# A Low Cost Miniature MMIC W-Band Transceiver with Planar Antenna

**Northrop Grumman**
**Electronic Sensors & Systems Division, Baltimore, Md. 21203**

Howard Fudem, Peter Stenger, Edward C. Niehenke,
Mike Sarantos, and Chris Schwerdt

## Abstract:

This paper presents design and performance of a unique, low cost, miniature planar all MMIC W-band transceiver. The transceiver incorporates a planar 4-element circularly polarized patch antenna, a monopulse comparator, two receiver channels, one for the sum and the other for a selectable difference in either azimuth or elevation. Two PIN diode switches provide the TR and difference channel switching. Each receiver has a balanced LNA, an image rejection/image enhancement subharmonic mixer and an IF amplifier. Test circuits are included for system calibration and verification. The double sided transceiver uses an optimal arrangement of quartz, alumina, and LTCC for an overall size less than 1 inch diameter and 0.25 inch thick. The antenna cross pole isolation is typically 15 dB with a monopulse null depth of 25 dB. The receiver gain is 30 dB with a 25 dB image rejection.

## Introduction:

The advent of many new millimeter wave MMIC processes has made it possible to build complex systems compactly. The transceiver described in this paper, with all its features, is among the smallest integration reported to date. To design a W-band planar low cost antenna which has desirable monopulse characteristics and is circular polarization is difficult. Some work has been reported [1] at W-band which down converts first and accomplishes the monopulse at the IF band. The present antenna design is completely at W-band and has both good monopulse characteristics and is circularly polarized.

## Transceiver Circuit

Figure 1 illustrates the block diagram of the transceiver and figure 2 shows the two-sided construction. The antenna uses four microstrip patch antennas and four low loss couplers to form the monopulse comparator for scanning in azimuth and elevation. The four couplers create the proper phase relationship between the patch

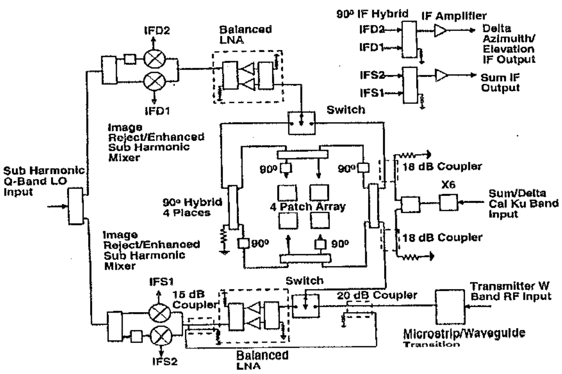


**Figure 1 Transceiver Block Diagram**

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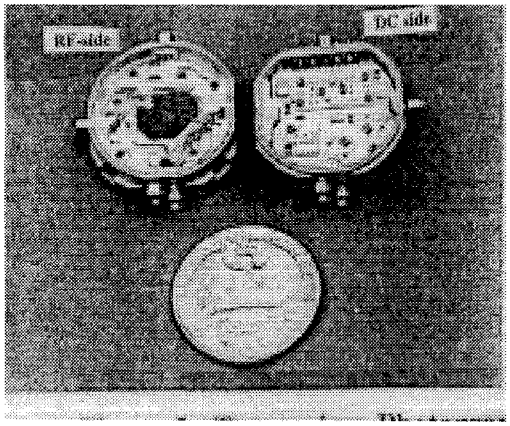



**Figure 2 Transceiver Photograph**

antennas which result in the sum of all four patches, the difference between top and bottom patches and the difference between the left and right patches. The performance of the monopulse comparator is, therefore, highly dependent on the coupler performance. Also, the couplers should have good return loss and low insertion loss to maximize system signal to noise. Figure 3 shows the performance of the W-band coupler measured with W-band wafer probes. The coupler loss is 0.3 dB and the phase was within 2° of 90°.

Previous work [2] had switches internal to the comparator, but for this application switchable polarization was unnecessary. The present design uses a single quartz substrate, and all switches are external to the comparator making it low cost and repeatable with no tuning required. The switches are pin diode SPDT switches with 1 dB of loss and 27 dB isolation. One switch is used for connecting the antenna sum port to either the sum channel LNA input on receive, or the receiver transmitter input on transmit. The transmit input is accomplished with a waveguide to microstrip transition machined into the housing. The other switch is used to switch the antenna delta azimuth, or delta elevation to the LNA input in the delta channel. The patches were configured to produce circular polarization for optimum system performance.

The receiver uses MMIC LNAs after the antenna to set the front-end noise figure. The LNAs were configured as a balanced pair using low loss couplers on quartz see Figure 4.

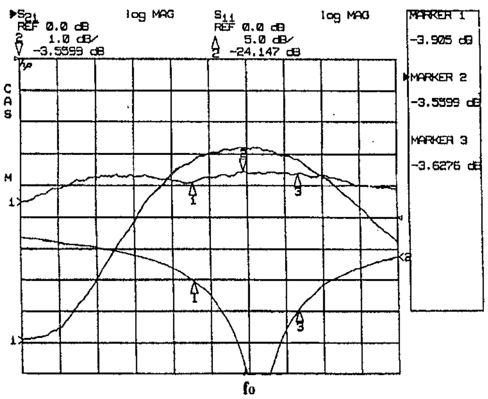



**Figure 3 W-Band Coupler Performance**

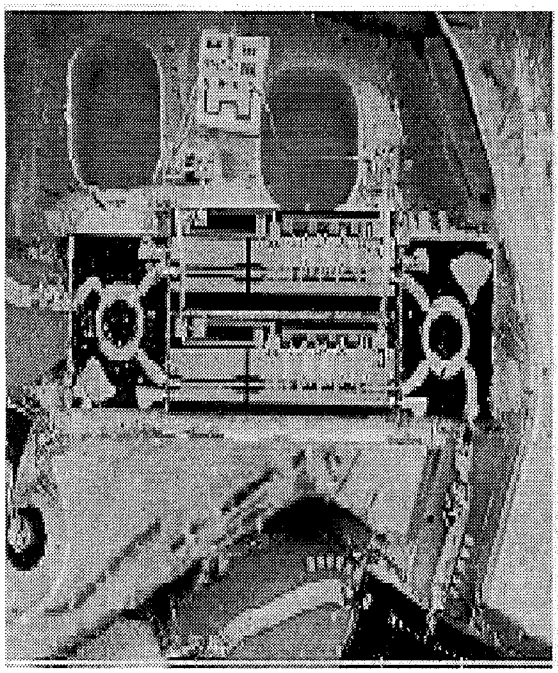


**Figure 4 Balanced LNA**

These are the same couplers used in the monopulse comparator. The balanced LNAs provide a good input/output match, a higher third order intercept, reduced noise due to antenna VSWR, and reduced phase and amplitude variation over frequency compared to a single ended amplifier.

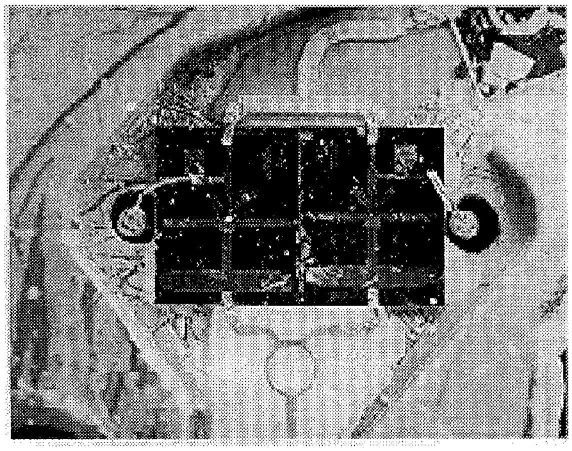


**Figure 5 Subharmonic Mixer**

After being amplified by the LNAs, the signal is then downconverted to the IF band using a MMIC based image rejection/ image enhancement/ subharmonic mixer. [3,4] This mixer configuration consists of two subharmonic mixers with the RF ports combined with a "Tee" junction giving a 0° phase split at the W-band input ports (see Figure 5). The LO ports are combined using a Wilkinson power combiner and an additional 45° length of line on one side of the combiner. The phase shifter is 45° instead to 90° because the input signal is LO/2 and the mixer generates the LO signal and doubles the phase shift. Last, the IF ports are combined using a miniature MMIC 90° coupler. The IF coupler insertion loss measured less than 0.5 dB (see figure 6

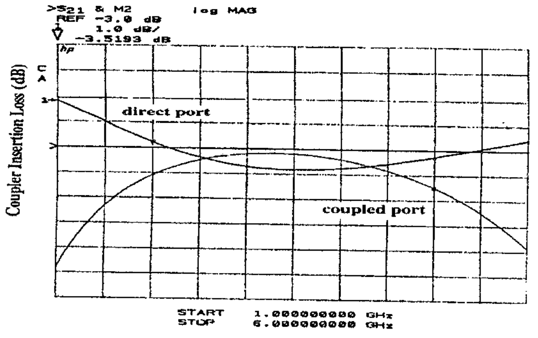



**Figure 6 IF MMIC Coupler Performance**

The image enhancement was predicted to lower the conversion loss by 0.8 dB. The two IF signals are fed through the housing. There they are combined in the IF couplers, and the signal is amplified in a MMIC IF amplifier resulting in a IF sum and IF delta outputs. This mixer configuration gives image rejection like a conventional image rejection down converter, but it also uses the subharmonic of the LO to drive the mixer greatly simplifing the LO drive requirements. Another feature to the mixer configuration results in image enhancement. Strong spurious signals are generated at the W-band RF input. The signal is R-4LO, but each mixer generates this signal and they are 180° out of phase. When these signals exit the mixer and reach the "Tee" junction they are reflected back into the mixer and down converted to the IF frequency.

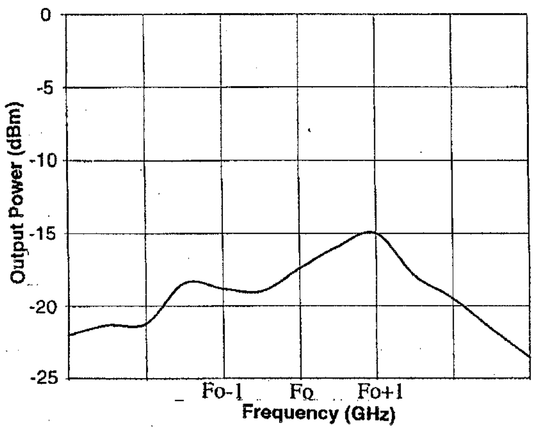



**Figure 7 MMIC X6 Passive Multiplier**

The transceiver also has a built-in sum/delta channel self calibration. A Ku-band signal is input to the transceiver. This signal is multiplied by six using a MMIC passive X6 multiplier. The W-band signal is then split to two 18 dB couplers which couple identical W-band signals into the sum and difference channel after the monopulse comparator. Figure 7 shows the performance of the MMIC passive X6 multiplier. The multiplier has on chip filtering to remove the 4th and 5th harmonic.

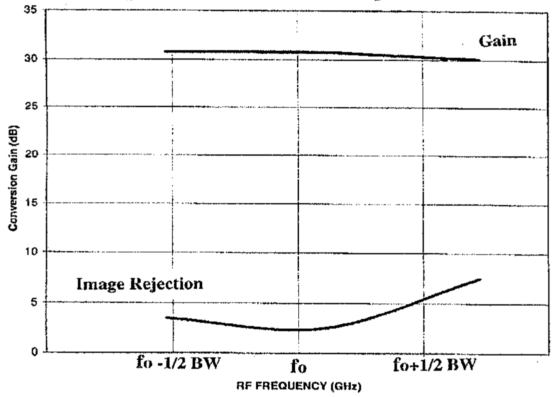
The DC side of the receiver has a multi-layer low temperature co-fired ceramic (LTCC) substrate for routing the dc bias and the IF signals. There is a switching voltage regulator for switching the LNAs off during the transmit pulse. Also, there is a PIN diode driver for switching between transmit and receive, and between azimuth and elevation, and positive and negative voltage regulators, and a line receiver for receiving the logic signals for controlling the transceiver.

The transceiver also has a transmitter Built In Test (BIT). This consists of a 20 dB coupler which samples the transmit signal, and another 15 dB coupler which injects the signal into the mixer input. This signal is then down converted. The LNAs are off during transmit and the couplers bypass the LNAs.

**Transceiver Measurements:**

The overall transceiver exhibited a measured gain of 30 dB with an image rejection better than 20 dB as shown in figure 8.

The measured antenna patterns with the entire transceiver located at the focal point feed for a small parabolic dish are shown in figures9, 10, and 11. Figure 9 shows the antenna sum and difference patterns (RHCP). Figure 10 shows




RF Frequency (GHz)

**Figure 8 Receiver Conversion Gain and Image Rejection**

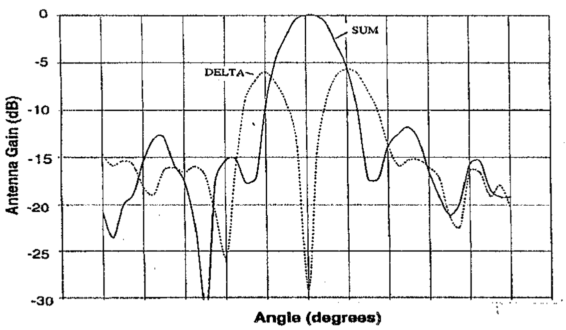



**Figure 9 Antenna Sum and Difference Pattern**

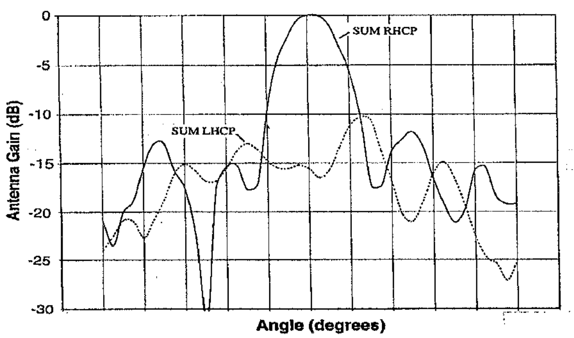



**Figure 10 Antenna Sum RHCP and Sum LHCP**

the measured antenna sum channel response Right Hand Circular Polarization and Left Hand Circular Polarization (LHCP) response. The cross-polarization insures that only a RHCP can be detected. Figure 11 shows the measured response of the delta azimuth channel for RHCP and LHCP signals.

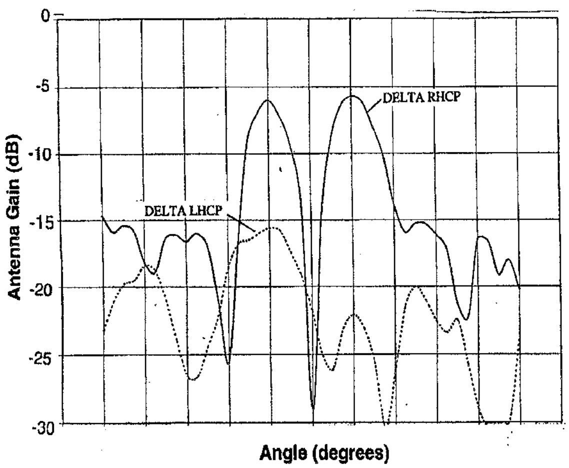



**Figure 11 Antenna Delta RHCP and Delta LHCP**

## Conclusion:

A W-band miniature Antenna/Receiver has been designed, built and tested. The receiver has greater than 30 dB of gain, and 20 dB image rejection. The antenna has a 25 dB difference null and greater than 15 dB of cross-polarization isolation. The patch antenna uses a single planar substrate allowing for high yield and low cost.

## References:

[1] G. Rebeiz, "94 GHz Slot-Ring Antennas for Monopulse Applications", Presentation to the Baltimore IEEE-MTT section, 14 Nov. 1996".

[2] E. Niehenke, P. Stenger, T. McCormick, C. Schwerdt, "A Planar 94 GHz Transceiver With Switchable Polarization," 1993 IEEE MTT-S International Microwave Symposium Digest, pp. 167-170.

[3] D. Blackwell, H. Henry, J. Degenford, M. Cohn, " 94 GHz Subharmonically Pumped MMIC Mixer," 1991 IEEE-S International Symposium Digest, pp. 1037-1039.

[4] E. Niehenke, M. Cohn, P. Stenger, U.S. Patent #5517678 "Subharmonic Image Rejection and Image Enhancement Mixer", granted May 14, 1996.