A NEW ODD NUMBER N-WAY POWER COMBINER/DIVIDER*

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Abstract

A new circuit configuration for odd number N-way power combiner/dividers is discussed, with emphasis on a planar microstrip structure. Theoretical results and experimental confirmation are included for a variety of odd number power divisions.

Summary

Many modern and future communication subsystems are incorporating solid state power amplifiers instead of the conventional traveling wave tube amplifiers. Power combining techniques are inherent in the implementation of high power solid state transmitters. Although planar combiners with binary power splits have been fully characterized and routinely manufactured, the design technique for odd number planar power combiners did not exist. The purpose of this paper is to present an odd number N-way power divider which is capable of splitting an input signal into any odd number of plural output ports, with particular emphasis on a planar version of a single layer microstrip circuit.

In the past the Wilkinson[1,2] power dividers were often used for splitting an input signal into odd number of plural output signals. However, the circuit is limited in that the circuit configuration cannot be achieved on a planar surface because the isolation resistors connected among the N-output ports require a physical crossover. These isolation resistors are connected in a floating starpoint (or in dual, e.g., deltas) configurations. These floating resistors limit the power handling capability of the dividers. Recently, a publication by Gysel[3] discussed a modified version of Wilkinson dividers allowing non-floating isolation resistors accomplished by a multilayer stripline circuit. In the design of high power amplifiers and phased array antennas, odd number N-way power dividers realized on a planar microstrip structure are often required and a method for achieving this has not yet been presented.

To overcome this difficulty, a new odd number N-way power divider circuit configuration has been developed. The design principles and experimental results of the power divider are described in this paper. The new circuit eliminates the floating isolation resistors in the Wilkinson circuit structure and provides a multiport cascadable device comprising a simple and symmetrical planar network of transmission line elements. The circuit also provides coupling between one input port and an odd number of plural output ports with isolation between output ports.

A general circuit of a p-section odd number N-way divider is illustrated in Fig. 1. The circuit is constructed by cascading p sections of stepped transmission line segments of equal length with the isolation resistors shunt-connected as shown in Fig. 1. All lines are a quarter-wave in length at the design center frequency. The $Z_k^{(p)}$ and Z_k values, p = 1, 2, ..., (N+1)/2 and k = 1, 2, ..., p-1, are the normalized characteristic impedance of the p^{th} shunt **and series sections, respectively.** The input port and all output ports are terminated with the normalized 1 ohm resistors. All output voltages are equal in magnitude and differ in phase by 90 degrees between any pair of two adjacent ports.

Design relations for the generalized odd number N-way power divider were obtained by using the odd and even mode analysis[4] and the method of induction. Details of the derivation of design formulas will be given in an expanded paper. The series and shunt line impedances are derived to be:

$$Z_k = \left(\frac{2k-1}{2k+1}\right)^{1/2} \qquad k = 1, 2, \ldots, \frac{N-1}{2}$$

$$\left.\begin{aligned} Z_1^{(p)} &= Z_{2p}^{(p)} = 1 \\ Z_h^{(p)} &= Z_{2p+1-h}^{(p)} = \frac{2p-3}{2(p-h)+1} \end{aligned}\right\} \text{ for } p = 1, 2, \ldots, \frac{N-1}{2} \text{ and } h = 2, 3, \ldots, p$$

$$Z_h^{(p)} = Z_{N-h}^{(p)} = \frac{N-2}{N-2h} \qquad \text{for } p = \frac{N+1}{2} \text{ and } h = 1, 2, \ldots, p-1$$

where N is the number of output ports.

To design an odd number N-way divider, one may use the general design formulas to determine the normalized characteristic impedances for a chosen number of output ports.

The circuit configurations for N=3, 5, and 7 are given in Fig. 2. It can be seen that the power divider circuits can be readily fabricated in simple planar structures. Figure 3 shows typical theoretical performance of input VSWR, power coupling and isolation between ports as a function of normalized frequency for a five-way power divider. The five output signals are equal in amplitudes and down 7 dB from the input signal, but differ in phase by 90 degrees between any two adjacent ports. The isolation between any two output ports is greater than 13.45 dB at the designed center frequency. The useful bandwidth with 0.1 dB power variation is approximately 4 percent. The input VSWR is seen to be excellent over a wide range of identical load mismatches, as shown in Fig. 4. The calculated results for a seven-way power divider are shown in Fig. 5. Over a 4 percent range frequency band, the input VSWR is less than 1.22, the isolation between output is greater than 11.26 dB, and the power division is equal to -8.45 dB.

The circuits shown in Fig. 2 involve no critical dimensions and are readily produced by conventional microwave printed circuit techniques. Several S-band power dividers are constructed in Teflon fiberglass board. Table 1 shows the theoretical and the experimental results of the three-way and five-way power dividers. A photograph of the five-way power divider is shown in Fig. 6.

An analytical design approach applicable to N plural input ports to 2N+1 plural output ports power dividers was developed and verified by experiment.

*Patent application filed.

Figure 7 shows a general circuit of the class of multiport power dividers. The circuit consists of 2N+1 parallel transmission lines of characteristic impedance Z_S joined by 2N pairs of transmission lines and N+1 isolation resistors shunt-connected as shown in Fig. 7. All transmission lines are chosen to be a quarter-wavelength long at the desired midband frequency. The explicit expressions for the normalized characteristic impedances, as a function of the number of input ports, were derived based on the method of induction and they are

$$Z_S = \left(\frac{N}{2N+1}\right)^{1/2}$$

$$Z_1 = Z_{2N} = 1$$

$$Z_2 = Z_{2N-1} = N$$

$$Z_k = Z_{2N+1-k} = \frac{N}{N+2-k} \quad \text{for } k = 3, 4, \ldots, N$$

where N is the number of input ports.

In order to test the practicality of the design formulas, a two-to-five microstrip experimental model was constructed, as shown in Fig. 8, for the 2.02 to 2.17 GHz band. Maximum measured VSWR is 1.2 and minimum measured isolation is 17 dB over a 7 percent range frequency band. Total insertion loss of the divider is 0.2 dB at 2.1 GHz. Measured data is compared with calculated results in Table 1. Details on the design technique and numerical and experimental results will be presented at the conference and published in the expanded paper.

These results demonstrate the feasibility of designing odd number N-way power divider on a planar surface. The transmission lines can be made from coaxial line, waveguide or alumina microstrip. In most applications, the choice of N=3, 5 and 7 seems to be quite satisfactory. Computer results for three-way and five-way power dividers are all in excellent agreement with the measured data over a wide frequency range. This effort has shown both theoretically and experimentally that it is possible to realize planar divider circuits having:

- A perfectly matched input port.
- A reasonable isolation between any two output ports.
- Substantial size and weight reduction over past methods.
- Low insertion loss compared with conventional divider design.

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References

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3. U. H. Gysel, "A New N-Way Power Divider/Combiner Suitable for High Power Applications," 1975 MTT Symposium Digest, pp. 116-118.
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Table 1. Summary of Results for 3-Way, 5-Way and 2-to-5 Power Dividers

Type of Coupler	Total Insertion Loss (at the designed center frequency)	0.1 dB Bandwidth		Minimum Isolation		Input VSWR (measured)
		Calculated	Measured	Calculated	Measured	
3-Way Power Divider	≈ 0.2 dB at 1.7 GHz	6%	5.7%	12 dB (ports 4-6)	≈12 dB	<1.2
5-Way Power Divider	≈ 0.5 dB at 2.25 GHz	4%	3.6%	13.5 dB (ports 6-7 and 9-10)	≈13.5 dB	<1.2
2-to-5 Power Divider	≈ 0.2 dB at 2.1 GHz	7%	6.6%	17 dB (ports 6-8 and 8-10)	≈17 dB	<1.2

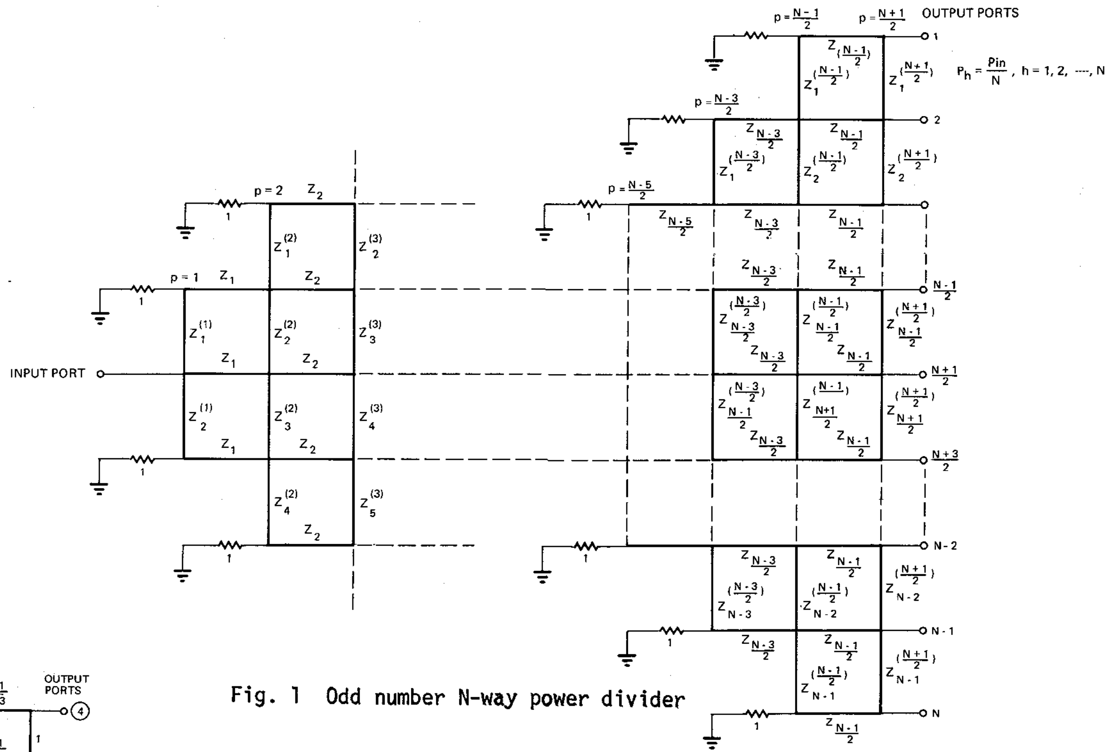

Fig. 1 Odd number N-way power divider

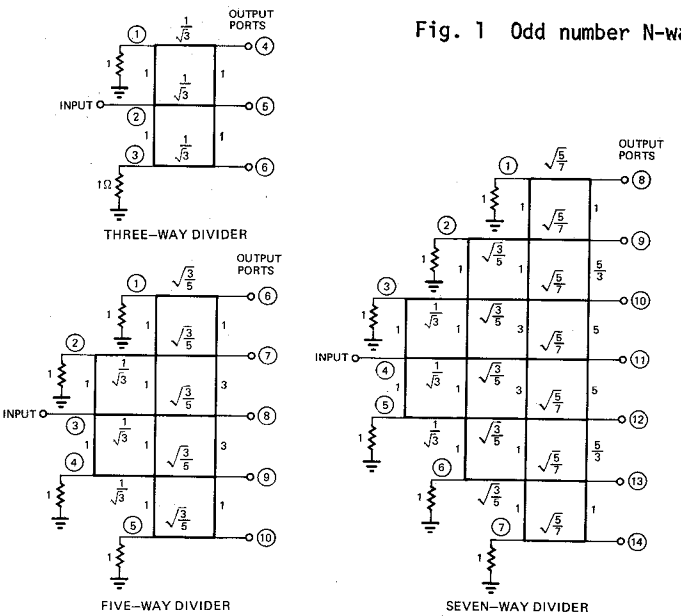

Fig. 2 Power dividers for N = 3, 5 and 7

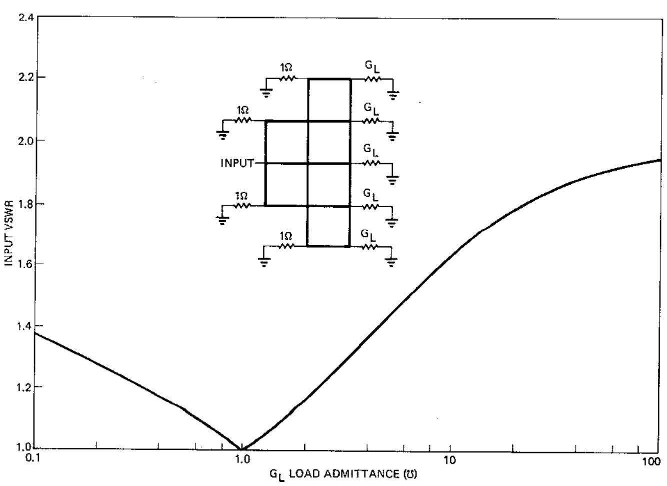

Fig. 4 Input VSWR vs. load mismatches

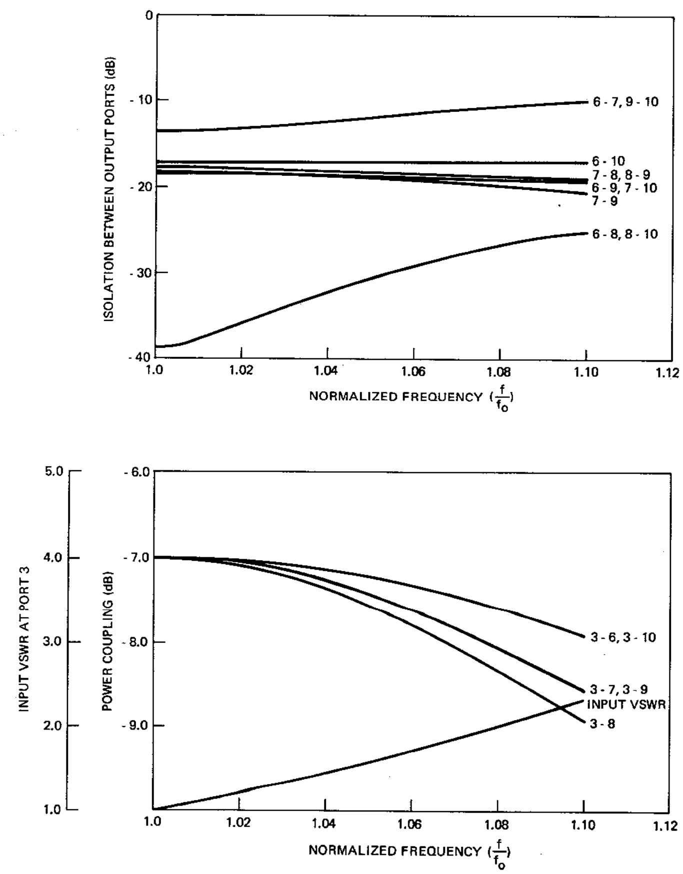

Fig. 3 Characteristics of a 5-way divider

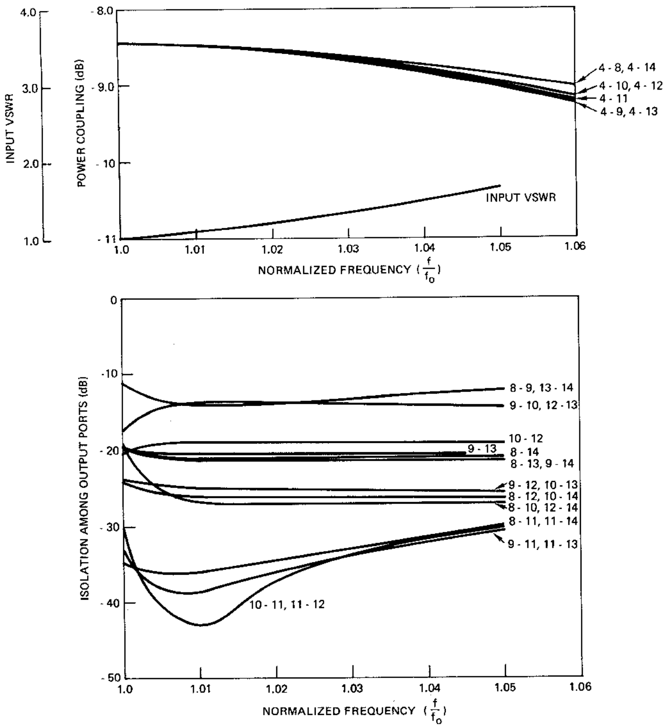

Fig. 5 Characteristics of a 7-way power divider

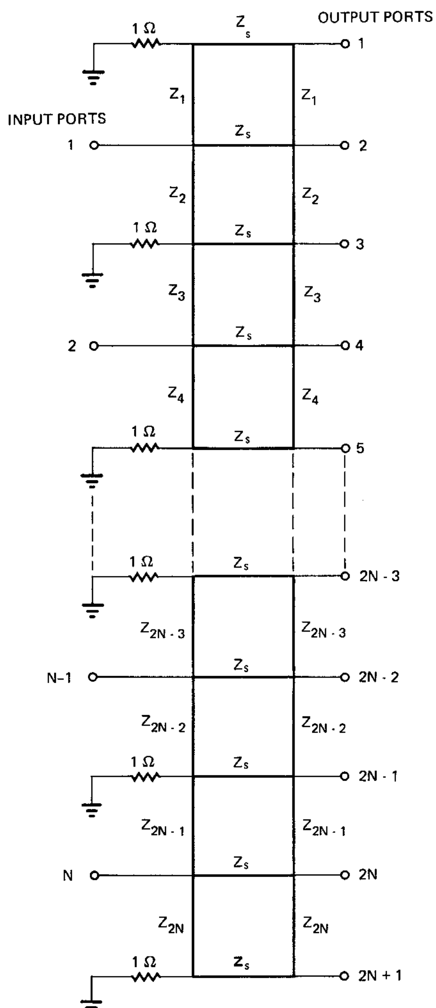

Fig. 7 N plural input ports to 2N+1 plural output ports power divider

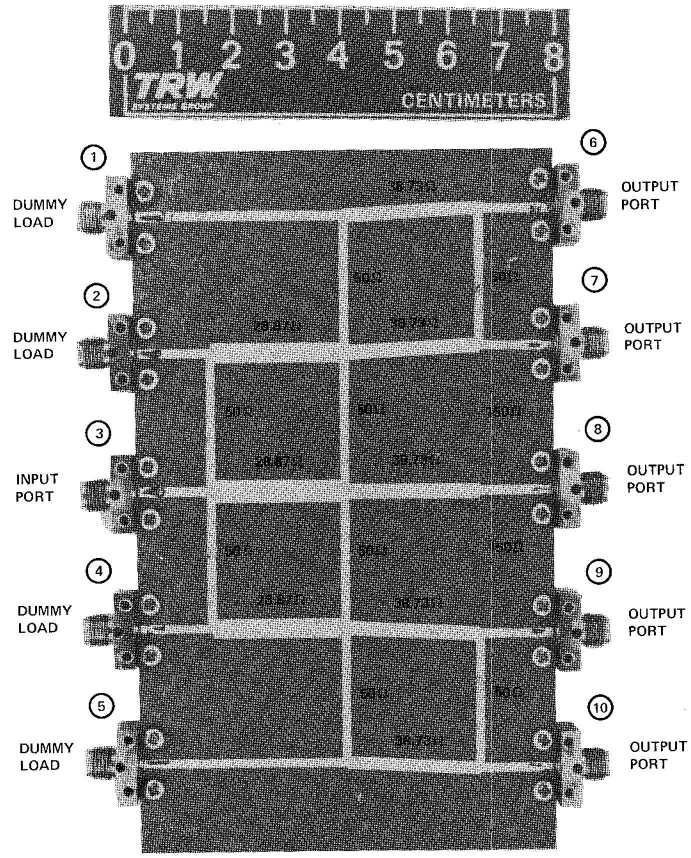

Fig. 6 Photograph of 5-way power divider

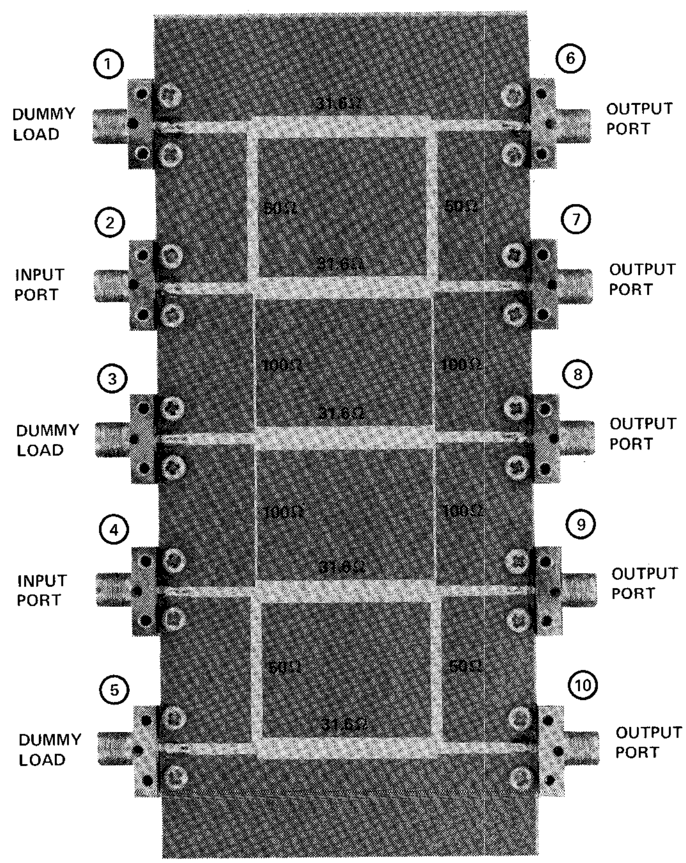

Fig. 8 Photograph of two-to-five power divider