A NEW N-WAY BROADBAND PLANAR POWER COMBINER/DIVIDER

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ABSTRACT

A new N-way broadband planar power combiner/divider was developed for ultra-broadband MMIC applications utilizing Dolph-Tchebycheff transmission line taper. The combiner/divider demonstrated a 5 to 18 GHz bandwidth with an insertion loss of less than 0.2 dB and an input VSWR of no more than 1.35.

INTRODUCTION

Recently, ultra-broadband (e.g., 6 to 18 GHz, 2 to 20 GHz, 2 to 40 GHz)[1-3] MMIC amplifiers have been developed. However, to meet future commercial and military system requirements for high power amplifiers, an efficient broadband power combiner/divider must be developed.

In this paper, we present a new broadband N-way planar power combiner/divider circuit that utilizes a Dolph-Tchebycheff tapered transmission line.[4] The distinguishing feature of this approach is that the isolation resistors connect between adjacent coupled transmission lines, as opposed to a common floating node, as in the case of the N-way Wilkinson combiner.[5] In addition, the tapered transmission line can perform power combining and impedance transforming at the same time. The new power combiner/divider also provides phase matching at each port to ensure efficient power combining.

DESIGN APPROACH

Power combining can be considered, in part, as an impedance transformation problem. The total N-way load (50/N) must be transformed to 50 ohms over the desired bandwidth. It has been shown that the Dolph-Tchebycheff taper is optimum in the sense that it has the minimum length for a specified maximum reflection coefficient magnitude in the passband.

The design of the N-way power combiner begins with the Dolph-Tchebycheff tapered transmission line. In general, the taper transforms from 50 ohms to 50/N to provide 50 ohm input/output impedance matching. The contour and the length of the taper determine the maximum in-band reflection coefficient and the low cutoff frequency, respectively. The frequency response is essentially high pass in character with equi-ripple in the passband.

The tapered transmission line is then divided into N coupled lines (see equivalent circuit in Figure 1a) and reanalyzed. To achieve equi-amplitude, and equi-phase power division at each port over the frequency band, the following conditions and approximations[6] must be fulfilled: 1) The N conductors have the same per unit length (PUL) capacitance to ground, 2) The PUL capacitances between adjacent conductors are identical, and 3) The PUL capacitance between nonadjacent conductors are negligible.

As shown in Figure 1b, each segment represents a nonuniform coupled quarter-wave impedance transformer at the center frequency. The combiner approach is similar in concept to the N-way planar power divider proposed by Nagai[7] and Schellenberg,[8] except that nonuniform coupled transmission lines are employed here. The impedance Zoe_n represents the even mode impedance in the signal propagation direction and must satisfy condition 1.

The odd mode equivalent circuit representation shown in Figure 1c is required to analyze the isolation resistor network. Zoo_n represents the equivalent odd mode impedance, which was calculated using the variational method[9] and the spectral domain method.[10] The analysis of the isolation resistor network is well documented[6,7] and will not be repeated here.

Note that fulfilling the above conditions requires conductors with different widths and spacings. The two end conductors, in particular, have to be narrower than the intermediate conductors, to account for the fringing capacitance at both ends.

Applying the techniques described above, we designed and fabricated a five-way power combiner/divider using a quartz (Er=3.78) substrate, 25 mils thick (Figure 2). Gap spacings between adjacent conductors were kept relatively small (1.5 mil) to ensure the coupled structure behaves like a Dolph-Tchebycheff tapered line. Chip resistors were employed in the isolation resistor network. Their calculated values are shown in Figure 1c. Each circuit has dimensions of 0.710 x 0.710 inch.

MEASURED RESULTS

S11 and S21 of a set of Dolph-Tchebycheff tapered transmission lines, connected back to back, were measured (Figure 3) from 2 to 18 GHz. A power combiner/divider set was also measured in the same fashion (Figure 4). The two measured results agree closely, implying that the coupled structure behaves identical to the tapered transmission line. The frequency response also demonstrates the high-pass characteristics of this type of circuit. The return loss demonstrates the characteristic of Tchebycheff equal ripple response. Due to multiple reflections, the 11 dB return loss corresponds to 17 dB (VSWR=1.35) for each combiner/divider. The insertion

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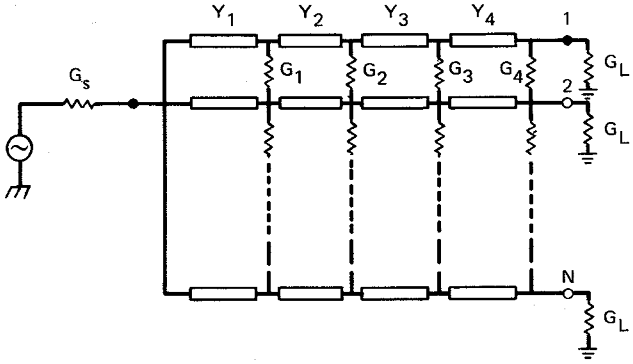

Fig. 1a Equivalent circuit of N-way power combiner

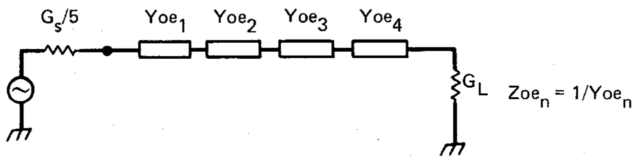

Fig. 1b Even mode representation of N-way power combiner

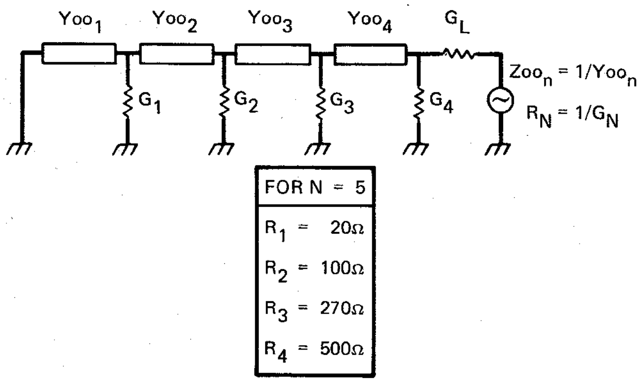

Fig. 1c Odd mode representation of N-way power combiner

loss of 0.35 ± 0.5 dB corresponds to approximately 0.2 dB for each divider.

Each output port measured a power split of -7.0 ± 0.5 dB across the whole described frequency band (Figure 5). Power deviation is no more than ±0.5 dB between each of the five output ports. The equi-power split between ports, along with the low insertion loss, is a good indication of equi-phase match at each port.

Port to port isolation measurements were performed. A minimum of 15 dB isolation between output ports was obtained across the 5 to 18 GHz bandwidth, as shown in Figure 6.

CONCLUSION

A novel broadband five-way power combiner/divider, utilizing a Dolph-Tchebycheff tapered transmis-

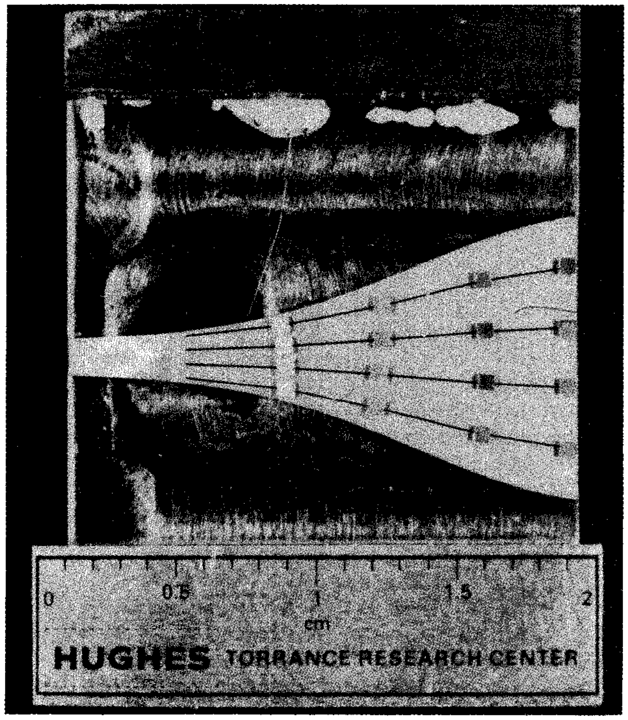

Fig. 2 A five-way planar power combiner/divider utilizing Dolph-Tchebycheff tapered transmission line

sion line, is demonstrated. It achieves a minimum of 100 percent bandwidth, which is believed to be the widest bandwidth reported by coupled line power combiner/dividers utilizing the described technique. The described combiner/divider was designed to operate over a 5 to 18 GHz bandwidth. However, due to its high-pass characteristic, it is expected to operate well beyond 100 percent bandwidth. The important aspect of this approach is

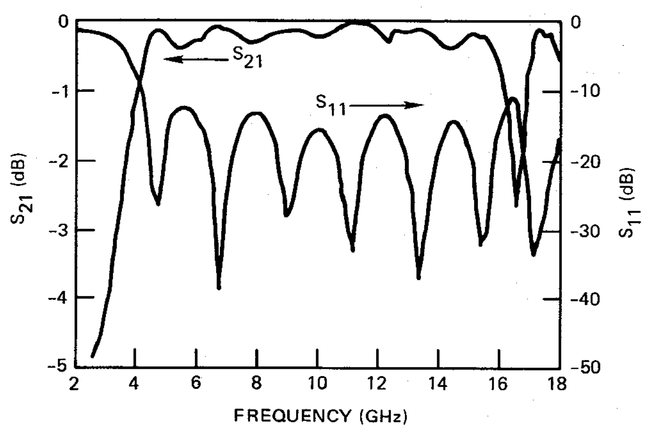

Fig. 3 S11 and S21 measurement of Dolph-Tchebycheff tapered transmission line

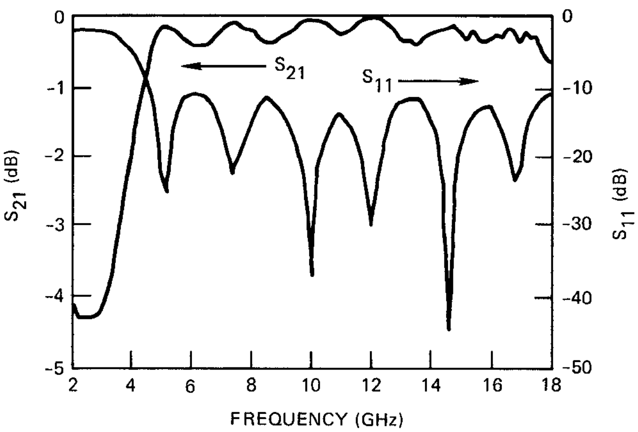

Fig. 4 S11 and S21 measurement of a set of five-way power combiner/divider utilizing Dolph-Tchebycheff tapered transmission line

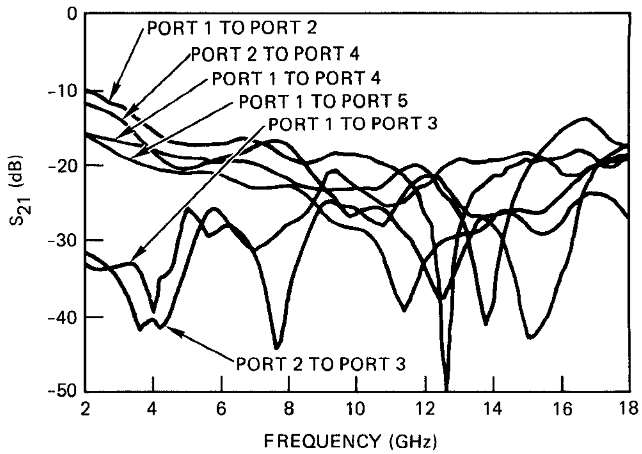

Fig. 6 Port to port isolation of five-way power combiner/divider

that it allows power combining and impedance transformation at the same time. Furthermore, the floating common node as required in the isolation resistors network of the Wilkinson combiner is eliminated.

The development of this power combiner/divider is the key step toward meeting the increasing demand for wideband and high-power hybrid/monolithic amplifiers in future commercial and military applications.

ACKNOWLEDGEMENTS

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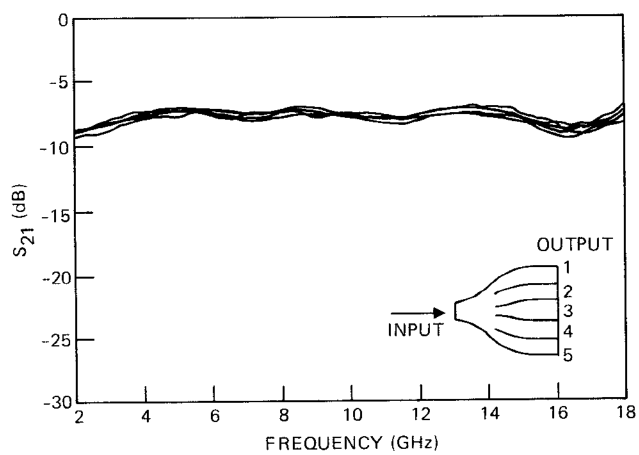

Fig. 5 Magnitude of power splits of five-way power divider