A Recombinant, In-Phase Power Divider

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***Abstract*—A new topology for a planar power divider suitable for realization using conventional microstrip fabrication techniques is described. This divider is capable of exciting an odd number of output ports with either equal or unequal power division. The recombinant approach produces bandwidth comparable to that of other techniques with fewer and more easily realized elements. Design equations and an example implementation are discussed. Measured data for an octave-bandwidth, three-way power divider at 10 GHz are presented.**

I. Introduction

A new topology has been developed for the synthesis of planar, wide-band power dividers suitable for use at RF and microwave frequencies. The recombinant topology provides in-phase power division with either equal-amplitude signals at all output ports or unequal signals whose amplitudes are symmetrical with respect to the center output port. Dividers with an odd number of three or more output ports can be realized using this approach.

In the design of a three-way divider topology, the variation of the values of the circuit elements results in the power available at the center arm being greater or less than that available at the outside arms of the divider.

A number of investigators have discussed planar versions of power divider topologies [1]–[4]. These approaches are usually limited by the physical dimensions of the high-impedance transmission lines adjacent to the common port as well as by their inherently higher insertion loss. The power divider described in this paper is also ultimately limited by the highest impedance that can be fabricated; however, its performance degrades more slowly than that of other configurations, as the high-impedance lines are reduced to achievable values.

One application of a divider of this topology is in triple-channel tracking receivers employing a calibration (or reference) channel and two receiving channels. It is often desirable to operate the calibration channel at a lower level of LO power than the receive channels since the compression of the calibration channel is not usually a factor in the receiver's design. This device allows the dynamic range of the receiver to be maximized by providing more power to the signal channels and allowing the reference channel to be operated at a lower level while maintaining the phase tracking required in RDF and missile equipment.

II. Description

A conventional corporate feed power divider design results in 2^n outputs, where n is the number of stages of division. If the second section in a corporate feed is designed to provide a 1:2 unequal power split (-1.77 dB, -4.77 dB), the two lower power arms can be recombined into a single center arm using an equal combiner. Fig. 1 shows the general topology for a recombinant device. This unique topology avoids several limitations of conventional designs.

Manuscript received October 29, 1990; revised February 28, 1991.

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IEEE Log Number 9101017.

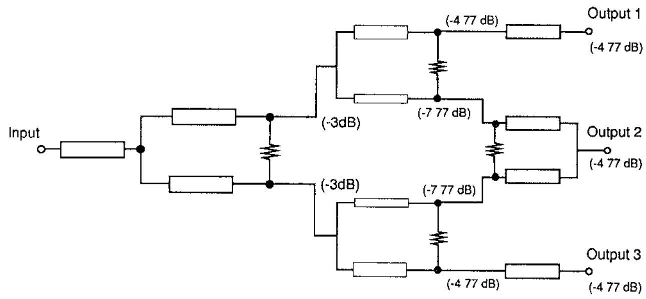

Fig. 1. Three-way recombinant power divider.

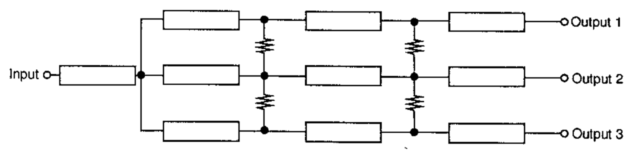

Fig. 2. "Planarized" conventional power divider.

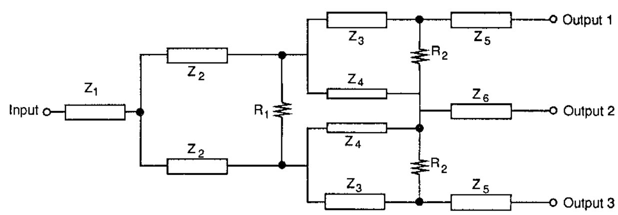

Fig. 3. Recombinant power divider.

Existing power divider designs, e.g. the dividers discussed by Wilkinson and Howe, require three-dimensional implementation, i.e., one or more floating nodes, for multiway power division [5], [6]. As previously discussed, there are two-dimensional approximations of these designs; however, a considerable bandwidth penalty is paid in "planarizing" the design.

A three-dimensional power divider containing two isolation sections, one input transformer and one output transformer requires six isolation resistors and achieves 120% bandwidth at the 20 dB isolation points in both adjacent and nonadjacent arms. The planarized version of the divider, shown in Fig. 2, reduces the number of resistors to 4 and also reduces the isolation bandwidth to 86%/84% in the adjacent/nonadjacent arms.

In a microstrip realization, the 105 Ω transmission lines would be very narrow and substantially increase the insertion loss of the design. The design can be modified to permit more desirable line impedances; however, the 20 dB isolation bandwidth quickly dips below 66% for a maximum line impedance of 80 Ω.

The recombinant divider achieves an 86%/76% isolation bandwidth and requires only three isolation resistors. Additionally, this topology allows some freedom in the choice of the impedances of the transmission lines in the divider sections, and the performance will degrade only to 72% bandwidth with a maximum transmission line impedances of 80 Ω.

In the recombinant divider topology, notice that the resistor nearest the center output arm does nothing to improve the isolation performance under any combination of excitations of

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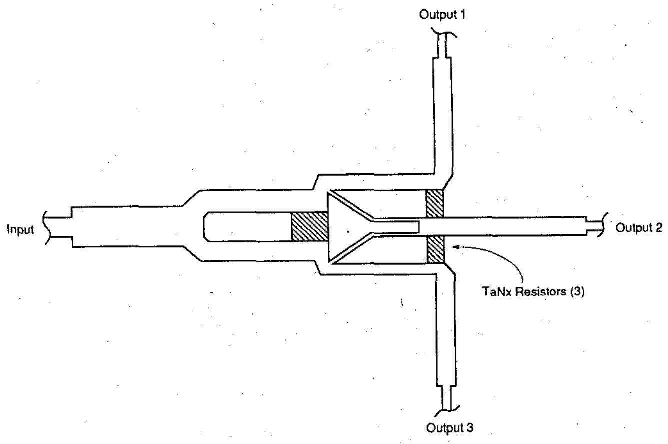

Fig. 4. Layout of three-way recombinant power divider.

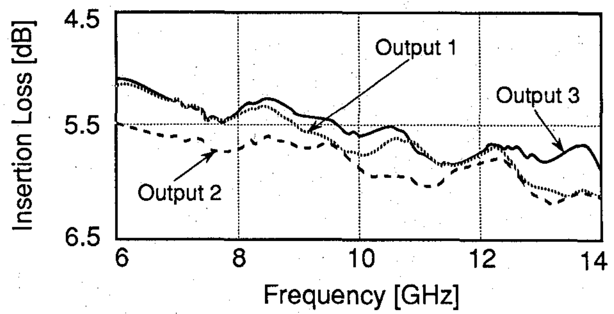

Fig. 5. Insertion loss of three-way recombinant power divider.

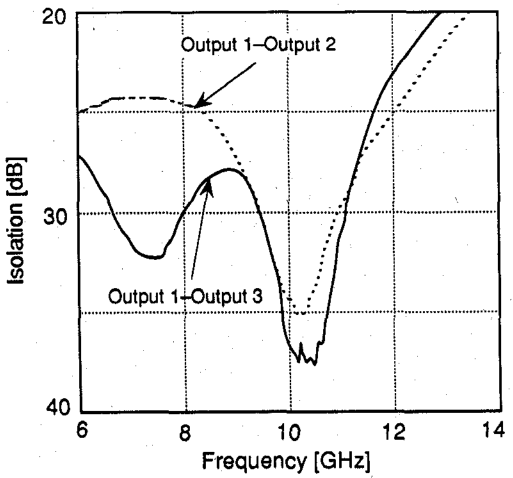

Fig. 6. Isolation of three-way power divider.

the output ports. If this resistor is removed and the two transmission lines at output port 2 are combined into a single line having half the characteristic impedance, the final result is the topology shown in Fig. 3. The synthesis method for this divider is discussed in the Appendix.

III. Example

A three-way recombinant divider at 10 GHz was designed to be fabricated in 25 mil (635 μm) thick 99.6% alumina. To obtain acceptable yield in RF performance, a decision was made to limit the highest impedance of the transmission lines to 80 Ω,

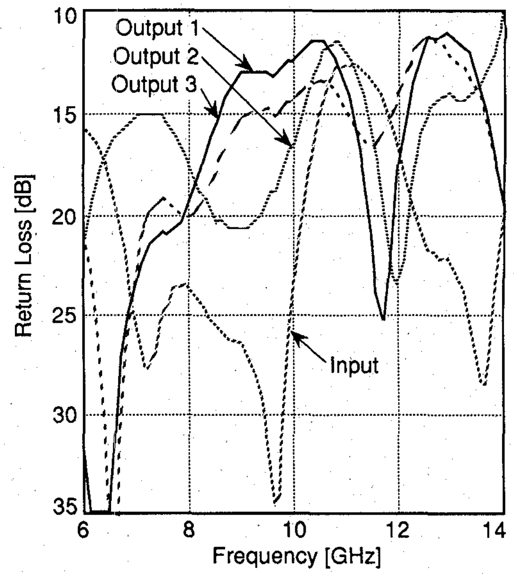

Fig. 7. Return loss of three-way power divider.

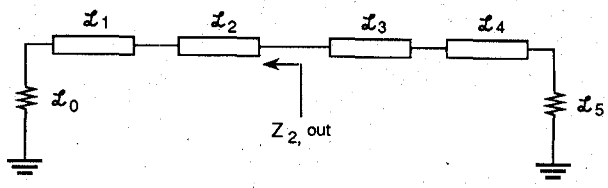

Fig. 8. Equivalent circuit for synthesis of a three-way divider under in-phase excitation.

resulting in approximately 4 mil (100 μm) line widths. This permitted fabrication using conventional etch-back techniques.

The final layout of the design is shown in Fig. 4 and its corresponding performance in Figs. 5–7. The final design values, in ohms, for the quarter-wavelength transmission lines were $Z1 = 36$, $Z2 = 40$, $Z3 = 40$, $Z4 = 80$, $Z5 = 40$, and $Z6 = 40$. The isolation resistors R1 and R2 were 50 and 100 Ω, respectively.

Over a 2:1 bandwidth, the center-to-side and side-to-side isolations exceed 20 dB. The insertion loss is somewhat high owing to the slightly mismatched input port (12 dB return loss). Note that the side-to-center insertion loss tracking is slightly degraded as the lines were slightly underetched and the higher impedance lines changed impedance faster than the lower impedance lines. This may also have exacerbated the mismatch loss and degraded the isolation bandwidth.

IV. Conclusion

The device discussed above can be synthesized in broader bandwidths or with more outputs than instanced. The optimum topology for a given bandwidth will depend on the requirements for its use in the system design. Through a suitable choice of transformation and isolation sections, return loss, insertion loss, and isolation can be optimized. This design concept has successfully been reduced to practice in a three-way divider using conventional MIC fabrication techniques.

The divider discussed above may provide a solution to engineering power distribution problems where power dividers with an odd number of three or more output ports need to be designed with equal or unequal power split.

Appendix

Synthesis

To illustrate the synthesis technique, a three-way divider will be designed. Cohn [7] describes an even/odd mode technique for the synthesis of two-way power dividers. While it is not technically correct to speak of an even mode in a three-way divider, the in-phase, equal amplitude excitation is still a necessary condition for the synthesis of the circuit.

Under in-phase excitation, the voltage across each isolation resistor is zero. This allows an equivalent circuit, shown in Fig. 8, to be generated for the divider. Synthesis is begun by generating a four-section transformer between Z_0 and $Z_0/3$. In the instant case, a 0.1 dB Chebyshev transformer was selected, resulting in the following impedances:

$$\mathscr{L}_0 = Z_0 \qquad \mathscr{L}_1 = Z1 = 0.91 Z_0 \qquad \mathscr{L}_2 = Z_2/2 = 0.70 Z_0$$

$$\mathscr{L}_3 = \frac{1}{2}\left(\frac{Z_3 Z_4}{Z_3 + Z_4}\right) = 0.48 Z_0 \qquad \mathscr{L}_4 = \left(\frac{Z_5 Z_6}{Z_5 + 2Z_6}\right) = 0.36 Z_0$$

$$\mathscr{L}_5 = Z_0/3. \tag{A1}$$

The power division ratio, k^2, as discussed by Parad and Moynihan [8], places additional requirements on the ratio of impedances of Z_4 and Z_3, shown in Fig. 3. These constraints are presented in the following relationships:

$$Z_{2,\text{out}} = \left(\frac{Z_2}{2Z_1}\right)^2 Z_0 = \frac{K^2}{K^2+1}\left(\frac{Z_3}{Z_5}\right)^2 \frac{Z_0}{2}$$

$$\frac{Z_4}{Z_3} = K\sqrt{2}\,\frac{Z_6}{Z_5}. \tag{A2}$$

In the above expressions, $Z_{2,\text{out}}$ is the terminal impedance presented by the first two sections of the power divider to the remainder of the divider. After considerable algebraic manipulation, these constraints can be distilled into the following expressions:

$$Z_6 = \frac{\mathscr{L}_3 \mathscr{L}_4\left(1 - K\frac{\sqrt{2}}{2}\right)}{\left(\frac{\mathscr{L}_2}{\mathscr{L}_1}\right)\mathscr{L}_4\sqrt{K^2+1} - K\frac{\sqrt{2}}{2}\mathscr{L}_3}$$

$$Z_5 = \frac{2\mathscr{L}_4 Z_6}{Z_6 - \mathscr{L}_4}$$

$$Z_4 = 2\mathscr{L}_3\left[1 + \frac{K\sqrt{2}}{2\mathscr{L}_4}(Z_6 - \mathscr{L}_4)\right]$$

$$Z_3 = \frac{2\mathscr{L}_3 Z_4}{Z_4 - 2\mathscr{L}_3}$$

$$Z_2 = 2\mathscr{L}_2$$

$$Z_1 = \mathscr{L}_1. \tag{A3}$$

To determine the value of the isolation resistors, the above technique can be repeated for out-of-phase excitation. By a proper selection of 0–180–0 or 0–0–180 degree signals at the output ports, the values of R1 and R2 can be determined.

Unfortunately, the above relationships are singular for the equal power division where $k^2 = 2$. It is, therefore, necessary to begin with the nonsingular values $(Z1, Z2)$ and solve for the remainder of the values iteratively.

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