A W-BAND DIELECTRIC-LENS-BASED INTEGRATED MONOPULSE RADAR RECEIVER

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Abstract— An integrated monopulse receiver has been developed for tracking applications at W-band frequencies. The receiver is based on dielectric-lens-supported, coplanar-waveguide-fed slot-ring antennas integrated with uniplanar subharmonic mixers. The design center frequency is 94 GHz and the IF bandwidth is 2–4 GHz. The measured DSB conversion losses of the individual receiver channels range from 14.4 to 14.7 dB at an LO frequency of 45.0 GHz and an IF of 1.4 GHz. This includes the lens reflection and absorption losses, backside radiation, RF feedline loss, mixer conversion loss, and IF distribution loss. Excellent monopulse patterns are achieved with better than 45 dB difference pattern nulls using IF monopulse processing. This translates to sub-milliradian angular accuracy for a 24 mm aperture. Better than 25 dB nulls are possible over a 600 MHz bandwidth.

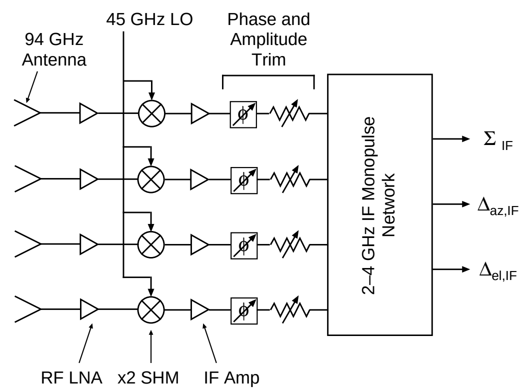

Fig. 1. Schematic of a four antenna monopulse receiver with subharmonic downconversion and IF processing.

I. Introduction

Millimeter-wave monopulse radars are attractive for high-resolution tracking applications such as anti-missile terminal guidance and communications satellite tracking. For such systems, an integrated circuit approach, consisting of planar antennas directly integrated with RF (MMIC) electronics, offers the possibility of more compact, lower-cost front ends compared to waveguide-based alternatives.

Several planar and quasi-planar W-band monopulse systems have been demonstrated to date using various antenna geometries to minimize substrate losses, as well as different monopulse processing configurations [1],[2],[3],[4].

A novel monopulse architecture based on micromachined integrated horn antennas [4] performed the monopulse processing in the IF vs. the RF. A schematic of a monopulse receiver with IF processing is shown in Figure 1. In a planar millimeter-wave system, IF processing can provide much deeper nulls (in excess of 35 dB) due to the ability to phase and amplitude trim the four input channels prior to the monopulse network. Moreover, losses in a planar RF monopulse (which could be in excess of 2–3 dB at 94 GHz) will degrade the system noise figure; it is generally impractical to insert RF LNAs prior to the planar comparator circuit.

A potential problem which arises in millimeter-wave ICs and integrated antennas is that of substrate modes. A convenient method for eliminating substrate modes is to place a CPW-fed slot-type antenna on a dielectric lens of roughly the same dielectric constant as the antenna wafer [5]. The lens appears as a dielectric half-space, and hence does not support surface waves. Furthermore, the antenna radiates preferentially into the dielectric, resulting in high-directivity patterns. This approach was utilized in a 35 GHz monopulse system based on slot-ring balanced mixers with polarization duplexed RF/LO [6].

In this work *CPW-fed* slot-ring antennas [7] are integrated with uniplanar subharmonic mixers [8] pumped with an on-chip LO to realize a W-band monopulse receiver. RF LNAs can be easily incorporated into the front-end and the need for quasi-optical LO injection is eliminated. Subharmonic mixing is utilized due to the relative ease of LO distribution at ~45 GHz, and the inherent RF/LO isolation, which is important (in the absence of a front-end LNA) in order to minimize the leakage of LO power to the antennas.

II. Monopulse Receiver Design

A schematic of the receiver design is shown in Figure 2. The design frequency is 94 GHz with an IF bandwidth of 2–4 GHz. A 2×2 array of slot-ring antennas is centered on the back side of a 24-mm-diameter dielectric lens at an extension length $L = 4400$ μm (the synthesized elliptical position) [7]. The center-to-center spacing of the slot-ring elements is chosen to be $0.8\lambda_d$ (746 μm) in order to avoid grating lobes while minimizing the effects of mutual coupling. The slot-ring antennas have a resonant input impedance of approximately 120 Ω. The RF signal received by each antenna is coupled to a uniplanar subharmonic mixer via a 74 Ω CPW quarter-wave matching section. Details of the mixer design are given in [8]; the mixer is based on University of Virginia SC1T7-D20 GaAs antiparallel Schottky diodes.

The receiver chip is mounted in an Aluminum package such that the periphery of the circuit exists over the package ground plane. For this reason, the LO input lines and the IF output lines transition from standard ungrounded CPW to Finite Ground Coplanar (FGC) lines in order to eliminate the excitation of parallel plate modes between the CPW gound planes and the package ground [9]. The FGC lines transition to spark-plug-type coaxial connectors using a straightforward CPW-to-coaxial transition; the LO inputs are V-connectors and the IF outputs are SMA connectors.

The LO source is a 42–46 GHz Gunn oscillator with WR-19 waveguide output. The LO signal is delivered to the receiver via a WR-19 Magic-T, WR-19-to-V-connector transitions, and V-connector cables. The Gunn source is connected to the Δ port of the Magic-T such that the colinear ports are 180° out-of-phase with each other; this is necessary since the left and right antenna pairs receive the LO from opposite directions on the receiver chip. The ~45 GHz LO signals are divided again on the receiver chip using CPW Wilkinson power dividers.

The IF monopulse comparator is the standard combination of 180° hybrids, and is preceded by SMA line-stretchers and variable attenuators for phase and amplitude trim (see Fig. 1).

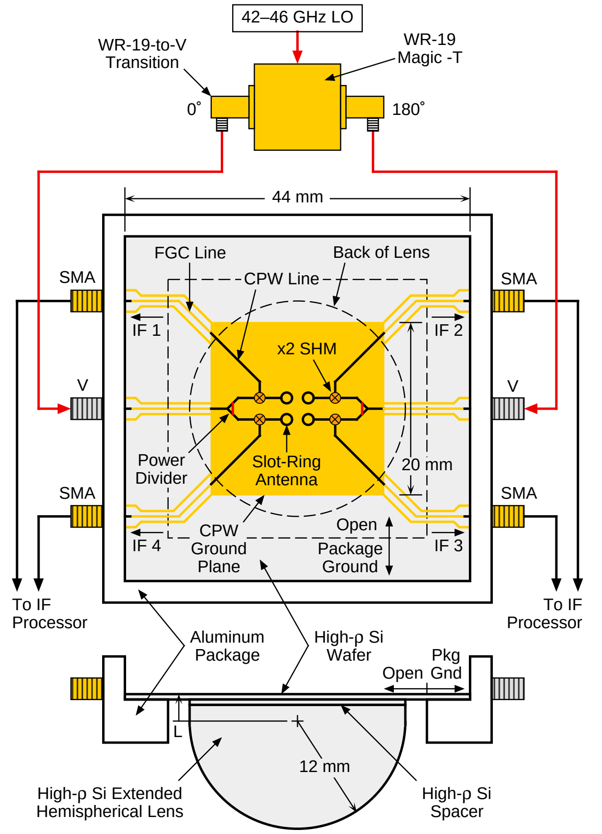

Fig. 2. Schematic of the W-band monopulse receiver, package, and LO source. $L = 4400$ μm.

III. Fabrication and Measurement

The fabricated monopulse receiver chip is shown in Figure 3. The receiver size excluding IF and LO distribution lines is 2.7 mm × 8.7 mm. Airbridges are included at various points in the circuit, particularly junctions, to suppress excitation of the undesired slotline (even) mode in the CPW line. The circuit was fabricated on 535-μm-thick high-resistivity (>2000 Ω·cm) silicon with a 3000 Å PECVD-grown Si_xN_y layer which is subsequently etched from the CPW gaps to avoid excessive line losses [8]. The bent sections in the RF feed lines are necessary to separate the mixer circuits by a reasonable spacing. The CPW center conductors and ground planes are 1.3-μm-thick evaporated Ti/Al/Ti/Au, which corresponds to 5 skin-depths at 94 GHz, and 3.5 skin-depths at 45.5 GHz. The airbridges are electroplated gold 3-μm-thick at a height of 3.5 μm above the CPW line. The 75 μm × 195 μm × 38-μm-thick antiparallel diode chip is mounted using flip-chip technology and bonded to the circuit using

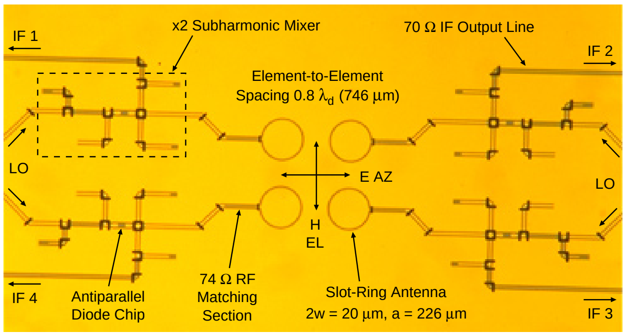

Fig. 3. Photograph of the fabricated slot-ring monopulse receiver. The LO Wilkinson power dividers are just out of the picture to the right and left.

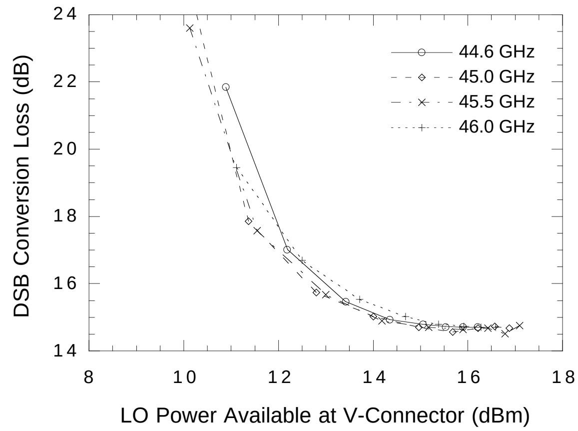

Fig. 4. Measured DSB conversion loss of channel #3 centered on the lens at the synthesized elliptical position ($L = 4400$ μm) vs. LO Power and frequency at an IF of 1.4 GHz.

EPO-TEK H20E silver epoxy[1].

Double sideband (DSB) conversion loss measurements were performed using the Y-factor method. Microwave absorber (ECCOSORB VHP-2-NRL)[2] at room temperature (290 K) or immersed in liquid nitrogen (77 K) provided the hot/cold load. The output of a given receiver channel was connected to a 1.4 GHz IF chain with a gain of 92 dB, a noise temperature of 68 K, and a bandwidth of 50 MHz. The first stage of the IF chain was an isolator which directs any IF reflection to a cold termination. The measurements represent the conversion loss from a plane at the lens surface to the IF SMA connector, and the LO power is defined at the LO V-connector (see Fig. 2).

The DSB conversion loss of a typical channel centered on the back of the lens vs. LO power and frequency is shown in Figure 4. The minimum DSB conversion loss is 14.5 dB at an available LO power of 15–16 dBm at 45.0 GHz. With the lens aligned to the center of the *array*, the DSB conversion loss of each channel was measured with the maximum LO power available from the source setup in Figure 2. The four channels had conversion losses within 0.3 dB of each other (14.4–14.7 dB) at an LO frequency of 45.0 GHz. The measured data includes lens reflection (2.7 dB) and absorption (1.9 dB) losses, backside radiation (0.2 dB), RF feedline loss (1.0 dB), mixer conversion loss (5 dB), and IF losses from the mixer through the SMA connector. The IF line loss from the mixer output port to the FGC-to-coaxial-connector transition is estimated from measured TRL data to be 1.4 dB; the loss in the transition to the SMA connector is not known. With the incorporation of an optimal matching cap layer on the lens, the reflection loss can be reduced by approximately 1.5 dB. Reduction of the lens absorption loss would require using a lower-loss material, such as semi-insulating GaAs. RF LNAs, not included in this concept demonstration, should be incorporated in a real system to establish the front-end noise figure.

Monopulse patterns were measured by shining a W-band plane wave (chopped at 1 kHz) on the 24 mm receiver lens aperture and detecting the sum and difference outputs of the comparator with a lock-in amplifier. Figure 5 shows the sum (Σ) port E- and H-plane co-polarized patterns and 45°-plane cross-polarized pattern at RF = 93 GHz and IF = 3 GHz. The sum pattern exhibits a 12.5° 3-dB beamwidth, a 25° first null beamwidth, and cross-polarization levels below -25 dB in the main beam. The relatively high sidelobe levels (-13 to -15 dB) are believed to be due to the receiver package and mounting structure.

Figure 6 shows the measured monopulse patterns. The null depths were measured using a spectrum analyzer to determine the peak-to-null ratios at the IF difference ports. Better than 45 dB null depths were achieved; this translates to sub-milliradian accuracy for a 24 mm aperture. Table I presents achievable null bandwidths with the IF monopulse comparator tuned for the maximum null at IF = 3 GHz and the LO held constant at 45.0 GHz. These bandwidths are limited by the IF network. Wider IF null bandwidths can be realized by using a Lange-coupler-based monopulse comparator [10]; however, realizing better than 40 dB nulls over a 2 GHz bandwidth will necessitate moving to a higher IF center frequency.

[1]EPO-TEK H20E is a product of Epoxy Technology, Inc., Billerica, MA.

[2]ECCOSORB VHP-2-NRL is a product of Emerson and Cuming, Canton, MA.

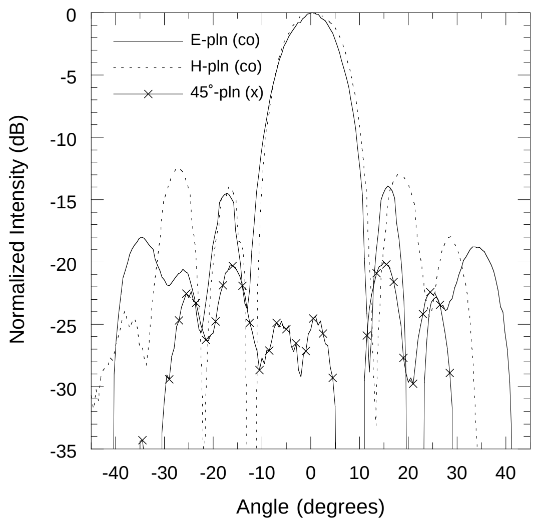

Fig. 5. Measured Σ port co-polarized E- and H-plane patterns, and cross-polarized 45°-plane patterns at RF = 93 GHz, IF = 3 GHz.

TABLE I

ACHIEVABLE NULL BANDWIDTHS.

Null (dB)	BW (MHz) Δ_{az}	Δ_{el}
45	100	200
35	250	600
25	600	2000

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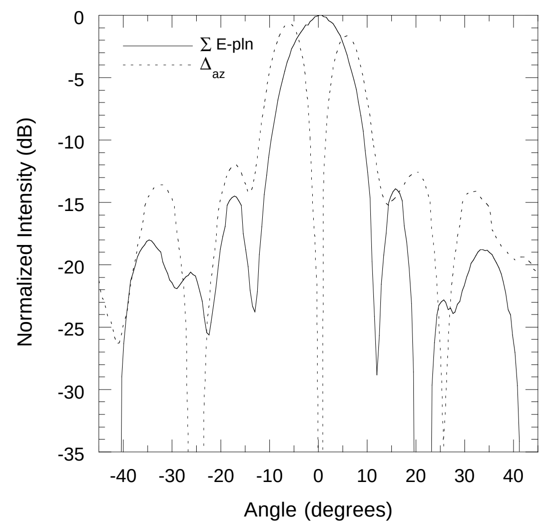
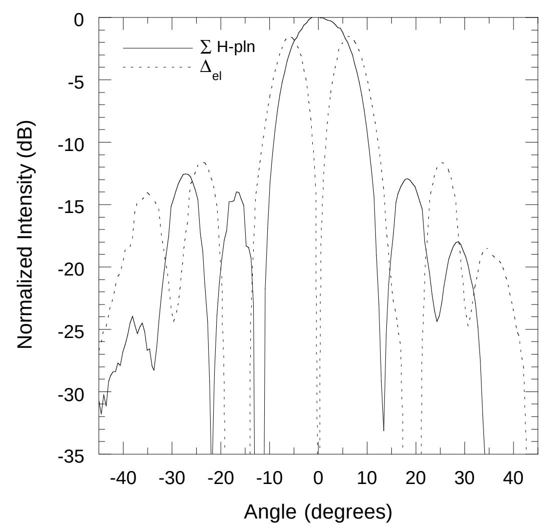


(a)



(b)

Fig. 6. Measured monopulse patterns at RF = 93 GHz, IF = 3 GHz. (a) Σ E-plane and Δ_{az}. (b) Σ H-plane and Δ_{el}.

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