A Variable-Ratio Microwave Power Divider and Multiplexer*

W. L. TEETER† AND K. R. BUSHORE‡

Summary—A microwave circuit is presented which provides continuous variation of microwave power between two outputs in any desired ratio. A typical device utilizing the circuit is described, and other uses of the circuit are discussed. An *X*-band power divider was constructed which had a vswr of less than 1.2 at all times over the frequency range of 8.6 to 9.6 kmc, divided the total input energy between the outputs in any ratio from 1/10,000 to 1, and had less than 0.4-db total insertion loss. No other losses were present. Adjustment could be made under maximum power levels of the waveguide. Another use of the circuit is to couple two high-power transmitters into one output, thus providing a dual frequency antenna coupler or diplexer. By cascading diplexers, multiplexing can be accomplished.

Introduction

THIS PAPER primarily describes theory and operation of a microwave power divider which can be adjusted so that microwave power is divided between two outputs in any desired ratio. Used conversely, the device has other applications, such as coupling two frequencies into one output.

During the past decade many power dividers have been developed by various organizations. Usually, each device was designed for a specific application and was not adaptable as a general laboratory tool because of such characteristics as limited bandwidth, high vswr, limited power handling capacity, high insertion losses, critical adjustment, or complicated construction.[1]

The device described herein obtains variable power division by controling the phase of one half of the incoming rf energy relative to the other half. Few, if any, of the limitations found in using other power dividers have been encountered in this device.

Operation

The basic power divider circuitry uses two broadband short-slot waveguide hybrids,[2] a convenient method of phase control such as a line stretcher or ferrite phase controller and connecting waveguides. A typical installation is shown in Figs. 1 and 2. The input microwave power is divided equally by hybrid *A-B* and establishes a 90° phase relationship between A_0 and B_0. Waveguide no. 1 is of constant electrical length, while the length of waveguide no. 2 can be varied with a line stretcher. Varying the line stretcher varies the phase relationships of the power arriving at C_i and D_i of hybrid *C-D*. The relative phase of the power arriving at C_i and D_i determines the ratio of power coupling to output no. 1 and to output no. 2. Power at output no. 3 of Fig. 1 is 30 to 40 db below the input level regardless of the line stretcher adjustment, therefore a low-power matching load is placed at output no. 3 merely to terminate that particular arm of the hybrid properly.

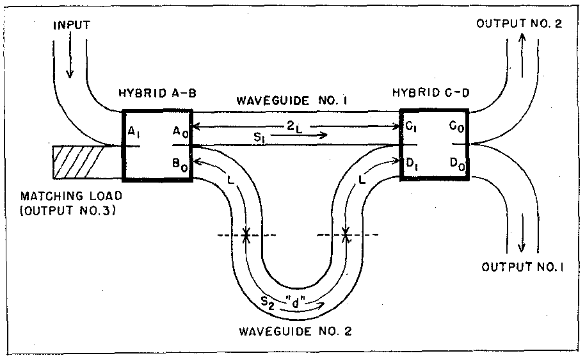

Fig. 1—Power divider circuitry.

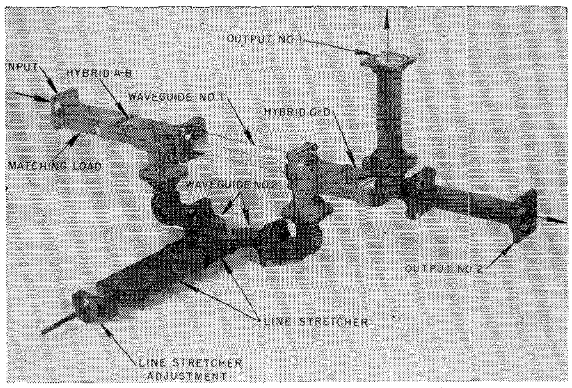

Fig. 2—Complete power divider (test model).

When waveguides no. 1 and no. 2 are the same electrical length ($d=0$) or if the difference length d is an exact multiple of the guide wavelength, the power from A_0 adds to the power from B_0 and proceeds to output no. 1.

As d is changed to one-fourth guide wavelength, the phase relationships at C and D are such as to cause an equal amount of power to appear at each output, no. 1 and no. 2.

When d is made equal to one-half guide wavelength, all power will proceed to output no. 2.

As d is increased further, the changing relative phases of the signals in hybrid *C-D* cause the power at output

* Manuscript received by the PGMTT, September 17, 1956; revised manuscript received, June 27, 1957.

† Lockheed Missile Systems Div., Palo Alto, Calif.; formerly with U. S. Navy Electronics Lab., San Diego, Calif.
‡ U. S. Navy Electronics Lab., San Diego, Calif.

[1] No specific devices will be mentioned here, since numerous texts and technical series carry descriptions of the various existing methods of power division.

[2] H. J. Riblet, "The short-slot hybrid junction," Proc. IRE, vol. 40, pp. 180–184; February, 1952.

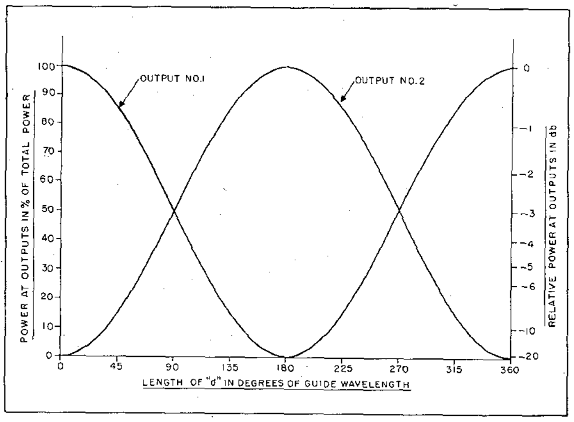

Fig. 3—Power out vs d in degrees of guide wavelength (theoretical).

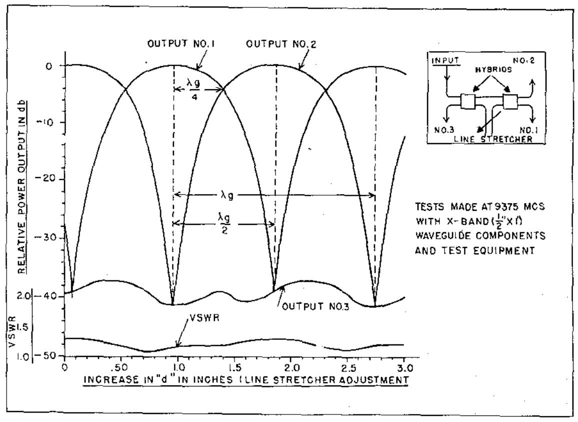

Fig. 5—Power out vs d in inches.

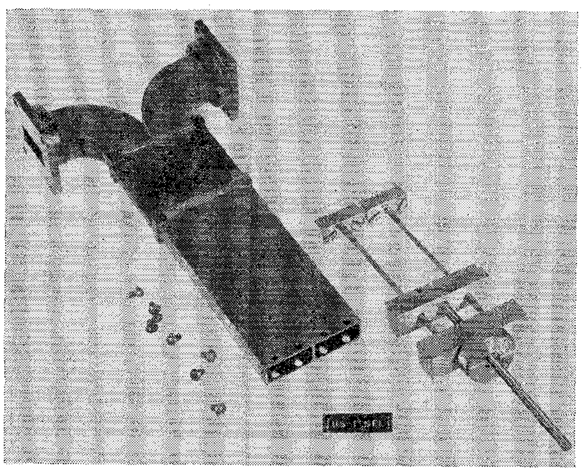

Fig. 4—Line stretcher.

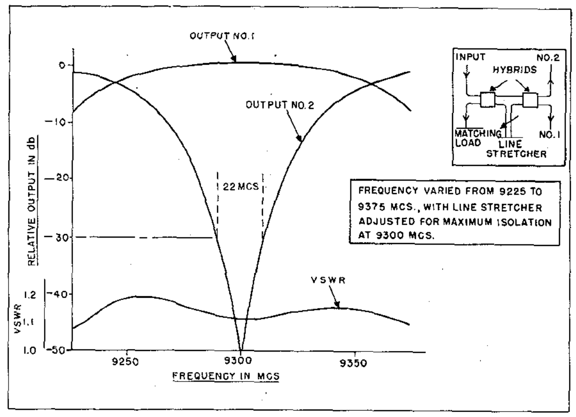

Fig. 6—Frequency-shift bandwidth.

no. 2 to decrease and the power at output no. 1 to increase, until at three-quarters guide wavelength the power is again equal at the two outputs. When d is increased to one wavelength, all the power appears at output no. 1, as is the case when both waveguides are the same length. The power variation while varying d from 0 to one guide wavelength is shown in Fig. 3.

Characteristics and Test Results

Fig. 2 shows the complete power divider system as used in obtaining test results reported here. It is composed of X-band (1 by $\frac{1}{2}$-inch od) waveguide components. Fig. 4 shows the waveguide line stretcher in detail. Many other configurations, or a ferrite device, could have been used to obtain the phase variation.

Power Variation

Fig. 5 shows the variation of power at outputs no. 1, and no. 2, and no. 3 vs movement of the line stretcher. Zero db in Fig. 5 represents the input power minus the 0.4-db copper losses in the waveguide circuitry.

The circuit shown in Fig. 2 performed satisfactorily with power in excess of 275-kw peak total without breakdown. Thus the power handling capability is essentially that of the waveguide and hybrids.

VSWR and Bandwidth

With the line stretcher locked at the position for 9300 mc which provides maximum power at output no. 1 and minimum at output no. 2, the frequency was varied and Fig. 6 was obtained. Thus, Fig. 6 is the effective bandwidth of the system for a particular adjustment of the phase control. Note that for the 30-db levels between outputs no. 1 and no. 2 a frequency range of 22 mc, or 0.24 per cent can be obtained. For the 3-db levels, the frequency range is 112 mc, or 1.2 per cent. Input vswr under these conditions is shown at the bottom of Fig. 6.

Other Uses

The power divider circuit may be used in many other applications. The circuit may be used, for example, for diplexing to couple two high-power transmitters into one output[3] and to provide a dual frequency antenna coupler. Cascading the diplexers results in multiplexing of any number of frequencies. The transmitter with the

[3] Although the dual frequency development discussed herein was accomplished before 1953 at the U. S. Navy Electronics Lab., the author has recently been notified of a basic circuit patent #2,702,371 issued in February, 1955 (filed February, 1949) to D. E. Sunstein, "Hybrid network for continuing and separating electromagnetic wave signals." This patent uses magic tees and covers the combining of signals of two differing frequencies into a common transmission line.

frequency (f_1) would be placed at the input of Fig. 1, and the transmitter with the other frequency (f_2) would be placed where the matching load is shown. When the line stretcher is properly set, the total power from both transmitters would be coupled into output no. 1. To provide maximum coupling of both frequencies into output no. 1, the line stretcher must be set so that for frequency f_1 the difference length d is an integral number of wavelengths, and for frequency f_2 the difference length d is an odd multiple of a half guide wavelength. By using the following equation the distance d can be calculated which must be used to provide the proper phasing for both frequencies:[4,5]

$$d = \left(\frac{\lambda g_2}{2}\right)\left(\frac{\lambda g_1}{\lambda g_2 - \lambda g_1}\right) \tag{1}$$

where

d = loop distance (see Fig. 1).
λg_1 = guide wavelength of f_1, and
λg_2 = guide wavelength of f_2.

An example of the use of (1) follows: where

$$f_1 = 9385 \text{ mc } (\lambda g_1 = 4.467 \text{ cm})$$

and

$$f_2 = 9273 \text{ mc } (\lambda g_2 = 4.574 \text{ cm})$$

$$d = \frac{(4.574)\ (4.467)}{2(0.107)} \times \frac{1}{2.54} = 37.478 \text{ inches.}$$

Thus, by using $d = 37.478$ inches in the line stretcher, maximum coupling of inputs with frequencies of 9385 and 9273 mc would be obtained. When using a ferrite line stretcher, d could be measured in electrical phase or current.

Any number of frequencies may be combined and hence filtered by cascading couplers. The power capacity would be essentially the full power of the waveguide as it would be largely determined by the hybrid couplers and phase shifter.

Other possible uses might be a broad frequency selective device for use in a receiver input, a variable ratio waveguide switch, etc.

The authors are indebted to K. Tomiyasu who made many helpful suggestions in the preparation of this paper.

[4] W. L. Teeter and K. R. Bushore, "A Dual-Frequency Micro wave RF Head," U. S. Navy Electronics Lab., Rep. 556; January 12, 1955.

[5] Eq. (1) of Teeter and Bushore, *ibid.*, is derived by stating the conditions described in the foregoing text. The distance d may also be expressed in more general terms from the following:

Let λg be the guide wavelength for the mean frequency f between f_1 and f_2 and λ, the air wavelength; λc is the cutoff wavelength.

$$V = \text{velocity of light.}$$

Then let

$$\phi = 2\pi \frac{d}{\lambda g}$$

substitute for λg,

$$\phi = 2\pi d \sqrt{\frac{1}{\lambda^2} - \frac{1}{\lambda_c^2}}$$

$$= 2\pi d \sqrt{\frac{f^2}{V^2} - \frac{1}{\lambda_c^2}}$$

and

$$\frac{d\phi}{df} = 2\pi d \frac{1}{\sqrt{\frac{f^2}{V^2} - \frac{1}{\lambda_c^2}}} \left(\frac{1}{2}\right)\left(\frac{2f}{V^2}\right) = \frac{\Delta\phi}{\Delta f}. \tag{3}$$

For the condition $\Delta\theta = \pi$ and where Δf is small; that is, both f_1 and f_2 are within the frequency of the hybrid slots and the waveguide, ($\Delta f = f_1 - f_2$).

Substitute for $\Delta\theta$ in (3)

$$\frac{\pi}{\Delta f} = \frac{2\pi d f}{V^2} \lambda g$$

and solve for d

$$d = \frac{V^2}{2f\lambda g \Delta f} = \frac{V}{2\Delta f} \frac{(V)}{(f)} \frac{(1)}{(\lambda g)}.$$

Since $f\lambda = V = 3 \times 10^{10}$ cm/sec, substitute for f, to get

$$d = \frac{V}{2\Delta f} \frac{(\lambda)}{(\lambda g)} \tag{4}$$

or

$$d = \frac{V}{2(f_1 - f_2)} \frac{(\lambda)}{(\lambda g)}. \tag{5}$$

Eq. (5) is plotted by Teeter and Bushore, *ibid.*