Short Papers

A Circular Waveguide "Hybrid-T" and its Applications

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Abstract—**A hybrid junction consisting of two mutually perpendicular rectangular waveguides, the broader side of one rotated through $\pi/2$, connected orthognally to a circular waveguide, has been designed and its properties studied. The junction has many useful applications as a variable power divider, duplexer, tuner, and an element of an impedance bridge.**

A hybrid junction consisting of two X-band rectangular waveguides (inner dimensions 0.9×0.4 in) and X-band circular waveguide (inner diameter 0.94 in) has been designed, fabricated, and studied. The two rectangular waveguides, mutually perpendicular to each other with the broader side of one rotated through $\pi/2$, are connected in series and shunt to the circular waveguide which is orthogonal to both. The hybrid junction thus obtained has the plane of symmetry passing symmetrically through the series and the shunt arms as described in Fig. 1. The device (termed as circular "hybrid-T") is a modified form of the four-port hybrid junction, commonly known as hybrid-T, with its main arms replaced by collinear circular waveguide arms. The circular hybrid-T is a six-port terminal pair device, as the plane polarized TE_{11} mode in the circular waveguide can always be resolved along the two orthogonal plane polarizations, thus furnishing two terminal pairs in each of the circular arms. The six ports of the junction are described in Fig. 1 along with the electric field vectors at each port. The scattering matrix of the device takes the form [2]

$$S = \begin{bmatrix} \alpha & \beta & \delta & \rho & 0 & 0 \\ \beta & \alpha & \delta & -\rho & 0 & 0 \\ \delta & \delta & \epsilon & 0 & 0 & 0 \\ \rho & -\rho & 0 & \epsilon' & 0 & 0 \\ 0 & 0 & 0 & 0 & \theta & \xi \\ 0 & 0 & 0 & 0 & \xi & \theta' \end{bmatrix}. \tag{1}$$

The properties of the hybrid junction can be derived directly from the scattering matrix (1). Evidently neither of the modes of the circular arms couples to the modes orthogonal to itself. The shunt and the series arms, 3 and 4, are completely decoupled from arms 5 and 6 and also from each other. When the junction is matched, ports 5 and 6 are completely decoupled from the rest of the ports and act as a straight-through arm, while the other four ports act like a conventional "magic-T." The scattering matrix of the matched device takes the form

$$S = \begin{bmatrix} 0 & 0 & 1/\sqrt{2} & 1/\sqrt{2} & 0 & 0 \\ 0 & 0 & 1/\sqrt{2} & -1/\sqrt{2} & 0 & 0 \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 & 0 & 0 & 0 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}. \tag{2}$$

It can be seen that the junction possesses all the properties of power dividing and mixing of a conventional magic-T while it can simultaneously propagate another undisturbed orthogonal TE_{11} mode. It might be noted that only one polarity of the TE_{11} mode is excited in the circular arms by the wave in arm 3 or 4—the one in which the maximum electric vector lies along the diameter of the circular waveguide that is in ports 1 and 2. Further, if a wave is incident in the circular waveguide such that its plane of polarization makes an angle θ with the plane of polarization in port 1 or 2, only the component of it, resolved along port 1 or 2, gets equally divided into ports 3 and 4, while the component resolved along ports 5 or 6 propagates undisturbed in port 6 or 5, respectively, making it a straight-through arm. Due to this property, the circular hybrid-T finds useful applications, not only as a variable power divider and duplexer, but also as an important element of the impedance bridge. In the reflection bridge, a circular hybrid-T has one distinct advantage over the conventional magic-T, that extra information about the rotation in the plane of polarization of the reflected wave can be obtained by measuring the power in port 5 or 6. The junction can thus be used conveniently for the measurements of Magneto–Kerr effect.

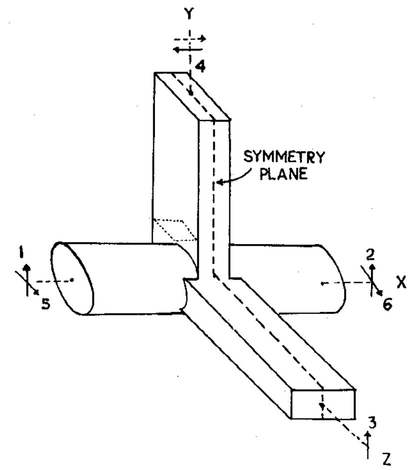

Fig. 1. The circular waveguide hybrid-T. The electric vector at each port is shown by the arrow.

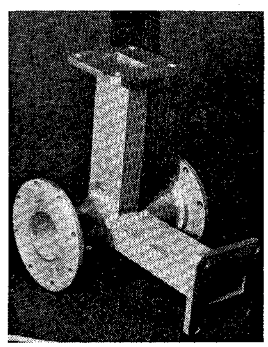

Fig. 2. A circular hybrid-T fabricated out of X-band waveguides.

A circular hybrid-T, fabricated out of X-band waveguides, is shown in Fig. 2. The properties of the junction have been studied over the frequency range of 8.2–10.5 GHz. The isolation between the series and shunt arms over the whole frequency range has been found to be more than 50 dB. The isolation of ports 5 and 6 from the other ports has also been found to be more than 30 dB. When the power is fed to one of the circular arms and others are terminated in matched loads, rotation of the input causes $\cos^2\theta$ variation of power in the series and the shunt arms, and $\sin^2\theta$ variation in the straight-through arm, θ being the angle between the electric vector of the incident wave and port 1. The VSWR, measured in various ports when the others are terminated in matched loads, has been presented as a function of frequency in Fig. 3. As may be seen from Fig. 3, the VSWR in port 4, when all the other ports are terminated in matched loads, is very high as compared to the VSWR in other ports. Attempts have been made to reduce the VSWR in port 4 by introducing an iris of thickness 1 mm as shown in Fig. 1 by dotted lines. The

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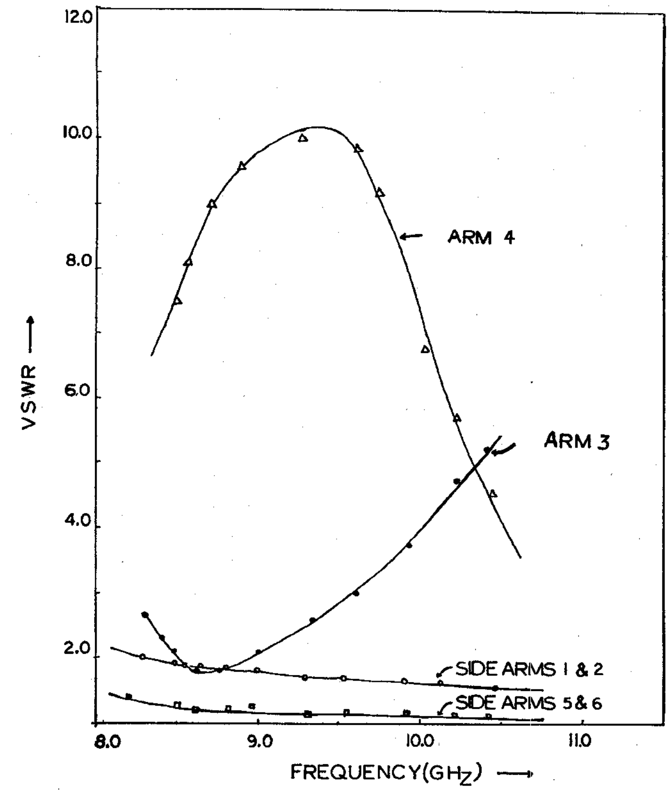

Fig. 3. The frequency response of the hybrid-T shown in Fig. 2.

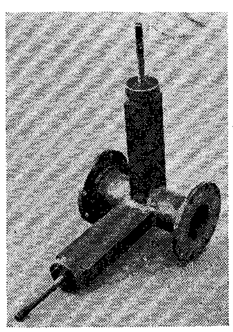

Fig. 4. A circular E–H tuner fabricated out of X-band waveguides.

insertion depth of the iris was varied to obtain a very low VSWR in this arm. The matching of port 4 was done at a frequency of 8.65 GHz where all the other ports are best matched, and a VSWR of 1.15 could be achieved in this port without affecting the VSWR in other ports by more than 5 percent.

The circular hybrid-T, using short circuits in the series and the shunt arms, is very useful where variable impedances are required to only one of the orthogonal modes propagating in the circular waveguide and in matching the circular waveguide components. By varying the position of short circuits in the series and shunt arms, a variable impedance can be offered to one of the polarizations of the collinear circular waveguide to which the series and shunt arms couple. A circular E–H tuner in the X-band and frequency range has been fabricated using the circular hybrid-T and is shown in Fig. 4. The circular E–H tuner has been successfully used to produce a VSWR of more than 100 in the frequency range 8.2–10.5 GHz. On the other hand, the circular E–H tuner has also been used to match the reflections from a circular to rectangular transition, and a VSWR of less than 1.05 could be achieved in the circular waveguide.

The circular hybrid-T discussed here could be very useful in systems applications, especially in circular waveguide networks propagating orthogonal polarized modes. As a tuner, it appears to be more useful and convenient as compared to the usual stub tuning devices.

Acknowledgment

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Characteristics of a Microstrip Two-Meander Ferrite Phase Shifter

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***Abstract*—A derivation for the image impedance of a microstrip line with one basic meander is presented. This shows a bandpass characteristic. A new simple technique is followed in designing a two-meander line on a G500 ferrite substrate. Scattering measurements (S band) made on a model show excellent agreement with theory. Measured nonreciprocal differential phase shift is shown.**

Introduction

In order to demonstrate that a microwave nonreciprocal network can still be practical while dependent on only a few degrees of nonreciprocal phase delay, a microstrip application is found for a ferrite phase shifter which exhibits limited but switchable differential phase.

Small amounts of nonreciprocal differential phase-shift require meander lines with only very few coupled meanders. Many formulations for conducting coupled strips in stripline assembly are given by Jones and Bolljahn [1]. One of these [1, Fig. 2(b), case 7], classified as an all-pass filter, is for a basic single meander-line configuration.

This short paper reanalyzes the basic single meander line in microstrip, taking proper account of unequal velocities for even and odd modes. The result, a modification of the Jones and Bolljahn result, shows a bandpass characteristic with a definite cutoff frequency. Further, using recent data on even- and odd-mode impedances and velocities on coupled microstrips, a matched line with two meanders is designed. Performance of an experimental model is given by scattering parameters measured at S band. Also shown are the measured nonreciprocal differential phase shift and insertion phase of this limited-meander meander line.

Theoretical Considerations

Fig. 1 shows two parallel conducting strips coupled in the microstrip transmission system which is to be considered lossless. Terminal input currents defined as in [1] and the indicated generator source currents are related by

$$i_1 = \tfrac{1}{2}(I_1 + I_2) \qquad i_3 = \tfrac{1}{2}(I_3 + I_4)$$
$$i_2 = \tfrac{1}{2}(I_1 - I_2) \qquad i_4 = \tfrac{1}{2}(I_4 - I_3). \tag{1}$$

Since infinite impedance current generators are employed, the strip voltage v_{a1} to the ground plane due to source current i_1 may be obtained from transmission-line theory as

$$v_{a1} = -j\,\frac{Z_{0e} i_1}{\sin \beta_e l} \cos \beta_e (l - x) \tag{2}$$

where Z_{0e} is the even-mode characteristic impedance, and $\beta_e = 2\pi f / v_e$ is the even-mode propagation constant along the strip. Similar expressions exist for contributions to v_a and v_b by the remaining current sources i_2, i_3, and i_4. For example

$$v_{a4} = -j\,\frac{Z_{0o} i_4}{\sin \beta_o l} \cos \beta_o x \tag{3}$$

where Z_{0o} is the odd-mode characteristic impedance, and $\beta_o = 2\pi f / v_0$ is the odd-mode propagation constant along the strip.

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