar, Part I: The Radar System, AFGL-TR-82-0321 (I), AD A125885.
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6. Ussailis, J.S., and Bassett, H.L. (1984) Polarization Diversity Addition to the 10 Centimeter Doppler Weather Radar, AFGL-TR-84-0239

Appendix

Specifications for High-Power Microwave Switch

A summary of the specifications of the high-power switch is presented in this appendix. These specifications refer to the performance of the combination of three switching circulators described in Section 2. The following list is intended to illustrate the performance of the system and does not reflect any modification of the complete formal specifications.

<u>PARAMETER</u>	<u>SPECIFICATION</u>
Peak transmitted power handling	800 kW minimum
Average transmitted power handling	800 W minimum
VSWR	≤ 1.3 to 1 (2700-2770 MHz) ≤ 1.2 to 1 (2710 $\pm$ 2 MHz)
Insertion loss (between transmitter port and "on" antenna port in each state of switch)	1.5 dB maximum
Pulse-to-pulse change in insertion loss (amplitude jitter) with switch remaining in the same state and alternating between opposite states	0.2 dB maximum

<u>PARAMETER</u>	<u>SPECIFICATION</u>
Pulse-to-pulse change in insertion phase shift (phase jitter) with switch remaining in the same state and alternating between opposite states	1° maximum
Power isolation between "on" antenna port and "off" antenna port during pulse (2710 ± 2 MHz)	40 dB minimum
Switching time from one state to the opposite state, with transmitter power off	≤ 10 microseconds
Switch operating frequency (equal to radar pulse repetition frequency)	Variable from 100 to 1300 Hz
Insertion loss in each receiving channel (between each antenna port and the corresponding receiver port)	1.0 dB maximum
Isolation between receiver ports for signals entering at the respective antenna ports (2710 ± 2 MHz)	40 dB minimum
Uncertainty in differential insertion loss (amplitude tracking) between receiving channels	0.1 dB maximum
Uncertainty in differential insertion phase shift (phase tracking) between receiving channels	1° maximum

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