A Single Layer Planar *K*-Band Monopulse Radar Receiver

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***Abstract* — In this paper, a *K*-band monopulse comparator and dual six-port junctions are combined to create a portable planar monopulse receiver. The architecture utilizes the phase offset of the difference signals to reduce the number of necessary downconverters. The full design was implemented with passive microstrip structures, silicon Schottky diodes, and a medium power amplifier. The performance of the design was measured at 24 GHz using a three-element series fed antenna supplied by a voltage-controlled oscillator.**

***Index Terms* — monopulse radar tracking, positioning, six-port architecture**

I. INTRODUCTION

Monopulse radar designs have been utilized for target tracking applications for over half a century [1][2]. As technology has advanced, high frequency components have become more precise, less expensive, and designed with reduced footprints. Due to these advances, it is possible to fabricate a portable monopulse receiver capable of high precision angle tracking. A compact design and high location tracking accuracy is desired in minimally invasive surgery, where internal procedure monitoring needs to be carefully tracked [3]. For this work, the focus is the angle sum and difference signal demodulators, which have been fabricated and tested. The microstrip structures, mixers, and patch antennas are designed to operate at 24 GHz. Test boards for the balanced mixer design, as well as the *I/Q* mixer design were used to verify functionality and measure conversion loss.

II. MONOPULSE RECEIVER DESIGN

Figure 1 shows an overview of the designed monopulse receiver while Fig. 2 shows the fully assembled dual *I/Q* mixer. This design was implemented on a 0.01” (0.254 mm) thick Rogers 3003 substrate. Four separate patch antennas feed into the comparator, which supplies the sum signal, as well as the azimuth and elevation difference signals. The equations for this comparator are as follows:

$$\Sigma = \frac{A + B + C + D}{2} \tag{1}$$

$$\Delta_{Az} = -j\frac{(A + B) - (C + D)}{2} \tag{2}$$

$$\Delta_{Diag.} = -\frac{(A + C) - (B + D)}{2} \tag{3}$$

$$\Delta_{El.} = -j\frac{(A + D) - (B + C)}{2} \tag{4}$$

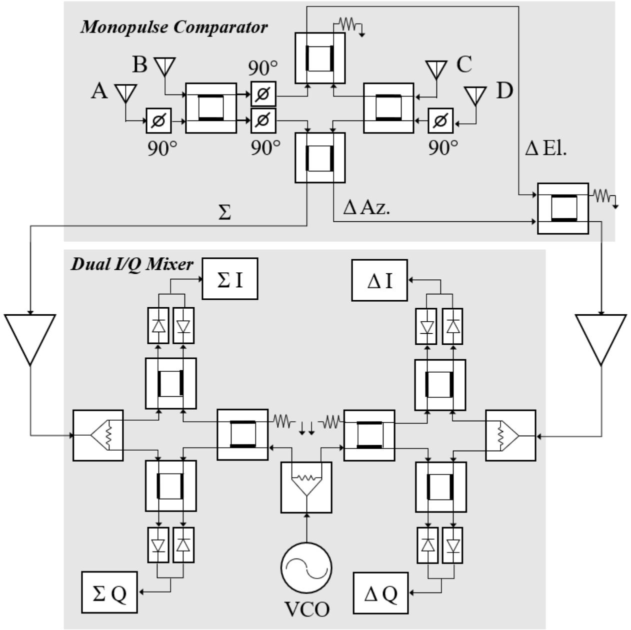

Fig. 1. Top-level block diagram of the proposed planar monopulse receiver with sum and difference signal *I/Q* mixers.

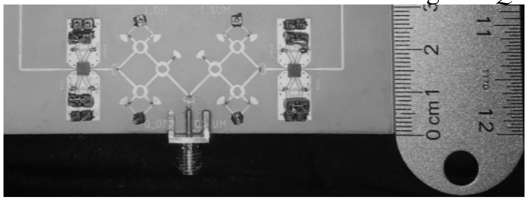

Fig. 2. Fabricated Dual I/Q mixer with amplifiers.

The two difference signals are then merged with a hybrid coupler, allowing them to be separated again after down converting [1]. This new joint difference signal, along with the sum signal, are then sent to an LNA followed by a balanced *I/Q* mixer. The outputs of the mixers connect to pins that are used to measure the baseband values.

A. Monopulse Comparator

The design for the monopulse comparator, based on those found in [1] and [3], follows the same principles. Four 90º 3dB couplers and four 90º lines are connected as shown in Fig. 1. Because of the configuration of the delay lines and the couplers, the resulting azimuth and elevation signals have the same phase offset, as seen in (2) and (4). Therefore, combining them with a hybrid coupler introduces a 90º phase offset and the signals can

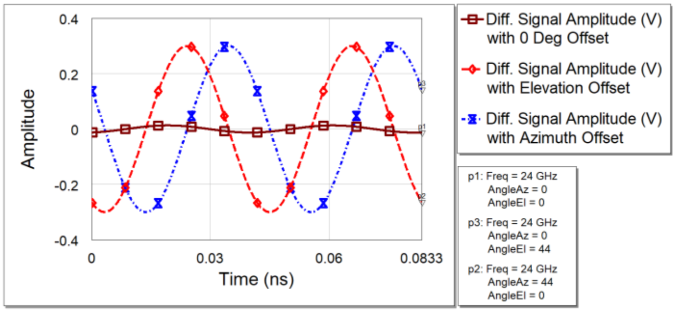

Fig. 3. Simulated combined comparator difference outputs demonstrating elevation and azimuth phase shifts.

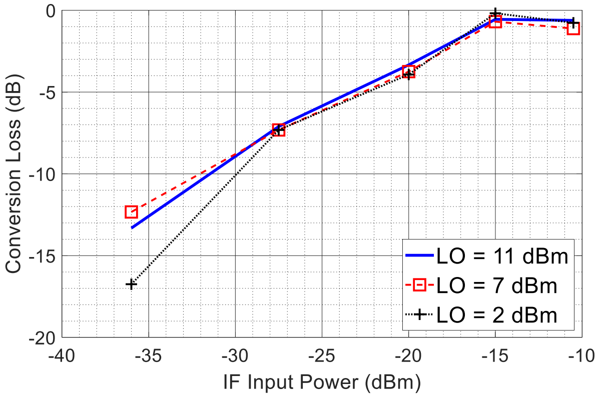

Fig. 4. Measured *I/Q* mixer conversion loss.

be consolidated on to one signal path. This new signal, when decoupled with an *I/Q* mixer, returns the original elevation and azimuth difference signals. This concept can be seen in Fig. 3, which shows the expected phase of the joint difference signal with elevation, azimuth, and no phase difference between the four input signals.

B. Balanced I/Q Mixer

With the difference signals offset by 90º, an *I/Q* mixer is used for down converting the sum and difference signals to baseband outputs. Ideally, the baseband signal will be formed through mixing the comparator outputs with the output of a voltage-controlled oscillator tuned to the same frequency. This method should produce a DC baseband output that represents the phase offset between the voltage-controlled oscillator (VCO) and the comparator outputs, which can easily be interpreted by a monitoring system or analog-to-digital converter.

The mixer design is a combination of two balanced diode mixers based on [6]. Each balanced mixer uses two Skyworks SMS7621-060 Schottky diodes in combination with the same 90º hybrid coupler used in the comparator structure. These two mixers are then supplied with outputs from a separate 90º hybrid coupler to provide LO signals offset by 90º. The total phase offset of the LO inputs should be consistent as the two mixers are identical and symmetrical, as shown in Fig. 1. Moreover, the VCO output is split into two signals with a 90º offset.

III. MEASUREMENT RESULTS

A. Balanced Mixer Conversion Loss

The balanced mixer design was verified on a test board using a 10 dBm 24 GHz VCO and a variable power signal generator, producing the results shown in Fig. 4. As the local oscillator signal power increased, the output signal level increased, but introduced signal distortion and saturation of the diodes. From these results, the desired RF input signal level is between -30 and -25 dBm.

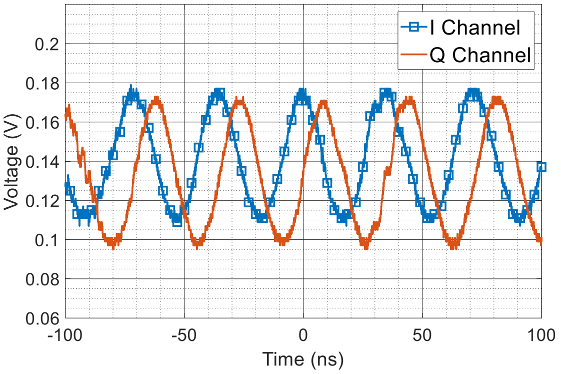

Fig. 5. Measured *I/Q* mixer outputs after down converting from 24 GHz to 2 MHz.

B. Balanced I/Q Mixer Phase Offset

Using another board, the balanced *I/Q* mixer design was tested to verify the desired 90º phase offset was present between the *I* and *Q* channels. The RF input was a -15 dBm 24 GHz signal and the LO input was a 10 dBm input tuned to generate an output signal at about 2 MHz, shown in Fig. 5. The results of this test were two signals with an average phase offset of 93.37º and an amplitude imbalance of 5.44 mV RMS.

IV. CONCLUSION

In this paper, the design of a portable planar *K*-band monopulse receiver is presented. Testing of the tuned *I*/Q mixer demonstrates a low-cost solution to acquiring the desired source offset angle and magnitude information needed for target tracking while maintaining the planar design. Planned future improvements to this design include adding phase calibration for the sum and difference signals, improving the directionality of the antenna, and adding an on-board VCO with a phase locked loop for better signal down conversion.

ACKNOWLEDGEMENTS

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