SUM-DIFFERENCE CIRCUITS USING 0 DB AND - 3 DB CO-DIRECTIONAL COUPLERS FOR HYBRID MICROWAVE AND MIMIC CIRCUIT APPLICATIONS

Sener Uysal, John Watkins and Charles W. Turner

Electromagnetic Modeling Group
Electrical and Electronic Engineering Department
King's College London, University of London
Strand, London WC2R 2LS, U.K.

ABSTRACT

A new design approach for microstrip $\Sigma - \Delta$ Magic-T circuits is described. The technique employs entirely planar 0 dB and -3 dB co-directional quadrature couplers. 17% bandwidth is demonstrated at X-band from a Magic-T circuit built on an one inch square alumina substrate. Multi-octave 0 dB coupling is also illustrated by a computed example.

Any other coupling level can be derived directly from the 0 dB co-directional coupler thereby simplifying mask layout and significantly reducing design time. Accurate design curves for co-directional couplers on alumina substrate are given in the paper.

1. INTRODUCTION

Sum-difference ($\Sigma-\Delta$) circuits have applications in communications and antenna sub-systems for radar applications such as monopulse comparators for direction finding systems.

Forward-wave branch-line $0^o - 180^o$ hybrids are usually employed for the realization of narrow-band $\Sigma - \Delta$ circuits using microstrip technology. Other forms of co-directional couplers have been reported by several authors [1-4]. The one reported by Ikalainen and Mathaei [4] employs very long coupled lines separated by a very large gap (to minimize backward-wave coupling). For wideband operation they use asymmetric (non-identical) lines. In this paper we use modified nonuniform coupled lines [5] which allow us to use a suitable value for minimum spacing for a given coupler length. The exact nature of S-parameters can be determined by the close-form equations reported in [6].

2. $\Sigma - \Delta$ CIRCUIT

The proposed sum-difference circuit is shown in Fig.1. It uses a 0 dB and a -3 dB co-directional coupler. The adjacent ports of these couplers are assumed to be perfectly isolated. The 0 dB coupler provides the desired constant 90^o phase-shift with respect to the signal input at the port denoted by A. Therefore a phase-reference line is connected to this port of the -3 dB coupler. Sum and difference signals are then formed at the two output ports of this coupler. The other two ports of the 0 dB coupler may be terminated by the impedance level of the coupler.

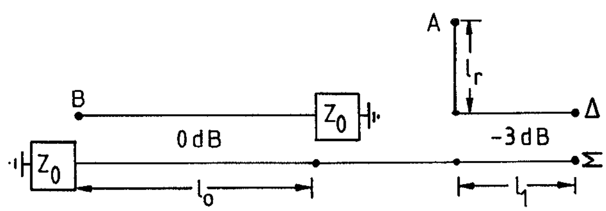

Fig.1 Schematic diagram of sum-difference circuit using 0 dB and -3 dB co-directional couplers. The line length l_r is the phase reference line for Magic-T performance with $\Sigma = j(A+B)/\sqrt{2}$ and $\Delta = (A-B)/\sqrt{2}$.

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The circuit of Fig.1 can be simplified by eliminating the terminations. This is possible by connecting either the sum or the difference channel into the isolated or the direct port of the 0 dB coupler. For practical realization, we choose the circuit of Fig.2; the sum port is fed into the isolated port of the 0 dB coupler. This provides an additional 90^o phase-shift for the signal which is needed for the second stage to construct the sum and difference patterns for a four antenna/array monopulse comparator. In this way two of the four 0 dB couplers are eliminated.

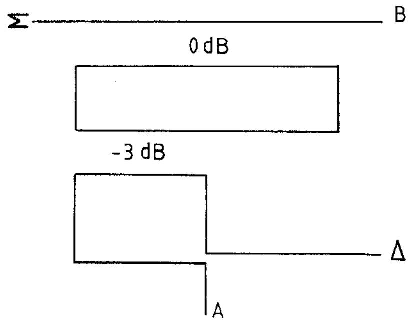

Fig.2 The circuit of Fig.1 as arranged on an one inch square alumina substrate. The sum port is connected to the isolated port of the 0 dB coupler.

3. DESIGN CURVES FOR CO-DIRECTIONAL COUPLERS

The fundamental design curves for this class of couplers are the phase velocities stated as a function of wiggle depth (in this paper we use triangular wiggling of the type first reported by Podell [7]) introduced into the coupled region. The derived design curves for alumina substrate are shown in Fig .3 at 10 GHz.

For an ideal, tapered co-directional coupler the S-parameters are given as follows:

$$|S_{11}| = 0 \quad (1)$$

$$|S_{21}| = 0 \quad (2)$$

$$|S_{31}| = sin[\omega(\int_0^l \frac{dx}{v_e(x,\omega)} - \int_0^l \frac{dx}{v_o(x,\omega)})] \quad (3)$$

$$|S_{41}| = cos[\omega(\int_0^l \frac{dx}{v_e(x,\omega)} - \int_0^l \frac{dx}{v_o(x,\omega)})] \quad (4)$$

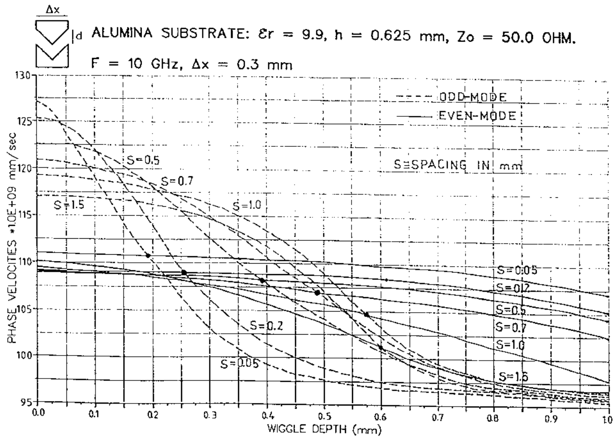

Fig.3 Phase velocities as function of wiggle depth on alumina substrate.

and $arg(S_{31}) - arg(S_{41}) = \pi/2$ with identical lines.

4. DESIGN EXAMPLE

The first step is the selection of phase-velocity functions for even- and odd-modes. Denoting the coupler center as x=0, we first choose the phase velocities at x=-l/2:

At f=1 GHz: $v_e = 104.10^9 mm/sec$ and $v_o = 96.10^9 mm/sec$

At f=20 GHz: $v_e = 102.10^9 mm/sec$ and $v_o = 96.10^9 mm/sec$

Phase-velocities at x=0 :

At f=1 GHz: $v_e = 113.10^9 mm/sec$ and $v_o = 96.10^9 mm/sec$

At f=20 GHz: $v_e = 108.10^9 mm/sec$ and $v_o = 96.10^9 mm/sec$

Variation of even-mode phase velocity is assumed to be linear; odd-mode velocity is taken as constant. The chosen phase-velocities should be achievable with the given substrate parameters.

The next step is the simulation of coupler performance for a given coupler length. Here we use 0 dB coupler length as 18.6 mm. It may be necessary to vary the length (as we have done in this case to arrive at this length) and the phase-velocities to achieve the desired performance. Once this is achieved the corresponding wiggle depths are obtained by using Fig .3

The computed performance for the X-band 0 dB coupler is shown in Fig.4. For -3 dB coupling we take one half of the 0 dB coupler. Although it is possible to design a separate -3 dB coupler, using the same design for both 0 dB and -3 dB coupling guarantees Magic-T performance from the circuit. It should also be noted here that as long as the two coupled lines are identical any other asymmetry does not affect phase quadrature since the coupling is co-directional with the input signal.

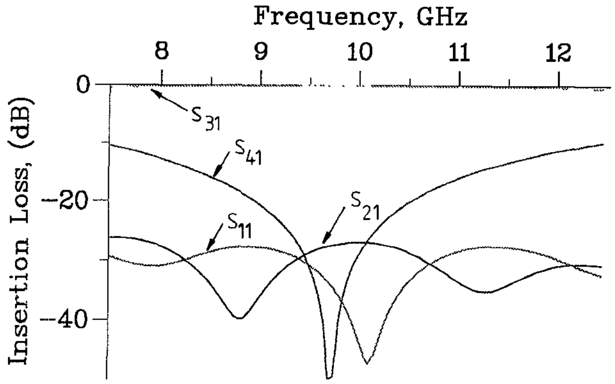

Fig.4 The computed performance of the 0 dB, 18.6 mm long X-band co-directional coupler.

For multi-octave performance, the variation in phase velocities must be more gradual; this implies that a longer coupler is needed for wideband operation. The computed performance for a wideband 0 dB 39.2 mm long co-directional coupler is shown in Fig.5.

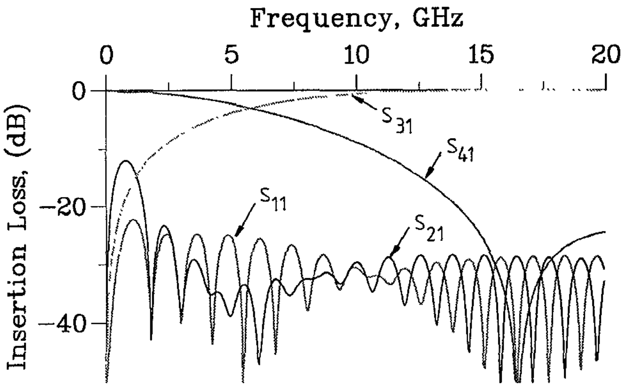

Fig.5 Multi-octave bandwidth 0 dB co-directional coupler.

5. MEASURED RESULTS

The circuit of Fig.2 is built on an one inch square alumina substrate with thickness 0.625 mm. It is first connected to an HP8510B Network Analyser at its A port and the signals at Σ and Δ ports are stored in the memory. The port B then becomes the isolated port for the 0 dB coupler. The circuit is then reversed and the measurements are repeated; in this case the signal at A is the isolation of the -3 dB coupler.

The measured results are shown in Fig.6 (a)-(h). Close agreement is observed between the computed and measured results. Fig.6 (a)-(d) show the measured Σ port. About 1.5 dB insertion loss is indicated by the sum port which includes the connector losses. The phase difference between the signals appearing at this port is $\pm 1.5^o$ from 9 to 10.2 GHz. Input match is below -10 dB in the design bandwidth with Isolation better than -20 dB.

Fig.6(e)-(h) give the results for the Δ port. Amplitude imbalance at this port is less than 0.5 dB in most of the band which results in a difference signal less than -25 dB. Input match is around -15 dB with Isolation better than -20 dB.

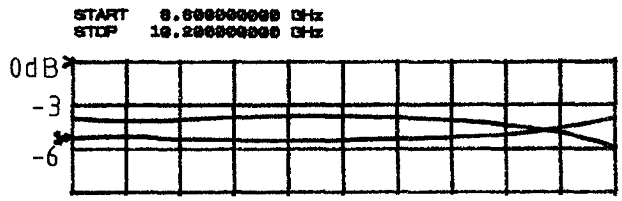

Fig.6(a) Signals A and B at the sum port.

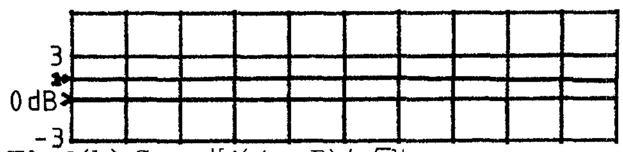

Fig.6(b) Sum $|[j(A+B)/\sqrt{2}]|$ port.

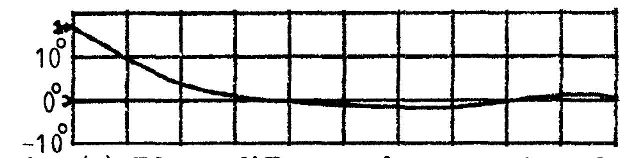

Fig.6(c) Phase difference between A and B.

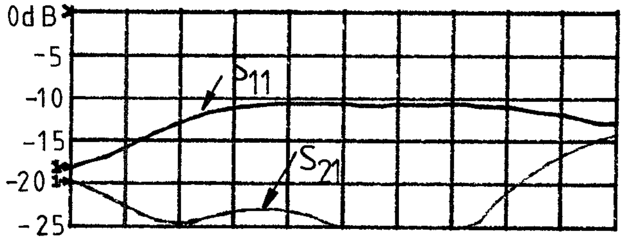

Fig.6(d) Input match and Isolation.

Fig.6(a)-(d) Measured sum port of the X-band Magic-T.

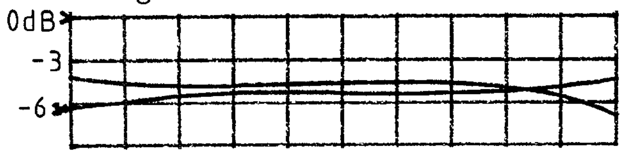

Fig.6(e) Signals A and B at the difference port.

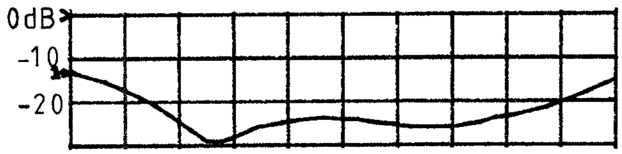

Fig.6(f) Difference $[(A-B)/\sqrt{2}]$ port.

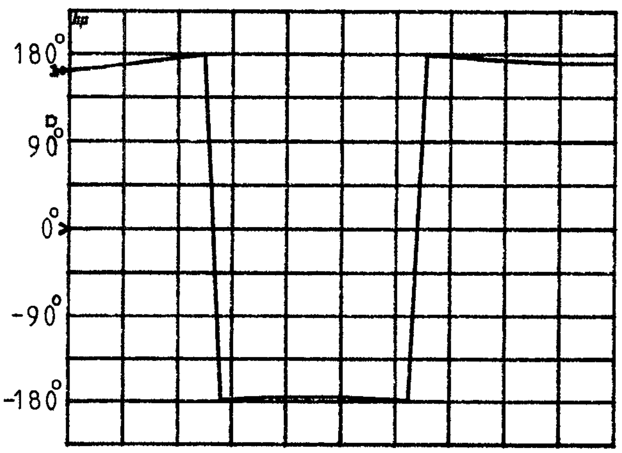

Fig.6(g) Phase difference between A and B.

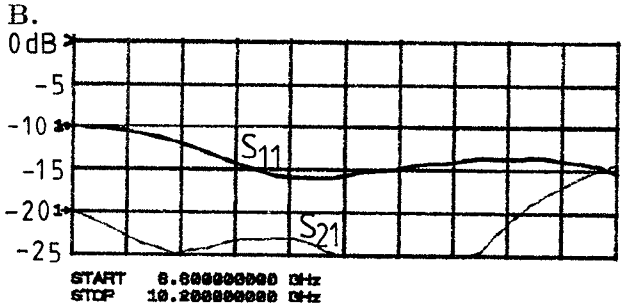

Fig.6(h) Input match and Isolation.
Fig.6(e)-(h) Measured difference port of the X-band Magic-T.

6. CONCLUSIONS

An accurate design procedure has been presented for $\Sigma - \Delta$ circuits using codirectional couplers. 17% bandwidth has been demonstrated at X-band in which the difference channel is below -25 dB. Multioctave performance is possible by employing longer couplers.

A separate design for -3 dB coupler may not be necessary; one half of the 0 dB coupler gives -3 dB coupling with quadrature performance.

Co-directional couplers can be realized with large conductor spacing; the minimum design gap used was 0.211 mm.

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