MILLIMETER-WAVE SLOT RING MIXER ARRAY RECEIVER TECHNOLOGY*

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ABSTRACT

This paper describes a novel quasioptical millimeter-wave (MMW) monolithic monopulse receiver and its performance when integrated with a quasioptical diplexer and antenna. Integration of the antenna, diplexer and receiver forms a complete MMW radar front end. The receiver, which is fabricated on 0.025 in. thick GaAs substrates, includes four monolithic chips. The entire receiver is packaged on the planar back surface of a 1.5 in. diameter lens. This lens, hyperhemispherical in shape, provides a dual function as a focussing lens and carrier for the monolithic receiver. Measured noise figure and conversion gain of the receiver is 8.7 dB and 19.0 dB, respectively, at 35.0 GHz.

INTRODUCTION

A monolithic MMW monopulse receiver has been demonstrated. The receiver is integrated with a quasioptical diplexer and cassegrain antenna/radome. The monolithic receiver consists of four MMIC chips integrated on a common substrate that is the back surface of a hyperhemispherical lens. The receive element chip is a 2 x 2 array of annular slot ring antennas with monolithically grown Schottky diodes oriented orthogonally to each other within each ring. The slot ring mixer elements provide instantaneous down conversion to the desired IF frequency when simultaneously illuminated with LO and RF energy. Each IF signal is filtered and then amplified by MMIC low noise amplifiers (LNAs). Two chips, each containing two LNAs, one for each antenna element, are electrically connected to the slot ring mixer array. The IF signals are then processed through a MMIC monopulse comparator network after amplification. The receiver was tested over a 2.0 GHz bandwidth, centered at 35.0 GHz, with measured results that compete with comparable waveguide systems.

ANTENNA AND DIPLEXER SYSTEM

The key components of the quasioptical front end system are a spherical radome, cassegrain antenna and a quasioptical diplexer feed (Figure 1). The subreflector is body fixed to the inner surface of the radome. Scanning of the antenna is accomplished by a movable primary reflector, a profiled high performance fiberglass dielectric sheet metallized on one side. The metallized dielectric sheet provides a common but slightly defocussed beam at the focal point of the antenna system for scan angles out to ±30 electrical degrees. The antenna is designed to have a 1.9 deg beamwidth, 36 dB gain and a 2:1 scan law.

A quasioptical polarization diplexer is used as the feed for the fixed subreflector. This optical assembly serves to relocate the focus of the feed to a point within the central optics tube of the quasioptical diplexer while preserving the monopulse information. The diplexer directs transmit, receive and mixer LO signals. There are four ports; one is the antenna feed that is located at the center of the primary reflector, while the remaining three ports are utilized for the transmit/crosspolar receive, copolar receive, and LO signals. A corrugated scalar feed horn is used in the transmit and LO ports to couple electromagnetic energy to and from the diplexer. A waveguide cross polarized receiver is integrated in the transmit path by means of a circulator and waveguide mixer. The slot ring mixer array is located in the copolarized port and couples to the electromagnetic energy via the hyperhemispherical lens.

A polarization grid fabricated on a low dielectric constant Duroid substrate performs the diplexing of orthogonally polarized signals. It reflects the vertically polarized LO and passes the horizontal polarized receive signal to the SMART receiver. The vertically polarized transmit signal is reflected towards the Cassegrain antenna while the cross polar (vertical polarization) receive signal is reflected into a waveguide, sum only, receiver (Figure 2).

SMART RECEIVER DESIGN

The quasioptical monolithic MMW receiver is a four-element focal-plane mixer array that downconverts an RF signal to an intermediate frequency (IF), then filters, amplifies and arithmetically processes the signals through a monopulse comparator. The above functions are performed on four 0.025 in. thick GaAs substrates. The entire receiver is assembled on a 1.5 in. diameter alumina lens. Figure 3 shows the assembled components of the receiver.

The focal-plane mixer array has four slot ring mixers configured in a 2 x 2 array with a spacing of 0.8 wavelengths in the dielectric. Each annular slot ring is 1.0 wavelength in circumference at the center frequency. Schottky diodes are grown by a Metallo-Organic Chemical Vapor Deposition (MOCVD) process in the gaps of the slot rings. Figure 3 shows the diodes oriented in a balanced configuration, orthogonally positioned relative to each other and located ±45 deg to the incident RF fields. Local oscillator and RF power is coupled into the slot ring via the quasioptical diplexer with a vertical and horizontal sense of polarization, respectively. An IF frequency is instantaneously generated at L-band in the slot ring mixers and coupled to coplanar waveguide filters by an air bridge. The filters are a two-section quarter wavelength stub design that reject the LO frequency and pass the L-band IF signals.

Low noise amplifiers are electrically connected by gold ribbon to the IF filters. A dual LNA chip contains two amplifiers fabricated by an ion implant process. Two dual amplifier chips are connected to two sides of the array. Gain and noise figure of the LNAs is 22.0 dB and 1.9 dB, respectively, at the desired IF frequency. Each IF signal is connected to a 50 ohm coplanar transmission line on the bottle cap substrate. The 50 ohm lines are the same electrical length to provide equal amplitude and phase to the active monopulse comparator.

A typical passive monopulse comparator is designed by integrating four quadrature hybrids, whereas the active comparator consists of a combination of eight sum and difference amplifiers. Figure 4 shows the circuit diagram containing the arrangement of the amplifiers to provide the monopulse arithmetic. An ion implant process is also used to fabricate the monolithic comparator.

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Each of the monolithic chips are nonconductively epoxied directly to the back of a hyperhemispherical lens. The lens consists of two alumina pieces as shown in Figure 5. One part is the hyperhemispherical portion and the other is a laser profiled substrate that aligns the monolithic chips on the back of the lens. The substrate is referred to as the "bottle cap" due to its likeness. A gold-plated alumina wall structure and Kovar lid are epoxied to the bottle cap substrate to protect the active components. The wall structure is 0.100 in. high and 1.0 in. square. The Kovar lid has an unnoticeable effect on the radiation patterns due to the electrically thick, high dielectric constant lens. The hyperhemispherical lens and bottle cap substrate are formed by isostatically pressing Alumina (99.5%) to shape. A quarter wavelength matching layer, Ryton R-40, is placed over the spherical portion of the lens to provide a low VSWR between the lens and free space.

SYSTEM PERFORMANCE

Measurement of the front end system included free space radiation patterns, conversion gain and noise figure. Monopulse radiation patterns of the receiver system and quasioptical diplexer were made with and without the cassegrain antenna and radome. Conversion gain of the diplexer and monopulse receiver was determined by comparing receive power to a scalar feed horn and waveguide mixer in free space. Noise figure (DSB) was measured by injecting the LO and noise diode signals into a waveguide orthomode transducer and scalar feed horn.

The monopulse radiation patterns were made over a 2.0 GHz bandwidth centered at 35.0 GHz. Sum and difference patterns of the entire front end system had typically 20 dB null depths, better than 14 dB sidelobes, and beamwidths between 2.25 and 2.5 deg in both the E- and H-planes. Figure 6 is representative of monopulse performance at 35.0 GHz. Null depths of 39.8 dB and 28.1 dB were measured for the E- and H-plane, respectively.

Conversion gain measured 19.7 dB at 35.0 GHz with a typical value of 19.0 dB across the band. Ideally, the conversion gain of the monopulse receiver should be 22.0 dB greater than the waveguide receiver system. The excess loss is primarily due to lower aperture efficiencies, higher mixer conversion loss and diplexer loss.

Noise figure of the slot ring mixer array receiver was measured without the quasioptical diplexer using the known Y-factor technique. The LO and noise signals were coupled into the hyperhemispherical lens by a scalar feed horn and orthomode transducer. Measured noise figure (DSB) of the receiver was 8.7 dB at 35 GHz and typically 9.0 dB across the band (measured with a 2.6 dB IF system). This measurement actually understates the performance of the mixer because the efficiency of the scalar feed and loss of the orthomode transducer have not been subtracted off the excess noise ratio of the noise source.

CONCLUSION

A monolithic monopulse slot ring mixer array receiver has been designed and tested at 35 GHz. The entire receiver (Figure 7) is supported on a 1.5 in. diameter hyperhemispherical lens. Performance of the receiver is very competitive with its waveguide counterparts. Raytheon Company has realized the need for lower cost and volume in MMW receiver front ends. It is believed that a significant step has been made in this area based on the performance discussed in this paper.

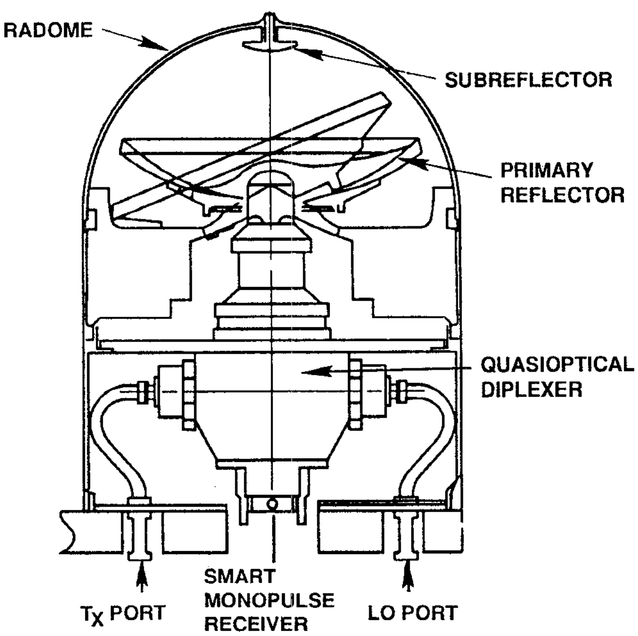

Figure 1. Millimeter-Wave (MMW) Front End System

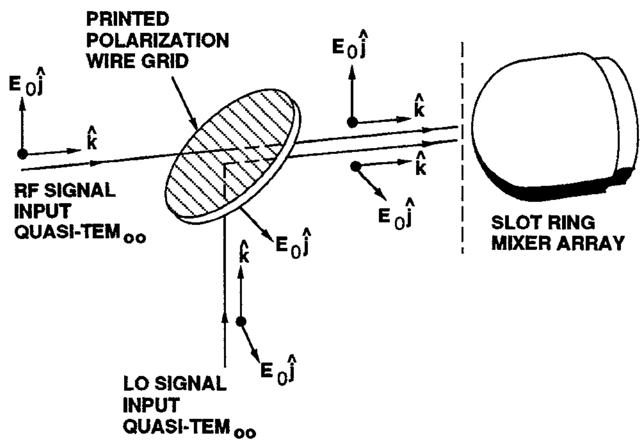

Figure 2. RF and LO Signals Diplexed by Polarization Grid

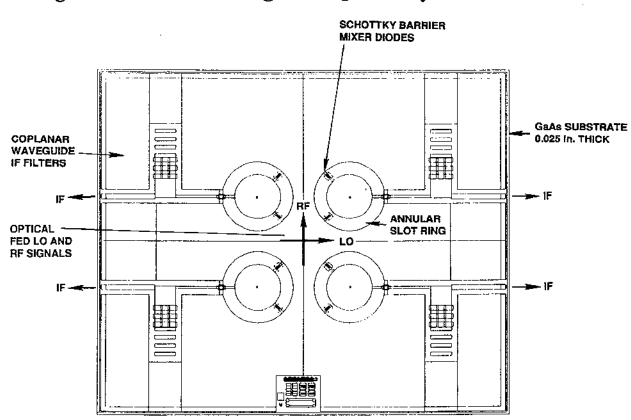

Figure 3. Monolithic Slot Ring Mixer Array Circuit

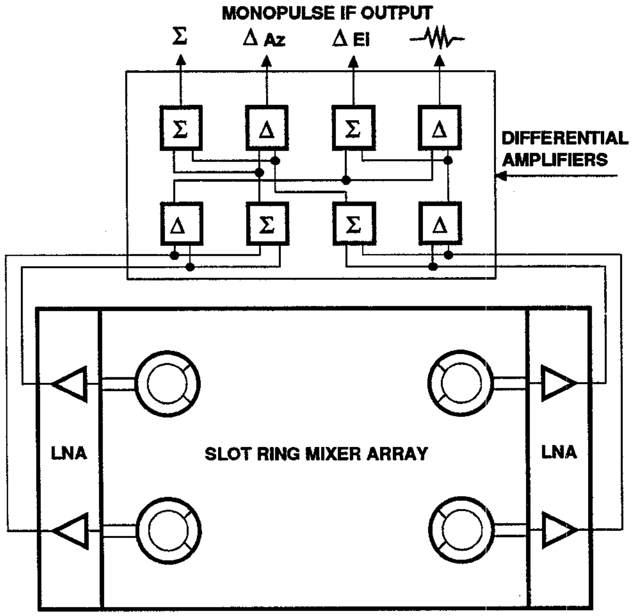

Figure 4. Circuit Diagram of the Four Monolithic Chips that Comprise the Slot Ring Mixer Array Receiver

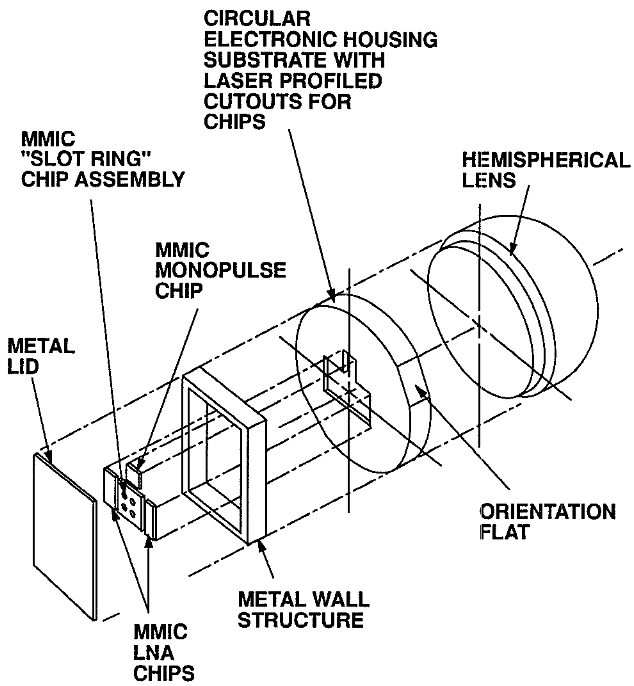

Figure 5. Millimeter-Wave (MMW) Monolithic Receiver Assembly Diagram

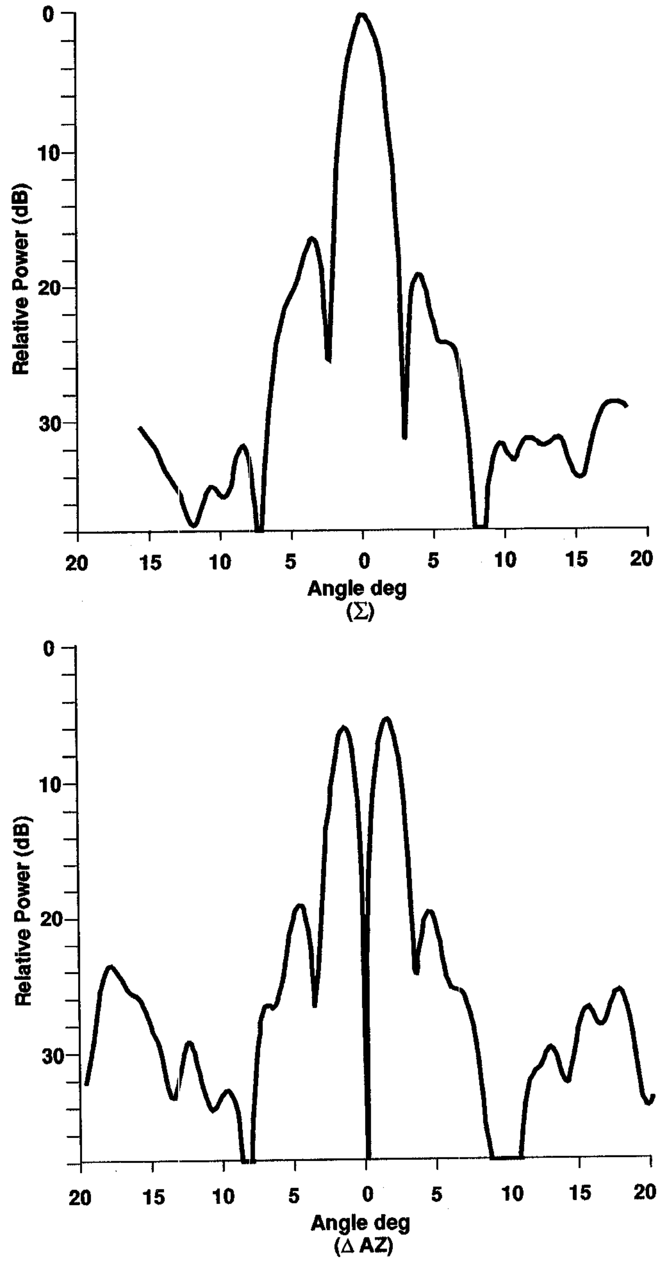

Figure 6. Measured E-Plane Monopulse Radiation Patterns of SMART Front-End at 35.0 GHz

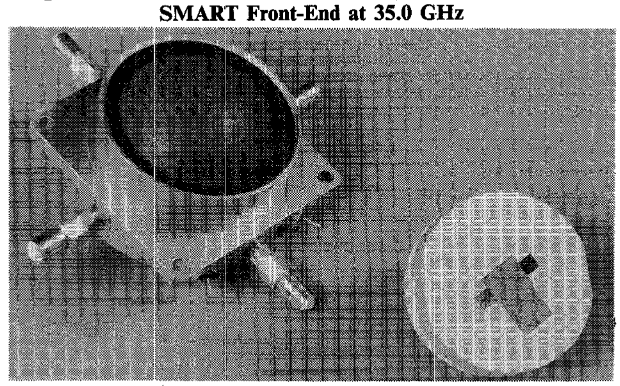

Figure 7. SMART Millimeter-Wave Receiver