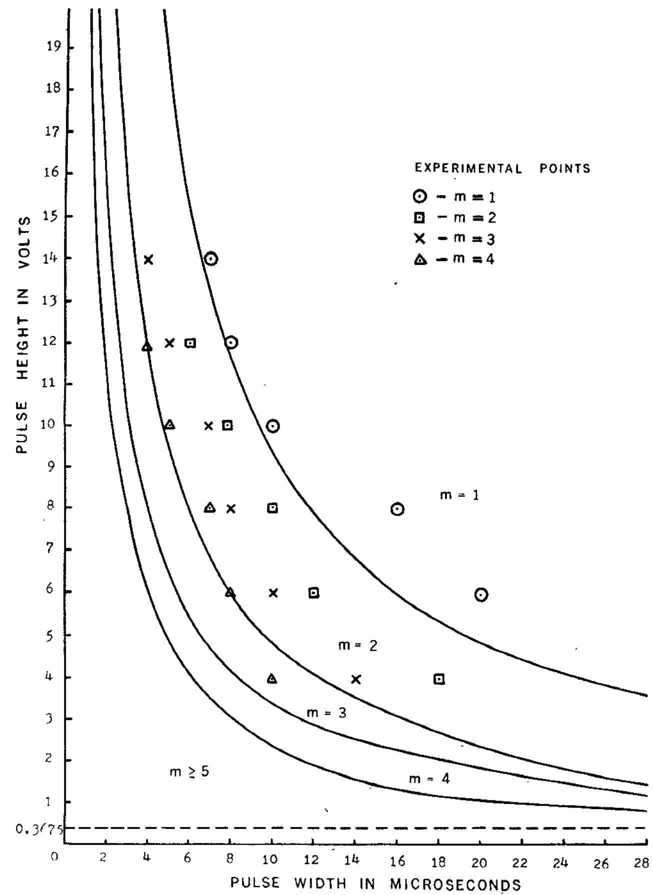

Fig. 7. Pulse height as a function of pulsewidth needed to switch a rectangular toroid of TT1-390 with m pulses.

CONCLUSION

Using (1) it is possible to model the major magnetostatic B–H loop of toroidal samples of some microwave ferrite materials in terms of characteristic measured parameters of the material. Approximate minor loops and switching trajectories such as those encountered in latching reciprocal phase shifters [7], [9] can be found through the use of (2). Temperature effects can also be incorporated in this model.

A relationship between the amplitude, pulsewidth, and number of pulses needed to switch a toroid was found in terms of the number of turns on the toroid, the switching current I, and the remanent flux Φ. This relation is in good agreement with the results obtained from latching experiments.

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Multiple Branch-Guide Directional Coupler Using TE_{01}-Mode Semicircular Waveguide

SHUICHI SHINDO

***Abstract*—This short paper describes experimental results derived from a newly devised branch-guide directional coupler using a TE_{01}-mode semicircular waveguide. The length of an experimental 0-dB coupler is about 150 mm, which is one-third shorter than the conventional coupled wave-type 0-dB coupler, and the loss is decreased in proportion to the reduction in length. Using this coupler, it is possible to manufacture more compact millimeter-wave diplexers with reduced insertion loss.**

INTRODUCTION

A semicircular waveguide-type diplexer for the millimeter-wave band has been developed consisting of two hybrid circuits and two cutoff filters with high-pass responses [1]. The hybrid is a coupled wave-type 3-dB directional coupler, which is composed of two parallel TE_{01}-mode semicircular waveguides, coupled to each other by a large number of small circular holes cut in the common wall of the semicircular waveguide. However, since the TE_{01}-mode semicircular waveguide is an oversized waveguide, the coupling length must be long in order to avoid spurious moding problems. For example, the length of the 3-dB directional coupler is about 270 mm for the 30-GHz band.

An alternative is the multiple branch-guide directional coupler using rectangular waveguide which is well known as being small in size. The multiple branch-guide directional coupler for rectangular waveguide has already been developed and its design method has been established [2], [3]. The multiple branch-guide

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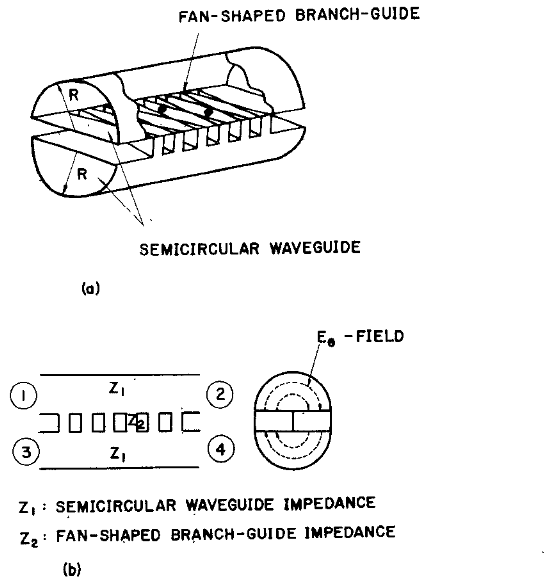

Fig. 1. TE_{01}-mode semicircular waveguide multiple branch-guide directional coupler. (a) Structure. (b) Equivalent circuit.

directional coupler has now been implemented using the TE_{01}-mode semicircular waveguide for the purpose of miniaturizing the previously mentioned diplexer. This multiple branch-guide directional coupler is one-half to one-third in length, in comparison with the conventional coupled wave-type directional coupler.

In the following, the structure and the approximate design method of the multiple branch-guide directional coupler using the TE_{01}-mode semicircular waveguide are presented and experimental results are given.

Structure and Design

The multiple branch-guide directional coupler using the TE_{01}-mode semicircular waveguide is composed of two parallel TE_{01}-mode semicircular waveguides, coupled to each other by a large number of fan-shaped branch guides. The fan-shaped waveguide has an inner radius R that is the same as the radius of two semicircular waveguides and has vertical angle ϕ, as shown in Fig. 1(a). The transverse electric and magnetic field of the TE_{01} mode in cylindrical polar coordinates are described as follows [4]:

$$E_\theta = -V_0\sqrt{2/\phi} \cdot J_1(\xi r)/RJ_0(X) \tag{1}$$

$$H_r = I_0\sqrt{2/\phi} \cdot J_1(\xi r)/RJ_0(X) \tag{2}$$

where X is the first root of $J_1 = 0$ except zero: $X = 3.83171$, $\xi = X/R$, and J_0 and J_1 are the first- and second-order of Bessel function, respectively.

If $\phi = \pi$, (1) and (2) represent the transverse electric and magnetic field for the TE_{01} mode in semicircular waveguide. The TE_{01} mode of semicircular waveguide and the TE_{01} mode of the fan-shaped waveguide have identical eigenvalue and propagation constants. It is assumed that the semicircular waveguide and the fan-shaped waveguide propagate only the TE_{01} mode. The design of this coupler is accomplished approximately by the same method as that used for the multiple branch-guide directional coupler of rectangular waveguide.

The S-matrix of the 4-port circuit, as shown in Fig. 1(b), can be obtained from the superimposition of results obtained in the even- and odd-mode cases [2]. In this method, it is necessary to calculate the ratio of impedance between the semicircular wave-

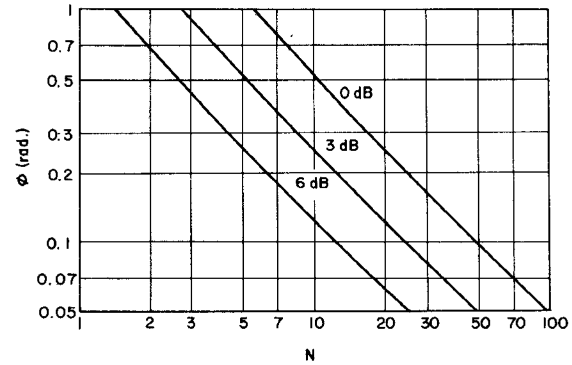

Fig. 2. Vertical angle ϕ versus number of branches N necessary to obtain 0-dB, 3-dB, and 6-dB coupling.

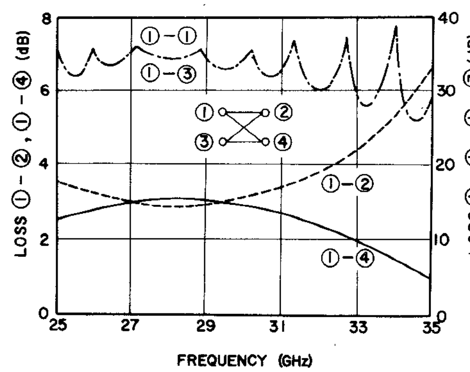

Fig. 3. Calculated frequency responses of the 3-dB coupler (22 branches).

guide and the fan-shaped waveguide. It has been found, after some experimental examination, that the ratio of impedance is

$$\alpha = Z_2/Z_1 = 2\phi/\pi. \tag{3}$$

From the previous equation, the required design parameters are easily calculated and are summarized in Fig. 2. The figure shows the vertical angle ϕ versus the number of branch-guides N necessary to obtain 0-dB, 3-dB, and 6-dB coupling. The calculated frequency responses for a 3-dB coupler of 22 branches are shown in Fig. 3, where the radius of the semicircular waveguide and the fan-shaped waveguide is 9 mm, the vertical angle of the fan-shaped waveguide is 0.11 rad, and the center frequency is 28 GHz. In the figure, the solid line is the coupling-loss value, the dotted line is the residual coupling-loss value, and the dot–dash line is the directivity value.

Experimental Results

In order to check the present design method, a multiple branch-guide 3-dB directional coupler for the 30-GHz band was manufactured, as shown in Fig. 4, and experimentally tested. Two semicircular waveguides and the fan-shaped waveguide were made individually and assembled in sandwich form. The radius of the semicircular and fan-shaped waveguides was 9 mm, the vertical angle and the length of the fan-shaped waveguide were 0.11 rad and 2.65 mm, respectively. In Fig. 2, the 3-dB coupling is obtained by 22 branches, where the vertical angle of the fan-shaped waveguide is 0.11 rad. The experimental data of the coupling loss and the residual coupling loss for the 0-dB coupler consisting of two 3-dB couplers are shown in Fig. 5, which agreed with calculated values. The insertion loss is decreased in proportion to the length of the 0-dB coupler. But the bandwidth of the 0-dB coupler is slightly narrow compared with the conventional coupled wave-type 0-dB coupler.

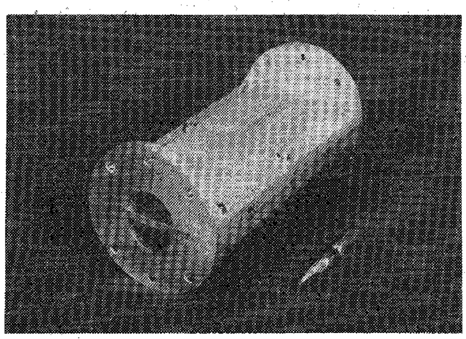

Fig. 4. Trial multiple branch-guide 3-dB directional coupler.

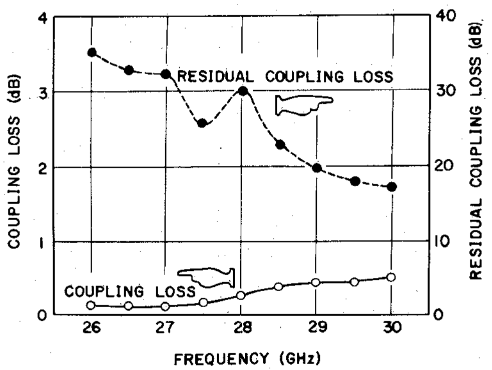

Fig. 5. Measured frequency responses of the 0-dB coupler (44 branches).

It was suspected that mode conversion may occur because the TE_{01}-mode semicircular waveguide is an overmoded waveguide. Especially, the TE_{21} mode may propagate because the propagation-constant difference between the TE_{21} mode and the TE_{01} mode is very small, and because the field distribution of the TE_{21} mode at the plane wall is similar to that of the TE_{01} mode. The mode-conversion ratio of the TE_{21} mode was experimentally measured using a tapered semicircular TE_{21}-mode transducer [5]. It was found that the mode-conversion ratio was less than -20 dB, the conversion loss is less than 0.05 dB, and the mode conversion of the TE_{21} mode has a negligible effect on the TE_{01} mode.

Conclusion

Design parameters of the present approximate theory have made it possible to construct multiple branch-guide directional couplers using a TE_{01}-mode semicircular waveguide. Since the length of the 0-dB coupler for the experimental model is about 150 mm, which is shorter than the conventional coupled wave-type 0-dB coupler, the insertion loss is proportionally decreased. It is possible to make a more compact diplexer and to decrease the insertion loss of the diplexer for the millimeter-wave band and also for the 20–30-GHz band.

It is expected that the technique will be used in the band-splitting filter for the 30-GHz band in the earth station of the Japanese domestic satellite communication system [6].

Acknowledgment

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A Frequency-Independent Large-Signal Equivalent Circuit for a BARITT Diode and Its Application to an Amplifier

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***Abstract*—A frequency-independent large-signal equivalent circuit having five elements with only one resistive element is presented for the BARITT diode. It is valid over the useful frequency range and is used for the investigation of the BARITT-diode amplifier.**

Introduction

The terminal characteristics of a microwave negative-resistance device are nonlinear. An equivalent-circuit representation [1] of the device, especially a frequency-independent equivalent circuit, is useful in the investigation of the device performance in a practical microwave circuit.

Recently, a large-signal frequency-independent equivalent circuit has been proposed for IMPATT-diode characterization by Gupta [2]. Although this equivalent circuit permits a useful frequency range of validity, it requires a complex process for evaluating the circuit elements and has a disadvantage in application to the amplifier design because of two or three resistive elements in the circuit [3]. The purpose of this short paper is to present a novel frequency-independent large-signal equivalent circuit having only one resistive element for a BARITT diode and an application to the investigation of a BARITT-diode amplifier performance.

Evaluation of the Equivalent Circuit

The frequency-independent equivalent circuit proposed here is shown in Fig. 1. The basic circuits of the equivalent circuit are a series resonant circuit with a negative resistance and a shunt resonant circuit. The admittance of the equivalent circuit $Y_{eq}(\omega)$ is

$$Y_{eq}(\omega) = \frac{R}{R^2 + [\omega L_s\{1 - (\omega_s/\omega)^2\}]^2} + j\left[\omega C_p\{1 - (\omega_p/\omega)^2\} - \frac{\omega L_s\{1 - (\omega_s/\omega)^2\}}{R^2 + [\omega L_s\{1 - (\omega_s/\omega)^2\}]^2}\right] \quad (1)$$

where $\omega_s = (\sqrt{L_s \cdot C_s})^{-1}$ and $\omega_p = (\sqrt{L_p \cdot C_p})^{-1}$.

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