

RESONANT FREQUENCIES OF RING, CIRCULAR AND TRIANGULAR PATCH MICROSTRIP X-BAND ANTENNAS IN PLASMA

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ABSTRACT

An effort has been made to study the effect of plasma environment on the resonant frequencies of three different shapes of patch antennas viz. annular ring, circular and triangular patch microstrip antenna. The study is carried out in TM_{11} mode of excitation of antenna. The resonant frequencies of the microstrip antenna have been calculated by taking into account the effective permittivity of the surrounding plasma medium. In the present study, it is found that the effective permittivity decreases and the resonant frequency increases significantly in plasma medium for all patch configurations under consideration.

Keywords: Microstrip Antenna; Annular Ring Patch; Gunn Diode; Radiation Pattern; Mismatch Loss.

1. INTRODUCTION

It is observed that when antenna is immersed in the plasma medium, electro-acoustic waves are generated along with usual electromagnetic waves [1-3]. The presence of these electro-acoustic waves changes the properties of microstrip antennas appreciably and gives rise to detuning of antenna to a great extent because of its narrow band width [4-6]. In the earlier studies of microstrip antennas in plasma medium, the effective permittivity of the antenna that affects the resonant frequency of antenna has been calculated for the free space. This gives erroneous results when the antenna is actually surrounded by a plasma medium [7-10]. The present study deals with the analysis of resonant frequencies of annular ring microstrip antenna (ARMA), circular patch microstrip antenna (CPMA) and equilateral triangular patch microstrip antenna (ETPMA) with three different types of substrates viz. PTFE-quartz reinforced ($\epsilon_r = 2.47$), polyphenylene oxide (PPO) ($\epsilon_r = 2.55$) and woven glass ($\epsilon_r = 2.67$) in plasma medium. The reason behind in choosing these geometries and substrate is that they are commonly employed in microstrip antenna

analysis and their input parameters are available. We have addressed two main issues in the present paper. Firstly, it refers to resonant frequencies of various patch antennas and secondly it accounts for the effective permittivity in each case with plasma permittivity included in it. The results obtained in the present work indicate that the effect of plasma environment is to reduce the effective permittivity and to enhance the resonant frequency quite significantly.

2. THEORETICAL CONSIDERATIONS

The configurations and coordinate systems of two different microstrip geometries viz annular ring microstrip antenna (ARMA), equilateral triangular patch microstrip antenna (ETPMA) are shown in Figures 1 and 2 respectively. Figure 1 shows an annular ring of size $w = b - a$, where 'a' and 'b' are the inner and outer radius of ring on a dielectric substrate of thickness h , which is backed by a ground plane. As the patch dimensions are small as compared with wavelength, so the region under the patch may be modeled as a thin cavity with leaking magnetic side walls. Such a cavity supports quasi discrete TM_{nm} modes. This annular ring microstrip antenna (ARMA) is reduced to circular patch microstrip (CPMA) antenna for $a = b$. Figure 2 shows the geometry of equilateral triangular patch (ETPMA), which consists of a thin conducting triangular patch of side length 'a' on a dielectric substrate of thickness h . The patch can be excited by a microstrip transmission line connected to the edge or by a coaxial line from the back at the plane $\phi = \phi_m$. The resonant frequencies of annular ring microstrip antenna (ARMA) (f_r'), circular patch microstrip antenna (CPMA) (f_r'') and equilateral triangular patch microstrip antenna (ETPMA) (f_r''') are expressed as [11-13]

$$f_r' = \frac{K_{nm} c}{2\pi \sqrt{\epsilon_{re}} (f)} \quad (1)$$

$$f_r'' = \frac{K_{nm} c}{2\pi a \sqrt{\epsilon_{re}} (f)} \quad (2)$$

and

$$f_r''' = \frac{2c}{3a \sqrt{\epsilon_{re}} (f)} (m^2 + mn + n^2)^{1/2} \quad (3)$$

where K_{nm} and X_{nm} are the roots of characteristics equations

$$J'_n(Kb)Y'_n(Ka) - J'_n(Ka)Y'_n(Kb) = 0$$

$$J'_n(x) = 0$$

respectively. Where $J_n(x)$ and $Y_n(x)$ are the Bessel's functions of first and second kind of order 'n' and the prime denotes the derivative with respect to x. For dominant mode $K_{nm} = 0.6773$ and $X_{nm} = 1.84118$. Also c is the velocity of the light, $\epsilon_{re}(f)$ and $\epsilon'_{re}(f)$ are the effective permittivity of the substrate material. For free space surrounding medium, $\epsilon_{re}(f)$ for annular ring microstrip antenna (ARMA) and circular patch microstrip antenna (CPMA) is given by [14]

$$\epsilon_{re}(f) = \frac{1}{2} \left\{ (\epsilon_r + 1) + (\epsilon_r - 1) \left(1 + \frac{10h}{w} \right)^{-1/2} \right\} \quad (4)$$

where w is the width of microstrip patch and ϵ_r is the relative permittivity of the substrate. However in equilateral triangular patch microstrip antenna (ETPMA), equation (4) is modified as [12]

$$\epsilon'_{re}(f) = \frac{1}{2} \left\{ (\epsilon_r + 1) + (\epsilon_r - 1) \left(1 + \frac{12h}{w} \right)^{-1/2} \right\} \quad (5)$$

As we have considered the plasma medium, therefore equations (4) and (5) can be modified by replacing factor '1' by relative permittivity of plasma (ϵ_p) which is given by

$$\epsilon_p = 1 - \left(\frac{\omega_p}{\omega_0} \right)^2 = A^2 \quad (6)$$

where A being the plasma parameter, ω_p and ω_0 are the plasma frequency and operating frequency respectively. Thus, for plasma embedded microstrip antenna, the effective permittivity given in equations (4) and (5) can be modified as

$$\epsilon_{rep}(f) = \frac{1}{2} \left\{ (\epsilon_r + \epsilon_p) + (\epsilon_r - \epsilon_p) \left(1 + \frac{10h}{w} \right)^{-1/2} \right\} \quad (7)$$

$$\epsilon'_{\text{rep}}(f) = \frac{1}{2} \left\{ (\epsilon_r + \epsilon_p) + (\epsilon_r - \epsilon_p) \left(1 + \frac{12h}{w} \right)^{-1/2} \right\} \quad (8)$$

The value of effective permittivity is determined by using equations (7) and (8) for circular, annular and triangular microstrip antenna. These values are reported in Table 1 for the substrates PTFE-quartz reinforced, polyphenylene oxide (PPO) and woven glass.

For dominant mode ($m = 1, n = 1$) equations (1), (2) and (3) will be modified including plasma effects equations (6) and (7)) as follows

$$f'_{\text{rp}} = \frac{K_{\text{nm}} c}{2\pi \sqrt{\epsilon_{\text{rep}}(f)}} \quad (9)$$

$$f''_{\text{rp}} = \frac{X_{\text{nm}} c}{2\pi a \sqrt{\epsilon_{\text{rep}}(f)}} \quad (10)$$

and

$$f''_{\text{rp}} = \frac{2c}{3a \sqrt{\epsilon_{\text{rep}}(f)}} \sqrt{m^2 + mn + n^2} \quad (11)$$

The resonant frequencies of annular ring microstrip antenna (ARMA), circular patch microstrip antenna (CPMA) and equilateral triangular patch microstrip antenna (ETPMA) are computed with the help of equations (9) – (11) for the three different substrates with same substrate height $h = 0.159$ cm at the operating frequency 10 GHz (X-band) and reported in Table 2.

3. DISCUSSION OF RESULTS

It is found from the above study that there is a significant change in the resonant frequencies of microstrip patch antenna due to plasma effect. As noticed from the given expressions, the resonant frequency is a function of effective permittivity and plasma frequency (ω_p). Figures 3 – 5 illustrate the variations of effective permittivity $\epsilon_{\text{rep}}(f)$ and $\epsilon'_{\text{rep}}(f)$ with different ratio of plasma to source frequency (ω_p/ω_0) whereas Figures 6 – 8 depict the variation

of resonant frequency for annular ring microstrip antenna (ARMA), circular patch microstrip antenna (CPMA) and equilateral triangular patch microstrip antenna (ETPMA) with different ratio of plasma to source frequency (ω_p/ω_0).

In these Figures, it is observed that the effective permittivity for all the cases of patch antennas decreases with increase in the ratio of plasma to source frequency. This decrease is maximum in annular ring microstrip antenna (ARMA) and minimum in circular patch microstrip antenna (CPMA) for all the three substrate. Also the percent decrement in effective permittivity with different ratio of plasma to source frequency for the three shapes are same. The percentage decrement is smallest in case of circular patch microstrip antenna (CPMA) and largest in case of annular ring microstrip antenna (ARMA) for all the three substrates. As a matter of fact, the resonant frequency is enhanced by substantial amount from the free space value (f'_f, f''_r, f'''_r) due to plasma effect. The increment in resonant frequency is largest in case of circular patch microstrip antenna (CPMA) and smallest in equilateral triangular patch microstrip antenna (ETPMA). The study also reveals that the resonant frequency increases slowly in low frequency plasma region while it rapidly increases in high frequency plasma region. The percentage decrements in the resonant frequency of all the three shapes are also same. But the decrement is minimum in annular ring microstrip antenna (ARMA) and maximum in circular patch microstrip antenna (CPMA) for the three types of substrates. But For an accurate estimation of resonant frequency, the fringing field effect must be taken in to account, and hence the effective dielectric permittivity and dimensions of microstrip patch must be incorporated. Several correction methods have been reported to calculate accurately the resonant frequencies of rectangular, circular, equilateral triangle and elliptical microstrip antennas separately [19 – 21]. Thus in present study it is concluded that there is a marked enhancement of resonant frequency in plasma environment as compared to free space for all the shapes and substrate considered.

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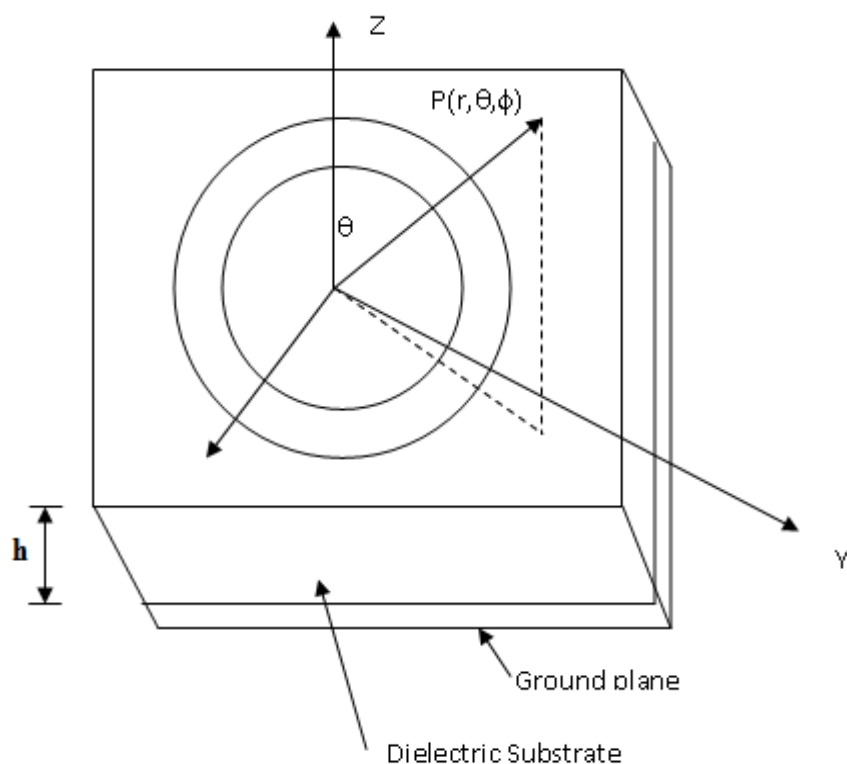


Figure 1 Geometry and coordinate systems of annular ring microstrip antenna (ARMA).

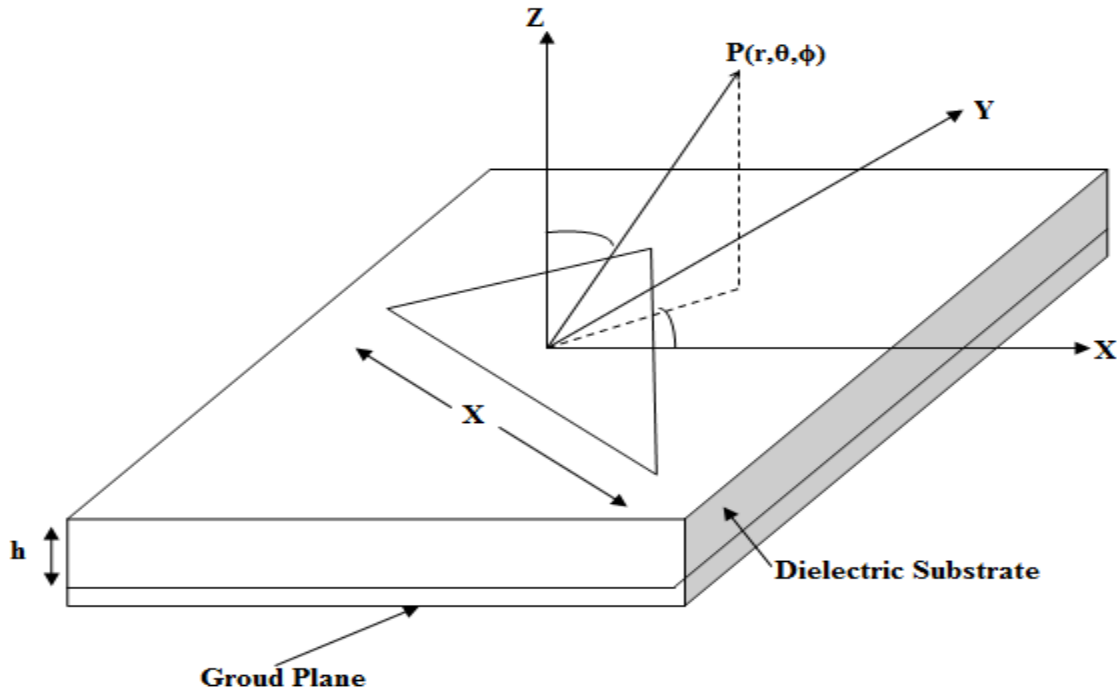


Figure 2 Geometry and coordinate systems of equilateral triangular patch microstrip antenna (ETPMA).

Table 1

Calculated values of effective permittivity $\epsilon_{rep}(f)$ with different ratio of plasma to source frequency (ω_p / ω_0).

$\epsilon_r = 2.47$ PTFE quartz reinforced

(ω_p / ω_0)	$\epsilon_{rep}(f)$		
	Circular	Annular	Triangular
0.0	2.284045	2.191435	2.260525
0.2	2.278985	2.183855	2.253325
0.4	2.263805	2.161115	2.237725
0.6	2.238505	2.123215	2.209225
0.8	2.203085	2.070155	2.169325
1.0	2.157545	2.001935	2.118000

$\epsilon_r = 2.55$ Polyphenyle oxide

(ω_p/ω_0)	$\epsilon_{rep}(f)$		
	Circular	Annular	Triangular
0.0	2.353925	2.256275	2.329125
0.2	2.348865	2.248695	2.321925
0.4	2.333685	2.225955	2.306325
0.6	2.308385	2.188055	2.277825
0.8	2.272965	2.134995	2.236712
1.0	2.227425	2.066775	2.186625

$\epsilon_r = 2.65$ Woven glass

(ω_p/ω_0)	$\epsilon_{rep}(f)$		
	Circular	Annular	Triangular
0.0	2.441275	2.337325	2.414875
0.2	2.436215	2.329745	2.407675
0.4	2.421035	2.307005	2.392075
0.6	2.395735	2.269105	2.363575
0.8	2.360315	2.216045	2.323550
1.0	2.314775	2.147825	2.272375

Table 2

Calculated values of resonant frequency (f_{rp}) with different ratio of plasma to source frequency (ω_p / ω_0).

$\epsilon_r = 2.47$ PTFE quartz reinforced

(ω_p/ω_0)	Resonant frequency (f_{rp})		
	Circular	Annular	Triangular
0.0	2.9096096	2.1856384	1.1519755
0.2	2.9128269	2.1894286	1.1538144
0.4	2.9225766	2.2200917	1.1578293
0.6	2.9390590	2.2204740	1.1652736
0.8	2.9627708	2.2487504	1.1759441
1.0	2.9936807	2.2867448	1.1901040

$\epsilon_r = 2.55$ Polyphenyle oxide

(ω_p/ω_0)	Resonant frequency (f_{rp})		
	Circular	Annular	Triangular
0.0	2.8660850	2.1540048	1.1348840
0.2	2.8691706	2.1576312	1.1366422
0.4	2.8784871	2.1686252	1.1404799
0.6	2.8942183	2.1873263	1.1475925
0.8	2.9166779	2.2143397	1.1580913
1.0	2.9463468	2.2505884	1.1712800

$\epsilon_r = 2.65$ Woven glass

(ω_p/ω_0)	Resonant frequency (f_{rp})		
	Circular	Annular	Triangular
0.0	2.8143432	2.1163288	1.1145525
0.2	2.8172643	2.1197688	1.1162178

0.4	2.8260827	2.1301904	1.1198516
0.6	2.8409658	2.1479066	1.1265827
0.8	2.8622029	2.1734687	1.1362447
1.0	2.8902207	2.2077162	1.1489679

Figure 5.5 Variation of effective permittivity ($\hat{\epsilon}_{rep}$, $\hat{\epsilon}_{rep}$) with different ratio of plasma to source frequency for $\hat{\epsilon}_r = 2.65$

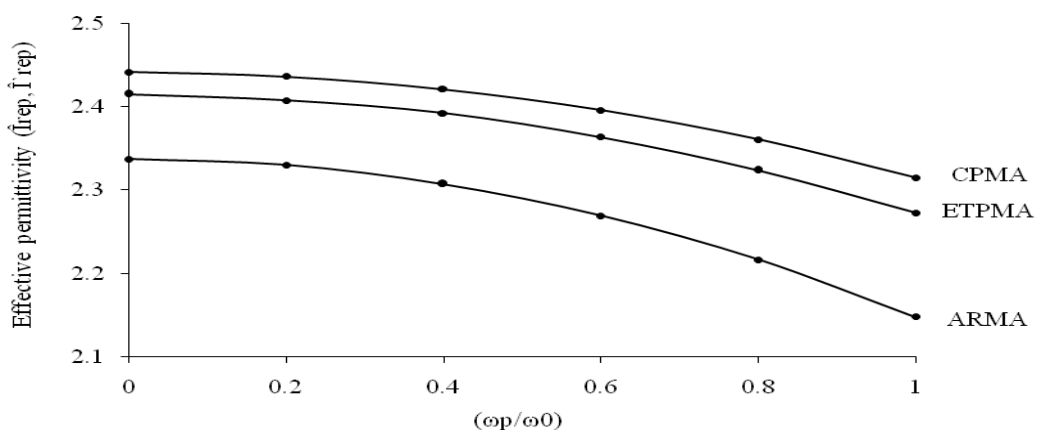


Figure 5.6 Variation of resonant frequency with different ratio of plasma to source frequency (ω_p/ω_0) for $\hat{\epsilon}_r = 2.47$

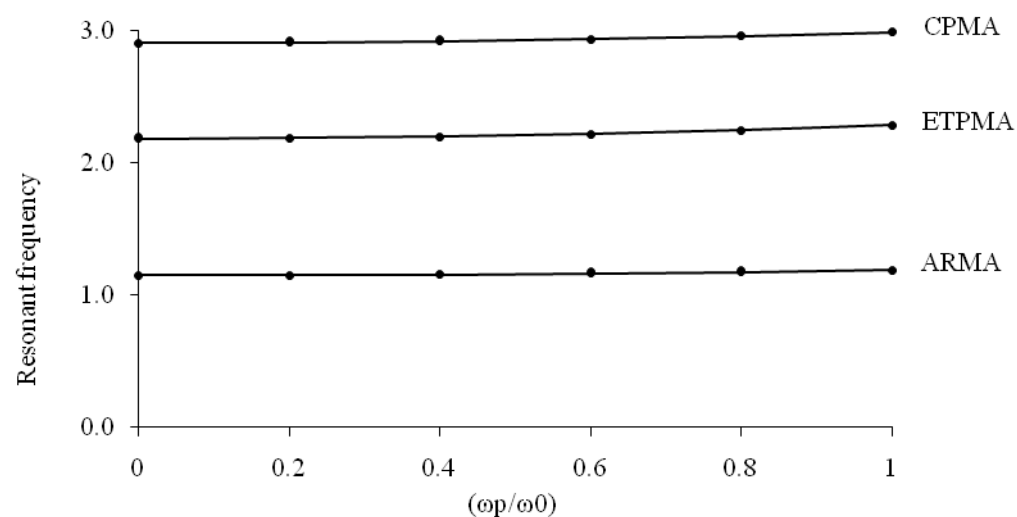


Figure 5.7 Variation of resonant frequency with different ratio of plasma to source frequency (ω_p/ω_0) for $\hat{I}_r = 2.55$

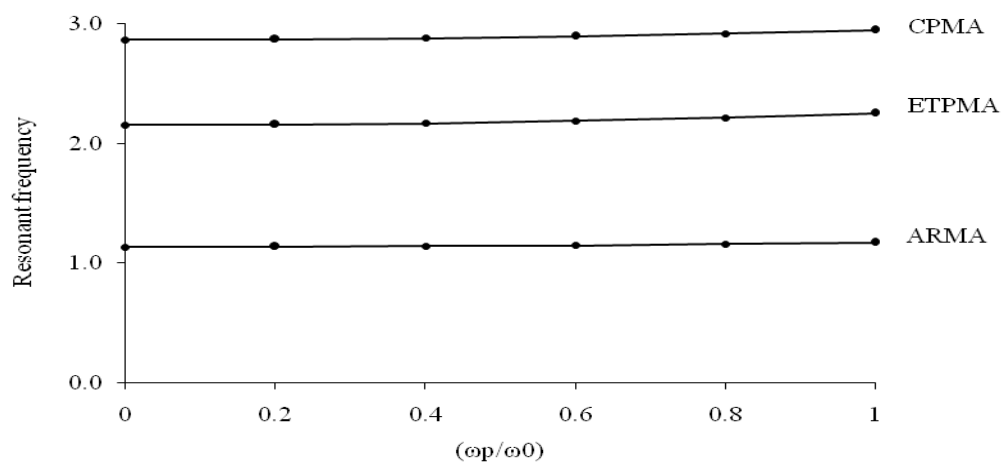


Figure 5.8 Variation of resonant frequency with different ratio of plasma to source frequency (ω_p/ω_0) for $\hat{I}_r = 2.65$

