W-Band Integrated Monopulse Radar Transceiver

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ABSTRACT

Millimeter wavelength components remain difficult and expensive to fabricate. The use of these components for integrated transceivers further complicates designs and results in higher costs. This paper describes an integrated 94 GHz monopulse transceiver using microstrip and insular guide transmission lines. This hybrid integration uses four dielectric rod antennas which feed four insular lines configured to provide the monopulse comparator circuit for the transceiver front-end.

I. Introduction

A radar's primary functions include detection and relative position of a target with respect to the antenna. Single channel tracking radar can correlate the amplitude return from a sequence of pulses and the antenna beam angle. This system, however, is sensitive to amplitude fluctuations caused by random variations in a target's radar cross-section(RCS). Another radar approach called monopulse uses a single reflected pulse return to determine a target's relative position. The approach is not as susceptible to fluctuations in a target's RCS as a conventional radar.

Monopulse radar requires processing of a single pulse by four antennas. The processing involves the addition and cancellation of the four individual signals, A, B, C and D, to obtain three outputs: the sum ($\Sigma = A + B + C + D$), the azimuth error ($\Delta AZ = (A + B) - (C + D)$) and the elevation error ($\Delta EL = (A + C) - (B + D)$). This circuit is called the monopulse comparator and it can be achieved using waveguide[1], coaxial cable, microstrip[2] or quasi-optical techniques[3]. Waveguides and coaxial systems provide good performance but tend to be bulky and expensive to fabricate. Microstrip is ideal for hybrid and monolithic integrated circuits since it reduces the size, weight and cost of a system. As frequencies of operation increase, however, the RF signal processing required causes considerable losses in the comparator circuit.

This paper describes an alternative solution to the monopulse transceiver at 94 GHz using insular guide[4]. Insular guide is an image line insulated from the ground plane by a substrate. This configuration exhibits less loss than microstrip, specially at millimeter and sub-millimeter wavelengths. Similar to microstrip, insular guide can be transformed to an efficient antenna for radiation. This transition allows the insular guide monopulse transceiver to be compact and reproducible as well as provide good performance.

II. Circuit Description

Figure 1 shows the monopulse transceiver system block diagram. It uses four dielectric rod antennas for efficient radiation and reception. The individual rod antenna performance is dependent on the width and height of the image line plus the length of the taper. The taper length affects the half-power beamwidths, sidelobe level and the directivity of the rod antenna. Several rod antennas tested at 94 GHz exhibited a typical side-lobe level of -15 dB and H- and E-plane half-power beamwidths of 31 and 37 degrees, respectively. The four rod antennas are configured in a 2 x 2 array with E-

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and H-plane spacing of 0.6l and 0.68l, respectively.

The comparator circuit presents the novelty of this design. It provides good performance over a relatively small coupling area. The comparator uses +90 and -90 degree phase shifter sections using modified insular guide cross-sections. Proximity coupling is used with modified image lines to realize the H- and E-plane couplers for the comparator. The monopulse comparator loss is estimated at 1.5 dB at 94 GHz. A complete description can be found in [5]. One of the four ports is matched while the other ports are transitioned from insular guide to microstrip in the transceiver section.

The transceiver section layout requires two 0.005" thick Cuflon substrates with ε_r of 2.17. One substrate contains three balanced mixers pumped by a single local oscillator (LO) and another identical oscillator is used for transmission. The balanced mixers contain two GaAs beam lead diodes connected to a 180 degree hybrid ring coupler. The LO is a two InP diode waveguide power combiner providing 20 dBm at 94 GHz. An identical oscillator is coupled to the sum channel and is used as the transmitter for target illumination.

The ΔAZ and Σ ports of the insular guide comparator are transitioned to microstrip and fed to two balanced mixers on the first substrate. Similarly, ΔEL port fed to a balanced mixer on the second substrate. Two 3-dB hybrid power splitters distribute the LO power to the two mixers of the first substrate as well as the third mixer on the second substrate. Pumping the third mixer requires a microstrip-to-waveguide-to-microstrip probe transition which allows the two substrates to fit back-to-back.

III. Experimental Results

The comparator performed reasonably well over the frequency range of interest, 94 ± 0.3 GHz. The sum channel gain was measured at 16 dBi with half-power beamwidths in the E- and H-planes of 26 and 24.5 degrees, respectively. The Σ channel sidelobe levels in the E- and H-plane are -10 and -18 dB, respectively. Similarly, the Δ channel sidelobe levels in the E- and H-plane are -9 and -20 dB, respectively. The null depth is less than -26 dB in both planes. Figures 3a and 3b shows that the H- and E-plane sum and difference patterns of the monopulse transceiver, respectively. The cross-polarization level of -18 dB. The monopulse comparator loss is estimated at 1.5 dB.

Other important characteristics for the monopulse radar transceiver include the Σ/Δ cross-over angles and levels for the E- and H-planes. H-plane cross-over angle is 30 degrees at the sum pattern levels of -3 and -3.5 dB. The E-plane cross-over angle is 32 degrees at the sum pattern levels of -3 and -7 dB. The E-plane asymmetry is due to housing interference and some channel imbalance.

IV. Conclusion

A monopulse integrated transceiver has been demonstrated at 94 GHz. The system integrates insular guide, microstrip and waveguide to develop the antennas, comparator and transceiver. The amplitude comparison monopulse radar has half-power beamwidths of ~25 degrees in both planes, -18 dB cross-polarization level, -26 dB null depth and 16 dBi of gain in the sum channel.

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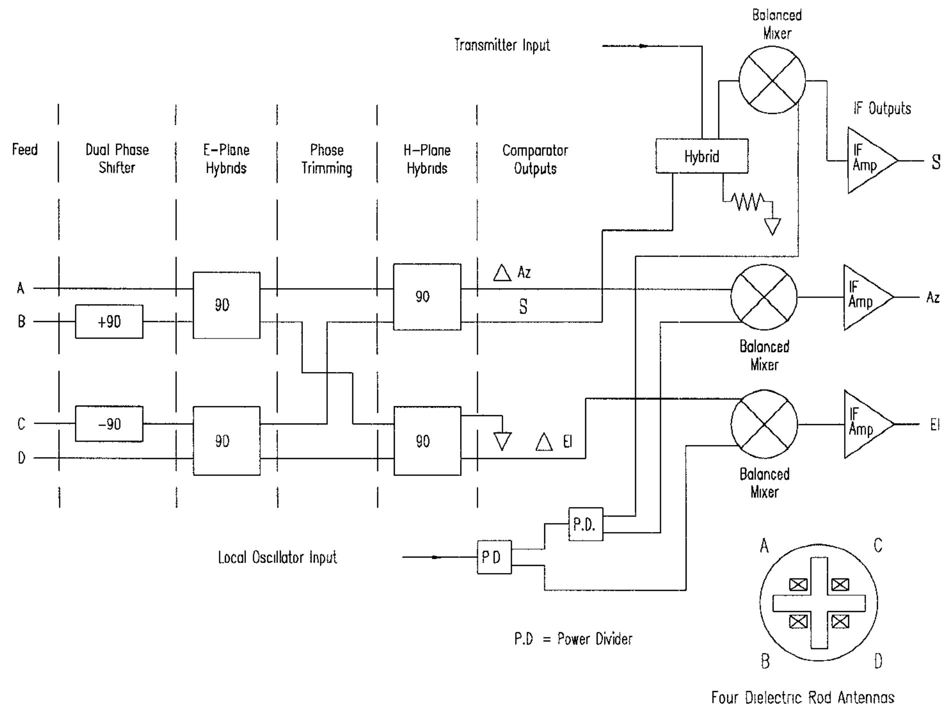

Figure 1. Block Diagram of Integrated Monopulse Transceiver

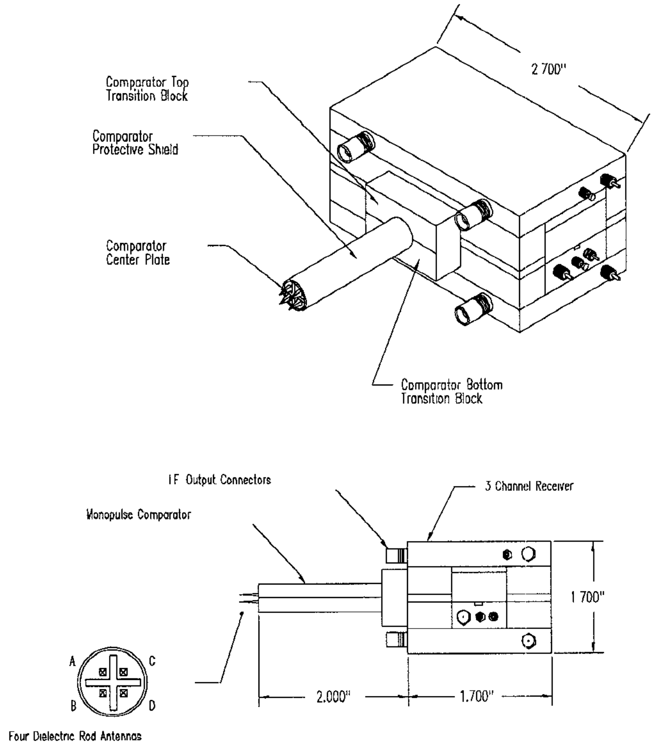

Figure 2 Integrated Monopulse Transceiver

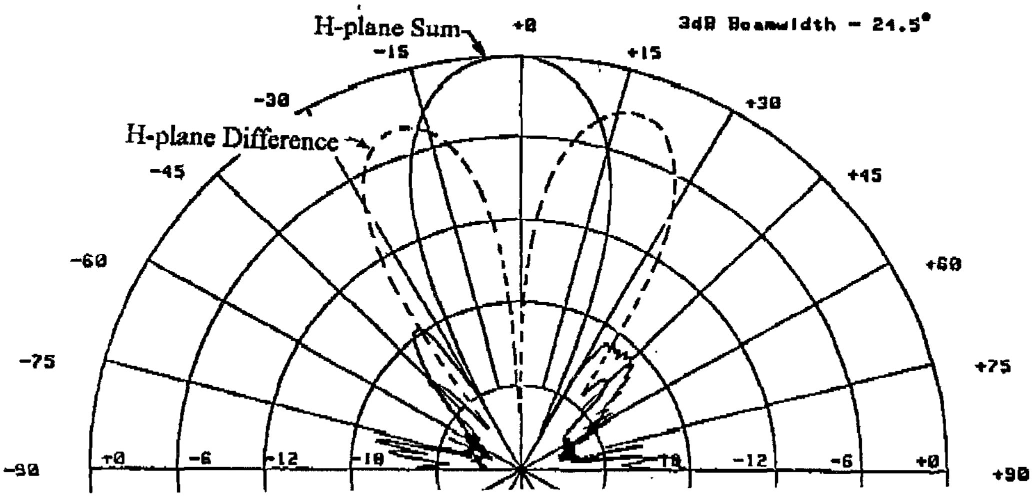

Figure 3a. H-plane Sum and Difference Patterns of Integrated Monopulse Transceiver.

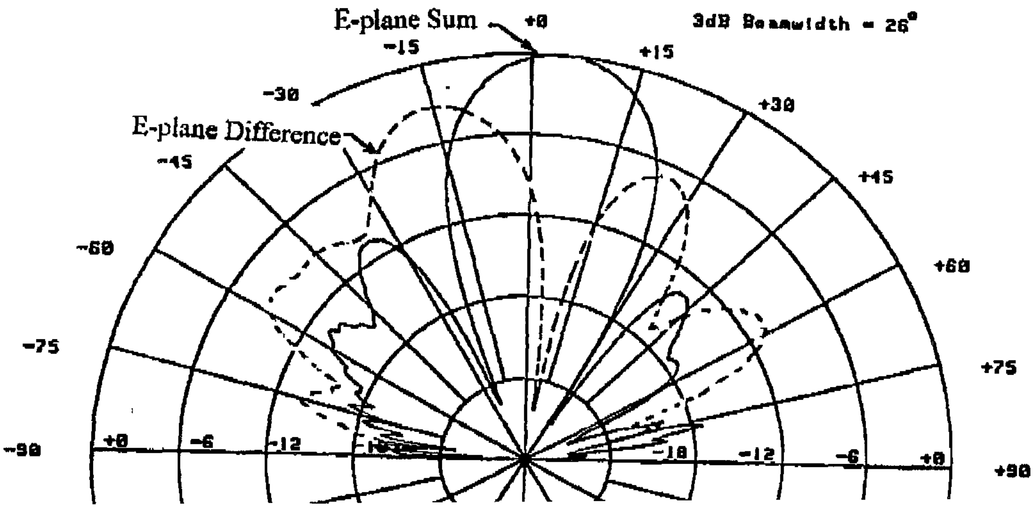

Figure 3b. E-plane Sum and Difference Patterns of Integrated Monopulse Transceiver.99