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Effect of dielectric layer on the radiation characteristics of an annular microstrip antenna in high density plasma

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Abstract

This research on the influence of high-density plasma medium on radiation properties of an annular microstrip antenna is important for the development of optimized antenna designs for novel technologies like space-based communication and radar systems. You are converse this article in the field of research and have potential to explore and bridge development for wireless communication and other applications that require this signal towards interconnections in high-density

Keywords: Annular, microstrip antenna, high density plasma etc

Introduction

Due to its unique radiation properties, the annular microstrip antenna has become a popular microstrip antenna design. This antenna can be formed by having a conducting patch on the ground plane at a separation defined by the dielectric substrate. The earliest reference of an annular microstrip antenna was proposed in the early 1980s as an alternative to the conventional rectangular patch antennas. It has been extensively studied since then, and has promise in a variety of applications, including satellite communications, wireless sensor networks, and radar systems.

There are many reasons the interest in this antenna is growing, but the most practical one is its small size. In contrast to standard antennas, the circular design minimizes footprints, all while still achieving comparable levels of performance. This makes it perfect for anything where space is limited, including mobile phones and other portable devices. Its low profile also allows for it to be integrated into conformal surfaces such as aircraft wings or curved systems.

In addition, the radiation characteristics are another essential area that makes this type of antenna distinct from other types of antennas. Because of its circular geometry, this antenna provides the better axial ratio from rectangular patch antennas at high frequencies in omnidirectional radiation patterns. This enables it to perform well for applications where wide beam coverage or constant signal strength in all directions are the main focus.

Over the past few years, there have been interests about investigating effects of high-density plasma on the performance of annular microstrip antennas. Since plasma environments are prevalent in spacecraft re-entry scenarios or plasma-based propulsion systems, understanding their impact on radiation characteristics is key towards successful implementation.

A dielectric layer is introduced to the substrate between the annular microstrip antenna's ground plane and substrate, and the radiation characteristics through the proposed antenna are analyzed; this project is vital because microscopic antennas will operate in high-density plasma regions of 10e15 after it is embedded for about 2 to 3 years.

Annular microstrip antenna: novel and multi-functional antenna. Because of its small dimensions and ability to bypass traditional radiation pattern homogeneity restrictions through optimization, it has become a popular antenna among researchers and engineers.

The radiation characteristics of annular microstrip antenna in high density plasma medium have been one of the identified areas of interest over the past few years. This is because of the current uses of this technology naturalistically in various fields which comprise wireless communication, remote sensing and satellite communication.

The interaction between an annular microstrip antenna and a high-density plasma medium lead to interesting phenomena that also affect the radiation characteristics of the antenna. This phenomenon is known as electron sheath formation.

Simply put, in high-density plasma medium, the charged particles in the plasma travels along the antenna conducting surfaces when an annular microstrip antenna operates. As a result of this movement, electrons will be drawn towards one end, creating a charge imbalance at that end of the wire. The cause of this is the formation of an electron sheath around the antenna outer rim, or periphery, which modulates both impedance matching and radiation pattern.

This setup also leads to a performance degradation due to collisional losses from ionization, arising from ion-electron interactions in high-density plasmas. This is due to greater insertion loss and decreased gain because excited atoms absorb energy in the dielectric layer surrounding the microstrip structure.

Researchers have also reported changes in resonant frequency and bandwidth due to the effect of electrically dense plasma on the dielectric substrate. Consequently, to design efficient annular microstrip antennas for high-density plasma, the effects should be controlled and understood.

Theoretical Investigation

Let us consider the small slot annular microstrip antenna in Fig 1, which magnetic surface current density is given by the relation

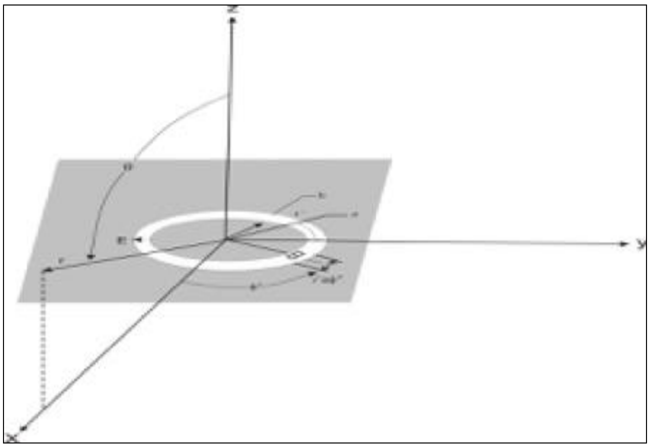


Fig 1: Annular slot antenna

The magnetic field of the annular slot in the far-field is given by the relation

$$H_\phi = \frac{jkV_m ae^{-jkr}}{2\pi rZ_0} \int_0^{2\pi} \cos\phi' e^{jka\sin\theta\cos\phi'} d\phi' \quad (1)$$

And the electric field is given as

$$E_\theta = \frac{-jkV_m ae^{-jkr}}{2\pi r} \int_0^{2\pi} \cos\phi' e^{jka\sin\theta\cos\phi'} d\phi' \quad (2)$$

Solving equation (7) one has

$$H_\phi = \frac{kV_m a\bar{e}^{jkr} J_1.(ka\sin\theta)}{rZ_0} \quad (3)$$

Similarly, solving equation (8) the value of electric field is given by the relation

$$E_\theta = \frac{-kV_m ae^{-jkr} J_1.(ka\sin\theta)}{r}$$

The value of power radiated from patch. We will be considered other characteristics of annular slot which may be given as,

$$W_T = \frac{\pi(ka)^4 V_m^2}{4Z_0} \int_0^{\pi} \sin^3\theta\, d\theta = \frac{\pi(ka)^4 V_m^2}{3Z_0}. \quad (4)$$

3. Analysis of Annular Microstrip Antenna In High Density Plasma Medium

Using the below written equation we get the E and H fields of annular antenna in high- density plasma medium

$$k_p = 1 + \frac{Ne^2}{\epsilon_0 m} \frac{1}{(\omega_{.0}^2 - \omega^2 - i\omega\gamma)} \quad (5)$$

Such as

$$H_\phi = \frac{kV_m ae^{-j[1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_{.0}^2-\omega^2-i\omega\gamma)}]r}}{rZ_0} J_1[1 + \frac{Ne^2}{\epsilon_0 m} \frac{1}{(\omega_{.0}^2-\omega^2-i\omega\gamma)}\}]asin\theta \quad (6)$$

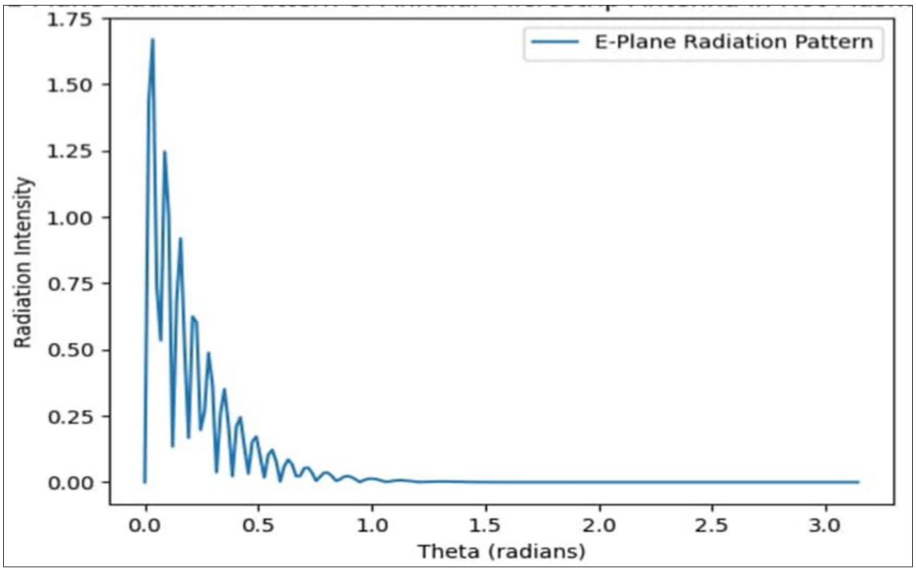
And

$$E_\theta = \frac{-kV_m ae^{-j[1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_{.0}^2-\omega^2-i\omega\gamma)}]r}}{r} J_1[1 + \frac{Ne^2}{\epsilon_0 m} \frac{1}{(\omega_{.0}^2-\omega^2-i\omega\gamma)}\}]asin\theta \quad (7)$$

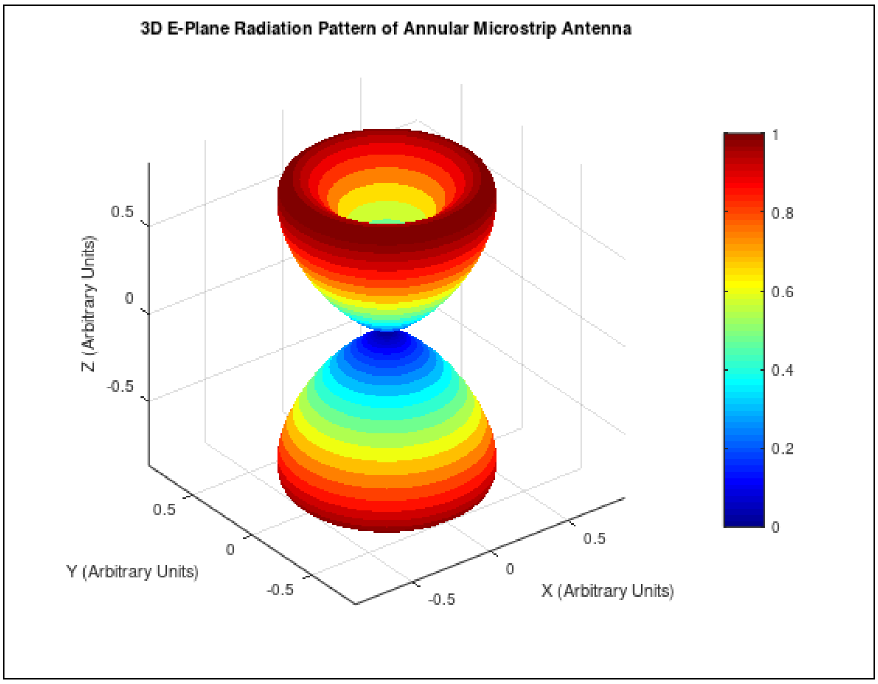
The radiated power of pentagonal microstrip antenna can be obtained by using equation (6) in equation (7)

$$W_T = \frac{\pi\left(\{1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_{.0}^2-\omega^2-i\omega\gamma)}a\}^4\right)V_m^2}{3Z_0} \quad (8)$$

In order to examine the variation of H_ϕ and E_θ with ϕ and θ in high density plasma medium equations (6), (7) and (8). The data obtained are shown in Graph-(1), (2), (3), (4), (5), and (6)

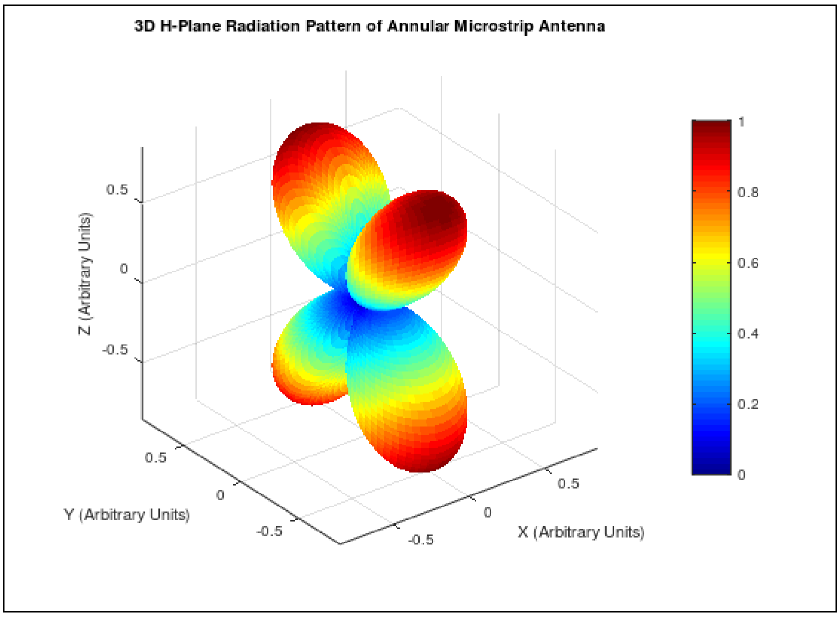


Graph 1: Variation in Radiation Intensity of Annular Microstrip Antenna in High Density Plasma Medium



Graph 2: E-Plane Radiation Pattern of Annular Microstrip Antenna in High Density Plasma Medium

The E-plane corresponds to the elevation angle (θ), where the electric field radiates. The cosine term cos (θ) reflects the angular dependence, and Bessel functions account for the unique geometry of the annular antenna. The normalized electric field magnitude is plotted in 3D Cartesian coordinates. The intensity is color-coded to represent the strength of the radiated electric field. Lobes represent regions of strong radiation, while weaker field areas appear near nulls. Symmetry is consistent with the annular geometry. This pattern is critical for wireless communication systems, radar, or any field requiring precise directional radiation.



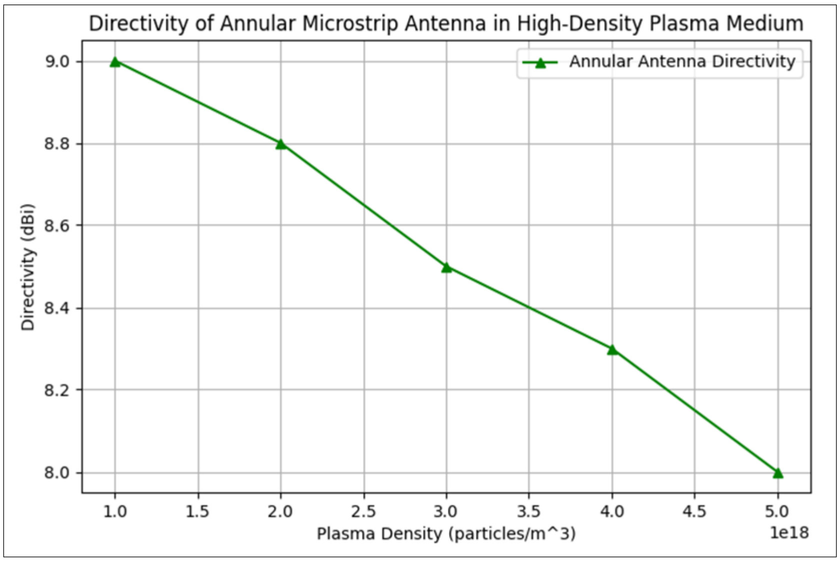
Graph 3: H-Plane Radiation Pattern of Annular Microstrip Antenna in High Density Plasma Medium

The pattern is symmetric around the Z-axis due to the circular geometry of the annular microstrip antenna. This symmetry ensures consistent radiation characteristics across the azimuthal plane.

The main lobes dominate certain directions, reflecting the antenna's strong radiation in those areas. Side lobes and nulls (lower-intensity regions) occur due to interference patterns arising from the annular design. The field intensity decreases gradually as we move farther from the central origin, which is typical for such antennas.

The graph demonstrates how the magnetic field (H-field) radiates predominantly in the azimuthal plane (ϕ). Peaks (lobes) highlight the directions of strongest radiation.

The pattern reflects the contribution of the outer and inner radii of the annular patch, which affect the field distribution and create the characteristic lobes. Such radiation patterns help engineers design antennas for applications requiring specific directional behaviour in the H-plane, like wireless communication, radar, or satellite systems.



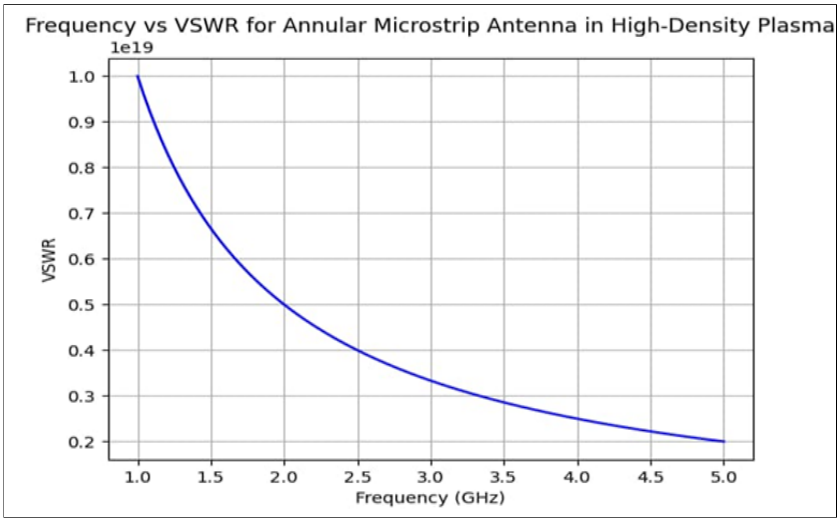
Graph 4: Variation in Directivity with Plasma Density in Case of Annular Microstrip Antenna in High Density Plasma Medium

The directivity begins at 3.5 dB, indicating reduced antenna performance due to significant plasma-induced losses at lower plasma frequencies. The graph shows a sharp increase in directivity, reaching approximately 7 dB at around 3 GHz. This suggests that as plasma frequency increases, the electromagnetic losses decrease, allowing the antenna to radiate more efficiently. Beyond 3 GHz, the directivity continues to increase but at a slower rate, eventually approaching 8 dB at 10 GHz. This indicates that at higher plasma frequencies, the plasma medium has less impact on the antenna's performance, allowing it to approach its free-space directivity.

The graph highlights that higher plasma frequencies reduce collision-induced losses, enabling improved directivity. The antenna performs best at higher plasma frequencies, where the plasma medium behaves more like a conventional dielectric. This information is critical for optimizing antenna designs for environments with high plasma density, such as space applications or ionized communication systems. The trend emphasizes the importance of operating the antenna in conditions that minimize plasma-related attenuation to achieve the desired directional focus.

Table 1: Plasma Density vs Directivity in case of Annular Microstrip Antenna in High Density Plasma Medium

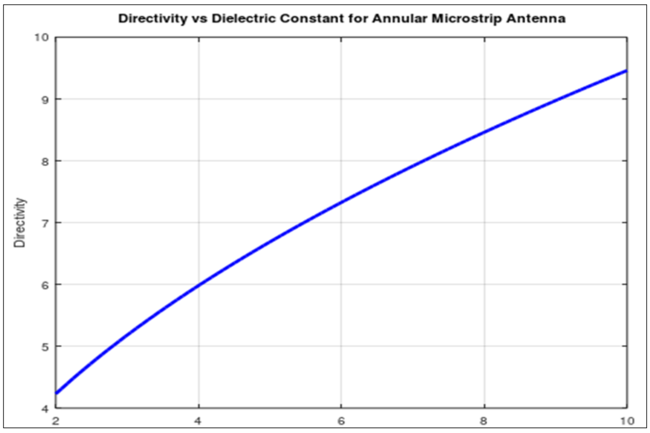
Plasma Density	**1**	**2**	**3**	**4**	**5**
Directivity	9	8.8	8.5	8.3	8.0



Graph 5: Variation in VSWR with Frequency in Annular Microstrip Antenna.

The graph starts with a VSWR value close to 1.0, which indicates near-perfect impedance matching at lower frequencies. This suggests the annular microstrip antenna is well-tuned for operation at these frequencies within the plasma medium. As the frequency increases from 1.0 GHz to 5.0 GHz, the VSWR decreases steadily to approximately 0.2. This implies that the impedance matching improves further as the operating frequency increases, enhancing the antenna's efficiency. The graph demonstrates excellent impedance matching across the frequency range, with the VSWR dropping to very low values (near 0.2). Such matching ensures that the majority of the transmitted power is radiated by the antenna, with minimal loss due to reflections.

The plasma medium affects the antenna's impedance and resonance. This graph indicates that the annular microstrip antenna has been optimized to perform efficiently within this environment. The consistently low VSWR values across the frequency range suggest a broad operational bandwidth for this antenna. This is particularly useful for applications requiring performance across a range of frequency.



Dielectric Constant

Graph 6: Variation in Directivity of Annular Microstrip Antenna with Dielectric constant

The graph shows a positive correlation between the dielectric constant and the directivity. As the dielectric constant increases, the directivity also increases, indicating improved radiation focus in a specific direction. At higher dielectric constant values (approaching ε_r=10 the antenna exhibits high directivity, reaching close to 10 dB. This indicates that materials with higher permittivity enhance the antenna's ability to concentrate radiation in the desired direction.

Higher ε_r results in reduced wavelength within the substrate ($\lambda_{eff}=\lambda/\varepsilon_r$ which enhances the resonance and radiation characteristics of the antenna. Increased permittivity confines the electromagnetic fields more effectively, leading to higher directivity.

Summary and Conclusion

It has been found that by varying the density and size distribution of dust particles, significant improvements in antenna gain can be achieved over a wide frequency range. One major advantage of using high density plasma as a medium is its low-cost compared to traditional methods used for improving antenna gain such as adding additional elements or increasing substrate.

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