NEW CONFIGURATIONS OF THE NONRECIPROCAL REMANENCE FERRITE PHASE SHIFTER

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Abstract

For the purpose of improving the performance characteristics of the nonreciprocal remanence ferrite phase shifter, new configurations are proposed here which are characterized by the adoption of the grooved waveguide. Some results calculated mainly as a function of the grooved waveguide height are shown and compared, in good agreement, with experimental values. The Figure-of-Merit and handling power level of the proposed phase shifter are discussed in comparison with those of the ordinary one.

Introduction

The nonreciprocal remanence ferrite phase shifter has been used especially for phased array radars because its performance characteristics are excellent.[1] So, many techniques for improving the performance characteristics have been developed.[2,3,4,5,6]

In this paper, new configurations of the nonreciprocal remanence ferrite phase shifter are proposed, which yield the improvement of the Figure-of-Merit (differential phase shift per insertion loss) and also the increase of both peak and average handling power levels.

Configuration

New configurations, illustrated in Fig.1, consist of a ferrite toroid placed in the center of the grooved waveguide, a dielectric rib intruded into the slot of the ferrite and switching wires. Moreover, in the configuration No.2, the metal plates are placed adjacent to the center place of the vertical ferrite walls.

In these configurations, it is possible to achieve lower thermal resistance between the ferrite and the waveguide and, therefore, handle higher average power than in the ordinary one.

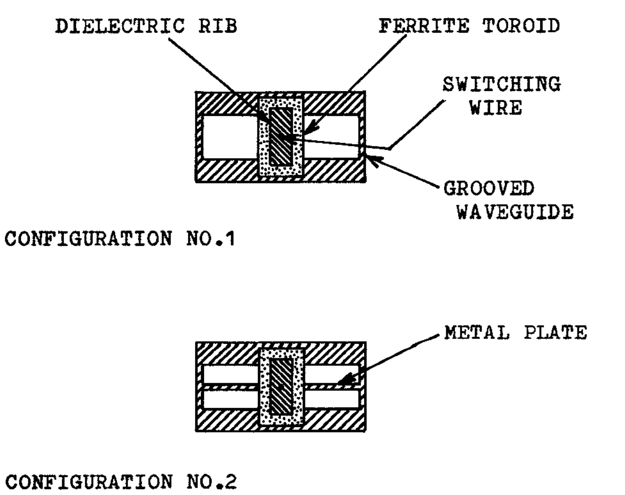

FIGURE 1: NEW CONFIGURATION OF THE NONRECIPROCAL REMANENCE FERRITE PHASE SHIFTER.

Analysis

Fig.2 shows the theoretical model and the coordinate system. With the assumption the transverse electric field of the fundamental mode is parallel to the Z-axis, the characteristic equation to compute the normalized waveguide wavelength can be obtained as the general way[2], as

$$\tan(\Gamma_2\cdot(w_2-w_1)/2.0)/\Gamma_2 = \frac{\left[b/g\cdot\Gamma_3\cdot\cot(\Gamma_3\cdot(w_3-w_2)/2.0) - \Gamma_1\cdot\tan(\Gamma_1\cdot w_1/2.0)\right]}{\left[((\Gamma_2)^2+(2\pi k/u/\lambda g)^2)/u_e+\Gamma_1/\lambda_0\cdot\tan(\Gamma_1\cdot w_1/2.0) + u_e\cdot b/g\cdot\Gamma_1\Gamma_3\cdot\cot(\Gamma_3\cdot(w_3-w_2)/2.0)\cdot\tan(\Gamma_1 w_1/2.0) + 2\pi k/u\cdot b/g\cdot\Gamma_3/\lambda_0/\lambda_g\cdot\tan(\Gamma_3\cdot(w_3-w_2)/2.0)\right]} \quad \text{-------(1)}$$

where $\Gamma_1=2\pi/\lambda\cdot\sqrt{\epsilon_1-(\lambda/\lambda g)^2}$, $\Gamma_2=2\pi/\lambda\cdot\sqrt{\epsilon_2 u_e-(\lambda/\lambda g)^2}$, $\Gamma_3=2\pi/\lambda\cdot\sqrt{1-(\lambda/\lambda g)^2}$, $u_e=(u^2-k^2)/u$.

u and k are diagonal and off-diagonal elements of tensor permeability. ϵ_1 and ϵ_2 are permittivities of the dielectric and the ferrite respectively. λ_0 is the free-space wavelength at the center frequency (f_0). λ/λ_0 and λ_g/λ_0 are the normalized free-space wavelength and waveguide wavelength.

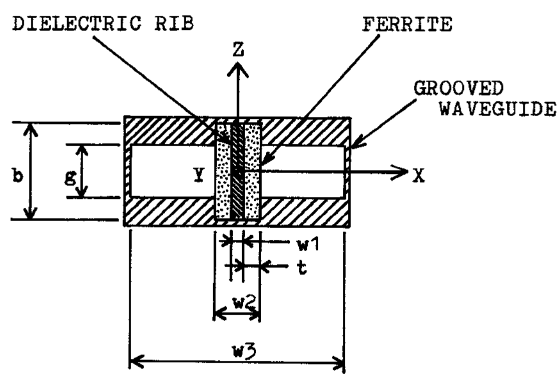

FIGURE 2: THEORETICAL MODEL OF THE NONRECIPROCAL REMANENCE FERRITE PHASE SHIFTER.

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The differential phase shift per unit length $\Delta\phi$ is

$$\Delta\phi = 1.2\cdot\lambda_0/\lambda_g(\lambda_0/\lambda_{g+} - \lambda_0/\lambda_{g-}) \text{ deg/cm·GHz} \quad \text{-------(2)}$$

where λ_{g+}/λ_0 and λ_{g-}/λ_0 are the solutions of eq.(1) in the case of positive and negative values of k which are equivalent to the positive and negative circular polarization.

On the other hand, the loss can be obtained as the sum of the dielectric, magnetic and conductive losses.[2]

Numerical results

Fig.3, 4, 5 and 6 show some results calculated under the following condition.

$\epsilon_1=13.0$, $\epsilon_2=12.0$, $4\pi\gamma Ms/f_0=0.67$

$4\pi Mr/4\pi Ms=0.774$, $b/\lambda_0=0.323$, $w_3/\lambda_0=0.724$

where $\gamma=2.8$ (MHz-Oe), $4\pi Mr$ and $4\pi Mr$ are the remanent and saturation magnetization respectively.

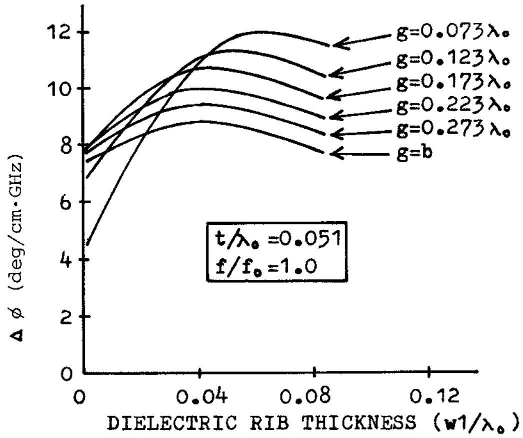

FIGURE 3: DIFFERENTIAL PHASE SHIFT ($\Delta\phi$) VERSUS DIELECTRIC RIB THICKNESS ($w1/\lambda_0$) FOR SEVERAL GROOVED WAVEGUIDE HEIGHT (g/λ_0).

The influence of dielectric rib thickness (Wl/λ_0) to the differential phase shift ($\Delta\phi$) is illustrated in Fig.3. This figure shows that $\Delta\phi$ increases according to the decrease of the grooved waveguide height (g/λ_0) and there exists the optimum thickness of wl/λ_0 over the range from 0.04 to 0.06.

The variation of $\Delta\phi$ and $L_{2\pi}$ (loss per 360° of differential phase shift) with g/λ_0 for several ferrite thickness (t/λ_0) is shown in Fig.4, which represents that the enlargement in $\Delta\phi$ and, consequently, the reduction in $L_{2\pi}$ can be achieved by setting g/λ_0 to the optimum value. For example, the increase of nearly 30% in $\Delta\phi$ and the decrease of nearly 25% in $L_{2\pi}$ are obtainable in the case of t/λ_0 to be 0.051.

Fig.5 shows the frequency characteristics of $\Delta\phi$ and $L_{2\pi}$ for several values of g/λ_0. The improvements in $\Delta\phi$ and $L_{2\pi}$ are achieved by the reduction of g/λ_0 as long as g/λ_0 is not an extremely small value.

The RF magnetic field distribution has been computed for several values of g/λ_0 and the results are shown in Fig.6(a) and (b) which are equivalent to positive and negative circular polarization respectively.

In the ordinary configuration ($g/\lambda_0=b/\lambda_0$), there exists only a small component of circular polarization within the ferrite because the intensity of x-component (hx) of the RF magnetic field is rather larger than that of y-component (hy). However, in order to increase $\Delta\phi$, it is desirable to excite the component of circular polarization as large as possible.

So, we introduce the grooved waveguide. As shown in Fig.6, it is possible to generate larger y-component, that is, larger component of circular polarization by the reduction of g/λ_0. But it must be taken a care that the performance becomes poor if g/λ_0 is set to an extremely small value.

Moreover, the maximum intensity of the RF magnetic field in the ferrite which occurs at the interface of the ferrite and the dielectric determines the peak handling power levels of the phase shifter. Then, by the decrease of g/λ_0 to the proper value, the peak handling power level can be increased because the maximum intensity becomes weak as recognized from Fig.6 (a).

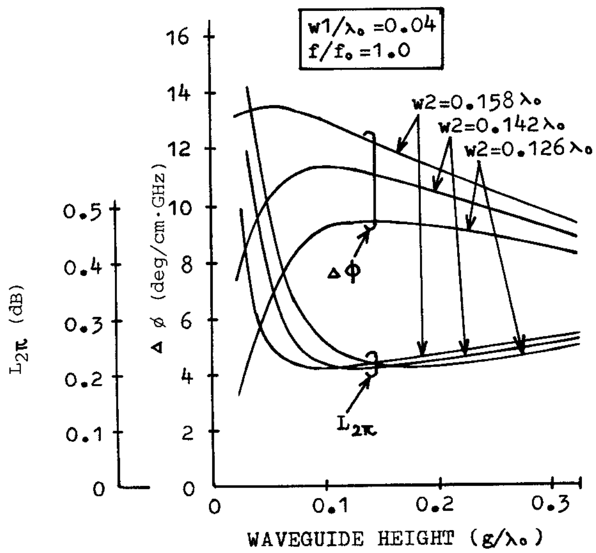

FIGURE 4: DIFFERENTIAL PHASE SHIFT ($\Delta\phi$) AND LOSS ($L_{2\pi}$) VERSUS GROOVED WAVEGUIDE HEIGHT (g/λ_0) FOR SEVERAL FERRITE THICKNESS (t/λ_0).

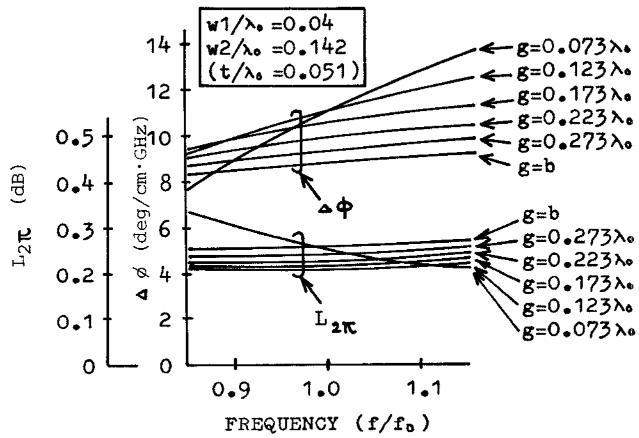

FIGURE 5: DIFFERENTIAL PHASE SHIFT ($\Delta\phi$) AND LOSS ($L_{2\pi}$) VERSUS FREQUENCY (f/f_0) FOR SEVERAL GROOVED WAVEGUIDE HEIGHT (g/λ_0).

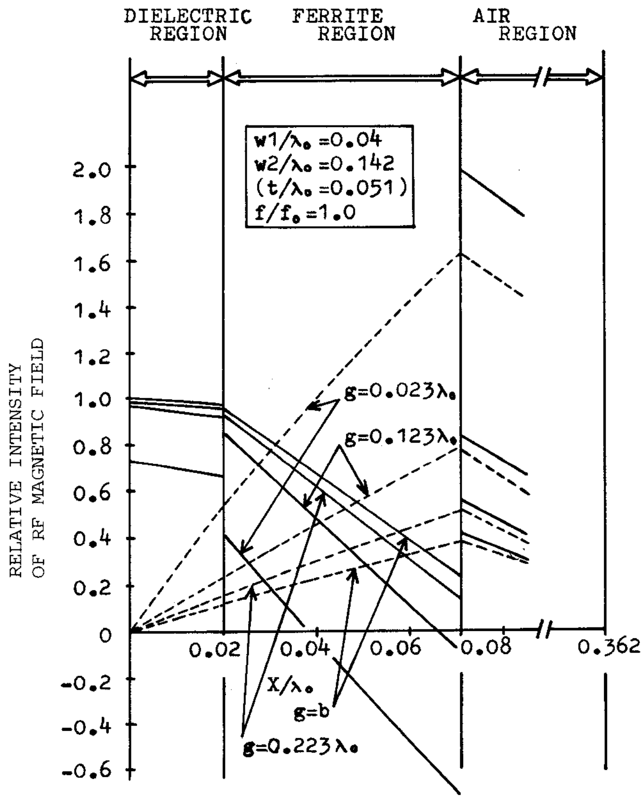

FIGURE 6(A): RELATIVE INTENSITY OF RF MAGNETIC FIELD DISTRIBUTION FOR SEVERAL GROOVED WAVE-GUIDE HEIGHT (g/λ_0) IN THE CASE OF POSITIVE CIRCULAR POLARIZATION.
(h_x^+ ———— , h_y^+ -------)

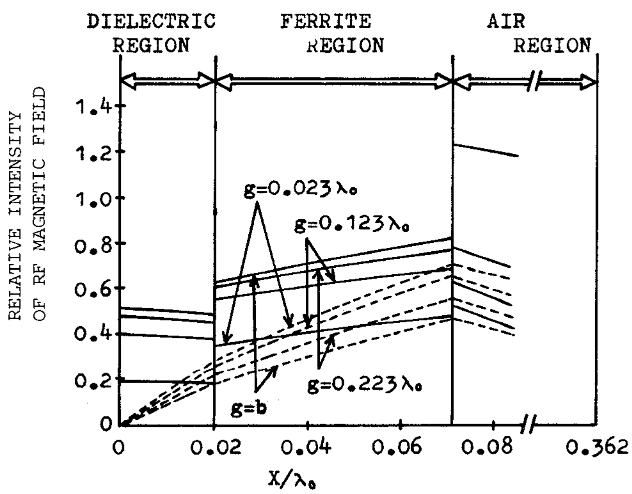

FIGURE 6(B): RELATIVE INTENSITY OF RF MAGNETIC FIELD DISTRIBUTION FOR SEVERAL GROOVED WAVE-GUIDE HEIGHT (g/λ_0) IN THE CASE OF NEGATIVE CIRCULAR POLARIZATION.
(h_x^- ———— , h_y^- --------)

Experimental results

In Fig.7, the dots show the experimental values over the frequency range from 9.0 to 10.0 GHz and the solid lines show the compensated theoretical results[2] which were calculated under the consideration of "Active"[7] dimmension of the ferrite.

The good coincidence between numerical and experimental values has been obtained. Consequently, the Figure-of-Merit of this phase shifter has been improved larger than 20% in comparison with the ordinary one.

Conclusion

By the adoption of a grooved waveguide for the nonreciprocal remanence ferrite phase shifter, the remarkable results have been obtained such as follows.

(I) The enlargements in $\Delta\phi$ and, therefore, the increases of the Figure-of-Merit are attainable as the results of exciting the large component of the circular plarization within the ferrite.

(II) The average handling power level can be increased by making the thermal resistance between the ferrite and the waveguide lower.

(III) It is expected that the peak handling power level can be increased by weakening the maximum intensity of RF magnetic field within the ferrite.

Reference

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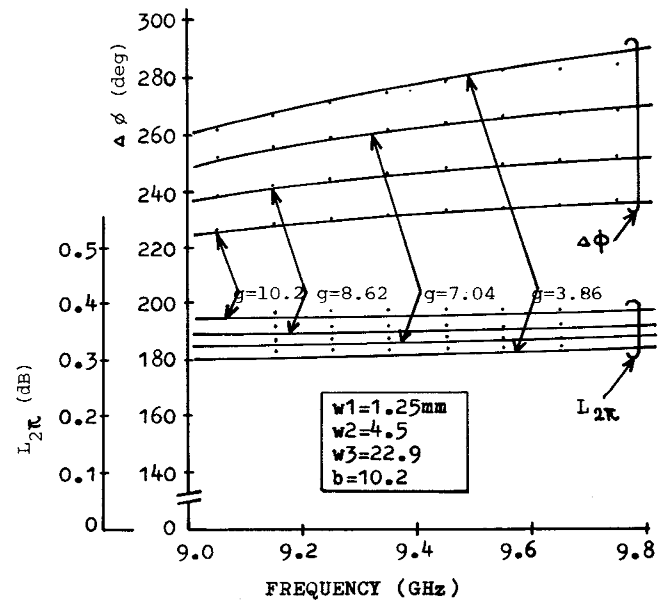

FIGURE 7: FREQUENCY CHARACTERISTICS OF DIFFERENTIAL PHASE SHIFT ($\Delta\phi$) AND LOSS ($L_{2\pi}$).
(SOLID LINE: NUMERICAL
DOT: EXPERIMENTAL)