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MICROWAVE FERRITE DUAL-MODE POLARIZATION TECHNOLOGY

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Abstract

Both nonreciprocal birefringent effect and variable polarization effect of microwave ferrite materials are discussed in the light of coupling wave theory, and with the help of these effects, a new type of dual-mode ferrite fast-speed variable polarizer is developed. On the other hand, the corresponding optimal magnetization field distribution(OMFD) is researched and numerically calculated, and the analog-test is also done.

Introduction

In recent years, polarization technology has found important application in improving the ECCM performance of radar and rapidly identifying physical characteristics of target. It has been reported that variable polarizer has been developed with the nonreciprocal character of microwave ferrite materials. This paper discusses a new type of dual-mode fast-speed variable polarizer which has, in addition to polarization agility and feature fast-speed switch, good electrical performance, simplestructure, small size and light weight in comparison with mono-mode dual-channel polarization circuit.

This paper applying coupling wave theory deals with nonreciprocal birefringent effect and variable polarization effect in case of symmetrical quadrupole-field, and the corresponding OMFD is reseached and calculation by using variation principle and numerical calculation, thus two methods of realizing variable polarization are proposed. In addition, the analog test is done.

Propagation Characters in Dual-Mode Waveguide

In the square waveguide of sidelength a, two fundamental modes H_{10} and H_{01} are a pair of degenerate waves. However they may split into different propagation constant after being filled anisotropy microwave ferrite materials in it. Many dual-mode devices can made with this feature. Recent designed microwave ferrite fast-speed variable polarizer is a type of dual-mode device by means of two kinds of symmetrical quadrucenters magnetization serving as magnetization field.

By using coupling wave theory in the case of wave propagation along the positive direction, the calculation for methods of magnetization as shown in Fig.1 will results in:

1. Nondegenerate and nonreciprocal normal wave(Fig.1(a))

In this case H_{10} and H_{01} with different propagation constant are a pair of normal waves, the mode-differential phase shift of them is

$$\Delta\beta = 2.99k/\mu a \qquad (1)$$

It is nonreciprocal birefringent effect.

2. Nonreciprocal coupling wave(Fig. 1(b))

Here H_{10} and H_{01} with identical pragation constant are a pair of coupling waves. Their coupling coefficient is

$$k_v = 2.126k/\mu a \qquad (2)$$

And the mode-differentical phase shift of corresponding normal wave is

$$\Delta\beta = 2k_v = 4.252k/\mu a \qquad (3)$$

It is nonreciprocal variable polarization effect.

Applying two methods of magnetization as shown in above, different polarization output waves can be obtained only by properly controling parameters of system.

3. Degenerate and nonreciprocal normal wave(Fig.1(c)and 1(d))

Here H_{10} and H_{01} are a pair of degenerate nonreciprocal normal waves, and their nonreciprocal differential phase shift are

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$$\Delta\beta=\begin{cases}1.63K/\mu a & (Fig\,1(c))\\ 1.22K/\mu a & (Fig\,1(d))\end{cases} \tag{4}$$

Two methods of magnetization as shown in Fig.1(c) and 1(d) can be used to make muti-polarization nonreciprocal phase shifter.

The Theoratical Analysis on Optimal Magnetization Field

Mode-differential phase shift or coupling coefficient for variable polarizer are closely related to the field distribution of magnetization field. Therefore, it is an important theoratical and engineering problem to find out a kind of magnetization field distribution that can optimize the variable polarization performance.

With solving coupling propagation eq., it may be obtained that the propagation constants of two nondegenerate normal waves are

$$\lambda_{1,2}=\frac{-(k_{11}+k_{22})\pm\sqrt{(k_{11}+k_{22})^2-4(k_{11}k_{22}-k_{12}k_{21})}}{2} \tag{5}$$

The mode-differential phase shift between them is

$$\Delta\gamma=\left\{\frac{1}{4}\left[j(Z_1-Z_2)\right]+\left(\frac{Z_{11}}{Z_1}-\frac{Z_{22}}{Z_2}\right)+2\left(T_{11}^{v}-T_{22}^{v}\right)\right]^2 + \left[\frac{Z_{12}}{\sqrt{Z_1Z_2}}+\sqrt{\frac{Z_2}{Z_1}}\,T_{12}^{v}+\sqrt{\frac{Z_1}{Z_2}}\,T_{12}^{1}\right]\right\}^{1/2} \tag{6}$$

Obviously, there are two terms, reciprocal differential phase shift and nonreciprocal differential phase shift, in formular (6).

1. Assume that $Z_{11}=Z_{22}$ and $Z_{12}=0$ (7)

At this time (6) can be simplified into

$$\Delta\gamma=\left[(T_{11}^{v}-T_{22}^{v})^2+(T_{12}^{v}+T_{12}^{1})^2\right]^{1/2} \tag{8}$$

where former expresses nonreciprocal differential phase shift for normal waves, latter expresses nonreciprocal differential phase shift for coupling wave.

A. The OMFD for nondegenerate and nonreciprocal normal wave

The mode-differential phase shift for normal wave is

$$\Delta\gamma=\frac{jk\pi}{\mu a^3}\int_{-a/2}^{a/2}\int_{-a/2}^{a/2}\left[G_1(x_1,x_2)\sin\frac{2\pi x_1}{a} - G_2(x_1,x_2)\sin\frac{2\pi x_2}{a}\right]dx_1dx_2 \tag{9}$$

By using variable principle, we get

$$G_1(x_1,x_2)=\pm\frac{\sin\frac{2\pi x_1}{a}}{\left[\sin^2\frac{2\pi x_1}{a}+\sin^2\frac{2\pi x_2}{a}\right]^{1/2}} \tag{10}$$

and the magnetic flux equation of corresponding optimal distribution is

$$\cos\frac{2\pi x_1}{a}-\cos\frac{2\pi x_2}{a}+C=0 \tag{11}$$

where c represents any constant. The destribution of the magnetic flux is shown in Fig2. Obviously (10) can meets with the condition (7).

When (9) is substituted by (10), the maximum mode-differential phase shift is

$$\Delta\beta=3.01K/\mu a \tag{12}$$

It is almost the same with (1).

B. The OMPD for nonreciprocal coupling wave

From (8), mode-differential phase shift for corresponding normal wave is

$$\Delta\gamma=\frac{2jk\pi}{\mu a^3}\int_{-a/2}^{a/2}\int_{-a/2}^{a/2}\left[G_1(x_1,x_2)\cos\frac{\pi x_1}{a}\sin\frac{\pi x_2}{a} + G_2(x_1,x_2)\sin\frac{\pi x_1}{a}\cos\frac{\pi x_2}{a}\right]dx_1dx_2 \tag{13}$$

as being solve above, obtain

$$G_1(x_1,x_2)=\pm\frac{\cos\frac{\pi x_1}{a}\sin\frac{\pi x_2}{a}}{\left[\left(\cos\frac{\pi x_1}{a}\sin\frac{\pi x_2}{a}\right)^2+\left(\sin\frac{\pi x_1}{a}\cos\frac{\pi x_2}{a}\right)^2\right]^{1/2}} \tag{14}$$

and the optimal magnetic flux equation is

$$\sin\frac{\pi x_1}{a}\sin\frac{\pi x_2}{a}+C=0 \tag{15}$$

where c represents any constant. The distribution of magnetic flux is shown in Fig.3.

When (13) is substituted by (14), the maximum mode-differential phase shift is expresses as

$$\Delta\gamma=4.26K/\mu a \tag{16}$$

It is almost the same with (3).

C. The optimal magnetizing field distribution for nonreciprocal normal wave and nonreciprocal coupling wave together.

From former results, assume that

$$G_1(x_1,x_2)=\pm\alpha\frac{\sin(2\pi x_1/a)}{[\sin^2(2\pi x_1/a)+\sin^2(2\pi x_2/a)]^{1/2}} \mp(1-\alpha)\frac{\cos(\pi x_1/a)\sin(\pi x_2/a)}{\{[\cos(\pi x_1/a)\sin(\pi x_2/a)]^2+[\sin(\pi x_1/a)\cos(\pi x_2/a)]^2\}^{1/2}} \tag{17}$$

where $0\leq\alpha\leq 1$, but $G_1(x_1,x_2)$ must satisfy

$$G_1^2(x_1,x_2)+G_2^2(x_1,x_2)=1 \tag{18}$$

When (8) is substituted by (17), the equation is depending on parameter α. With the help of calculation by computer, $\Delta\gamma$ will reach maximum value when $\alpha=0$. This is the same with that of nonreciprocal coupling wave.

2. Assume that $T_{11}^{v}=T_{22}^{v}$ and

$$\sqrt{Z_2/Z_1}\,T_{12}^{v}+\sqrt{Z_1/Z_2}\,T_{12}^{1}=0 \tag{19}$$

As the same method, therefore

A. The optimal magnetizing field distribution for reciprocal normal wave is

$$G_1(x_1,x_2)=0 \quad ; \quad G_2(x_1,x_2)=\pm 1 \qquad (20)$$

and corresponding maximum reciprocal differential phase shift is

$$\Delta\gamma \simeq (1/2) j \beta_0 (K/\mu)^2 \qquad (21)$$

where $\beta_0=[\omega^2\varepsilon_0\mu_0\varepsilon\mu-(\pi/a)^2]^{1/2}$.

B. The OMFD for reciprocal coupling wave is

$$G_1(x_1,x_2)=-G_2(x_1,x_2)=\pm 1/\sqrt{2} \qquad (22)$$

and the maximum reciprocal differential phase shift is

$$\Delta\gamma=2\sqrt{\omega^2\varepsilon_0\mu_0\varepsilon[\mu-(K/\mu)^2]-[1-(K/2\mu)](\pi/a)^2} \qquad (23)$$

C. The OMFD for reciprocal normal wave and reciprocal coupling wave together is

$$G_1(x_1,x_2)=\pm\frac{1}{\sqrt{2}}\left\{\frac{1-\frac{64}{\pi^4}}{\frac{[1+\sqrt{1-(k/\mu)^2}]^2}{4\sqrt{1-(k/\mu)^2}}-\frac{64}{\pi^4}}\right\}^{1/2} \qquad (24)$$

It is obvision that field distribution function is a weak function of k/μ. If $k/\mu \leqslant 0.6$, the influence upon field distribution can be neglected entirly. Therefore the OMFD is the almost same with that of reciprocal coupling wave.

In addition, applying nonlinear program theory, the OMFD can be generated for nonreciprocal normal wave and reciprocal normal wave, as shown in Fig.2, and for nonreciprocal coupling wave and reciprocal coupling wave, as shown in Fig.3.

Experimental Results

We have designed and developed a new type of dual-mode ferrite fast-speed variable polarizer, its scheme is shown in Fig. 4. In the process of developing, we tried our best to make magnetization method to approach the OMFD. We employed the way,as shown in Fig.1(a), to make variable polarizer, due to the difficulties in processing of structure of magnetic yoke shown in Fig.1(b).

In the experiment,parameters of device $4\pi M=0.5$, rectangular rate $S=0.7$, $a/\lambda_0=0.21$, $a=1.1$cm. It is calculated from (1) that $\Delta\beta$ equals 54.5 deg./cm, which is approximately coincident with 51 deg./cm measured in the experiment. For the incident wave in $\pm 45°$, the measured performance of the variable polarizer are listed as follows

$f=\pm 3.5\%$	VSWR$\leqslant 1.30$
$\alpha \leqslant 0.7$ dB	ellipticity $e \leqslant 1.0$dB

normal isolation 20 dB
switch time $\leqslant 10\,\mu s$
peak power $\hat{p} \geqslant 20$ kw
average power $\bar{p} \geqslant 20$ w

The relation between the differential phase shift and magnetization current is shown in Fig.5. The frequency dispersion curve of mode-differential phase shift is shown in Fig.6. While Fig.7 is the photo. of variable polarizer.

The variable polarizer may also resulted in other microwave devices, such as power distributor/combimer, procise variable attenuation, fast-speed variable polarization phase shifter, modulater and switch.

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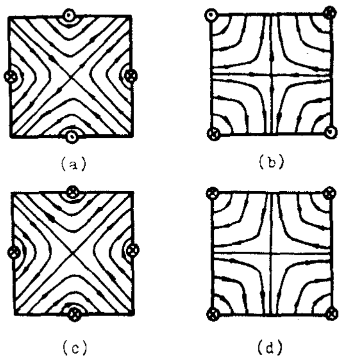

Fig.1 Four kinds of symmetrical quadrucenter magnetization field.

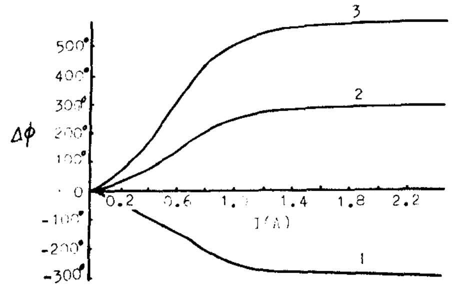

Fig.5 Differential phase shift curve for analog polarizer. 1.phase shift of H_{10}, 2.phase shift of H_{01}, 3.mode-differential phase shift between H_{10} and H_{01}. (f=5.6 GHz)

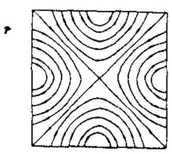

Fig.2 The OMFD for nondegenerate and nonreciprocal normal wave.

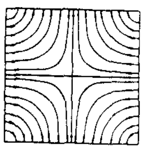

Fig.3 The OMFD for nonreciprocal coupling wave.

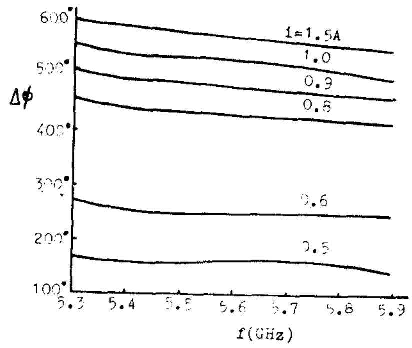

Fig.6 Dependence of mode-differential hase shift on frequencies,with various magnetization current being parameters.

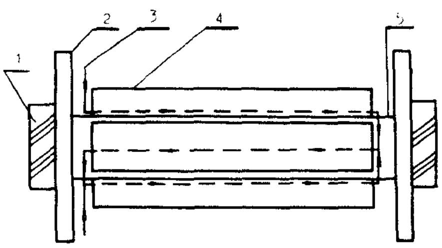

Fig.4 Scheme of the dual-mode ferrite fast-speed polarizer. 1.matching block, 2.flange, 3.latching driving wires, 4.ferrite yokes, 5.metallized ferrite waveguide.

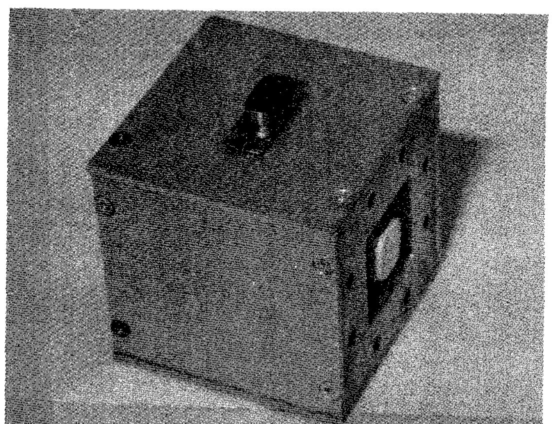

Fig.7 Photo. of variable polarizer