dian J. Phys. 77B (5), 579-582 (2003)

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A right isosceles triangular microstrip antenna in warm ionized plasma medium

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Received 11 November 2002, accepted 4 July 2003

Abstract : The radiation properties of a right isosceles triangular microstrip antenna (RITMA) are investigated theoretically in warm ionized plasma medium. The modal expansion technique with vector potential approach is applied to determine the radiation behaviour of this antenna in free space while hydrodynamic theory is applied to compute its performance in plasma medium. This theoretical study is carried out in TM_{11} mode of excitation of antenna and a significant variation in radiation conductance and radiation efficiency of RITMA structure with the variation in the ratio of plasma to source frequency (ω_p / ω) is recorded. For better understanding, the computed E and H plane radiation patterns in plasma medium are compared with theoretically obtained free space patterns.

Keywords Microstrip antenna, ionized plasma medium, radiation properties

PACS Nos. 52 40.Fd, 84 40 Ba

Antenna technology has developed very rapidly in recent years due to unique and attractive features of microstrip antennas. Intense interest in the use of printed circuit antennas for arrays has led to the studies of resonance and radiation properties of variety of planner antenna shapes like rectangular, circular and annular ring *etc*. In contrast, other shapes were either investigated purely numerically or received crude analytical attention. Only a handful of investigations are carried out on triangular geometries [1].

In the present communication, the radiation properties of a right isosceles triangular microstrip antenna (RITMA) are investigated theoretically in free space as well as in ionized plasma medium. Modal expansion technique with vector potential approach is used to obtain radiation properties of antenna in free space while hydrodynamic theory is applied in plasma medium. Initial assumptions and basic equations regarding plasma medium are discussed elsewhere [2]. When an antenna is mounted on a space vehicle, it interacts with warm and non-drifting ionized plasma medium during its voyage through space. The effect of ionosphere plasma medium on the radiation properties of microstrip antenna is negligibly small because plasma oscillation frequency (f_p) is much smaller than the source frequency (f_r). However, a plasma medium with high charge density created due to friction at the time of re-entry of the space vehicle in earth's atmosphere; significantly affects the radiation performance of antennas. Here, this plasma medium is assumed to be warm, isotropic, loss-less, homogeneous, non-drifting continuum of electrons and singly charged ions. The presence of singly charged ions is ignored since it does not affect the radiation properties of antenna to a great extent. Under these conditions, antenna radiates two types of waves namely, electromagnetic waves (EM waves) and longitudinal plasma waves (LP waves) [3].

A triangular patch with dimensions a, a and $\sqrt{2}.a$ is shown in Figure 1 over a ground plane with substrate thickness h and substrate dielectric constant ε_r. Because of its simplicity in nature and reliability of results, Modal expansion technique with vector potential approach is applied in this paper to carry out mode-dependent study of antenna in free space. Since electric

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fields within the substrate are considered to be z-directed with interior modes as quasi-discrete TM_{mnm} modes to z, the total electric field at the aperture of antenna are written as the sum of the fields associated with different modes so that [4]

$$E_z(x_1, y_1) = \sum C_m \cos \frac{m\pi x_1}{} \cos \frac{m\pi y_1}{} \qquad (1)$$

where C_m is the mode amplitude coefficient and (x_1, y_1) is the coordinates of feed point

$$x_1 = \frac{1}{\sqrt{2}}(x + y - a), \qquad y_1 = \frac{1}{\sqrt{2}}(y - x). \qquad (2)$$

In this paper, the feed point on antenna is obtained by rotating the coordinate system in X-Y by an angle 45° and shifting it along the bisector to the point O' as shown in Figure 1.

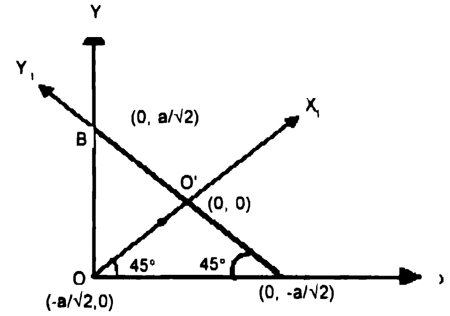

Figure 1. Geometry of RITMA structure with coordinate system

Z-directed orthonormalised mode vectors satisfy the wave equation and eigen values satisfy the separation equation. The propagation constant in plasma medium is

$$\beta_e = \omega A\sqrt{\mu_0\varepsilon_0} \qquad (3)$$

and $A = \left|1 - \frac{\omega_p^2}{\omega^2}\right|^{1/2}$

Here, (ω_p / ω) is defined as the ratio of plasma to source frequency.

By applying the concept of equivalent sources and image theory, the surface magnetic current density at different edges of the patch is evaluated to find vector electric potential (F) and hence expressions for far zone field pattern factor in electromagnetic mode are derived *i.e.*

$$R_{thEM} : \left(|E_\theta|^2 + |E_\phi|^2\right),$$

here

$$E_\phi = -j\omega\frac{\eta}{A}\left[F_x \cos\theta\cos\phi + F_y \cos\theta\sin\phi\right], \qquad (4)$$

$$E_\theta = +j\omega\frac{\eta}{A}\left[F_x \sin\phi - F_y \cos\phi\right].$$

Similarly in the longitudinal plasma mode, the far zone field pattern factor are obtained following [2] *i e*

$$R_{thEM} = E_r \qquad \frac{ev_0}{\varepsilon_0\varepsilon_p\beta_p^2}\nabla n \qquad ; (5)$$

Here, n is the perturbation of electron population density given by

$$n = \frac{\omega_p^2}{4\pi j e v_0^2 \eta_d}\oint_v (\nabla . M)\frac{\exp\left[-j\beta_p(r - r')\right]}{|r - r'|}dv, \qquad (6)$$

v_0 is the r.m.s. thermal velocity of electrons present in the plasma medium, η_d is the wave impedance in the dielectric medium. M represents the magnetic current density at the edges of the patch. The propagation constant of longitudinal plasma waves (β_p) is given by

$$\beta_p = (\omega/v_0)A = \beta_e\left(\frac{c}{v_0}\right). \qquad (7)$$

This technique is first tested on a RITMA structure ($\theta_1 = 45^0$) in free space by substituting plasma parameter $A = 1$ in eqs. (1) to (4). Radiation patterns and other parameters of antenna are computed with this technique and are validated with simulation software IE3D with fairly good agreement. Computed and simulated E-plane directive gain of this antenna in upper hemisphere is shown in Figure 2 with excellent agreement.

Table 1. Radiation parameters of RITMA structure in E- and H-plane

S No	Parameters	E-plane ($\phi = 0^0$)			H-plane ($\phi = 90^0$)		
1	Plasma parameters A	1.0	0.5	0.2	1 0	0.5	0.2
2	Direction of main lobe(θ)	0^0	0^0	0^0	0^0	0^0	0^0
3	Direction of side lobe(θ) (if any)	-	-	-	-	-	-
4	3 dB beamwidth of main lobe	118^0	Omni- directional	Omni- directional	75^0	87^0	90^0

The far zone field pattern factors for RITMA structure in EM mode are computed in $(\phi = 0)$ and $(\phi = \pi / 2)$ planes for TM_{11} mode of excitation by using eq. (4). These results are shown in Table 1 for different A values while free space simulated three-dimensional pattern is shown in Figure 3. It can be seen from Table 1 that the 3dB beam width of free space patterns ($A =$) is less than those in plasma medium (A = 0.2, 0.5). All the parameters in this paper, are computed by using $h = 0.159$ cm, a = 5.645 cm, $\varepsilon_r = 2.32$ and $f_r = 2.403$ GHz.

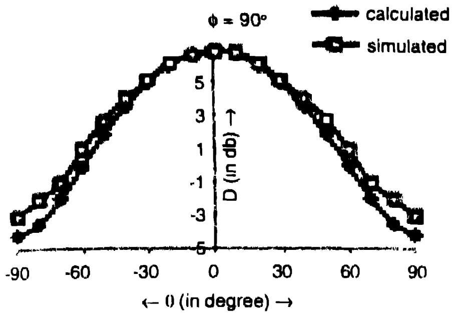

Figure 2. Comparison between computed and simulated directive gain of

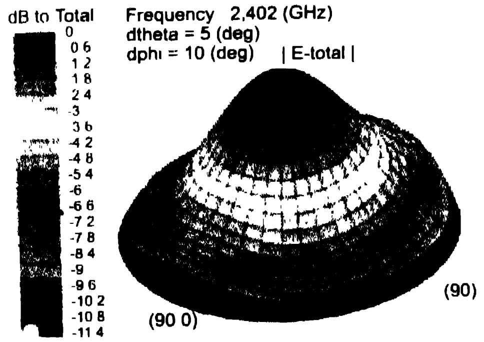

Figure 3. Three-dimensional simulated radiation pattern of RITMA structure

The E-plane radiation patterns in longitudinal plasma mode are drawn in Figure 4 for (A = 0.5) for a limited range *i.e.* $\theta = 45°$ to 65° by applying eqs. (5) to (7). Its nature is similar to those patterns drawn for other conventional antennas operating in the plasma medium [5] *i.e.* it contain several closely spaced well-defined lobes. However in this pattern, separation between any two successive prominent maximas is almost same.

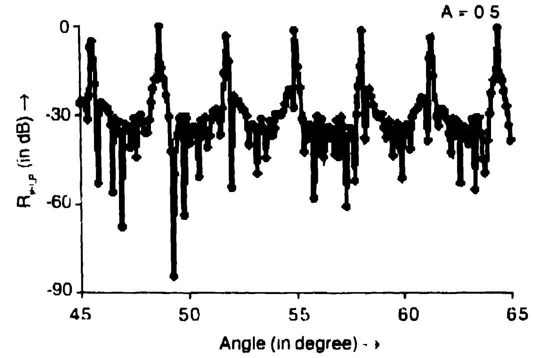

Figure 4. LP mode radiation pattern of RITMA structure in E-plane

The variation in several antenna parameters with plasma parameter A values in EM mode is shown in Table 2. The values of radiation conductance are obtained by integrating complex poynting vector over the upper hemisphere. The radiation conductance (G_e) is maximum in free space (A=1.0) and decreases slightly on decreasing the plasma parameter (A) value. On the other hand, in longitudinal plasma mode, (G_p) increases significantly on decreasing plasma parameter (A). The resultant effect of these parameters can be seen on the percent radiation efficiency (η%) of antenna in the plasma medium.

The variation of percent radiation efficiency of antenna in the plasma medium as a function of plasma parameter A as shown in Table 2, indicates that on decreasing plasma parameter, undesired power contributed by electroacoustic waves, dominates over the contribution by electromagnetic waves and

Table 2. Variation in different antenna parameters in EM mode with plasma parameter (A) in TM_{11} mode of excitation.

Plasma parameter A	(ω_p / ω)	Quality factor Q_t	Band-width (%)	Directive gain (in dB)	Efficiency (%)	Radiation conductance G_e
0.1	0.995	234.58	0.30	4.79	0.04	0.0033
0.2	0.98	140.98	0.50	4.86	0.33	0.0066
0.3	0.954	102.51	0.69	4.96	1.12	0.0096
0.4	0.917	82.16	0.86	5.12	2.70	0.0124
0.5	0.866	70.05	1.01	5.31	6.34	0.0148
0.6	0.800	62.47	1.13	5.56	13.03	0.0168
0.7	0.714	57.69	1.23	5.85	23.72	0.0183
0.8	0.600	54.86	1.29	6.20	39.76	0.0193
0.9	0.436	53.49	1.32	6.59	57.90	0.0199
1.0	0	53.29	1.33	7.03	100	0.0199

hence the percent radiation efficiency of antenna decreases significantly in plasma medium that is assumed 100% in free space.

The values of total quality factor, directivity and bandwidth (VSWR 2:1) of RITMA structure are shown in Table 2, as a function of plasma parameter *A*. Low value of total quality factor of antenna in free space indicates that antenna is radiating power more effectively in free space. On the other hand, plasma fields (EA) are longitudinal in nature and their contribution to radiation or reception of signal by antenna is not at all useful. Their presence even deteriorates the performance of radiating structure. Hence at low *A* values; energy radiated in the form of plasma waves increases, which increases the quality factor of antenna in plasma medium. The EM mode bandwidth and directivity values of antenna are also higher in free space than that in plasma medium.

The work reported in this paper is purely of theoretical nature but results are interesting. The reported results in plasma need experimental verification before any possible application, which is not possible currently since in any part of country, facilities to create and sustain high-density plasma medium for a longer duration are not available.

Acknowledgment

The authors are thankful to Dr. S.Pal, Dr. Lakshmeesha of ISAC, Bangalore for granting permission to use IE3D simulation software at their center and to Mr. Praveen Kumar for his help during execution of this software.

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