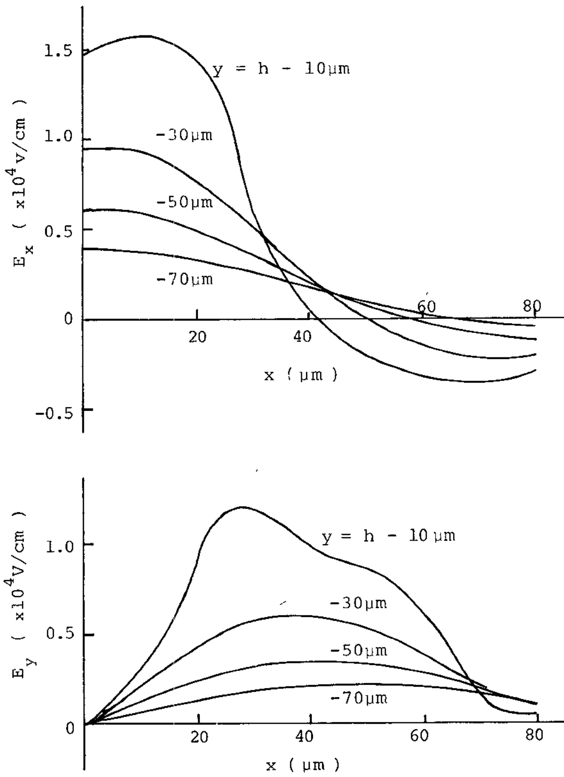

Fig. 7. Electric field distribution near electrodes.

resistance connected between the electrodes [5]. Since the dimensions of the electrodes can be made extremely small by microelectronics techniques, the modulation bandwidth Δf can be large and the required modulation power P can be small. Therefore, effective modulators with a low value of $P/\Delta f$ can be expected for a thin optical beam.

When the uniform electrooptic effects in the cross section of a passing optical beam are required, however, the electrode spacing has to be increased. As a result, the increase of $P/\Delta f$ is inevitable.

VI. Traveling-Wave Structures

When the modulation frequency is high so that the wavelength becomes comparable to the electrode length, the modulator can be treated as a transmission line. The two important quantities of traveling-wave modulators are the modulation wave velocity v and the characteristic impedance Z. These are, within the TEM wave approximation, obtained from the preceding capacitance and the formulas [7]

$$v = \sqrt{\frac{C_0}{C}}\, v_0 \tag{19}$$

$$Z = \frac{1}{v_0\sqrt{CC_0}} \tag{20}$$

where v_0 is the velocity of light in vacuum, C is the capacitance per unit length of the transmission line, and the C_0 is the capacitance per unit length for the same transmission line conductors in vacuum. The velocity of modulation waves is designed to match that of light in the crystal for the traveling-wave modulation.

If the two matching conditions on the velocity and impedance [1] are satisfied by selecting the dimensions of the modulator, the coplanar electrode modulator with a very narrow gap is expected to be of high efficiency and broad bandwidth.

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Central Metal Post in Stripline Circulators

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Abstract—**A central metal post of a suitable radius increases the bandwidth of a 3-port stripline circulator considerably. It helps to realize a compact circulator and gives more flexibility in the design.**

Introduction

The insertion of a central metal post was considered in the design of broad-band 3-port waveguide circulators [1]–[4]. In the case of stripline circulators, the efforts were mainly concentrated to obtain broader bandwidth using external matching elements [5]–[9].

We prove here that the insertion of a central metal post, in the case of 3-port stripline circulators, can increase up to three times the bandwidth of the simple junction. The radius of the ferrite disk can be reduced. Generally, a central metal post gives more flexibility in the design.

Field Analysis and Computational Results

Consider a metal post of radius a placed at the center of a ferrite disk of radius R. The z component of the electric field

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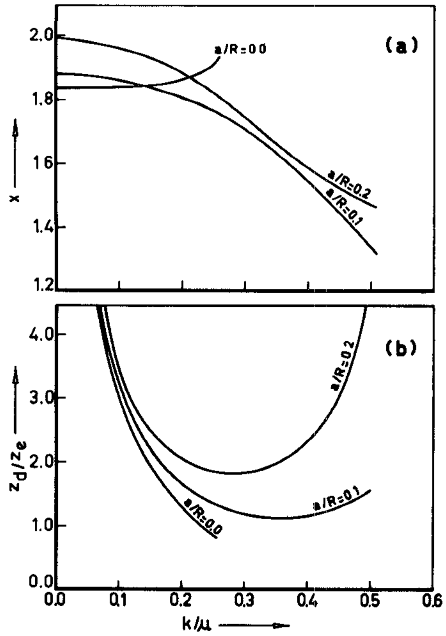

Fig. 1. The dependence of (a) the normalized radius x and (b) the impedance ratio Z_d/Z_e on k/μ for different metal post radii (a/R = 0, 0.1, 0.2). ψ = 18°.

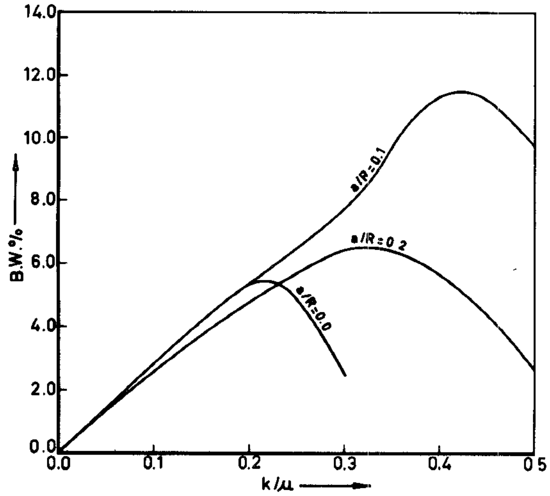

Fig 2. The relative bandwidth versus k/μ for different metal post radii (a/R = 0, 0.1, 0.2). ψ = 18°.

and the azimuthal component of the magnetic field within the ferrite disk [10] can be put in the form

$$E_z(r,\phi) = \sum_{n=-\infty}^{\infty} a_n T_n(\alpha r) e^{jn\phi} \tag{1}$$

$$H_\phi(r,\phi) = jY_e \sum_{n=-\infty}^{\infty} a_n [T_n'(\alpha r) - (k/\mu) n T_n(\alpha r)/\alpha r] e^{jn\phi} \tag{2}$$

where

$$T_n(\alpha r) = J_n(\alpha r) + \lambda_n Y_n(\alpha r) \tag{3}$$

$$T_n'(\alpha r) = J_n'(\alpha r) + \lambda_n Y_n'(\alpha r) \tag{4}$$

$$\alpha = \omega(\varepsilon_0 \varepsilon \mu_0 \mu_e)^{1/2} \tag{5}$$

$$Y_e = 1/Z_e = (\varepsilon_0 \varepsilon/\mu_0 \mu_e)^{1/2} \tag{6}$$

$$\mu_e = (\mu^2 - k^2)/\mu. \tag{7}$$

k and μ are the diagonal and off-diagonal components of the tensor permeability of the ferrite. The z component of the electric field must vanish at the metal–ferrite interface; therefore,

$$\lambda_n = -J_n(\alpha a)/Y_n(\alpha a). \tag{8}$$

Let

$$x = \alpha R. \tag{9}$$

Substituting $T_n(x)$ and $T_n'(x)$ in place of $J_n(x)$ and $J_n'(x)$, respectively, into the expressions of K, L, and M [11], leads to the modified circulation conditions for the metal post case.

Using up to the ninth space harmonic, the circulator parameters (x, k/μ, and Z_d/Z_e)[1] are computed for $\psi = \pi/10$.[2] Fig. 1 shows the dependence of the normalized radius x and the impedance ratio Z_d/Z_e on k/μ for different values of a/R. Varying the metal post size, the normalized radius and impedance ratio curves change considerably. This gives more flexibility in the design.

The relative bandwidth is defined as the ratio of the band over which the isolation at port 3 is higher than 20 dBs to the central circulation frequency. The relative bandwidth is computed and plotted in Fig. 2 as a function of k/μ for different sizes of the metal post [the variations of x and Z_d/Z_e with k/μ and a/R (Fig. 1) are taken into consideration]. For the simple junction ($a/R = 0$), the increase in the anisotropic splitting k/μ results in an increase in the relative bandwidth [12]. However, for higher values of k/μ the higher order modes affect the circulation action. This leads to a decrease in the bandwidth [13]. Hence the value of k/μ cannot be chosen very high (for $a/R = 0$). Fig. 2 shows that the insertion of a central metal post permits the use of large anisotropic splitting as was suggested by Bosma [13]. Therefore, the maximum bandwidth for the simple junction (5.4 percent for $k/\mu = 0.22$, $a/R = 0$, and $\psi = 18°$) can be increased using a suitable central metal post.

The dependence of the maximum bandwidth (the peaks of Fig. 2) and the corresponding values of k/μ on a/R are shown in Fig. 3(a). As a/R increases, the maximum bandwidth and k/μ show a sharp increase followed by a slow decay. The optimum bandwidth (16 percent) occurs at a/R = 4 percent. This optimum value is nearly three times larger than that of the simple junction case. It is worth noting that the optimum bandwidth will be practically higher than 16 percent due to the losses in the ferrite, which is not considered here [11], [12]. A further increase in the bandwidth can be obtained using external matching elements [5]–[9] and/or by the optimum choice of the stripline coupling angle [14], [15].

The values of x and Z_d/Z_e corresponding to the maximum bandwidth may be deduced for a/R = 0, 0.1, 0.2 (Figs. 1, 2). The complete dependence of these parameters on a/R is shown directly in Fig. 3(b). A sharp decrease in the normalized radius x is noticed for a/R = 4 percent. Thus a compact broad-band stripline circulator can be realized using a 4-percent central metal post (ψ = 18°). Fig. 3 can be used for design purposes.

Conclusions

The circulator parameters (the normalized radius x, the ratio k/μ, and the impedance ratio Z_d/Z_e) can be conveniently controlled by the size of the metal post. This provides more flexibility in the design.

[1] Z_d is the wave impedance of the dielectric filling the striplines [11].
[2] ψ is half the stripline coupling angle.

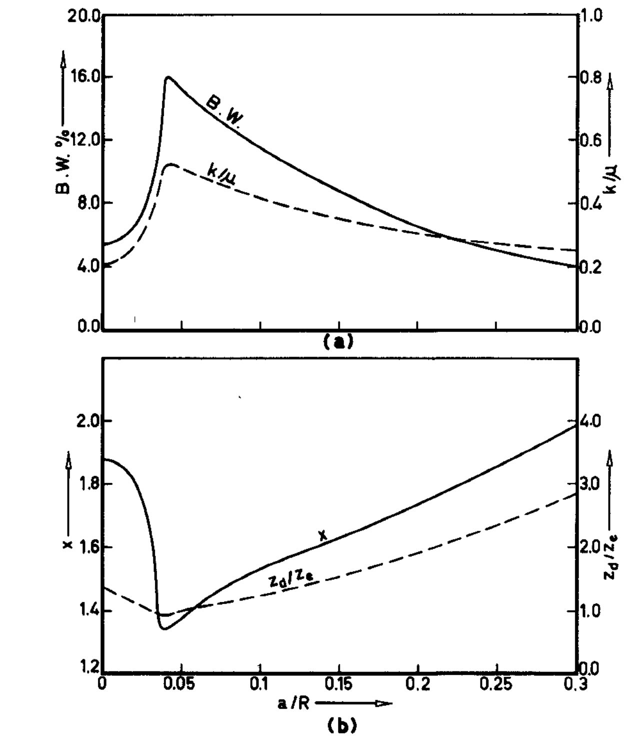

Fig. 3. The dependence of the maximum bandwidth and the corresponding values of k/μ, x, and Z_d/Z_e on the relative size of the metal post. $\psi = 18°$. (a) The maximum bandwidth and the ratio k/μ. (b) The normalized radius x and the impedance ratio Z_d/Z_e.

A compact broad-band stripline circulator can be realized using a 4-percent central metal post for $\psi = 18°$.

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Full-Band Low-Loss Continuous Tracking Circulation in K Band

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***Abstract*—The continuous tracking principle is applied to the design of a wide-band Y-junction stripline circulator for the 18–26.5-GHz frequency band. Near octave low-loss and high isolation performance is demonstrated without the need for repeated design cycles. Design data and construction details are presented.**

I. Introduction

In a recent paper [1], Wu and Rosenbaum discovered the continuous tracking technique for the design of octave bandwidth stripline and microstrip Y-junction circulators. By retaining terms up to the third order in the expressions for the electromagnetic fields, they obtained solutions for the perfect circulation roots and the intrinsic junction impedance ratio. This impedance ratio (Z_{eff}/Z_d) was found to be a nonmonotonic function of the anisotropic splitting ratio k/μ. It was further shown that by judicious choice of disk coupling half-angle, the intrinsic and external junction impedance ratios could be matched over the range $0.5 < k/\mu < 1.0$, thereby obtaining perfect circulation over a two-to-one frequency range. This continuous tracking technique was verified with a microstrip design. Moderately high isolation was found from 6.5 to 13 GHz, but the junction loss of approximately 1 dB was relatively high for a Y-junction circulator.

This short paper describes the application of the continuous tracking principle to the design of a wide-band stripline Y-junction circulator for the 18.0–26.5-GHz frequency band. High isolation as well as low loss have been obtained over the desired frequency range without the need for repeated design cycles. This indicates a high degree of both usefulness of the design principle and accuracy of the design procedure.

II. Wide-Band Circulator Design Procedure

Since the circulator described in this short paper is applied in the design of a low-noise Gunn-effect reflection amplifier, high isolation with minimum loss is required [2]. It was therefore decided, also in view of the high frequency of operation, to utilize balanced stripline construction. As a preliminary to the determination of the value of the coupling half-angle Ψ, which yields a matched impedance ratio over the widest possible frequency range, the following initial assumptions and material choices were made.

1) Assume a disk structure, implying

$$H_i = H_a - 4\pi M_s$$

where H_i is the internal magnetic field, H_a is the applied magnetic field, and $4\pi M_s$ is the saturation magnetization of the ferrite.

2) Set $H_i = 0$; therefore,

$$\omega_m/\omega = k/\mu$$

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