# HIGH POWER FOUR - WAY POWER DIVIDER/COMBINER

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## ABSTRACT

A new 4-way waveguide power divider/combiner has been developed using a radial waveguide. The divider has an insertion loss of less than 0.5 dB and a power balance of ± 0.2 dB over a bandwidth of 2.5 GHz at X-band. A power combiner using this circuit and four Gunn oscillators has been demonstrated with over 70 percent combining efficiency. The circuit should have applications in millimeter-wave power combining and high power microwave systems.

## I. INTRODUCTION

Power dividers/combiners with high power handling capability are required for many radar, communication and electronic warfare systems [1-3]. The waveguide hybrid coupler/divider provides two-way power dividing [4]. Power dividers/combiners using coaxial radial line [5], microstrip radial line [6] and circular waveguide transitions [1] have been reported. This paper reports a novel circuit which gives a four-way power division using a radial waveguide as the power distributing network. The divider has an insertion loss of less than 0.5 dB and a power balance of ± 0.2 dB over a 2.5 GHz bandwidth at X-band which is equivalent to a bandwidth of over 20 percent. A power combiner was built by connecting four Gunn oscillators to the four rectangular waveguide ports of the radial waveguide. A combining efficiency of over 70 percent was achieved at X-band. Since all the input and output circuits are waveguides, the network is especially useful for high power systems and millimeter-wave power combining applications.

## II. OPERATING THEORY

Figure 1 shows a radial waveguide with five input - / output - ports. All the coupling ports are rectangular waveguide with dimensions of 10.16 × 22.86 mm. The radial line waveguide has a radius of 12.3 mm and a height of 27.5 mm. For a radial line waveguide shown in Figure 2, the cutoff frequencies for various modes can be calculated by [7]

$$f_{c,nm} = c\sqrt{\left(\frac{n}{2b}\right)^2 + \left(\frac{m}{2\pi r}\right)^2} \qquad (1)$$

Several modes have the cutoff frequencies above the operating frequency. However, since the input rectangular waveguide operating at $TE_{10}$ mode, only the $TE_{10}$ mode of the radial waveguide can be efficiently excited. This can be explained in the following.

The fields for $TE_{10}$ mode in a rectangular waveguide in Cartesian coordinate system are [4]:

$$E_y = -j\, A\, Z_h \frac{\beta}{k_c} \sin \frac{\pi x}{a} \qquad (2a)$$

$$H_x = \frac{j\beta}{k_c} A \sin \frac{\pi x}{a} \qquad (2b)$$

$$H_z = A \cos \frac{\pi x}{a} \qquad (2c)$$

where $A$ is a constant, $\beta$ is the propagation constant, $k_c$ is the cutoff wave number and $Z_h$ is the wave impedance.

The fields for $TE_{10}$ mode in a radial waveguide in cylindrical coordinate system are [7]:

$$E_\phi = B \sin \frac{\pi z}{d} \quad (3a)$$

$$H_z = C \sin \frac{\pi z}{d} \quad (3b)$$

$$H_r = D \cos \frac{\pi z}{d} \quad (3c)$$

where $B = \frac{V}{2\pi r}$, $C = 2\frac{I}{d}$, and $D = -j\sqrt{\frac{\epsilon_0}{\mu_0}}\frac{V}{2\pi r}\frac{\pi}{kd}$, $k$ is the wave number, $V$ is the voltage and $I$ is the current.

At the interface between the rectangular waveguide and the radial waveguide, the two coordinate systems are related to each other in the following way:

$$x \ldots . z$$

$$y \ldots . -\phi$$

$$z \ldots . r$$

From Equations (2) and (3), the field distributions in the two waveguide systems have the same variations for $TE_{10}$ modes. Therefore, the $TE_{10}$ mode in rectangular waveguide can efficiently excite the $TE_{10}$ mode in the radial waveguide and vice - versa.

## III. EXPERIMENTAL RESULTS FOR DIVIDER

A circuit was built at X-band using five rectangular waveguides and a radial waveguide. Figure 3 shows a photograph of the circuit.

Measurements were conducted using a HP 8510 network analyzer. The resulting coupling among the input port and four output ports is shown in Figure 4. It can be seen that the coupling is between 6 and 6.5 dB which is close to the ideal case of 6 dB over a 2.5 GHz bandwidth. The insertion loss is less than 0.5 dB and the coupling is well balanced. The input VSWR measurement is shown in Figure 5. It can be seen that a VSWR of less than 1.6:1 was achieved over the frequency range of interest. Similar results were obtained for VSWR measurements at other ports.

## IV. POWER COMBINER

To demonstrate this circuit as a combiner, four Gunn oscillators were connected to ports 2, 3, 4 and 5. The output power was extracted from port 1. The Gunn oscillators were injection-locked to each other due to the coupling. A combining efficiency of over 70 percent was achieved.

## V. CONCLUSIONS

A waveguide 4-way power divider/combiner has been developed. Low insertion loss and VSWR have been achieved over a 20 percent bandwidth. The circuit uses waveguides in input and output and, thus, can handle high power. The results should have applications in millimeter-wave power combining and high power devices used in radar, communications, and EW systems.

## VI. ACKNOWLEDGEMENTS

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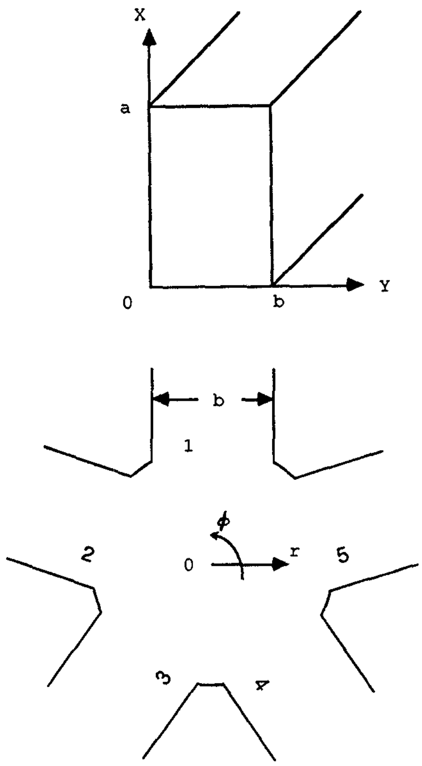


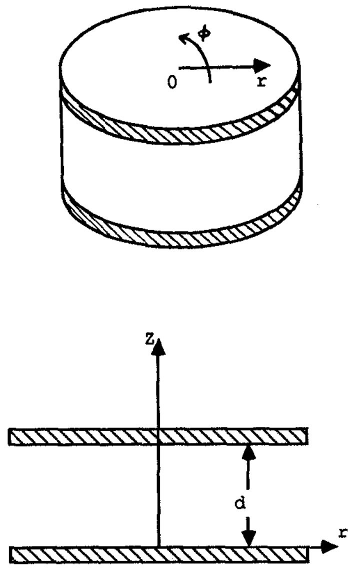


Fig 2 Radial waveguide configuration

Fig 1 A 4 - way power divider/combiner

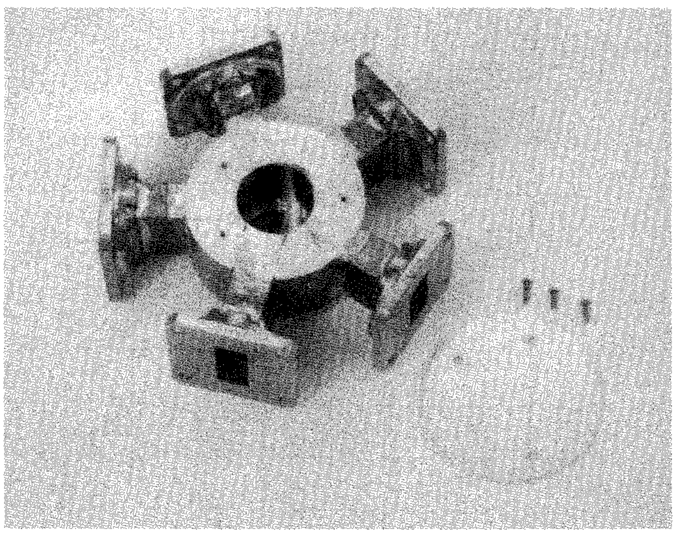

Fig 3 A photograph of the 4 - way power divider/combiner

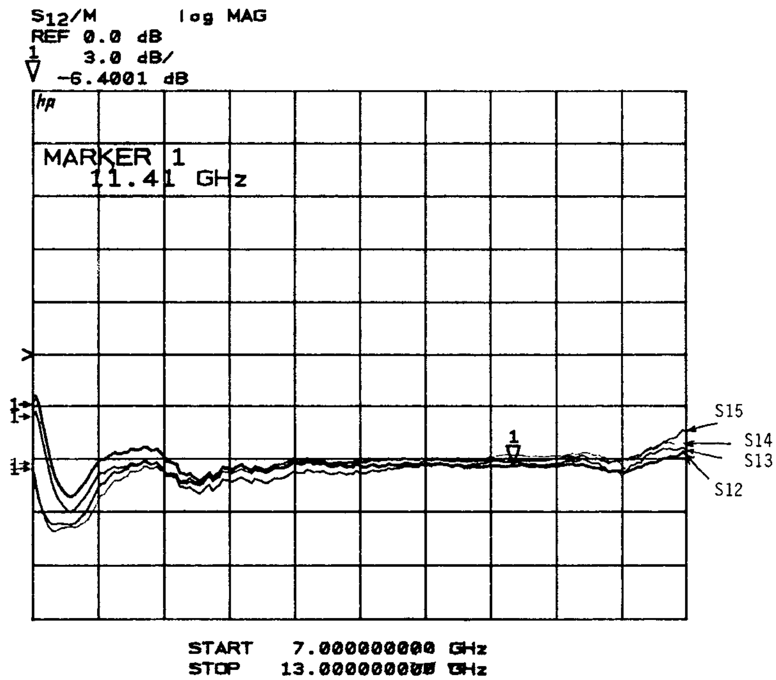


Fig 4 Coupling between input (port 1) and other four output ports for the 4 - way power divider/combiner

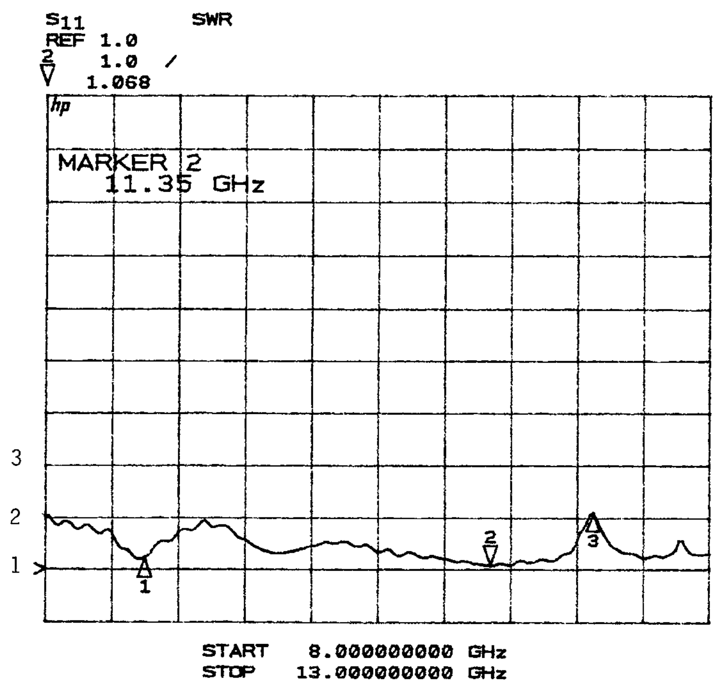


Fig 5 Input port VSWR measurement over the frequency