

Effect of ionized plasma medium on the radiation from a RITMA structure on ferrite substrate*

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Abstract. This paper presents theoretical investigations on the radiation properties of a right isosceles triangular microstrip antenna (RITMA) printed on a magnetized ferrite substrate $\text{Ni}_{0.62}\text{Co}_{0.02}\text{Fe}_{1.948}\text{O}_4$ in the presence of ionized plasma medium. The theoretical study on RITMA structure in free space is carried out in TM_{11} mode of excitation by applying cavity model-based modal expansion technique while hydrodynamic theory is used for its analysis in plasma medium. By varying the bias magnetic field, far-field radiation patterns in free space and plasma medium are obtained which in turn are applied in computing radiated power, directivity, quality factor and bandwidth of antenna. It is found that the presence of plasma medium affects the performance of RITMA structure significantly.

Keywords. Microstrip antenna; plasma medium; hydrodynamic theory.

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1. Introduction

Microstrip antenna technology has developed very rapidly in recent years due to the unique and attractive features of microstrip antennas. Studies of resonance and radiation properties of a variety of planar antenna shapes like rectangular, circular, annular ring etc. are carried out. However, other shapes are either investigated purely numerically or received crude approximate analytical attention. Only a handful of investigations are carried out on triangular geometries (Danial *et al* [1]).

An antenna mounted on a space vehicle interacts with high-density warm and non-drifting ionized plasma medium during its re-entry into the Earth's atmosphere. This high-density plasma medium affects the radiation performance of the antenna significantly. In the present paper, effect of this plasma medium on the radiation properties of a right

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isosceles triangular microstrip antenna (RITMA) designed on a typical ferrite substrate $\text{Ni}_{1.062}\text{Co}_{0.02}\text{Fe}_{1.948}\text{O}_4$ in the presence of DC magnetic bias field, normal to the direction of propagation of electromagnetic waves, are investigated theoretically. Cavity model-based modal expansion technique is used to obtain radiation properties of RITMA structure in free space while hydrodynamic theory is applied to obtain its radiation properties in plasma medium. Simplifying assumptions and basic equations regarding plasma are discussed elsewhere (Salem *et al* [2]).

2. Theoretical considerations

The dimensions of different edges of the patch shown in figure 1, over a ground plane with substrate thickness h and dielectric constant ϵ_r are a , a and $\sqrt{2} \cdot a$. The total electric field at the aperture of the antenna is given as the sum of the fields associated with different modes so that

$$E_z(x, y) = \sum_m C_m \cos\left(\frac{m\pi x}{a}\right) \cos\left(\frac{m\pi y}{a}\right).$$

The effective permeability within the ferrite is determined by considering the direction of propagation of electromagnetic waves normal to the direction of magnetic field, i.e., transverse case.

The resonance frequency of the antenna is given by

$$f_r = \frac{2c\sqrt{\mu_0}}{3a_e\sqrt{\epsilon_r\mu_{\text{eff}}}} \sqrt{m^2 + mn + n^2},$$

where a_e is the effective side length of the patch considered to incorporate the fringe fields. By applying the concept of equivalent sources and image theory, the surface magnetic current density is evaluated to find vector electric potential, F . Expressions for electromagnetic mode far zone field components, E_θ and E_ϕ , are derived by computing the components of the surface current density at different edges of the patch and hence vector electric potential is computed. The far zone TM_{11} mode E -plane field pattern factors for RITMA structure in EM mode is shown in figure 2 for $A = 0.5$ with different biased magnetic

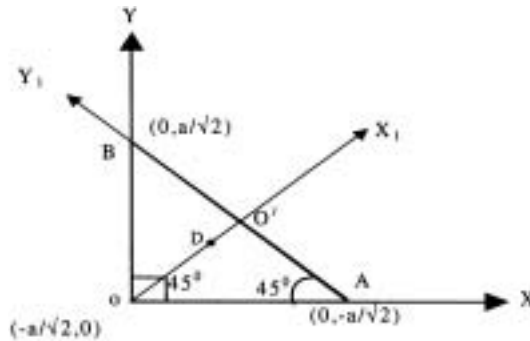


Figure 1. Dimensions and coordinate system for RITMA.

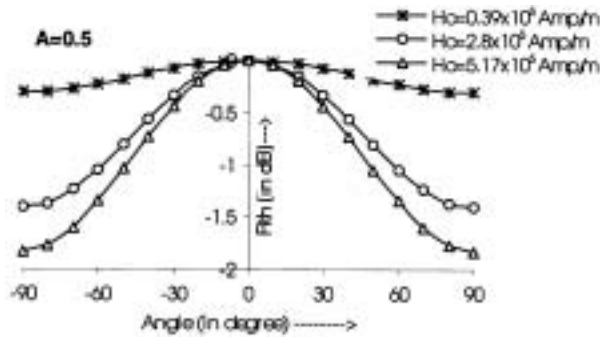


Figure 2. E-plane radiation pattern of RITMA for different H_0 .

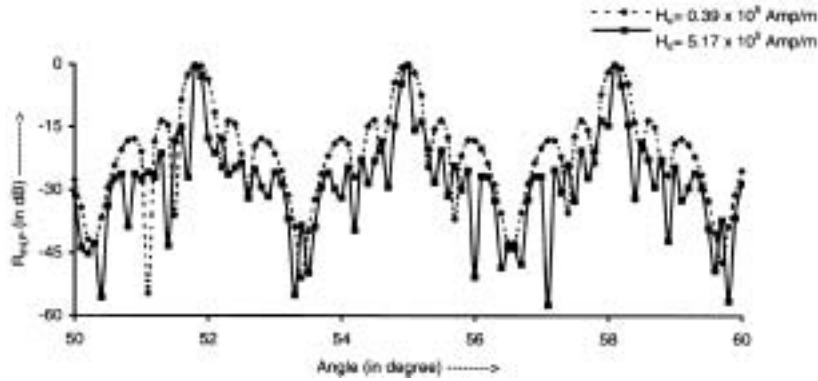


Figure 3. Plasma mode radiation pattern of RITMA at different H_0 .

Table 1.

A	Directivity in dB	Quality factor	Bandwidth
0.2	4.797	17.75	3.984
0.4	4.881	17.14	4.124
0.6	5.022	16.62	4.254
0.8	5.220	16.19	4.367
1.0	5.482	15.85	4.461

field H_0 . Here plasma parameter $A = \sqrt{[1 - (w_p/w)^2]}$ where w_p/w is the plasma-to-source frequency ratio.

The free space patterns of the same antenna are presented elsewhere (Bhatnagar *et al* [3]). In the longitudinal plasma (LP) mode, the far field components R_{thLP} are obtained for two H_0 values and are shown in figure 3 as a function of angle θ . The total Q factor, directivity, bandwidth and radiation efficiency of the antenna in free space and in plasma medium are computed in TM_{11} mode of excitation by using $h = 0.159$ cm, $a = 2$ cm, $\epsilon_r = 15$ at different externally biased magnetic field H_0 . These results are shown in table 1.

3. Conclusions

Based on the calculations carried out in this paper, some important conclusions are drawn. As shown in figure 2, in the presence of an applied magnetic field, E-plane patterns in plasma medium are symmetrical and almost omnidirectional for all the values of the applied magnetic field. These patterns are also almost omnidirectional in free space for low values of applied magnetic field but become directional on increasing the magnetic field. The plasma mode fields are shown in figure 3 for limited range of angle θ and it contains several closely spaced well-defined lobes. For low H_0 values, number of lobes present on ferrite-based antenna is less than those on non-magnetic low permittivity substrate-based antenna. Under similar plasma conditions, the number of closely packed lobes of this antenna in LP mode increases on increasing the applied magnetic field as shown in figure 3. If we presume an envelope that contains these lobes, then the shape of this envelope does not change much on changing H_0 . The computed values of directivity, quality factor and bandwidth of this antenna for $H_0 = 0.39 \times 10^5$ Amp/m are given in table 1 for different values of plasma parameter A . The directivity and bandwidth of RITMA structure designed on a ferrite substrate is maximum in free space ($A = 1$) and decreases on increasing plasma-to-source frequency ratio. The bandwidth of such a structure is much larger than that of similar antenna designed on pure dielectric substrate.

Note added in proof

This work is completely of theoretical nature and it requires experimental verification before any use and that cannot be done at this center due to lack of experimental facilities.

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