A NEW N-WAY POWER DIVIDER/COMBINER SUITABLE FOR HIGH-POWER APPLICATIONS

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Abstract

Theoretical and experimental results are presented on a new N-way power divider/combiner, which is an extension of the N-way combiner by Wilkinson. The main advantages of the new design are (1) external isolation loads, permitting high-power loads, (2) easily realizable geometry, and (3) monitoring capability for imbalances at the output ports. A trial 8-way combiner with 20% bandwidth at a center frequency of 1.15 GHz fully verified the new design concept.

Introduction

N-way dividers/combiner are used in numerous applications, most recently to combine the output of several semiconductor devices in order to realize high power solid-state oscillators and amplifiers. The N-way divider/combiner devised by Wilkinson[1] is the device most widely used to combine transistor amplifiers. Its main advantages are (1) low insertion loss, (2) high isolation between output ports, and (3) matched conditions at all ports. The useful bandwidth, which is a function of the number of output ports, is moderate. The main disadvantage of the Wilkinson combiner is that the resistive star required is difficult to realize in practice, particularly for a large number of output ports. The chip resistors usually employed for the resistive star limit the power-handling capability of the Wilkinson combiner to less than 100 watts CW, because adequate heat sinking of the resistors is not possible.

The new combiner described in the following sections represents an extension of the N-way combiner by Wilkinson that overcomes most difficulties of the old design. Its main advantages over the original Wilkinson design are (1) external isolation loads (high-power load resistors), (2) easily realizable geometry, and (3) monitoring capability for imbalances at the output ports. A trial 8-way divider/combiner has been built with a center frequency of 1.15 GHz to verify the new design, and the measured results compare very favorably with the previous combiners.

New N-Way Divider/Combiner Scheme

The new divider/combiner schematic is shown in Figure 1. A transmission line of characteristic impedance Z_1 and N transmission lines of characteristic impedance Z_2 lead from the common input port to the N output ports. All transmission lines are one quarter-wavelength long at the center frequency of the divider. In the original Wilkinson combiner $Z_1 = Z_0$, and a resistive star was connected directly between the N output ports, leading to a physically complicated arrangement. The new divider replaces the resistive star with a combination of transmission lines and shunt-connected resistors of value R. Transmission lines of characteristic impedance Z_3 connect each output port with what is called its associated load port. All load ports are connected by means of transmission lines of characteristic impedance Z_4 with a common floating starpoint. In practice, the shunt-connected loads of value R can be replaced by a transmission line of characteristic impedance R of arbitrary length and terminated in a load of value R. It is convenient to select $R = Z_0$, but other values are possible. Thus the loads become external elements and high-power loads can be utilized. Therefore, the loads are no longer the power-limiting factor of the combiner; rather the breakdown voltage of the combiner transmission lines determines its ultimate power-handling capability.

For design purposes, the divider is analyzed in terms of its equivalent four port network,[2] as shown in Figure 2, which is easily separated in generalized even and odd modes.

Closed solutions for optimum values for the design parameters do not exist. Computer-aided design techniques have to be used to obtain parameter values that yield minimum VSWRs at the input port and the N output ports as well as maximum isolation between output ports. Theoretical results for an 8-way combiner are shown in Figure 3. For comparison, the results for an 8-way Wilkinson combiner and a modified Wilkinson combiner are indicated. The modified Wilkinson design uses also a resistive star connected between the N output ports, but includes the transmission line of impedance Z_1 as an additional variable element in the circuit. The new design was optimized for 20% bandwidth. Over that frequency range it is clearly superior to the original Wilkinson combiner and compares favorably with the modified Wilkinson combiner. The somewhat higher VSWRs in the passband of the new design compared with the other two are insignificant, because junction effects and connector VSWRs are likely to be the dominant factors, particularly at higher frequencies.

Construction of the divider/combiner is relatively easy either in stripline, slabline, or microstrip. The power-handling capability is restricted only by the breakdown voltage of the transmission lines or the heat-dissipation capacity of the lines. The latter is the limiting factor for stripline and microstrip designs under CW conditions. But designs capable of handling combined CW output powers of 10 kW at L-band and of 5 kW at S-band are realizable. The power handling ability of the loads must also be considered.

To a limited degree the new combiner offers directional coupler characteristics. Under perfectly balanced conditions, the power delivered to the N terminations R is equal (zero at midband). Power incident only at one output port, say i, is mostly dissipated in its associated load resistor. For an 8-way combiner, the various insertion losses between the output port i and any other port are 1.25 dB to loadport i, 9.03 dB (1/8) to the input port and 17.5 dB to any other loadport. Therefore, loadport i exhibits 16.25 directivity with respect to any other load port for power incident only at output port i. This feature can be utilized advantageously to monitor imbalances in the power delivered to the output ports in the case of a combiner, or if the device operates as a divider, to monitor unequal load VSWRs.

Experimental Results

An 8-way divider was designed, built, and tested with a center frequency of 1150 MHz and a nominal bandwidth of 20%. A photograph of the divider is shown in Figure 4. The model is constructed in stripline on 1/16 inch Duroid circuit board with a relative dielectric constant of $\epsilon_r = 2.22$. The input line Z_1 is realized in coaxial form. All other lines are printed on two separate circuit boards. Measured results for the divider are presented in Figures 5 and 6. The agreement between calculated and measured values is excellent. However, further refinement of some design details should reduce the input VSWR to a value closer to that calculated (1.1 maximum). Figure 6 gives measurement results for the power transfer between input or output ports and load ports.

Conclusions

Results have been presented for a new power divider/combiner that seems very attractive for combining high-power active devices. The major advantages of the new approach are primarily its high power-handling capability, because external high-power isolation loads can be utilized, and the possibility to monitor and adjust the imbalance of the combined amplifiers or oscillators. The new combiner can be realized with a small increase in circuit complexity and negligible increase in insertion loss over that of the Wilkinson combiner (calculated 0.12 dB versus 0.1 dB for identical transmission-line losses).

References

1. E. J. Wilkinson, "An N-Way Hybrid Power Divider," IRE Trans. on Microwave Theory and Techniques, Vol. MTT-8, pp. 116-118 (January 1960).

2. J. J. Taub and B. Fitzgerald, "A Note on N-Way Hybrid Power Dividers," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-12, pp. 260-261 (March 1964).

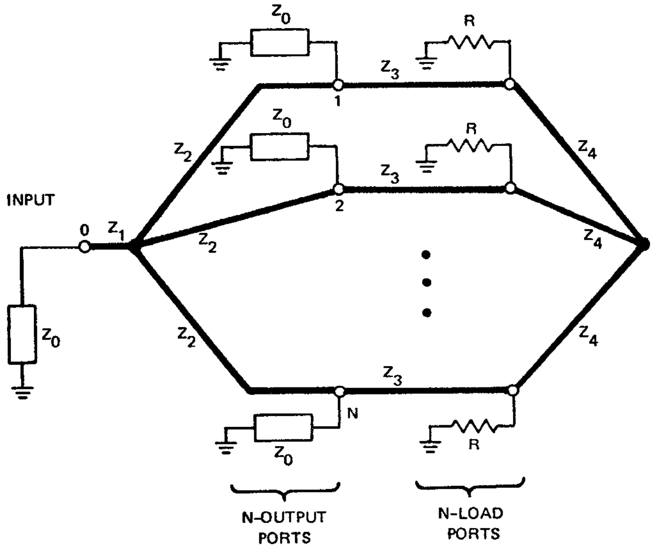

FIGURE 1 HIGH-POWER N-WAY DIVIDER/COMBINER (all transmission lines are a quarter-wavelength long at midband)

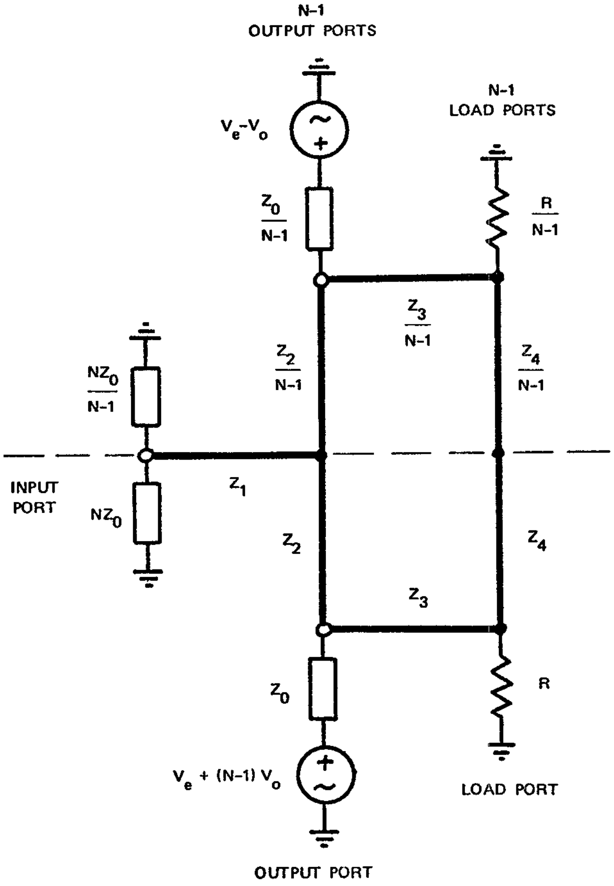

FIGURE 2 EQUIVALENT FOUR-PORT FOR THE N-WAY COMBINER

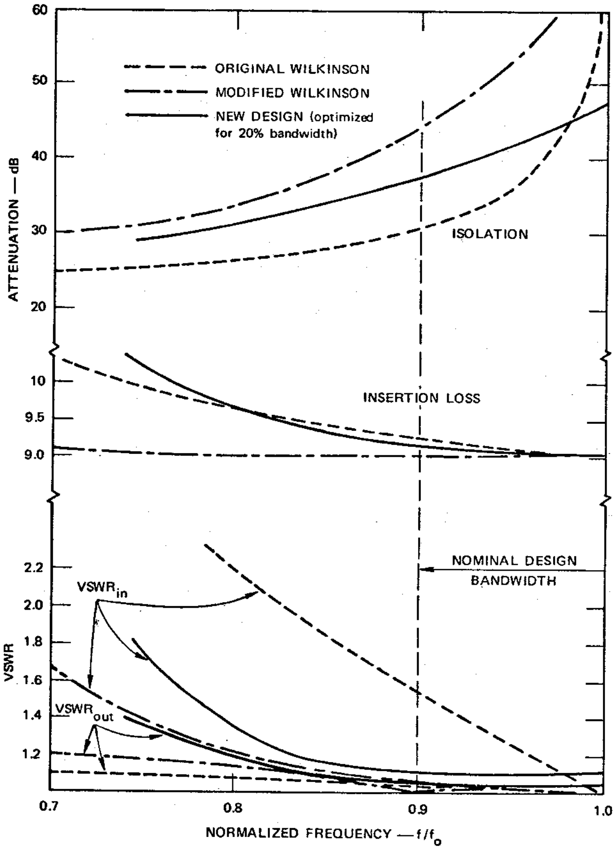

FIGURE 3 THEORETICAL PERFORMANCE OF THREE DIFFERENT POWER DIVIDERS

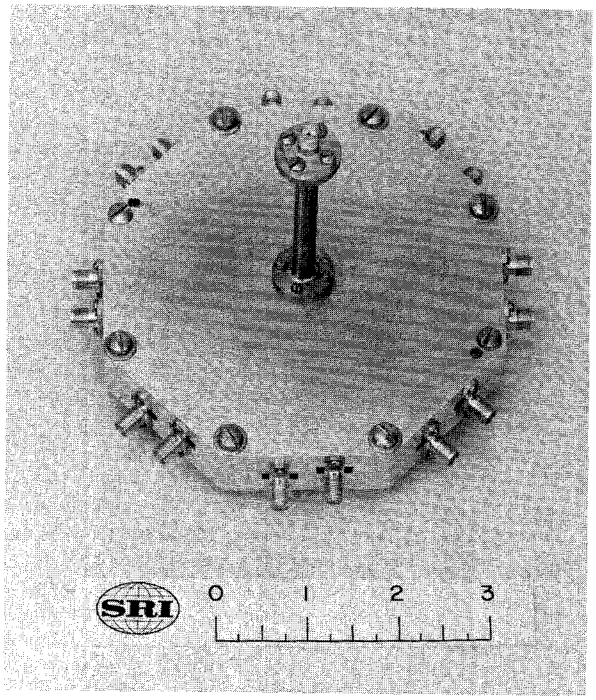

FIGURE 4 PHOTOGRAPH OF EXPERIMENTAL 8-WAY DIVIDER/ COMBINER (center frequency 1.15 GHz, 20% bandwidth)

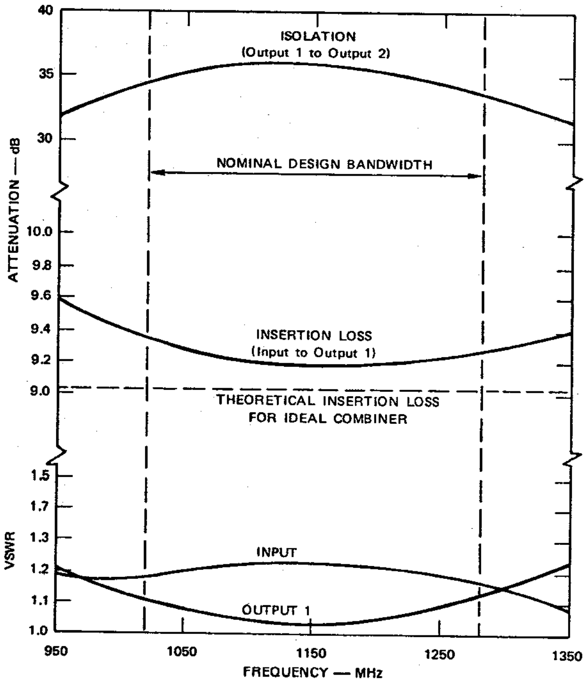

FIGURE 5 MEASURED VSWRs, INSERTION LOSS, AND ISOLATION FOR EXPERIMENTAL POWER DIVIDER

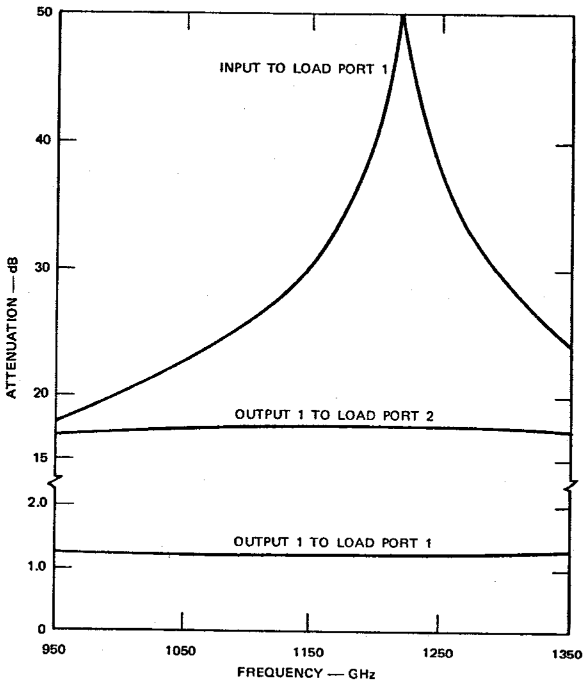

FIGURE 6 MEASURED LOAD-PORT ATTENUATIONS FOR EXPERIMENTAL POWER DIVIDER