A Wide-Band Monopulse Comparator With Complete Nulling in All Delta Channels Throughout Sum Channel Bandwidth

Kian Sen Ang, *Member, IEEE*, Yoke Choy Leong, and Chee How Lee

***Abstract*—A broad-band monopulse comparator with complete nulling in the three delta channels throughout the sum channel bandwidth is presented in this paper. It is based on a new broad-band 180° hybrid with amplitude and phase balances that are theoretically perfect and frequency independent. Using this 180° hybrid, a microstrip monopulse comparator was realized on a low-cost FR-4 board. The comparator was fully characterized by its eight-port S-parameters to generate the sum and delta channel frequency responses. Over 30-dB null depths was achieved in the three delta channels across the sum channel passband from 1.1 to 3.3 GHz.**

***Index Terms*—180° hybrids, four-channel monopulse, monopulse comparator.**

I. Introduction

THE monopulse comparator circuit is a critical component in monopulse radar systems. It processes the four inputs from the antenna to generate SUM and DELTA signals, as shown in Fig. 1. The SUM, DELTA 1, and DELTA 2 signals are used to determine the angular position (azimuth and elevation) of the target return relative to the antenna boresight. When the target is at the boresight, all the four inputs will add up in the SUM channel and cancel out in the DELTA channels. In four channel monopulse systems [1], the DELTA 3 signal is also used to provide nulling of main beam jammers. Thus, the monopulse approach is a standard radar technique for high-accuracy tracking, with applications such as air traffic control, aircraft, and ship defense.

As shown in the block diagram of Fig. 1, the monopulse comparator consists of an interconnection of four 180° 3-dB hybrids. The most commonly known 180° hybrids are the hybrid waveguide junction (magic-tee) and the planar hybrid ring (rat-race). Waveguide monopulse comparators using waveguide junctions provide good performance, but tend to be bulky and expensive to fabricate. For planar monopulse processors, the hybrid ring is hardly used because its port positions are not conveniently located for the interconnections required in Fig. 1. Instead, planar 90° couplers in conjunction with a 90° delay line are frequently used to mimic the function of a 180° hybrid [2], [3]. Unfortunately, such a circuit can only achieve perfect 180° phase balance at the center frequency. Consequently, monopulse comparators using these “180° hybrids” exhibit only a single null in the frequency responses of the three DELTA channels. The typical bandwidths achieved for 30-dB null depths are limited to ±4%. To increase the null bandwidth, Barker and Rebeiz [2] employ a 0-dB coupler as a crossover, eliminating the need for 90° delay lines in two of the hybrids. Although this approach increases the 30-dB null bandwidth for the DELTA 2 channel to approximately ±20%, the null bandwidths for the other two DELTA channels remain unchanged.

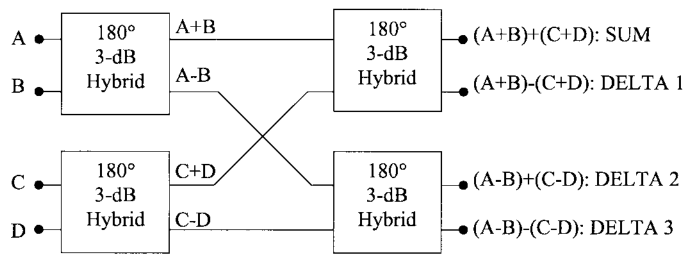

Fig. 1. Monopulse comparator block diagram using 180° 3-dB hybrids.

Recently, a new planar broad-band 180° hybrid has been reported [4]. Its port positions are conveniently located for the interconnections required in Fig. 1. More importantly, its theoretical amplitude and phase balance is perfect and frequency independent. Therefore, when it is employed in the monopulse comparator, the nulling of all three of the DELTA channels will also be perfect and frequency independent. Practical results of a planar monopulse comparator using this broad-band 180° hybrid will be presented in this paper.

II. Planar Broad-Band 180° Hybrid

The design and characteristics of this broad-band 180° hybrid have already been described previously [4]. Therefore, only the structure and performance will be briefly summarized here. Fig. 2 shows the circuit layout of the 180° hybrid with the port designations. It consists of a combination of an in-phase power divider and a Marchand balun. The power divider consists of a pair of $\lambda/4$ transmission lines, while the Marchand balun consists of a pair of coupled-line structures, which are shorted at one end. In this implementation, three-conductor coupled lines [5] are employed to achieve the required coupling. Air bridges, similar to those used in Lange couplers, are used to connect the outer conductors of the two couplers and to provide crossovers for the power divider. Sections of 50-Ω microstrip lines are included for external interconnections.

Theoretically, the sum and difference paths exhibit bandpass responses with amplitude and phase balances, which are perfect

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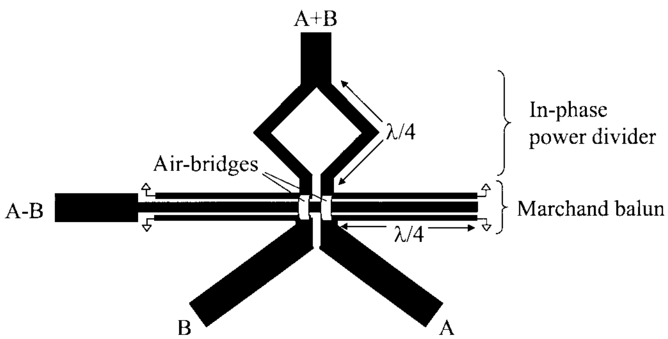

Fig. 2. Layout of the broad-band 180° 3-dB hybrid with its port designations [4].

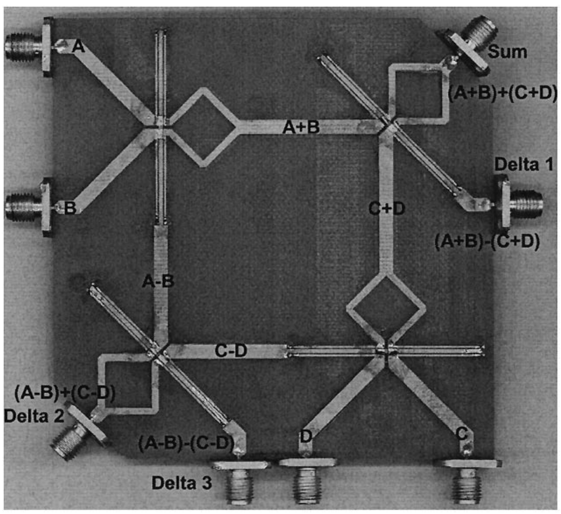

Fig. 3. Photograph of the fabricated monopulse processor with the signal designations at the eight ports and the interconnections.

and frequency independent. Practically, amplitude balance within 0.5 dB and phase balance less than 5° was achieved from 1 to 3 GHz using microstrips on low-cost FR4 boards [4].

III. Monopulse Comparator Using Broad-Band 180° Hybrid

Fig. 3 shows a photograph of the fabricated monopulse comparator using the broad-band 180° hybrid previously described. It consists of four identical hybrids directly interconnected using 50-Ω microstrip lines. The signal designations at the eight ports and the interconnections are also indicated in Fig. 3.

The circuit was fabricated on a low-cost FR-4 board where the traces are defined by a T-tech printed circuit board (PCB) router. The air bridges were implemented by soldering stripes of copper tapes across the microstrip traces. The short circuits for the coupled lines were obtained by soldering copper wires through substrate vias. Care was taken to ensure symmetry between the respective signal paths. The overall circuit dimension is approximately 9×9 cm^2.

The fabricated monopulse comparator was fully characterized based on two-port S-parameter measurements on a vector network analyzer. A total of 28 two-port measurements were made, without any circuit tuning, to obtain the 64 network parameters of the eight-port comparator. For each two-port

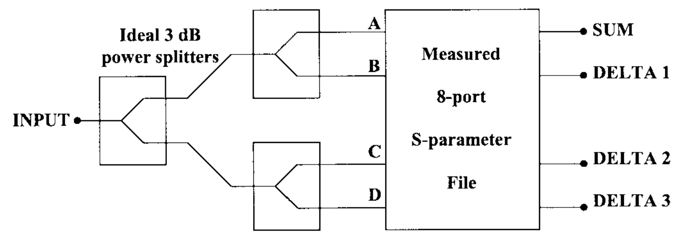

Fig. 4. Schematic diagram for generating the SUM and DELTA channel frequency responses based on S-parameters simulations and measured eight-port S-parameter file.

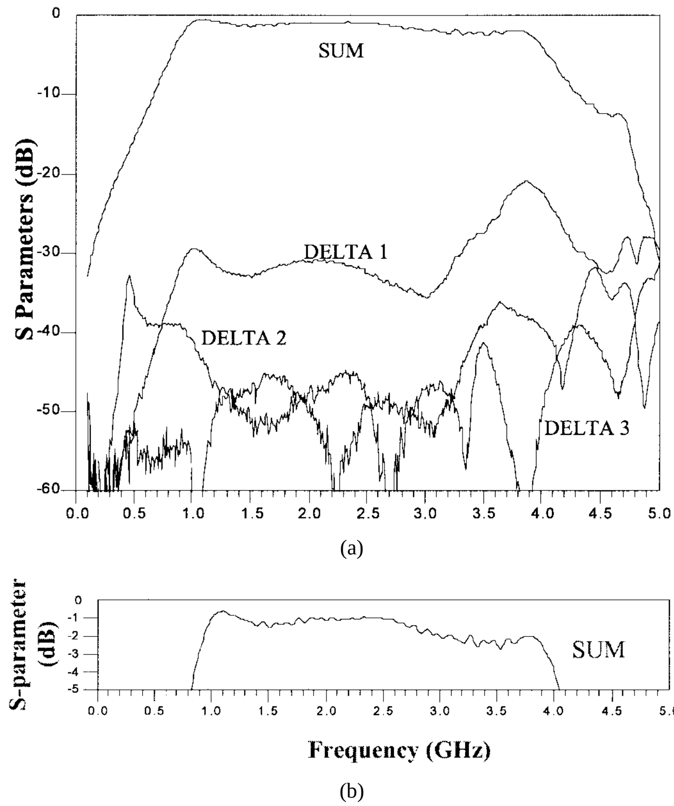

Fig. 5. (a) Frequency response of the SUM and DELTA channels based on S-parameters simulations using the measured eight-port S-parameter file. (b) Close-up view of the SUM channel passband in (a).

measurement, the other six unconnected ports were terminated in coaxial 50-Ω loads. The results were used to generate an eight-port S-parameter file.

To evaluate the nulling performance of the monopulse comparator, the measured S-parameter file was then input into an HP-ADS[1] circuit simulator. Fig. 4 shows the schematic diagram for generating the SUM and DELTA channel frequency responses based on S-parameter simulations. Ideal 3-dB in-phase splitters were used to simulate a target return at boresight, where all the input signals are equal in amplitude and in-phase.

Fig. 5(a) shows the S-parameters of the SUM and DELTA channels obtained. The SUM channel exhibits a wide bandpass response from 1.1 to 3.8 GHz. A close-up view of the SUM passband is shown in Fig. 5(b). The insertion loss is within 1.5 dB up

[1] *Agilent Advanced Design System (ADS)*, ver. 1.3, Agilent Technol., Palo Alto, CA.

to 2.6 GHz and increases to approximately 2.5 dB at the higher frequency end of the passband. For the lower frequency end of the SUM channel passband, from 1.1 to 3.3 GHz, >30-dB nulls were achieved in DELTA 1 and >45-dB nulls were achieved in DELTA 2 and 3. At the higher end of the passband, the null depth in DELTA 1 degrades to approximately 20 dB, while the null depths of DELTA 2 and 3 degrades to approximately 40 dB.

The degradation of the null depths with increasing frequency can be attributed to the increasing amplitude and phase imbalances due to unequal even- and odd-phase velocities of the nonhomogeneous microstrip coupled lines. The better nulling in channels DELTA 2 and 3 compared to DELTA 1 may be explained as follow. Referring to Fig. 3, DELTA 2 and 3 are the sum and difference of two difference signals, while DELTA 1 is the difference of two sum signals. Therefore, the signal amplitudes at the inputs of the hybrid with DELTA 2 and 3 are much smaller than that of the hybrid with DELTA 1. Consequently, with the same amplitude and phase imbalance in these hybrids, the residual error in the signal cancellation will be smaller in DELTA 2 and 3, resulting in better null depths.

IV. Conclusion

Previous planar monopulse comparators using 90° couplers exhibit narrow nulls in the frequency responses of the DELTA channels. This paper has demonstrated that, by employing a new broad-band 180° hybrid, complete nulling can be achieved in all the DELTA channels. Practically, >30-dB nulls was achieved in DELTA 1 and >45-dB nulls was achieved in DELTA 2 and 3, throughout a SUM channel passband from 1.1 to 3.3 GHz. This comparator design can be scaled up to higher frequency bands like 2–6 and 6–18 GHz. It is also valuable in IF-based millimeter monopulse systems [6], [7] for processing of the down-converted wide-band IF monopulse signals.

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