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Generation of circular polarization from microstrip scanned array antenna on YIG ferrite substrate

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Abstract : Two modes of circular polarization are generated when the magnetic bias is applied to an antenna geometry designed on ferrite substrate. In this communication, circular polarized properties of a 4 × 4 element planar array of circular patch microstrip antenna printed on YIG ferrite with a normal bias field and em wave propagation parallel to the biasing field, are presented. The computed values of antenna parameters of array geometry like directive gain, efficiency and bandwidth are also presented for both the modes of circular polarization for four different values of biasing fields.

Keywords : Microstrip antenna, circular polarization, ferrite substrate

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1. Introduction

Ferrite substrates have been the subject of much interest for microstrip antennas recently due to a number of novel properties not found with normal dielectrics. These unique and inherent features as beam steering, gain and bandwith enhancement, RCS (Radar Cross Section) control, surface wave reduction, switchability and circular polarization, which have been discussed by a number of investigators in recent years [1–6]. The high permittivity of the ferrite (ε_r = 15) reduces the patch dimensions allowing miniaturisation. Patch antennas on ferrite substrate are attractive because they offer greater agility in controlling the radiation characteristics and their inherent anisotropy and nonreciprocal properties, permit variable frequency tuning and antenna polarization diversity.

On applying a DC magnetic bias normal to the ferrite substrate, the resonance splits into two separate frequency modes, one right-hand and the other left-hand circular polarization. The explicit dependence of the propagation constant of the two modes is given as [7]

$$\frac{K_\pm}{K_d} = \left(\frac{\omega_0 + \omega_m \mp \omega}{\omega_0 \mp \omega}\right)^{1/2}, \quad (1)$$

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where $K_d = \frac{2\pi f}{C}\sqrt{\varepsilon_r}$. (2)

K_+ and K_- are the propagation constants for right-handed and left-handed circularly polarized modes (RHCP and LHCP) respectively.

Here, $\omega_0 = \gamma H_0$ and $\omega_m = \gamma 4\pi M_s$ are the precession and forced precession frequencies respectively and ω is the angular operating frequency. H_0 is the bias field, $4\pi M_s$ is the saturation magnetization, γ is gyromagnetic ratio as γ = 2.8 MHz/Oe.

In this paper, radiation performance (radiation patterns, directive gain, efficiency and bandwidth) of 4 × 4 element planar array geometry printed on YIG ferrite substrate at 3 GHz (S-band) for both the modes, *i.e.* RHCP and LHCP, taking four different values of biasing fields, are presented.

2. Theory

The array geometry and its coordinate system are shown is Figure 1. It consists of 16 identical circular antenna elements of radius a printed on YIG ferrite substrate of thickness h = 1.27 mm and substrate permittivity ε_r = 15, $\tan\delta$ = 0.0002, $4\pi M_s$ = 1720 Gauss, and H_0 = 1500, 1750, 2000

Table 2. Pattern characteristics of the array geometry for *H*-plane

Pattern characteristics	H_0 = 1500		H_0 = 1750 Oe		H_0 = 2000 Oe		H_0 = 2500 Oe	
	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
Direction of maximum radiation (major lobe)	10°	45°	10°	20°	15°	20°	15°	20°
Half power beam width (major lobe)	5°	8°	6°	8°	8°	6°	6°	8°
Direction of maximum radiation (first minor lobe)	30°	16°	35°	50°	36°	46°	40°	46°
Half power beam width (first minor lobe)	11°	10°	12°	13°	9°	14°	10°	12°
Side lobe level (SLL) (dB)	-15.0	-5.0	-8.0	-10.0	-4.0	-7.0	-7.0	-6.0

Directive gain

The directive gain of an antenna in a given direction is defined as the ratio of the radiation intensity (U) in given direction to the average radiated power P_r. It is expressed as [8]

$$D_g = \frac{4\pi U_{max}}{P_r}. \tag{7}$$

For the present array geometry, D_g may be written as

$$D_g = \frac{4\pi M_e}{I}, \tag{8}$$

where $M_e = R(\theta,\phi) = |E_{\theta t}|^2 + |E_{\phi t}|$

and $I = \int_0^{2\pi}\int_0^{\pi} M_e \sin\theta d\theta d\phi$.

Efficiency :

Efficiency of an antenna can be calculated as [8]

$$\eta(\%) = \frac{P_r}{P_T} \times 100, \tag{9}$$

where P_T is the total power which includes the power radiated and power attenuated in the disk resonator owing to the finite conductivity of the disk resonator and imperfect substrate, and is given as

$$P_T = P_r + P_c + P_d, \tag{10}$$

where $P_c = 1.68 \times 10^{-10} \times f^{-3/2} E_0^2$

and $P_d = 0.805 \times 10^{-4} \times h \tan\delta\, E_0^2 / f$.

Here, f is in GHz and $\tan\delta = 0.0002$ is the loss tangent of the substrate.

Bandwidth :

The bandwidth of an antenna is calculated as [8,10]

$$BW = \frac{f_r}{Q_T}, \tag{11}$$

Q_T is the total stored energy given as

$$Q_T = \frac{\omega W_T}{P_T} = \frac{2\pi f_r W_T}{P_T}. \tag{12}$$

W_T is the total stored energy given as,

$$W_T = \varepsilon / 2 \iiint |E_z|^2 dv,$$

$$= \frac{h\varepsilon E_0^2}{2}\pi \int_0^a J_n^2(k\rho)\rho d\rho,$$

$$\frac{hE_0^2}{8\omega f\mu} J_n^2(ka)\{(ka)^2 - n^2\}. \tag{13}$$

The values of directive gain, efficiency and bandwidth have been calculated for the array geometry using above expressions for unbiased and biased (H_0 = 1500, 1750, 2000 and 2500 Oe) ferrite material by taking the same input parameters for RHCP and LHCP modes taking $\beta_x = \beta_y = \pi/2$. The integral involved in above equations have been solved using numerical method [11]. The calculated values are given in Table 3.

It is observed from the Table 3 that there is a significant change in the values of antenna parameters on applying and changing magnetic field to the ferrite substrate. Also the effect of applied magnetic field strength H_0 on directive gain, efficiency and bandwidth are shown in Figures 10, 11 and 12 respectively.

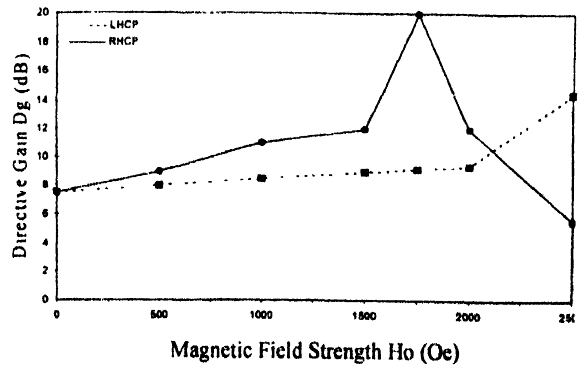

Figure 10. Directive gain of 4 × 4 CPMA on YIG ferrite measured as a function of externally applied magnetic field for both modes of circular polarization.

Table 3. Computed values of antenna parameters for the array geometry

Antenna parameters	$H_0 = 0$		H_0 = 1500 Oe		H_0 = 1750 Oe		H_0 = 2000 Oe		H_0 = 2500 Oe	
	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP	RHCP	LHCP
Directive gain D_g (dB)	7.5	7.5	12 1	9 0	20 7	9.2	12.5	9 4	5 6	14 5
Efficiency η (%)	24 8	24 8	79.9	71 0	31 8	74 4	65 0	75.6	24.8	56 9
Bandwidth (%)	16.2	16.2	10 0	21 9	36 7	42 4	23 4	46 8	65 0	21 4

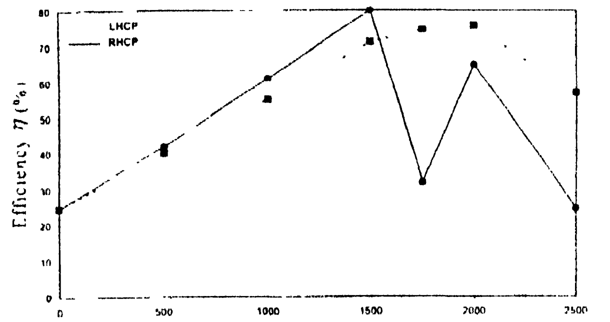

Figure 11. Efficiency of 4 × 4 CPMA on YIG ferrite measured as a function of externally applied magnetic field for both modes of circular polarization

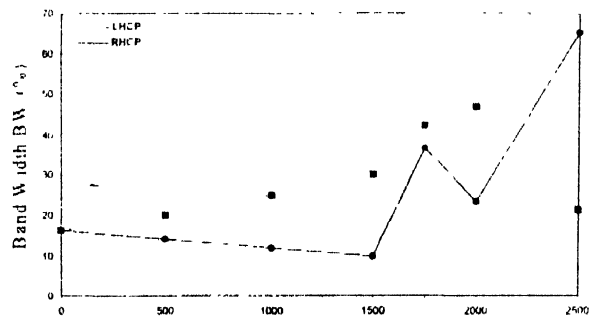

Figure 12. Bandwidth of 4 × 4 CPMA on YIG ferrite measured as a function of externally applied magnetic field for both modes of circular polarization

3. Discussion and conclusion

This paper has presented two modes of circular polarization for planar array geometry on normally biased YIG ferrite substrate. Paramaters for the case study are : ferrite substrate : YIG, $4\pi M_s$ = 1720 gauss, bias fields H = 1500, 1750, 2000, 2500 Oe, ε_r = 15, h = 1.27 mm, f = 3 GHz. In case of unbiased ferrite, $4\pi M_s$ = 0, H_0 = 0. The radiation patterns, directive gain, efficiency and banwidth are computed and plotted for four different values of biasing H_0 and for RHCP and LHCP mode taking $\beta_x = \beta_y = \pi/2$ and are shown in Figures [2–12]. The computed values of pattern characteristics, D_g (directive gain), η (efficiency) and BW (bandwidth) are given in Tables [1–3]. In Figures (2–5), the radiation patterns for two biasing field H_0 = 1500 Oe and 2000 Oe in two different planes *i.e.* *E* and *H*-planes for RHCP mode and LHCP mode are plotted. It is clear from pattern that on application of biasing field H_0 = 1500 Oe, the position of maximum radiation for RHCP and LHCP modes are found at 10° and 45° respectively, while at H_0 = 2000 Oe, these positions of maximum radiation changed to 15° and 20°. Further, we have observed a scanning phenomenon in the radiation patterns (Figures 6 and 7) biased near magnetic saturation, *i.e.* 1750 Oe for RHCP and LHCP modes in two planes. Thus, it is obvious from these results that a proper selection of biasing can be used to scan the radiation in any desired direction for both the two modes of circular polarization.

The variation of directive gain, efficiency, and bandwidth for the present array geometry with the applied magnetic field strength are shown in Figures 10, 11 and 12 respectively. Directive gain attains high value, *i.e.* 20.7 dB at H_0 = 1750 Oe for RHCP mode. Efficiency is recorded maximum 79.9% for RHCP mode at H_0 = 1500 Oe. The maximum value of bandwidth is measured to be 65.0% for RHCP mode at H_0 2500 Oe.

It is concluded that the array geometry designed on YIG ferrite exhibit useful radiation performance in terms of RHCP and LHCP modes when biased with a DC magnetic field, and can be employed for search/track applications in radar systems.

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