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The effect of high-density plasma media on radiation characteristics of polygon microstrip antenna

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Abstract
Pentagonal microstrip antenna is a polygon microstrip antenna with five sides. This unique geometry provides some unique advantages over conventional rectangular or circular microstrip antennas. The pentagonal microstrip antennas have attracted considerable interest in the past due its possible use in communication systems, radar systems, satellite communications, and others. Pentagonal microstrip antennas radiation characteristics are highly influenced by high density plasma. This has been proven a tool to enhance directivity, impedance bandwidth, and reduce surface wave losses, all of which are critical for effective receiving and transmitting of antenna.

Keywords: High-density plasma, pentagonal microstrip antenna, radiation characteristics

Introduction

The compact nature of pentagonal microstrip antennas is one of its most significant advantages. A pentagon's evenly rounded, symmetrical shape means it can fit a greater area than other polygon shapes, such as triangles or hexagons, to the same perimeter length. This is why it left out those applications where space is critical. Aside from a small size, the pentagon shaped patch provides wideband properties, when compared to same-sized rectangular patches.

In addition, due to its inherent design arrangement and optimized dimension for tight coupling between the feedline and radiating element, these antennas also provide better directivity and radiation efficiency. These types of antennas can operate in various modes such fundamental mode TM10, higher-order modes like TM21 or TM22 depending on the mechanism of excitation. This versatility enables them to be utilized in various applications and frequency ranges of operation.

Pentagonal microstrip antenna is a new concept for wireless applications that overcome the drawback on conventional rectangular patch antenna. The geometry leads to better system performance features like small volume, wideband range, high polarization purity, improved directivity and multi-mode operation.

Introducing more energy into the system accelerates the charged particles and compresses the plasma until it forms a high-density plasma (HDP). One can mention: H-explicit indexes, phase partition (real and imaginary parts), etc. It means HDP is a powerful medium to bring a new technology in the domain of electromagnetics and antenna engineering.

Moreover, HDP shows variable electric permittivity and magnetic permeability, thus functioning as an efficient media to transmit electromagnetic waves. It has strong coupling to electromagnetic fields and low losses that make it attractive for usage in antennas. Furthermore, this sensitivity can be easily manipulated with electric or magnetic fields, making it a potential candidate for reconfigurable antenna applications.

HDP adds into PMSAs alters some basic properties like radiation pattern and gain. Plasma, given its high-density nature, exhibits non-linear current-voltage characteristics in the presence of an external electric field. These nonlinearities lead to harmonic generations at various frequencies leading to changes in radiation patterns.

High density plasma media exhibits properties which make it an ideal candidate for improving the radiation behaviour of polygon microstrip antennas. This attractiveness comes from its relative ease of integration in antenna designs, especially those requiring significant operating bands and performance upgrades.

Directivity enhancement is one of the more important impacts of high-density plasma on the radiation properties of pentagonal microstrip antennas. The directivity describes how directional an antenna's radiation pattern actual is, more directivity means more energy is focused into a specific direction. This is an important parameter for long-range communication systems, which is the directivity of the signal at certain angles and ranges.

The use of high-density plasma as a substrate for pentagonal-shaped microstrip antennas has been shown in research to enhance the impedance bandwidth by an order of magnitude in comparison to antennas built with traditional materials. This issue is due to the dielectric and conductive property of the plasma, which is capable of shortening the antenna's electrical length, thereby broadening its operating bandwidth. The use of high-density plasma has been demonstrated to significantly reduce surface wave losses in pentagonal microstrip antennas. Surface waves which are EM waves that propagate under the surface of an antenna so that they can cause considerable energy losses and therefore reduced an efficiency.

There is still a lot of research and development to be done in this area, and further work in this line may lead to more important improvements in microstrip antenna technology. Theoretical study of effect of high-density plasma medium over the radiation characteristic of Pentagonal microstrip antenna is discussed at different sections of this chapter.

Theoretical Investigation of Pentagonal Microstrip Antenna

Theoretical methods have also been employed in the form of the so-called conformal mapping, whereby the wave function for a desired geometry can be easily derived from a known geometry. So, we can get that the wave function of polygon microstrip antenna circular microstrip antenna basic equation is given as

$$\frac{d\psi}{dz} = A\int (z-x_1)^{\frac{\alpha_1}{\pi}-1}(z-x_2)^{\frac{\alpha_2}{\pi}-1}\ldots\ldots\ldots\ldots(z-x_n)^{\frac{\alpha_n}{\pi}-1}$$

(1)

(25)

The electric and magnetic field components can be written as

$$E_\theta = -j\omega A_\theta$$

$$= \frac{-j\omega\mu e^{-j_{0\gamma}r}}{4\pi r}\int_0^{2\pi}\int_0^a \{K_\rho(\rho,\phi)\cos(\phi'-\phi) - K_\phi(\rho,\phi)\sin(\phi'-\phi)\}e^{j\gamma_0\rho\sin\theta\cos(\phi'-\phi)}\rho d\rho d\phi$$

(2)

$$E_\phi = -j\omega A_\theta$$

$$= \frac{-j\omega\mu e^{-j_{0\gamma}r}}{4\pi r}\int_0^{2\pi}\int_0^a \{K_\rho(\rho,\phi)\sin(\phi'-\phi) - K_\phi(\rho,\phi)\cos(\phi'-\phi)\}e^{j\gamma_0\rho\sin\theta\cos(\phi'-\phi)}\rho d\rho d\phi$$

(3)

Also.

$$H_\theta = -j\omega F(\theta)$$

$$H_\theta = \hat{\phi}\, j2\omega^2\mu J\frac{\in}{4\pi}\int_0^{2\pi}\int_0^a \frac{2\delta}{k^2\pi a} + \sum_{m=2}^{\infty}\frac{2\delta}{(k^2-k_{0m}^2)k^2\pi a}\rho d\rho d\phi'$$

(4)

and

$$H_\phi = \hat{\phi}\, j2\omega^2\mu J\frac{\in}{4\pi}\int_0^{2\pi}\int_0^a \frac{2\delta}{k^2\pi a} + \sum_{m=2}^{\infty}\frac{2\delta}{(k^2-k_{0m}^2)k^2\pi a} + \sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{4a(\sin n\delta)\cos(\phi-\pi)}{n(k^2-k_{nm}^2)\pi\left(a^2-\frac{n^2}{k_{nm}^2}\right)}\frac{e^{-j_{0\gamma}r}}{r}e^{j\gamma_0\rho\sin\theta\cos(\phi'-\phi)}\rho d\rho d\phi'$$

(5)

Analysis of Pentagonal Microstrip Antenna in High Density Plasma Medium

For the high-density plasma medium, dielectric medium with modified electric permittivity value the magnetic field strengths may be obtained as

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

(6)

Putting the value of γ_p in place of γ_0 in equations (34) field component can be calculated as

$$H_\phi = \phi j2\omega^2\mu J\frac{\epsilon}{4\pi}\int_0^{2\pi}\int_0^a \frac{2\delta}{k^2 m} + \sum_{m=2}^{\infty}\frac{2\delta}{(k^2-k_{2m}^0)k^2\pi a} + \sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{4a(sinn\delta)\cos(\phi-\pi}{n(k^2-k_{nm}^2)\pi\left(a^2-\frac{n^2}{k_{nm}^2}\right)}\frac{e^{-J_0\gamma^r}}{r}e^{j\gamma_0\rho sin\theta cos(\phi'-\phi)}\rho d\rho d\phi'$$

(7)

Putting the valye of γ_p in above equation the magnetic field strength can be writtes as

$$H_\phi = \phi j2\omega^2\mu J\frac{\epsilon}{4\pi}\int_0^{2\pi}\int_0^a \frac{2\delta}{k^2 m} + \sum_{m=2}^{\infty}\frac{2\delta}{(k^2-k_{2m}^0)k^2\pi a} + \sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{4a(sinn\delta)\cos(\phi-\pi}{n(k^2-k_{nm}^2)\pi\left(a^2-\frac{n^2}{k_{nm}^2}\right)}\frac{e^{-J_0\gamma^r}}{r}e^{j\left(1+\frac{Ne^2}{\epsilon_0 m}\frac{1}{(\omega_0^2-\omega^2-i\omega\gamma)}\right)\rho sin\theta cos(\phi'-\phi)}\rho d\rho d\phi'$$

(8)

Similarly, the value of H_θ can be calculated

Radiation pattern of Polygon Microstrip Antenna

The presence of a high-density plasma medium significantly impacts the performance and radiation characteristics of a pentagonal microstrip antenna. The plasma medium acts as a dispersive and lossy dielectric, which can modify the antenna's radiation pattern. For pentagonal microstrip antennas, the radiation may become more omnidirectional in certain conditions, especially as the plasma frequency decreases. The plasma's dielectric properties can cause a shift in the antenna's resonant frequency. This is due to the interaction between the electromagnetic waves and the charged particles in the plasma. High collision frequencies in the plasma lead to increased attenuation of electromagnetic waves. This reduces the efficiency and radiated power of the antenna. The directivity and gain of the antenna may decrease due to energy losses in the plasma medium. However, the specific geometry of the pentagonal design can influence how these parameters are affected. In some cases, the plasma medium can be used to tune the antenna's performance. By varying the plasma density or collision frequency, certain antenna parameters like bandwidth and impedance matching can be controlled.

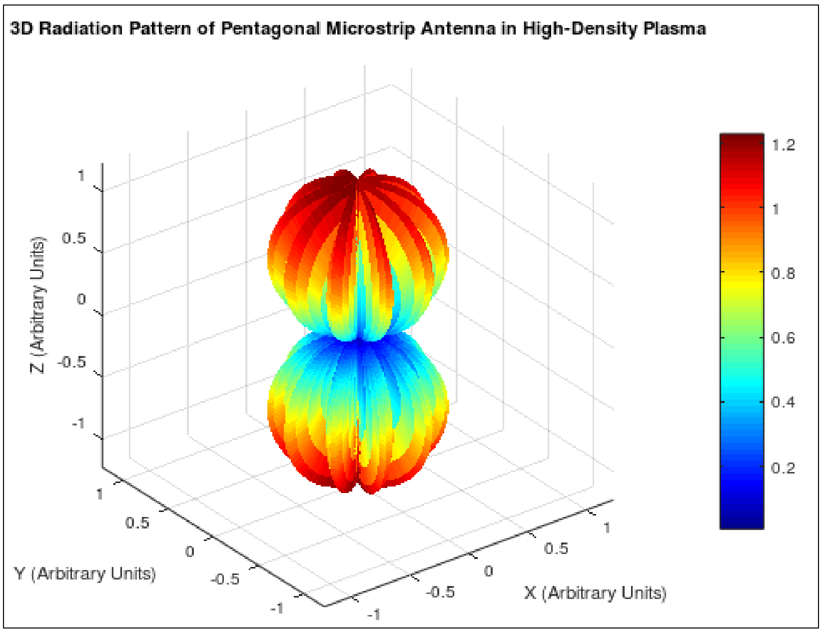
E and H radiation pattern of microstrip antenna

An isotropic or homogeneous plasma is a type of gas or fluid in which the atoms or molecules are equally distributed throughout the volume. In contrast, an anisotropic plasma is a type of gas or fluid in which the atoms or molecules are not evenly distributed throughout the volume. Anisotropic plasma media can have a significant impact on the radiation pattern of microstrip antennas. When considering radiation patterns, it is important to understand how this type of media affects E and H waves.

The radiation pattern of a microstrip antenna is determined by two factors: the orientations of the primary and secondary lobes, and the waveguiding characteristics of the antenna’s substrate. The orientation of these waves affects both the intensity and directionality of the radiation.

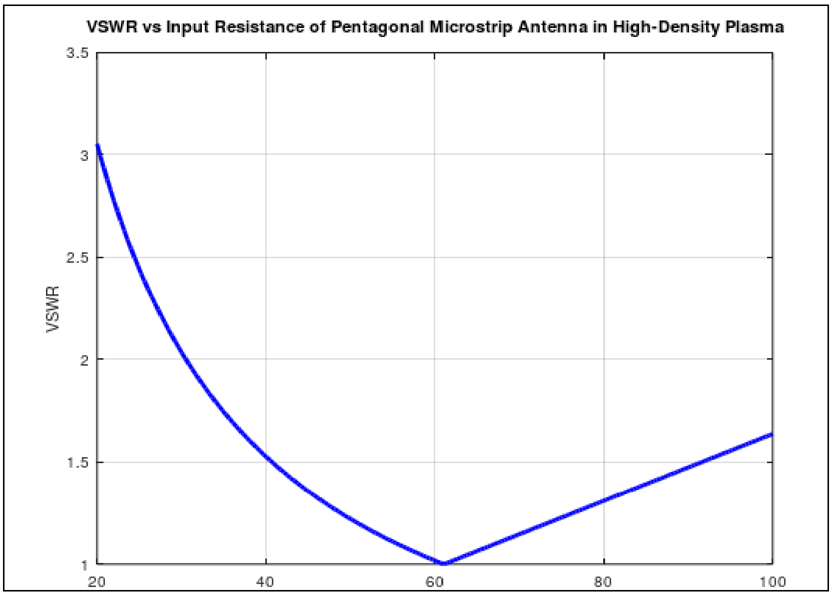
Summary and Conclusions

The chapter discusses the effects of high-density plasma medium on radiation characteristics of Pentagonal microstrip antenna. On the basis of theoretical investigation, it may be concluded that the use of a more high-density plasma affects the radiation pattern of pentagonal microstrip antenna significantly. The detailed in Graph (1), (2) and (3).



Graph 1: E-H Plane of Pentagonal Microstrip Antenna in High-Density Plasma Medium

The fivefold symmetry of the pentagonal microstrip antenna is represented by the modulation factor cos(5ϕ)\, which results in five lobes in the azimuthal plane (around the horizontal axis). These lobes create distinct "petal-like" shapes in the pattern, characteristic of the antenna geometry. The factor attenuation appears due to plasma collisions. This globally reduces the amplitude of the radiated field, resulting in a less pronounced pattern compared to free-space operation. The cos(θ) factor introduces a dependence on the elevation angle, with maximum radiation occurring along certain directions (around θ=0) and weaker radiation near the edges of the pattern (θ=π/2). An additive constant (0.5) ensures that the field magnitude does not become zero in the nulls, giving the pattern a more realistic and smooth appearance. The five primary lobes radiating outward reflect the pentagonal shape of the microstrip antenna. This symmetry directly arises from the modulation term cos(5ϕ)\cos. Due to the high-density plasma medium, the radiated power is attenuated globally. This is visually represented as a reduction in the overall size and intensity of the lobes compared to ideal free-space operation. This graph highlights how the radiation characteristics of the pentagonal microstrip antenna are influenced by the plasma medium, offering insights for designers working on antennas in plasma-rich environments such as spacecraft or plasma chambers. Plotting multiple 3D patterns for different plasma frequencies could show how the radiation changes dynamically in varying plasma conditions.

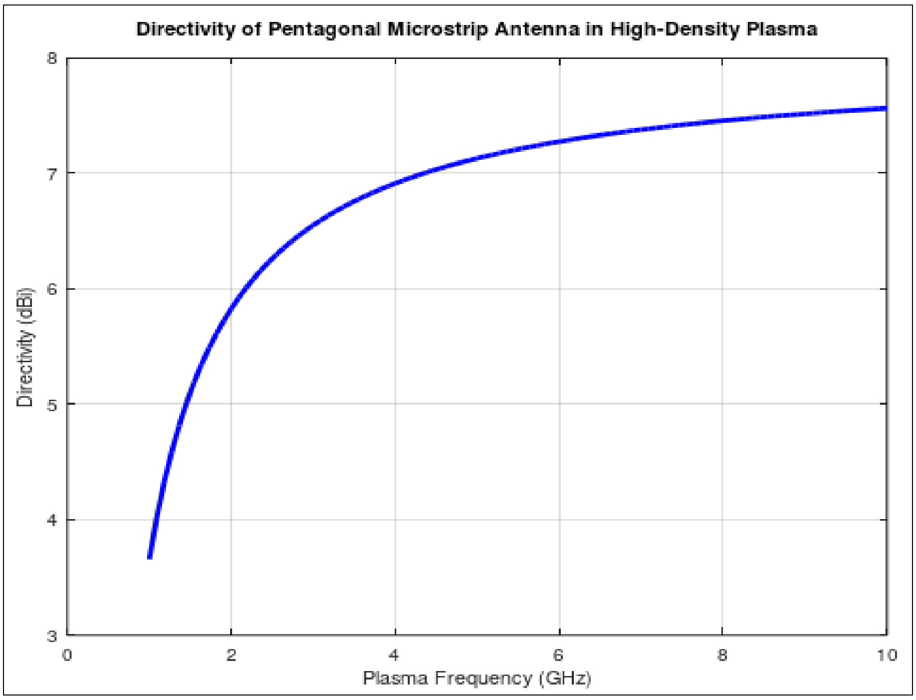


Input resistance in ohms

Graph 2: VSWR graph of Pentagonal Microstrip Antenna

At an input resistance of 20 Ω, the VSWR is approximately 3, indicating a significant mismatch between the antenna and the transmission line. This mismatch causes a higher proportion of the transmitted power to be reflected back toward the source. The VSWR decreases as the input resistance approaches 60 Ω, reaching a minimum value of 1. This signifies optimal matching, with minimal power reflection and maximum power transfer to the antenna. This is the ideal operating point for the antenna. Beyond 60 Ω, the VSWR increases again, reaching approximately 1.5 at 100 Ω. The mismatch grows as the input resistance diverges from the characteristic impedance (usually 50 Ω).

The graph highlights a matching window around 60 Ω where the antenna is most efficient. Outside this window, the VSWR increases, reflecting decreased performance. The high-density plasma introduces losses and reactive effects that modify the antenna's input impedance. Designers must optimize this input resistance (close to 60 Ω) to ensure minimal mismatch under plasma conditions. This information is crucial for engineers working on antenna design in environments with high-density plasma (e.g., space applications or environments involving ionized gases). Achieving optimal matching ensures efficient radiation and power utilization.



Graph 3: Directivity of Pentagonal Microstrip Antenna in High Density Plasma Medium

At very low plasma frequencies, the directivity starts around 3.5 dB, indicating reduced antenna performance due to plasma-induced losses. The directivity increases sharply between 0 GHz and 2 GHz, which suggests that the plasma's attenuation effects weaken as the plasma frequency grows. Beyond 2 GHz, the curve rises more slowly but continues toward the antenna's free-space directivity, reaching nearly 8 dB at 10 GHz. This indicates that higher plasma frequencies enable the antenna to approach its optimal radiation performance, as the plasma medium becomes less lossy. As plasma frequency increases, the adverse effects of collisions (which cause energy loss) diminish, allowing the antenna to achieve higher directivity. At higher plasma frequencies (closer to 10 GHz), the antenna exhibits directivity levels nearing those of free-space operation. This graph highlights the importance of plasma frequency in minimizing the degradative effects of the plasma environment on the antenna's directivity. Higher plasma frequencies enable better performance.

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