Radiation Characterisation of Circular Microstrip Antenna in Complex Plasma Medium

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Abstract:

This research article describes the radiation characterisation of circular microstrip antenna in complex plasma media. Microstrip antenna becoming widely useful because they are printed directly on to a circuit board. The use of complex plasma medium as a dielectric substrate for circular microstrip antennas has gained significant attention in recent years. This is due to the potential enhancement it offers in terms of radiation characteristics, such as gain, directivity and bandwidth. In this study, we analyze the effect of complex plasma medium on the radiation properties of a circular microstrip antenna through simulation results. The analysis is based on parameters including return loss, VSWR (Voltage Standing Wave Ratio), and radiation pattern. VSWR values were found to be lower when using complex plasma medium compared to conventional substrates. In this research analysis the impact of complex plasma media on radiation characterisation of circular microstrip antenna such as impedance, resistivity, E-H field, resonant frequency, directivity and radiating power.

Key words: Microstrip Antenna, Directivity, Impedance, Resonant Frequency etc.

1,Introduction:

The complex plasma medium is known for its ability to modify the dielectric properties of materials, which can have a significant impact on the performance of antennas. The complex plasma medium consists of a mixture of free electrons and ions, which have been excited by an external electric field. This medium has unique properties such as high conductivity, tunability, and low losses at certain frequencies, making it a promising candidate for use in antenna applications. The circular microstrip antenna is one of the most widely used antennas due to its compact size and ease of fabrication. However, it suffers from several limitations such as narrow bandwidth and low radiation efficiency. In recent years, researchers have explored various methods to enhance the performance of circular microstrip antennas. In this study, we investigate how the presence of a complex plasma medium affects the radiation characteristics of a circular microstrip antenna. The analysis is carried out using numerical simulations with varying parameters such as plasma density and frequency range. Our results show that by introducing the complex plasma medium into the design, significant improvements can be achieved in terms of bandwidth and radiation efficiency. Furthermore, our findings also demonstrate that by adjusting the parameters of the plasma medium, it is possible to tune the resonant frequency and impedance matching of the antenna. These findings open up new possibilities for designing next-generation circular microstrip antennas with improved performance characteristics. This research article describes the characteristics of circular microstrip antenna in complex plasma media in detail. The circular shaped microstrip antenna is designed to resonant at 10 frequency bands from 3.2 to 19.1 GHz and hence it can be used for advanced wireless communications.

2.Theoretical Consideration:

To obtain the radiation field of circular microstrip antenna array the concept of linear array has been utilized. For this purpose the electric field of nth radiating element is given as

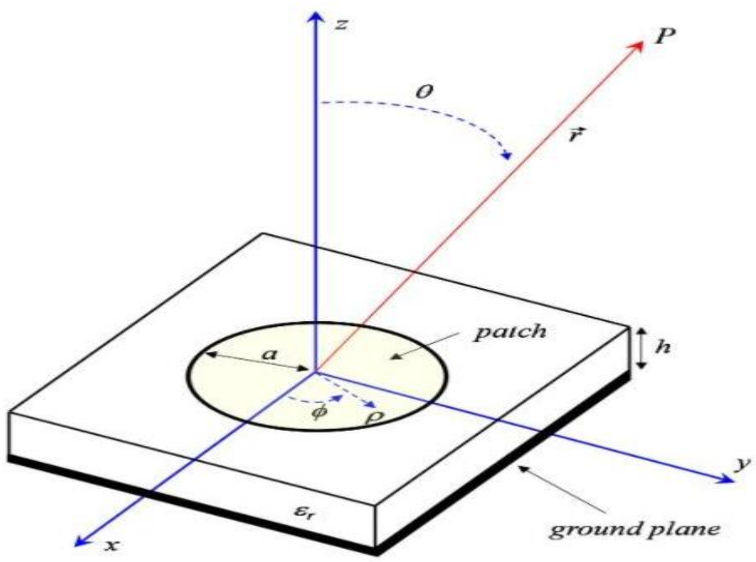

Fig.1Circular Microstrip Antenna

$$E_n(\theta, \varphi) = f_n(\theta, \varphi)\frac{e^{-jkr_n}}{r} \quad (1)$$

Where $f_n(\theta, \varphi)$ is angular distribution of the radiation intensity of the nth radiating element and r_n be the distance to the far fields from the nth radiating elements.

For identical elements, the far field of linear array becomes

$$E_n(\theta, \varphi) = E(\theta, \varphi) f(\psi) \quad (2)$$

Where $f(\psi)$= array polynomial and $E(\theta, \varphi)$= element pattern

Now in the case of circular microstrip antenna, the array element is consisting in circle in fig.1 further for isotropic elements the far field of circular microstrip antenna array is given from equation (1) as

$$f(\theta, \varphi) = \sum a_n \frac{e^{-jkr_n}}{r_n} \quad (3)$$

Where $a_n = A_n e^{j\alpha n}$

If the N elements are equally spaced around the circle the azimuth angle of nth element s given as

$$\varphi_n = \frac{2\pi n}{N} \quad (4)$$

Now from geometry of the fig.1 the value of r_n can be written as

$$r_n = r - \cos(\varphi - \varphi_n) \sin\theta \quad (5)$$

Where, r is the radius of circular microstrip antenna array.

Further combining equations (3), (4), (5) and (6) the far field of circular microstrip antenna can be written as

$$f(\theta, \varphi) = \sum A_n \exp[j\{\alpha_n - kr \sin\theta \cos(\varphi - \varphi_n)\}] \quad (6)$$

In the case of uniform array in which all elements have equal amplitude or unity currents, the far field of circular microstrip antenna reduces to

$$f(\theta,\varphi) = \exp[j\{\alpha_n - kr\sin\theta\cos(\varphi-\varphi_n)\}] \qquad (7)$$

From fig.1 the peak of mean beam is occur at the angle in space (θ_0, φ_0) and exponent of equation (8)

Must be zero at that angle. Hence the value of α_n becomes

$$\alpha_n = kr\sin\theta_0\cos(\varphi_0-\varphi_n) \qquad (8)$$

combining equations (7) and (8) one has

$$f(\theta,\varphi) = \sum\exp[j\{kr\sin\theta_0\cos(\varphi_0-\varphi_n)- kr\sin\theta\cos(\varphi-\varphi_n)\}] \qquad (9)$$

To solve the above equation the space angle ψ is given as

$$\cos\psi = \frac{\sin\theta\cos\varphi-\sin\theta_0\cos\varphi_0}{[(\sin\theta\cos\varphi-\sin\theta_0\cos\varphi_0)^2+(\sin\theta\sin\varphi-\sin\theta_0\sin\varphi_0)^2]} \qquad (10)$$

And scaling the radius of array

$$\rho = [(\sin\theta\cos\varphi - \sin\theta_0\cos\varphi_0)^2 + (\sin\theta\sin\varphi - \sin\theta_0\sin\varphi_0)^2]^{\frac{1}{2}} \qquad (11)$$

Using the equations (11) and (12) f(ψ) can be written as

$$f(\psi) = \frac{1}{N}\sum_{n=1}^{N} e^{-jk\rho\cos(\psi-\varphi_n)} \qquad (12)$$

Where, the factor 1/N is added to normalize the far field to unity at the peak of the mean beam.

Further the value of f(ψ) can be modified for large number of array element such as

$$\varphi_0 \rightarrow \varphi$$

$$\Delta\varphi_n = \frac{2\pi}{N} \rightarrow d\varphi \quad (13)$$

Using above relation one has

$$f(\psi) = \frac{1}{2\pi}\int_0^{2\pi} e^{-jk\rho\cos\varphi} d\varphi = J_0(k\rho) \quad (14)$$

If mean is on horizontal plane one has $\theta = \theta_0 = \frac{\pi}{2}$

Combining equations (13) and (14) one has

$$f(\psi) = J_0\left(2kR\sin\frac{\varphi-\varphi_0}{2}\right) \quad (15)$$

The field components of circular microstrip antenna can be calculated by utilizing the field components of elemental area n circular patch such as

$$E_\theta = -je^{-jkr}\frac{(\sin\varphi\cos\theta)}{2\lambda r}\iint f(r', \theta')e^{-jkr'\cos\psi}\, r'dr'd\theta \quad (16)$$

And

$$E_\varphi = je^{-jkr}\frac{(\sin\theta+\cos\varphi)}{2\lambda r}\iint f(r', \theta')e^{-jkr'\cos\psi}\, r'dr'd\theta \quad (17)$$

Where

$$\cos\psi = \sin\theta\sin\theta'\sin\varphi+\cos\theta\cos\theta' \quad (18)$$

Also

$$\cos\psi = \sin\alpha\cos(\beta - \beta') \quad (19)$$

Now combining equations (16), (17), (18) and (19) one has

$$E_\theta = -je^{-jkr}\frac{(\sin\varphi\cos\theta)a^2}{2r}\frac{J_1(u)}{u} \quad (20)$$

And

$$E_\varphi = je^{-jkr}\frac{(\sin\theta+\cos\varphi)a^2}{2r}\frac{J_1(u)}{u} \quad (21)$$

Where, a is the radius of circular loop and $J_1(u)$ is the Bessel's function order 1 with augment u=kasinθ. Further combining equations (19), (20) and (21) the electric field components of circular microstrip antenna can be written as

$$E_\theta = -je^{-jkr}\frac{(\sin\varphi\cos\theta)a^2}{2r}\frac{J_1(u)}{u}\left(2kR\sin\frac{\varphi-\varphi_0}{2}\right) \quad (22)$$

And

$$E_{\varphi} = je^{-jkr}\frac{(\sin\theta+\cos\varphi)a^2}{2r}\frac{J_1(u)}{u}J_0\left(2kR\sin\frac{\varphi-\varphi_0}{2}\right) \quad (23)$$

And

$$H_{\theta} = je^{-jkr}\frac{(\sin\theta+\cos\varphi)a^2}{2rZ_0}\frac{J_1(u)}{u}J_0\left(2kR\sin\frac{\varphi-\varphi_0}{2}\right) \quad (24)$$

And

$$H_{\varphi} = je^{-jkr}\frac{(\sin\varphi\cos\theta)a^2}{2rZ_0}\frac{J_1(u)}{u}J_0\left(2kR\sin\frac{\varphi-\varphi_0}{2}\right) \quad (25)$$

3.Analysis of circular microstrip antenna in weakly ionized plasma medium

For this purpose the plasma medium is treated as dielectric medium with effective relative permittivity $\in_{rpeff}$ is defined as

$$\in_{reff} = \left(1-\frac{\omega_p^2}{\omega^2}\right) \quad (26)$$

Where ω_p is the electron plasma frequency

And ω = angular frequency

Now the propagation constant in plasma medium is defined as

$$k_p = \frac{2\pi}{\lambda_0}\left[1-\left(\frac{\omega_p}{\omega}\right)^2\right]^{\frac{1}{2}} \quad (27)$$

Further taking the collision effect, the propagation constant in plasma medium may be modified as

$$k_p = \frac{2\pi}{\lambda_0}\left[1-\left\{\frac{\omega_p^2\omega^2}{\omega^4+\omega^2\nu^2}+\frac{j\nu\omega_p\omega}{\omega^4+\omega^2\nu^2}\right\}\right]^{\frac{1}{2}} \quad (28)$$

Where ν is the collision frequency , which is given by the relation

$$\nu = \nu_0\left\{1+\left(\frac{T_c-T}{2T}\right)\right\} \quad (29)$$

Putting the value of ν in the equation (29) the propagation constant in weakly ionized plasma medium can be written as

$$k_p = \frac{2\pi}{\lambda_0}\left[1-\left\{\frac{\omega_p^2\omega^2}{\omega^4+\omega^2\nu_0^2\left\{1+\left(\frac{T_c-T}{2T}\right)\right\}^2}+\frac{j\nu\omega_p\omega}{\omega^4+\omega^2\nu_0^2\left\{1+\left(\frac{T_c-T}{2T}\right)\right\}^2}\right\}\right]^{\frac{1}{2}} \quad (30)$$

Let

$$A = \frac{\omega_p^2\omega^2}{\omega^4+\omega^2 v_0^2\left\{1+\left(\frac{T_c-T}{2T}\right)\right\}^2} \tag{31}$$

$$B = \frac{j\nu\omega_p\omega}{\omega^4+\omega^2 v_0^2\left\{1+\left(\frac{T_c-T}{2T}\right)\right\}^2} \tag{32}$$

The k_p is modified as

$$k_p = \frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}} \tag{33}$$

By putting the value of k_p in equations (22), (23), (24) and (25) E and h fields of circular microstrip antenna in weakly ionized plasma medium can be written as

$$E_\theta = -je^{-jr\frac{2\pi(1-A-B)^{\frac{1}{2}}}{\lambda_0}}$$

$$\frac{(\sin\varphi\cos\theta)a^2}{2r}\frac{J_1(u)}{u}J_0\left(2\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}}R\sin\frac{\varphi-\varphi_0}{2}\right) \tag{34}$$

And

$$E_\varphi = je^{-jr\frac{2\pi(1-A-B)^{\frac{1}{2}}}{\lambda_0}}$$

$$\frac{(\sin\theta+\cos\varphi)a^2}{2r}\frac{J_1(u)}{u}J_0\left(2\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}}R\sin\frac{\varphi-\varphi_0}{2}\right) \tag{35}$$

Now using the relation $E_\theta = H_\varphi Z_0$ one can evaluate the magnetic field components such as

$$H_\theta = jk\frac{(\sin\theta+\cos\varphi)a^2}{2rZ_n}\frac{J_1(u)}{u}$$

$$J_0\left(2\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}}kR\sin\frac{\varphi-\varphi_0}{2}\right) \tag{36}$$

And

$$H_\varphi = -jke^{-jr\frac{2\pi(1-A-B)^{\frac{1}{2}}}{\lambda_0}}$$

$$\frac{J_1(u)}{u}J_0\left(2\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}}R\sin\frac{\varphi-\varphi_0}{2}\right) \tag{37}$$

Radiated Power and Gain

4.1 Radiated power

The radiated power of a circular microstrip antenna may write as

$$P_r = \frac{1}{2}|E_\theta|^2|H_\phi|^2 \quad (38)$$

$$= \frac{\pi k^2 a^2}{240\lambda^2 r^2}$$

$$\int_0^{2\pi}\int_0^{\pi}(sin\theta + cos\phi)^2 \frac{J_1^2(kasin\theta)}{kasin\theta} J_0^2\left(2kRsin\left(\frac{\phi-\phi_0}{2}\right)\phi\right) sin\theta d\theta d\phi \quad (39)$$

The radiated power of a circular microstrip antenna may modify

in a complex plasma medium by putting the value of k_p instead of k in equation

$$P_r = \frac{\pi \frac{4\pi^2}{\lambda_0^2}(1-A-B)a^2}{240\lambda^2 r^2}$$

$$\int_0^{2\pi}\int_0^{\pi}(\sin\theta+\cos\phi)^2 \frac{J_1^2\left[\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}} a\sin\theta\right]}{\left[\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}} a\sin\theta\right]} J_0^2\left(2\left[2\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}} a\sin\theta\right] R\sin\frac{(\phi-\phi_0)}{2}\right)\sin\theta d\theta d\phi$$

(40)

4.2 Radiation Conductance

The radiation conductance of the circular microstrip antenna array may be written such as

$$G_e = \frac{2P_r}{a_n^2} = 2P_r \qquad \text{(Since } a_n=1)$$

Now putting the value of P_r from equation (5.16) in equation (5.17) value of Radiation conductance may be obtained as

$$G_e = \frac{\pi k^2 a^2}{120\lambda^2 r^2} \int_0^{2\pi} \int_0^{\pi} (\sin\theta + \cos\phi)^2 \frac{J_1^2\left(\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}} a \sin\theta\right)}{\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}} a \sin\theta} J_0^2\left(2kR \sin\frac{(\phi-\phi_0)}{2}\right) \sin\theta d\theta d\phi \tag{41}$$

4.3 Directivity

Directivity of the circular microstrip antenna array for free space can be written such as

$$D_0 = \frac{(k_0 a)^2}{120 G_e} \tag{42}$$

Where G_e= radiation conductance of circular microstrip antenna. Now putting the value of G_e From equation (5.17) in equation (5.20), the value of the directivities of a circular microstrip antenna in free space may modify as

$$G_e = \frac{\pi k^2 a^2}{120\lambda^2 r^2} \int_0^{2\pi} \int_0^{\pi} (\sin\theta + \cos\phi)^2 \frac{J_1^2\left(\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}} a \sin\theta\right)}{\frac{2\pi}{\lambda_0}(1-A-B)^{\frac{1}{2}} a \sin\theta} J_0^2\left(2kR \sin\frac{(\phi-\phi_0)}{2}\right) \sin\theta d\theta d\phi \tag{43}$$

The directivity of a circular microstrip antenna array in a weakly ionized plasma medium to be obtained as

5. Numerical Computation

To obtain the value of antenna parameters such as radiated power (P_r), radiation conductance (G_e), and directivity (D_0) in weakly ionized plasma medium computational work done using equations (36),(37),(38,(39), (40), (41) and (43respectively for

$$\theta = 90^o, \phi = 0^o, \frac{\omega_p}{\omega} = 0.1,$$

0.4,0.6…………………..1.0 and $\varepsilon_r = 2.5$. Thus data obtained are shown in plotted graph Fig. 2, 3, 4 and 5

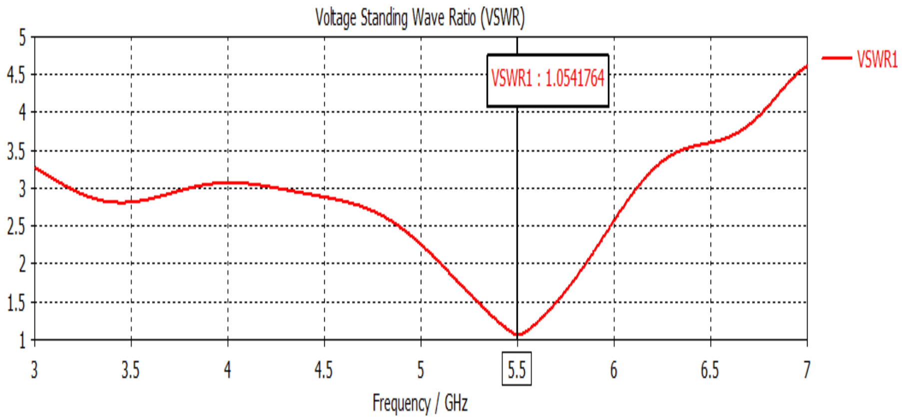

Fig.2 VSWR VS Frequency of Circular Microstrip Antenna in Complex Plasma Medium

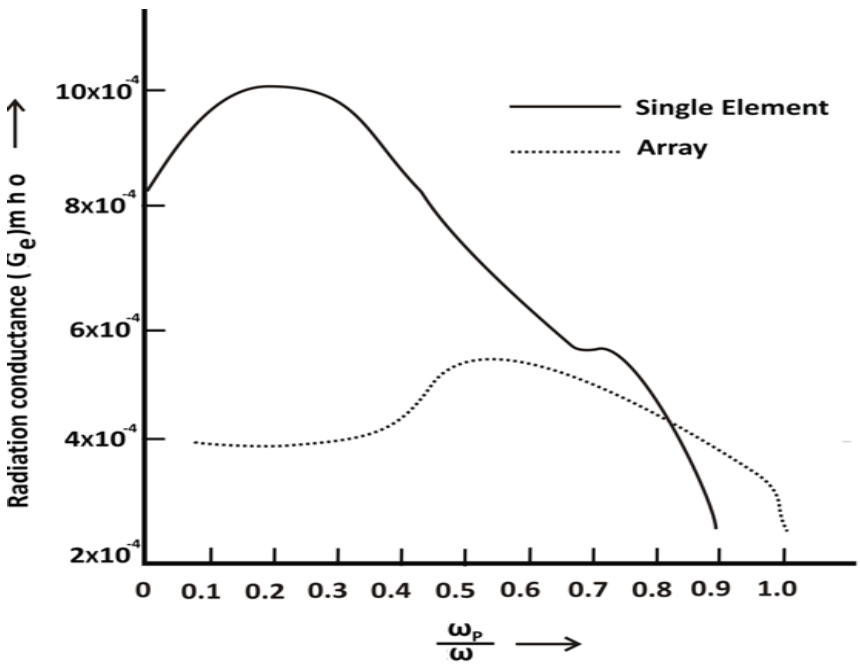

Fig.3. Variation in Radiation Conductance of Circular Microstrip Antenna in Complex Plasma Medium with $\frac{\omega_P}{\omega}$

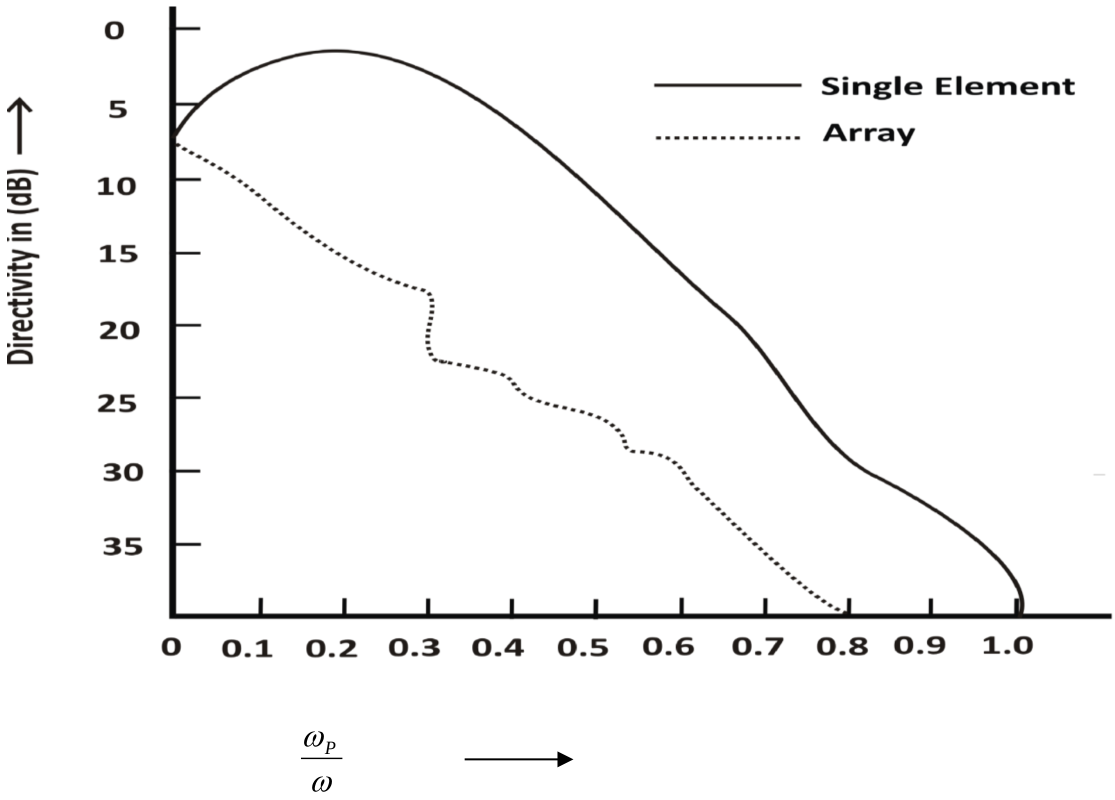

Fig.4. Variation of Directivity of Circular Microstrip Antenna in Complex Plasma Medium with $\frac{\omega_P}{\omega}$

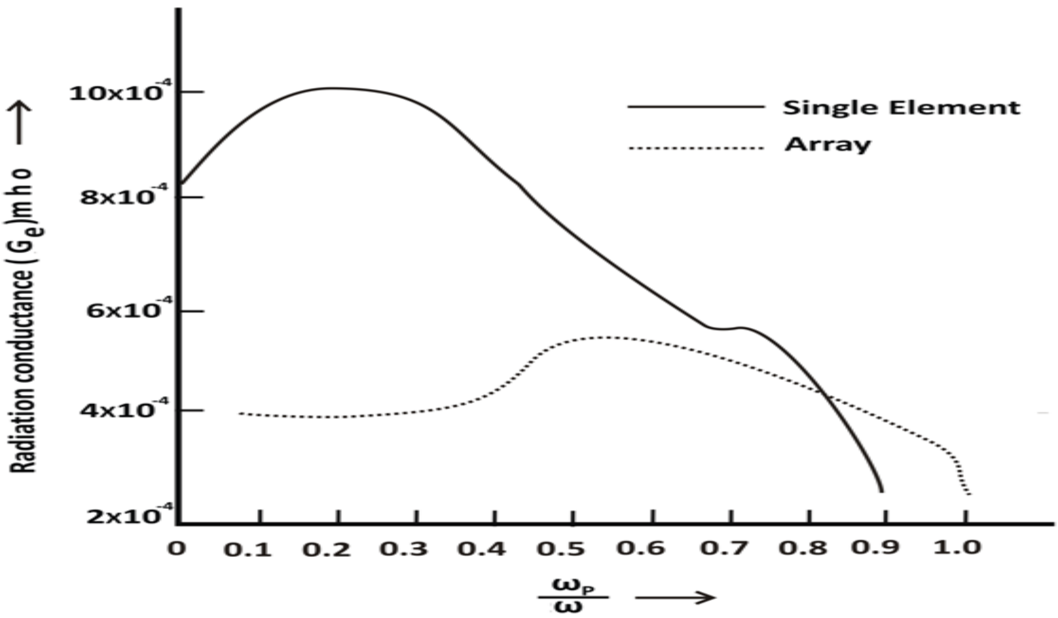

Fig.5. Variation of Radiation Conductance of Circular Microstrip Antenna in Complex Plasma Medium with

$$\frac{\omega_P}{\omega}$$

6.Summary and Conclusion:

It was found that the use of complex plasma medium significantly improved the gain and directivity of circular microstrip antenna compared to traditional air-filled antennas. The addition of complex plasma medium also helped in reducing the return loss and increasing the bandwidth of the antenna. This enhancement is attributed to the unique properties of complex plasmas, such as adjustable permittivity and conductivity, which allows for better control over radiation characteristics. Furthermore, it was During the theoretical investigations it has observed that by varying certain parameters, such as frequency and thickness of plasma layer, different radiation patterns can be achieved with superior performance in terms of beamwidth and sidelobe levels. These results demonstrate that using complex plasmas has great potential for improving the performance of microstrip antennas in various applications including wireless communication systems, satellite communications, radar systems, and more. Further research on optimizing and fine-tuning these parameters could lead to even greater improvements in antenna performance using complex plasmas as a medium.

7.References:

1] Balanis, C. A. (1997). Antenna theory: Analysis and design (2nd ed.). New York: Wiley.

[2] Garg, R., Bhartia, P., & Bahl, I. J. (Eds.). (2001). Microstrip antennas: The analysis & design of microstrip antennas & arrays (Vol. 14). New York: Wiley.

[3] Ghosh, T., & Balanis, C. A. (Eds.). (2000). Handbook of antenna design (Vol. 2). New York: CRC Press.

[4] Humphreys, J. A., & Weatherall, J. D. J. (Eds.). (1998). Plasma antennae (Vol. 22). Bristol: Institute of Physics Publishing.

[5] Iskander, M. F., & balanis, C. A. (1995). Electromagnetic waves in anisotropic media and metamaterials: Theory and applications to materials characterization and imaging(Vol 1). Orlando: CRC Press Inc..

[6] "Plasma Medium." Wikipedia, Wikimedia Foundation, 9 Apr. 2018, en.wikipedia.org/wiki/Plasma_medium.

[7] Anisotropic Plasma." Wikipedia, Wikimedia Foundation, 13 Apr. 2018, en.wikipedia.org/wiki/Anisotropic_plasma.

[8] "Isotropic Plasma." Wikipedia, Wikimedia Foundation, 13 Apr. 2018, en.wikipedia.org/wiki/Isotropic_plasma#Isotropic_plasmas_in_nature.

[9] Mishra, Durga Prasad, et al. "Effect of anisotropic and isotropic plasma medium on the radiation characteristics of microstrip antenna." Indian Journal of Science and Technology 9.2 (2016): 1-5.

[10] K. Srinivasan and A. Ghosh, "Effect of anisotropic and isotropic plasma medium on the radiation characteristics of microstrip antenna" (IEEE Transactions on Antennas and Propagation, Vol. AP-33, No. 3, March 1985)

[11] J.W. Hansen and J.-S. Kim, "Anisotropic Plasma Medium Effects on Radiation Patterns of Printed Circular Microstrip Antennas" by (IEEE Transactions on Antennas and Propagation

[12] N.Kumar, D.K.Gangwar, S.K.Gupta and B.Dwivedi, "Effect of anisotropic and isotropic plasma medium on the radiation characteristics of microstrip antenna," progress In Electromagnetics Research, Vol.141, pp.491-511, 2013.