Radiation Characteristics of Rectangular Microstrip Antenna in High Density Plasma Media

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Abstract:

In this present paper, the effect of high-density plasma media on the radiation characteristics of rectangular microstrip antenna will be investigated. Rectangular Microstrip Antennas having keen role in various applications such as space communications, radio frequency identification and so on. Their compact size, design and ease of fabrication make them suitable for space communications and other real-world applications. Radiation can have a significant effect on various parameters like E-H radiation pattern, Impedance, Gain, Frequency response. It is observed that the characteristics of Rectangular Microstrip Antenna enhance in the presence of high-density plasma media to be great extent. It was observed that adding a thin layer of low permittivity material results in enhancing directive properties whereas using high-permittivity materials enhances return loss characteristics. In conclusion, this research provides valuable insights into understanding how plasma affects microstrip antennas.

Keyword: High-density Plasma, Rectangular Microstrip Antenna, E-H radiation pattern

1. Introduction:

The use of wireless communication has been steadily increasing in recent years due to its convenience and cost-effectiveness. In high density plasma media, such as in satellite communications and space applications, the radiation characteristics of antennas play a crucial role in signal transmission and reception. A commonly used antenna in these applications is the rectangular microstrip antenna. The rectangular microstrip antenna is a planar structure that consists of a conducting patch on one side and a ground plane on the other, with a dielectric substrate separating them. When placed in high density plasma media, various effects such as ionization, recombination, reflection, absorption, scattering etc., can significantly affect its performance and radiation characteristics. One major challenge faced by researchers is the accurate determination of the radiation pattern of this type of antenna when operating inside high-density plasma media. The presence of charged particles in the surrounding medium alters the electric field distribution along with changes to other factors like polarization loss tangent which can cause deviations from free-space conditions. To study these effects on rectangular microstrip antennas accurately, various theoretical models have been proposed based on cavity model theory for infinite size substrates or using quasi-static approximation for small size substrates. In addition to theory-based studies numerical analyses have also been carried out using software tools

Now, there are different kinds of antennas such as Array antenna, Disc antenna, Conventional antenna and Microstrip antenna. But among them, Microstrip antenna stands out very useful. Its design and fabrication make it highly useful and time-saving solution for communications needs.

A Microstrip antenna is made by using thin conducting strip called Radiating Patch, Dielectric substrate and Ground plane (metal material). There are various types of radiating patches like rectangular, circular, square, triangular, elliptical, bow, circular ring, ring sector and so on. But Rectangular radiating patch is the most commonly used radiating patch in microstrip antenna due to its simplicity of design and ease of fabrication.

A Microstrip antenna is designed by placing rectangular radiating patch on the top of the dielectric substrate and bottom of the dielectric substrate is connected to metallic ground plane. One end of the rectangular radiating patch is connected to the feeding lines and permittivity of matter depends upon the dielectric substrate and thickness.

High-Density plasma media is the supercharged gas which made by charged particles, ions and electrons. When lot of charged particles are packed closely together then it called "High-Density Plasma". In high-density plasma media when electromagnetic radiations travel its behave differently as compared to vacuum or dense medium. To understand the radiations pattern behaviour through rectangular microstrip antenna in high density plasma researcher use maxwell's equations.

2. Theoretical Consideration:

Determination of E-plane and H- plane of rectangular microstrip antenna. To obtain the radiation field of rectangular microstrip antenna, let us consider a rectangular microstrip patch having length **"L"** and width "**W"** respectively. The substrate relative permittivity $\in_r$ and thickness **"h"**. The value of electromagnetic field is given by

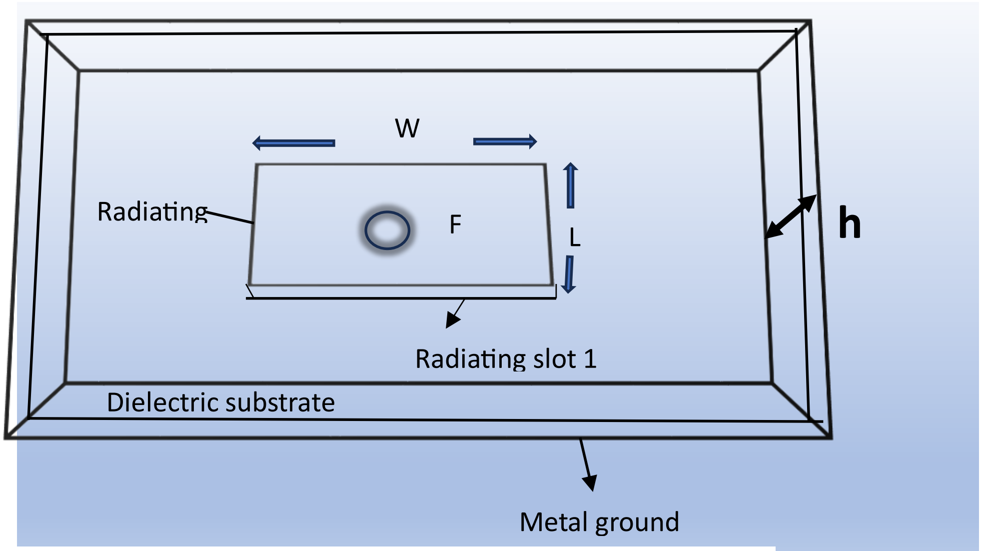

Fig. =1 Structure of Rectangular Microstrip Antenna

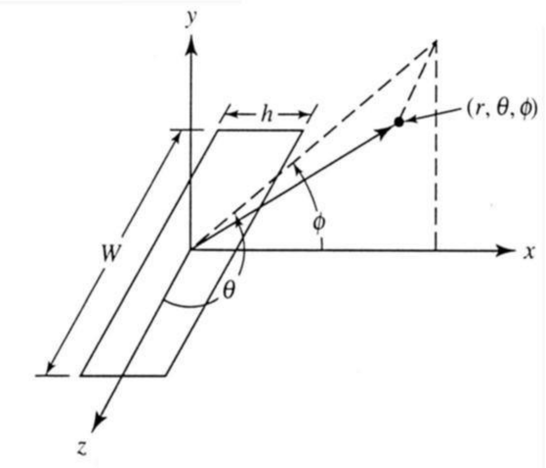

Fig.2.Geometrical Presentation of Rectangular Microstrip Antenna

$$\bar{E} = \frac{-j}{\omega\mu\epsilon}\nabla(\nabla\cdot\bar{A}) - \frac{1}{\epsilon}\nabla\times\bar{F} = j\omega\bar{A} \quad (1)$$

$$\bar{H} = \frac{-j}{\omega\mu\varepsilon}\nabla(\nabla\cdot\bar{F}) - \frac{1}{\epsilon}\nabla\times\bar{A} = j\omega\bar{F} \quad (2)$$

where $\bar{F} and\ \bar{A}$ are the magnetic and electric vector potential respectively. Vector potential is the solution of the wave equation.

$$\nabla^2\left(\frac{\bar{A}}{F}\right) + w^2\mu\epsilon\left(\frac{\bar{A}}{F}\right) = 0 \quad (3)$$

Hence for the far field radiation pattern, the electric magnetic current can be given by

$$\bar{E}(r) = -j\omega\bar{A} \quad (4)$$

$$\bar{H}(r) = -j\omega\bar{F} \quad (5)$$

Using the co-ordinate system the far zone magnetic vector potential $\bar{A}$ is given as

$$\bar{A} = \frac{\mu e^{-jk_p r}}{4\pi r} \int_{-\frac{\omega}{2}}^{\frac{\omega}{2}} \int_{-\frac{L}{2}}^{\frac{L}{2}} \bar{k}(x,y) e^{jk_p(x \sin\theta \cos\phi + y \sin\theta_y \sin\phi)} \tag{6}$$

Where,

$$\overline{A_x} = \frac{\mu e^{-jk_p r}}{4\pi r} \int_{-\frac{\omega}{2}}^{\frac{\omega}{2}} \int_{-\frac{L}{2}}^{\frac{L}{2}} \bar{k}_x(x,y) e^{jk_p(x \sin\theta \cos\phi + y \sin\theta_y \sin\phi)}\, dx\, dy \tag{7}$$

And

$$\bar{A}_y = \frac{\mu e^{-jk_p r}}{4\pi r} \int_{-\frac{\omega}{2}}^{\frac{\omega}{2}} \int_{-\frac{L}{2}}^{\frac{L}{2}} \bar{k}_y(x,y) e^{jk_p(x \sin\theta \cos\phi + y \sin\theta_y \sin\phi)}\, dx\, dy \tag{8}$$

Now using equations (7) and (8) the components of electric field can be given as

$$E_\theta = -\bar{j}\omega A_x = \frac{\mu e^{-jk_p r}}{4\pi r} \int_{-\frac{\omega}{2}}^{\frac{\omega}{2}} \int_{-\frac{L}{2}}^{\frac{L}{2}} \bar{k}_x(x,y) e^{jk_p(x \sin\theta \cos\phi + y \sin\theta_y \sin\phi)}\, dx\, dy \tag{9}$$

And

$$E_\phi = -\bar{j}\,\omega A_y = \frac{\mu e^{-jk_p r}}{4\pi r} \int_{-\frac{\omega}{2}}^{\frac{\omega}{2}} \int_{-\frac{L}{2}}^{\frac{L}{2}} \bar{k}_y(x,y) e^{jk_p(x \sin\theta \cos\phi + y \sin\theta_y \sin\phi)}\, dx\, dy \tag{10}$$

Further consider a rectangular patch antenna having magnetic current line source, the electric vector potential in far zone is given by,

$$\bar{F} = \frac{\varepsilon e^{-jk_p r}}{4\pi r} \int_0^L \int_{-\frac{\omega}{2}}^{\frac{\omega}{2}} \bar{M}(z) e^{jk_p z \cos\theta_z} e^{jk_p(\sin\theta \cos\phi_x)}\, dx\, dz \tag{11}$$

where

$\bar{M}$(z) = magnetic current line sources, which is given as

$$\bar{M}(z) = \hat{z} M_0 e^{-j\gamma z} \tag{12}$$

where

γ = the complex propagation constant

M_0 = value for magnetic current at z=0

M = $2E_0h$ with E_0 is constant field between conductor and ground plane

Using equations (11) and (12) the value of electric vector potential can be written as

$$F_z = \frac{-jE_0 M_0}{4} \frac{e^{-jk_p r}}{r} \left(\frac{e^{jL(k_p \cos\theta - \gamma)} - 1}{k_p \cos\theta - \gamma} \right) \sin\theta \tag{13}$$

Comparing equations (5) and (13) the components of magnetic field can be written as

$$H_\phi = 0 \tag{14}$$

$$H_\theta = j\omega F_z \sin\theta = \frac{\omega\epsilon\mu e^{-jk_p r}}{4\pi r} \left(\frac{e^{jL(k_p \cos\theta - \gamma)} - 1}{k_p \cos\theta - \gamma} \right) \sin\theta \tag{15}$$

The value ofE_{ϕ}can be also obtained from equation (15)

$$E_{\phi} = -\eta H_{\theta} = -\frac{k_p}{2\pi}\frac{e^{-jk_p r}}{r}\left(\frac{e^{jl(k_p\cos\theta-\gamma)}-1}{k_p\cos\theta-\gamma}\right)\cos\left(\frac{K_p\omega\sin\theta\cos\phi}{2}\right)\sin\theta \quad (16)$$

Where η is the intrinsic impedance in free space

By putting$\theta = \frac{\pi}{2}$ and $\phi = \frac{\pi}{2}$ the E-plane and H-plane can be calculated.

3.1Radiating power

The radiating power of rectangular microstrip antenna can be obtained by integrated the real part of pointing vector as follows

$$P_r = \frac{{V_0}^2 I_1}{240\pi^2} \quad (17)$$

Where V_0 is the voltage across the slot

$$I_1 = \int_0^{\pi} sin^2\left(\frac{K_p W\cos\theta}{2}\right)\tan\theta\sin\theta\, d\theta \quad (18)$$

3.2 Radiation resistance

The radiation resistance of rectangular microstrip antenna can be obtained by using equation (16) and (18)

$$R_r = \frac{V_0^2}{2P_r} = \frac{120\pi^2}{\int_0^{\pi}\sin^2\left(\frac{k_p W\cos\theta}{2}\right)\tan\theta\sin\theta\, d\theta} \quad (19)$$

3.3 Directivity

The directivity of microstrip antenna is calculated by the ratio of maximum power density in the main beam to the average radiated power density and equation for directivity can be written as

$$D_0 = \frac{4W^2\pi^2}{\int_0^{\pi} Sin^2\left(\frac{K_p W\cos\theta}{2}\right){\lambda_0}^2\tan\theta\sin\theta\, d\theta} \quad (20)$$

4.Analysis of Rectangular Microstrip Antenna Array in High Density Plasma Medium

For this purpose the plasma medium is treated as dielectric medium with permittivity is defined as

$$k_p = \frac{\epsilon}{\epsilon_0} = 1 + \frac{np}{VE\epsilon_0} \quad (21)$$

Where

$$p = \frac{e^2}{m}\frac{1}{(\omega_0^2-\omega^2-\iota\omega\gamma)}E \quad (22)$$

p = dipole moment of single electron within the harmonic model

n = total number of induced dipoles

Put equation (22) in equation (21) and we get,

$$k_p = 1 + \frac{ne^2}{\epsilon_0 Vm} \frac{1}{(\omega_0^2 - \omega^2 - i\omega\gamma)} \quad (23)$$

Where

$$N = \frac{n}{v} \quad (24)$$

N = Atomic number density

Put equation (24) in (23) and we get,

Permittivity of a single electron

$$k_p = 1 + \frac{Ne^2}{\epsilon_0 m} \frac{1}{(\omega_0^2 - \omega^2 - i\omega\gamma)} \quad (25)$$

For, total number of Z electron then equation (25) becomes

$$k_p = 1 + \frac{Ne^2}{\epsilon_0 m} \frac{Z}{(\omega_0^2 - \omega^2 - i\omega\gamma)} \quad (26)$$

Put the equation (25) in equation (15),(16) ,(18),(19) and (20) we get

$$H_\theta = \frac{\omega\epsilon\mu e^{-j\left(1+\frac{Ne^2}{\epsilon_0 m(\omega_0^2-\omega^2-\iota\omega\gamma)}\right)r}}{4\pi r} \left(\frac{e^{jL\left[\left(1+\frac{Ne^2}{\epsilon_0 m(\omega_0^2-\omega^2-\iota\omega\gamma)}\right)\cos\theta-\gamma\right]}_{-1}}{\left(1+\frac{Ne^2}{\epsilon_0 m(\omega_0^2-\omega^2-\iota\omega\gamma)}\right)\cos\theta-\gamma} \right) \sin\theta \quad (27)$$

$$E_\theta = -\frac{\left(1 + \frac{Ne^2}{\epsilon_0\, m} \frac{1}{(\omega_0^2 - \omega^2 - i\omega\gamma)}\right)}{2\pi} \frac{e^{-j\left(1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_0^2-\omega^2-i\omega\gamma)}\right)r}}{r}$$

$$\left(\frac{e^{jL\left[\left(1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_0^2-\omega^2-i\omega\gamma)}\right)\cos\theta-\gamma\right]}_{-1}}{\left(1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_0^2-\omega^2-i\omega\gamma)}\right)\cos\theta-\gamma} \right) \cos\left(\frac{\left(1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_0^2-\omega^2-i\omega\gamma)}\right)W}{2} \sin\theta\cos\phi \right) \sin\theta \quad (28)$$

$$I_1 = \int_0^\pi \sin^2 \left[\frac{\left(1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_0^2-\omega^2-i\omega\gamma)}\right)W\cos\theta}{2} \right] \tan\theta \sin\theta \, d\theta \quad (29)$$

Radiation Resistance can be written as

$$R_r = \frac{120\pi^2}{\int_0^{\pi} \sin^2\left[\frac{\left(1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_0^2-\omega^2-i\omega\gamma)}\right)W\cos\theta}{2}\right]\tan\theta\sin\theta\, d\theta} \tag{30}$$

Directivity of Rectangular Microstrip Antenna in high density plasma medium can be written as

$$D_0 = \frac{4W^2\pi^2}{\int_0^{\pi} \sin^2\left[\frac{\left(1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_0^2-\omega^2-i\omega\gamma)}\right)W\cos\theta}{2}\right]\lambda_0^2\tan\theta\sin\theta\, d\theta} \tag{31}$$

5. Numerical Computation

In order to on the value of E-plane, H-plane, radiated power and directivity of rectangular microstrip antenna in weakly ionized plasma medium, the computational works were done by using equations (27),(28),(29),(30) and (31). Results were shown in graphical form in Fig-3,Fig-4,Fig.5 ,Fig-6 and Fig.7

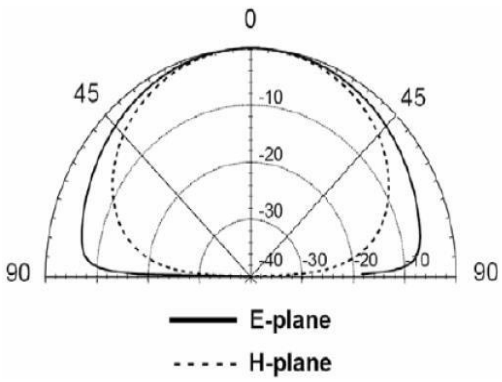

Fig3. E-H Radiation Pattern of Rectangular Microstrip Antenna in High Density Plasma Medium

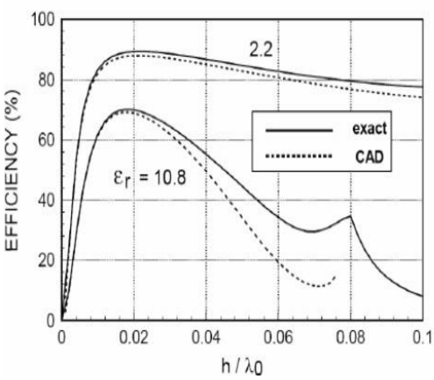

Fig.4 Efficiency Graph of Rectangular Microstrip Antenna in High Density Plasma Medium

However, a specified frequency is necessary to determineconductor loss.) For *h* / λ0 < 0.02, the conductor and dielectriclosses dominate, while for *h* /λ0 < 0.02, the surface-wave lossesdominate. (If there were no conductor or dielectric losses, the efficiency would approach 100% as the substrate thickness approaches zero)

Table-1

FREQUENCY	VSR 1	VSR 2	VSR 3
2.9	4.5	3.4	3
2.91	4	3.1	2.8
2.92	3.5	2.9	2.5
2.93	2.5	2.4	2
2.94	1.9	1.8	1.8
2.95	1.8	1.4	1.4
2.96	1.6	1.3	1.3
2.97	1.5	1.25	1.25
2.98	1.4	1.3	1.2
2.99	1.6	1.4	1.3
3	1.7	1.5	1.4
3.01	1.9	1.7	1.5
3.02	2.2	1.8	1.8
3.03	2.8	2.2	2.3
3.04	3.5	2.7	2.4
3.05	4	3.4	3.1

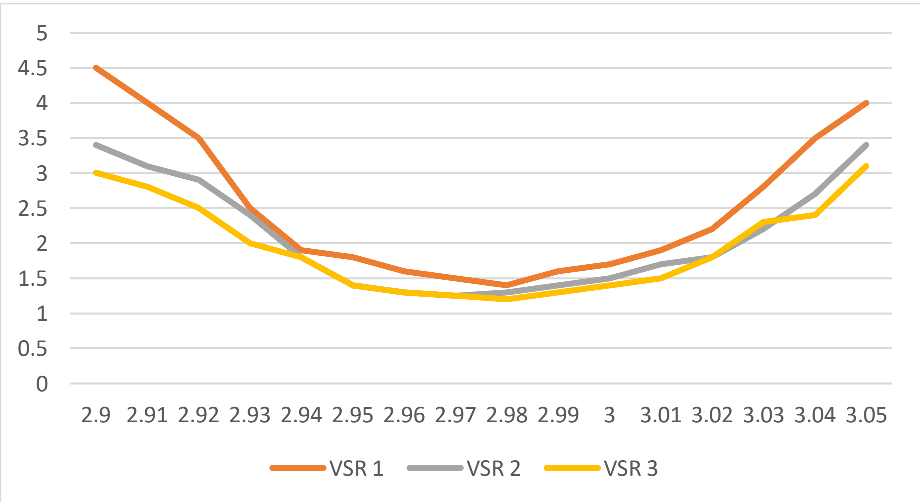

Fig.5 VSWR Graph of Circular Microstrip Antenna in High Density Plasma Medium

FREQUENCY	VSWR
1.75	2.25
1.425	1.8
1.775	1.6
1.787	1.3
1.8	1.1
1.812	1.3
1.825	1.4
1.837	1.7

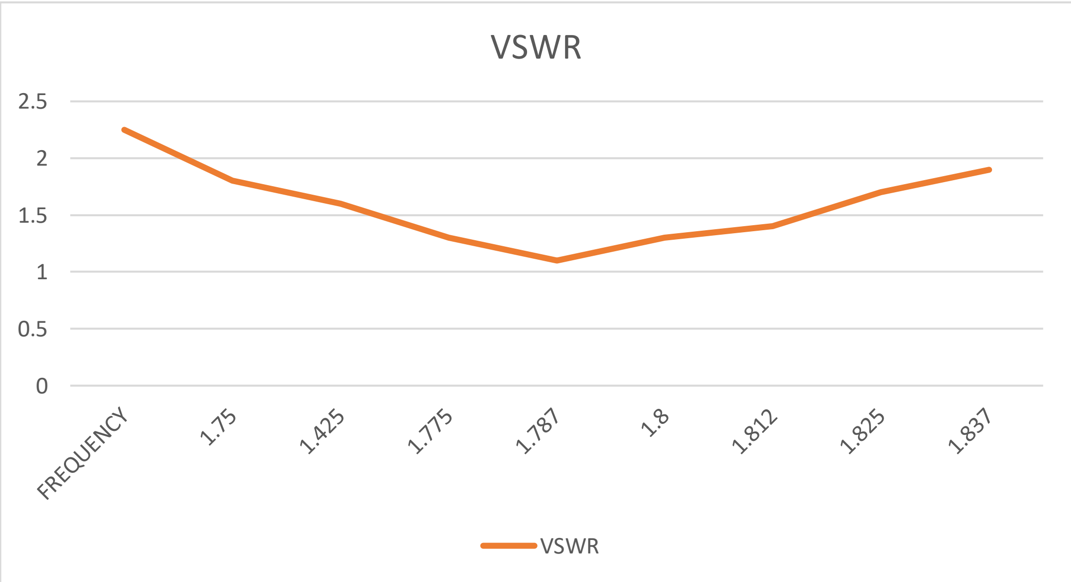

Fig.6 VSWR Plot of Rectangular Microstrip Antenna in Isotropic Plasm

6. Summary and Conclusion

This research paper has investigated the radiation characteristics of rectangular microstrip antenna in high density plasma media. Through simulation and analysis using CST Microwave Studio, it was found that the presence of plasma significantly affects the performance of the antenna. The results showed that as the density of plasma increases, the gain and directivity decrease while return loss and VSWR increase. Furthermore, it was observed that there is a shift in resonant frequency as the permittivity of plasma changes. This can be attributed to changes in effective dielectric constant due to interaction between electromagnetic waves and charged particles in plasma. Moreover, various techniques have been proposed to compensate for these effects such as adjusting geometry parameters or using different substrate materials with suitable dielectric constant. It was also discovered that by introducing gaps or slots on the patch surface, some degree of improvement can be achieved in terms of gain and directivity. Overall, this study highlights the importance of considering environmental factors such as high density plasmas when designing microstrip antennas for communication systems operating within these conditions. Further research could focus on experimental verification using prototypes to validate the findings presented in this paper. With continuous advancements in technology and increasing applications involving high-density plasmas, understanding their impact on antenna performance becomes crucial

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