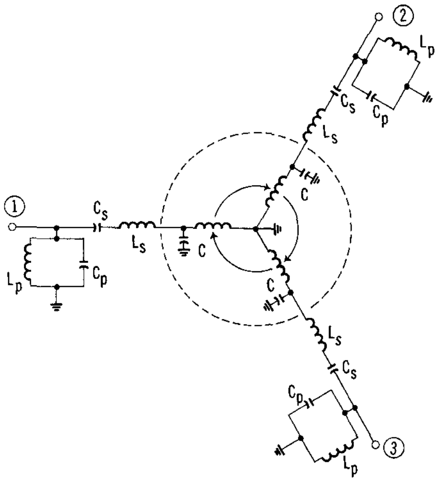

Fig. 1. Equivalent circuit of triple-tuned circulator.

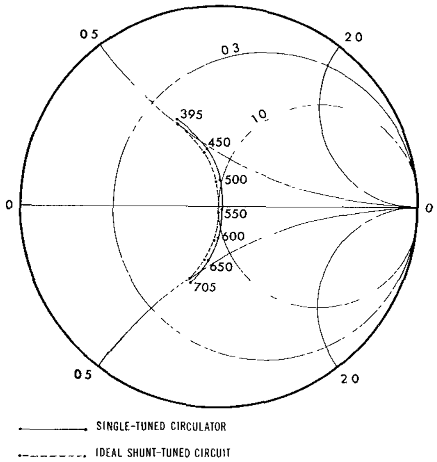

Fig. 2. Impedance response of the single-tuned circulator.

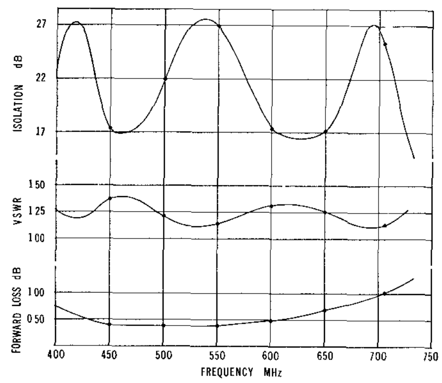

Fig. 3. Performance of triple-tuned circulator.

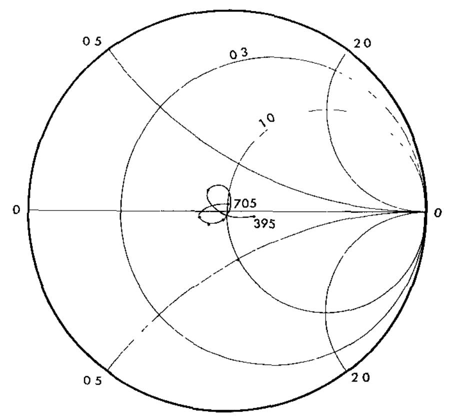

Fig. 4. Impedance plot of triple-tuned circulator.

curves show an equal ripple characteristic with a minimum isolation of 17 dB. The insertion loss reaches a maximum of 1.0 dB at the high end of the band and is typically 0.6 dB or less over most of the band. The corresponding impedance plot is indicated in Fig. 4. The packaged unit is $3\frac{11}{16}$ inches in diameter by $1\frac{1}{4}$ inches in height.

In comparison with previously reported conventional junction circulators, this circulator has greater bandwidth for comparable isolation and insertion loss and has a possible cost advantage in that the ferrite volume required is considerably less.

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Cutoff Characteristics of the Channel Waveguide

Some time ago, Vilmur and Ishii[1] reported the results of an investigation to determine the cutoff characteristics of the channel waveguide. Their analysis was based on the methods of Iashkin and Cohn. However, they found that the two approaches produced appreciably different results. Subsequently, Roth and Ishii[2] attempted to resolve this discrepancy by experiments. Their observations seemed to indicate that there were indeed two modes of propagation, one following Iashkin's method and one following Cohn's method.

The purpose of this correspondence is to verify that over a certain range of channel-width to guide-width ratios there exist two modes with similar cutoff characteristics, to identify these modes by their field configurations and to present accurate cutoff data. These data were obtained using an existing computer program and the accuracy is of the order of 0.1 percent.

Our analysis is based on the method of finite differences which replaces the Helmholtz equation and boundary conditions by a set of algebraic equations in terms of the field values at discrete mesh points. Solutions to the resulting matrix eigenvalue problem are obtained using successive over-relaxation for the field values, a variational expression for the cutoff wavenumber and mesh halving until sufficient accuracy is obtained. Details of the method and the development of a computer program to solve for arbitrarily shaped waveguides have been published in a recent paper.[3]

Figure 1 shows the electric field configuration for the two modes which are of interest to the present discussion. The mode depicted in Fig. 1(a) corresponds to the TE_{10} mode in a rectangular waveguide and the mode of Fig. 1(b) reduces to the TE_{01} mode if the channel is removed. Figure 2 is a graph of the cutoff characteristics for the two modes for a channel waveguide having $b_1/a_1=0.444$, $b_1/b_2=0.5$, and a_2/a_1 varying from 0 to 1. All higher-order modes have cutoff frequencies outside of the range shown on Fig. 2.

The results show that the effect of the channel is to increase the cutoff frequency of the TE_{10} mode and to decrease that of the TE_{01} mode. In fact, over a wide range of a_2/a_1, the TE_{01} mode replaces the TE_{10} mode as the dominant mode in the channel waveguide.

Comparing these results with those obtained by Roth and Ishii,[2] it seems reasonable to conclude that the method of Iashkin gives an approximation to the TE_{10} mode, whereas

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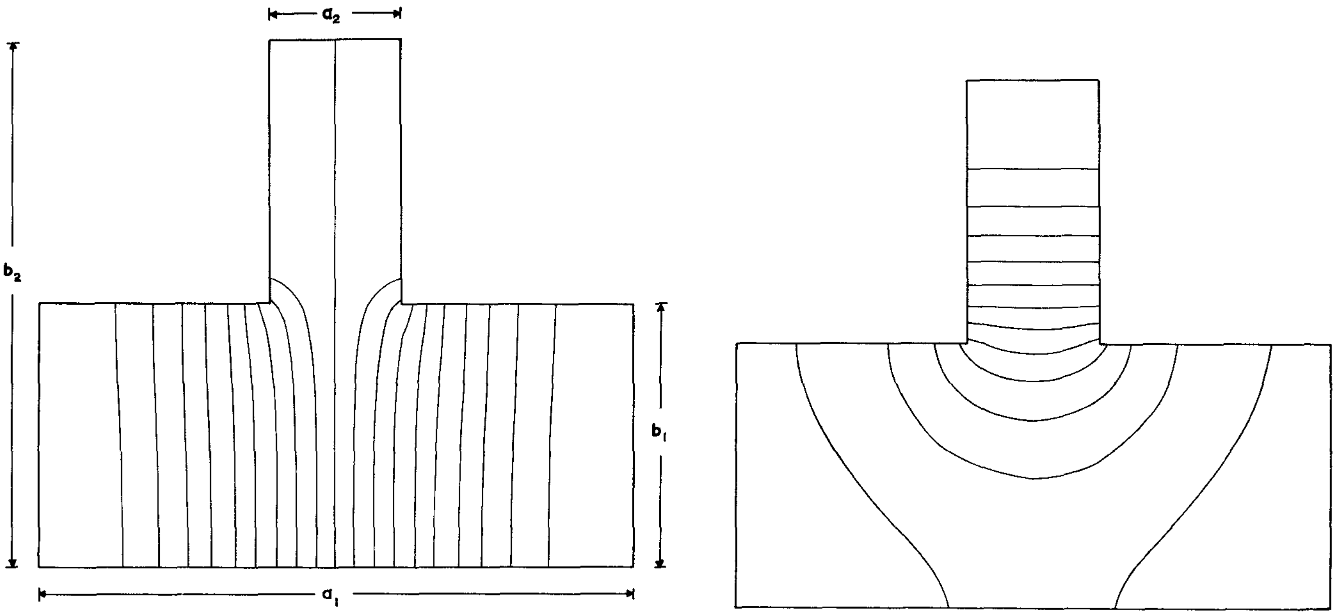
[1] R. J. Vilmur and K. Ishii, "The channel waveguide," *IRE Trans. on Microwave Theory and Techniques*, vol. MTT-10, pp. 220–221, May 1962.

[2] J. P. Roth and K. Ishii, "The cutoff characteristics of the channel waveguide," *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-12, pp. 245–247, March 1964.

[3] J. B. Davies and C. A. Muilwyk, "Numerical solution of uniform hollow waveguides with boundaries of arbitrary shape," *Proc. IEE (London)*, vol. 113, pp. 277–284, February 1966.



(a) (b)

Fig. 1. (a) Electric field configuration for the TE_{10} mode. (b) Electric field configuration for the TE_{01} mode.

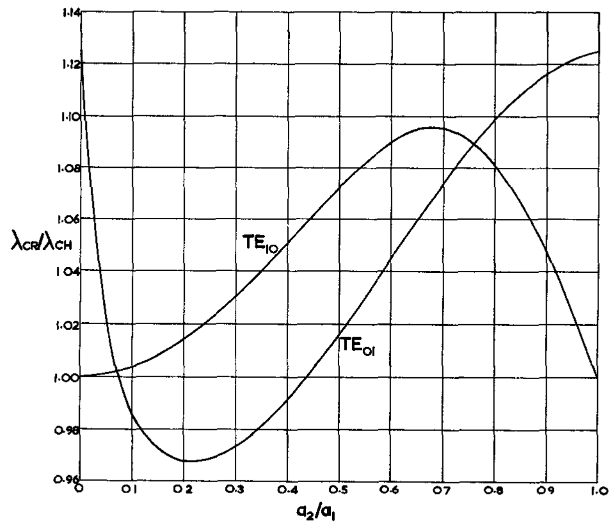


Fig. 2. Cutoff characteristics for the TE_{10} and TE_{01} modes in a channel waveguide having $b_1/a_1=0.444$ and $b_1/b_2=0.5$. λ_{CR} is the cutoff wavelength of a rectangular waveguide with broad dimension a_1, and λ_{CH} is the cutoff wavelength of the channel waveguide.

Cohn's method approximates the fundamental mode. As a_2/a_1 is increased from 0 to 1, Cohn's method initially follows the TE_{10} mode, then switches to the TE_{01} mode as it becomes the dominant mode, and finally changes back to the TE_{10} mode.

For practical applications the TE_{01} mode is obviously unwanted because its power-handling capacity is very small; however, it should be quite easy to ensure that only the TE_{10} mode is excited, because the polarizations of the two modes are orthogonal.

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Corrections to "Fringing Capacitance in Strip-Line Coupler Design"

The author of the above[1] wishes to thank Charles Lamensdorf, of the Hazeltine Corp., Greenlawn, N. Y., for pointing out the following.

A pi (π) symbol is missing in the first equation for the parameter s/b. The equation should read

$$\frac{s}{b}=\frac{2}{\pi}\operatorname{arc\,tanh}\left[\exp\frac{\pi\eta_0}{4\sqrt{\epsilon_r}}\left(\frac{1}{Z_2}-\frac{1}{Z_1}\right)\right].$$

While in the third equation given for s/b, the characteristic impedance (Z_0) should not appear under the radial sign. The equation should read

$$\frac{s}{b}=-\frac{1}{\pi}\ln\left[\tanh\left(\frac{\pi\eta_0}{4Z_0\sqrt{\epsilon_r}}\frac{k}{\sqrt{1-k^2}}\right)\right].$$

An additional correction is needed.

$W/b \geq 0.35$ rather than $W/b \to 0.35$.

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Manuscripts received November 28, 1966 and December 16, 1966.

[1] J. Singletary, Jr., *IEEE Trans. on Microwave Theory and Techniques (Correspondence)*, vol. MTT-14, p. 398, August 1966.