INTERNSHIP REPORT

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DECLARATION

I hereby declare that the research internship work entitled **"Design and Simulation of Plasma Antenna and Its Application"** submitted at NIT, Patna is a record of original work done by me under the guidance of Dr. Rajan Agrahari, Assistant Professor, Department of Electronics and Communication Engineering at NIT, Patna. I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea, data, fact, or source in my submission.

I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources, which have not been properly cited, or from whom proper permission has not been taken when needed.

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Signature of Supervisor Date Signature of Student

ACKNOWLEDGEMENT

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Introduction to Plasma Antenna

A plasma antenna is a type of antenna that utilizes ionized gas as a conductive medium instead of traditional metal elements. The concept of using ionized gas for transmitting and receiving signals dates back to 1919, proposed by J. Hettinger, with the first experimental results demonstrated by Askaryan and Raveskii in the 1960s.

Plasma antennas operate by creating and destroying plasma using bursts of RF power applied to discharge tubes. When the plasma is not energized, it is non-conducting and invisible to electromagnetic radiation. Conversely, when energized, plasma becomes a conductor, enabling it to transmit radio signals or allow incident microwave pulses to pass through without interaction or reflection, provided the plasma frequency in the antenna is sufficiently low.

Key Advantages of Plasma Antennas:

- **Electrical Control:** Unlike metallic antennas, plasma antennas can be controlled electrically rather than mechanically. This means the antenna can be switched on and off quickly, and its properties can be adjusted dynamically without the need for physical movement or reconfiguration.
- **Stealth Capabilities:** In military applications, plasma antennas offer significant stealth advantages. Since they can be made non-conductive when not in use, they are less detectable by hostile radars. This makes them ideal for covert operations where minimizing the risk of detection is crucial.
- **Rapid Reconfiguration:** Plasma antennas can be rapidly reconfigured to change radiation patterns. This is particularly useful in applications where different radiation patterns are needed in quick succession or where the antenna needs to adapt to changing conditions without suffering perturbations from unused elements.
- **Increased Degrees of Freedom:** Plasma antennas offer more degrees of freedom than traditional metal antennas. This increased flexibility allows for more innovative designs and applications, providing opportunities for advancements in telecommunications, radar, and other fields.
- **Efficiency and Low Noise:** Plasma antennas have been shown to be efficient and generate low noise levels. This makes them suitable for narrowband high-frequency (HF) and very high-frequency (VHF) communications, where maintaining signal clarity and strength is essential.

Inactive State Advantages:

When inactive, plasma antennas function as dielectric tubes with minimal radar cross-sections. This property makes them suitable for stealth communications by reducing their visibility to radar systems. Additionally, the rapid deactivation of plasma antennas, extinguishing the plasma within microseconds to milliseconds, helps in minimizing co-site and parasitic interferences.

Research and Applications:

- **Space Communications:** Plasma antennas are highly suitable for space applications due to their ability to be reconfigured and their low radar cross-section when inactive. Their wide frequency range and adaptability make them ideal for communication with satellites and spacecraft.
- **Dynamic Frequency Tuning:** Plasma antennas can be rapidly reconfigured to operate across a wide frequency range. This adaptability is beneficial for applications requiring frequency agility, such as in dynamic communication environments or multi-band communication systems.
- **Wideband Communication:** Plasma antennas are capable of operating over a broad frequency spectrum, making them suitable for wideband communication applications. This allows them to support high data rates and multiple communication channels simultaneously.
- **Interference Reduction:** The ability to quickly switch between active and inactive states helps in reducing co-site and parasitic interferences. This feature is advantageous in environments with multiple communication systems operating in close proximity.
- **Advanced Research:** Plasma antennas are used in experimental setups and research to explore new communication technologies and plasma physics. Their unique properties provide valuable insights into the behavior of electromagnetic waves in ionized media.
- **Emergency and Tactical Communications:** Their rapid reconfiguration and adaptability make plasma antennas useful in emergency and tactical situations where quick adjustments and reliable communication are critical.
- **Low Radar Cross-Section (RCS)**: Plasma antennas can be made nearly invisible to radar when the plasma is turned off, reducing their detectability. This makes them useful for stealth applications.

Despite the progress made in the study and application of plasma antennas, comprehensive experimental studies of specific plasma antenna parameters remain an ongoing area of research. The potential applications and advantages of plasma antenna technology continue to attract significant interest, highlighting its promising future in various fields. The continued development and refinement of plasma antennas are likely to lead to even more innovative uses and enhancements in communication, radar, and other advanced technologies.

Ringing Effect in Plasma Antennas

What is the Ringing Effect?

The ringing effect refers to oscillations or repeated reflections of electromagnetic waves within an antenna structure, which persist after the initial signal has been transmitted. This phenomenon occurs when there is an abrupt change in the system, such as switching the plasma on or off, leading to transient effects. These oscillations can degrade the performance of the antenna by causing signal distortion, reducing efficiency, and introducing noise and interference.

Causes of Ringing in Plasma Antennas

- **Rapid Plasma State Changes:** The plasma state can change rapidly when it is turned on or off or when its density is adjusted. These abrupt changes can introduce transient effects leading to ringing.
- **Impedance Mismatch:** Similar to traditional antennas, impedance mismatches between the plasma antenna and the transmission line or other components can cause reflections, leading to oscillations within the system.
- **Intrinsic Plasma Oscillations:** Plasma can support various oscillatory modes, such as plasma waves, which can contribute to ringing when excited by an external signal.
- **Nonlinearities in Plasma Behavior:** The nonlinear nature of plasma can lead to complex interactions with the electromagnetic waves, contributing to ringing effects.

Impacts of Ringing in Plasma Antennas

- **Signal Distortion:** Ringing can cause significant distortion of the transmitted or received signals, degrading communication quality and data integrity.
- **Efficiency Loss:** Oscillations caused by ringing consume energy that would otherwise be used for effective radiation or reception, leading to a loss in antenna efficiency.
- **Interference and Noise:** Ringing can introduce unwanted noise and interference, both within the antenna system and with external systems, potentially impacting overall performance.

Mitigation Strategies

- **Smooth Plasma Transitions:** Implementing techniques to smooth the transitions when the plasma state changes can help reduce transient effects and minimize ringing.

- **Impedance Matching:** Ensuring proper impedance matching between the plasma antenna and the associated transmission lines and components can minimize reflections and reduce ringing.
- **Damping Mechanisms:** Incorporating materials or designs that absorb excess energy can help dampen oscillations. This can include resistive elements or specific plasma configurations designed to reduce oscillatory modes.
- **Optimized Plasma Control:** Using precise control over plasma parameters such as density, collision frequency, and ionization levels can help mitigate nonlinearities and reduce ringing.
- **Simulation and Modeling:** Advanced simulation tools, like CST, can be used to model the behavior of plasma antennas and predict potential ringing effects. This allows for optimization of the design before physical implementation.
- **Frequency Filtering:** Employing filters to remove unwanted frequencies that contribute to ringing can help clean up the signal and improve overall performance.

Practical Considerations

- **Real-Time Adjustments:** Implementing real-time monitoring and adjustment mechanisms to control plasma parameters dynamically can help mitigate ringing effects as operating conditions change.
- **Experimental Validation:** Conducting thorough experimental testing to validate simulation results and refine the design based on real-world performance is crucial for minimizing ringing.

By carefully considering these factors and implementing appropriate mitigation strategies, the impact of ringing in plasma antennas can be significantly reduced, leading to improved performance and reliability.

Functionality and Advantages of Plasma Antennas

Plasma antennas exhibit versatile functionality, serving as both receivers and transmitters, and can even act as reflectors under certain conditions. Their unique properties make them advantageous for various electromagnetic communication applications.

Operational Characteristics:

- **Frequency Reflection:** Plasma antennas can reflect electromagnetic waves within specific frequency ranges. Particularly, frequencies lower than the plasma frequency are reflected, allowing the plasma to function as a reflector. This capability provides plasma antennas with significant versatility, enabling them to operate effectively across different frequency intervals.

- **Transparency and Transmission:** When active, plasma antennas are transparent to electromagnetic waves with frequencies higher than the plasma frequency. This characteristic facilitates efficient wave transmission and minimizes interference in the communication channel.
- **Adaptability:** Plasma antennas offer adjustable features including frequency, gain, and beamwidth. They can be rapidly reconfigured electrically, allowing for adjustments within microseconds to milliseconds, which contrasts with slower mechanical reconfiguration methods. This adaptability enhances their utility in dynamic environments.
- **Array Configuration:** Multiple plasma antennas, each tuned to different frequencies, can be stacked into arrays without interference. This stacking capability increases the antenna system's versatility and effectiveness.

Inactive State Advantages:

When inactive, plasma antennas function as dielectric tubes with minimal radar cross-sections. This property makes them suitable for stealth communications by reducing their visibility to radar systems. Additionally, the rapid deactivation of plasma antennas, extinguishing the plasma within microseconds to milliseconds, helps in minimizing co-site and parasitic interferences.

How Plasma Antennas Work with Low Radar Cross Section?

Plasma antennas can effectively minimize radar cross section (RCS) due to their unique properties:

- **Active State:** When active, plasma antennas operate like traditional antennas, with the plasma serving as the conductive medium for transmitting and receiving electromagnetic signals. The radar cross section during this phase is comparable to other antenna types.
- **Inactive State:** When deactivated, plasma antennas transform into dielectric tubes with minimal conductivity. In this state, the plasma is extinguished, and the antenna's structure resembles a low-loss dielectric material. This configuration significantly reduces the radar cross section because the dielectric material reflects and absorbs radar waves differently than metals.

Key Points:

- **Minimal Reflection:** As dielectric materials, inactive plasma antennas reflect fewer radar waves compared to metal antennas, reducing their visibility on radar.
- **Quick Transition:** The plasma can be rapidly turned on or off, allowing for swift changes between active and inactive states. This fast transition helps in minimizing detection during critical times.
- **Reduced RCS:** In the inactive state, the antenna's radar cross section is substantially lower, making it less detectable by radar systems and enhancing stealth capabilities.

Introduction to Plasma

Plasma is often considered the fourth state of matter, distinct from the traditional solid, liquid, and gaseous states. It is an ionized gas consisting of positively charged ions and free electrons. Plasma forms when a gas is energized to a point where the energy supplied is sufficient to overcome the binding energy of electrons, causing them to be ejected from atoms and creating a mixture of ions and electrons.

This state of matter is unique due to its conductive properties and its strong interactions with electromagnetic fields. Plasmas are electrically conductive and respond strongly to magnetic and electric fields, which makes them particularly useful in a range of technological applications. For instance, in fluorescent lights and plasma TVs, the ionized gas inside emits light when electric current passes through it. Similarly, plasma is used in industrial processes such as plasma cutting and coating, where its high temperature and energy enable precise and efficient material processing.

In nature, plasma is abundant, comprising more than 99% of the observable universe. Stars, including our sun, are primarily composed of plasma. The high temperatures and pressures in these celestial bodies ionize the gas, leading to the formation of plasma.

In modern science and technology, plasma is an area of significant research interest. It is explored for its potential in advanced fields such as plasma propulsion for space exploration, plasma-based medical treatments, and fusion energy research, which aims to harness the power of plasma to achieve sustainable nuclear fusion.

Overall, plasma's distinctive properties and versatility make it a crucial component in both natural phenomena and innovative technologies.

Parameters of Plasma Physics for Plasma Antenna

Plasma, being an ionized gas, can exhibit significant electrical conductivity when highly ionized. This property allows plasma to replace metallic media in various applications, including antennas. Plasma filaments, due to their conductive nature, can function as transmission line elements for guiding electromagnetic waves or as surfaces for radiation in antennas. To effectively design and optimize plasma antennas, it is crucial to understand the interaction between the plasma medium and electromagnetic waves. Two fundamental plasma parameters are particularly important: **plasma frequency** and **collision frequency**.

1. **Plasma Frequency** (fp **)**

   Plasma frequency is a key parameter in plasma physics and represents the natural oscillation frequency of electrons in a plasma. It is defined as the frequency at which the collective oscillations of free electrons occur. Plasma frequency can be calculated using the following formula:

   $$w_p = \frac{\sqrt{\frac{n_e\, e^2}{m_e \varepsilon_0}}}{2\pi}$$

   where:

   - e is the electron charge,
   - n_e is the electron density,
   - ϵ_0 is the permittivity of free space,
   - m_e is the electron mass.

   At frequencies below the plasma frequency, the plasma behaves as a reflective medium for electromagnetic waves, whereas at frequencies above the plasma frequency, the plasma becomes transparent. This characteristic is crucial for designing plasma antennas, as it determines the operational frequency range and the efficiency of wave propagation.

2. **Collision Frequency** (ν**)**

   Collision frequency refers to the rate at which electrons in the plasma collide with neutral atoms or other electrons. It is an important parameter because it affects the overall conductivity of the plasma and the attenuation of electromagnetic waves. The collision frequency can be expressed as:

   $$\nu = n_e K(T_e)$$

A higher collision frequency results in increased energy dissipation and attenuation of electromagnetic waves. Therefore, in plasma antenna design, it is essential to consider the collision frequency to ensure that the plasma medium provides effective wave transmission and minimal loss.

Design Considerations

When designing plasma antennas, these plasma parameters must be carefully considered to ensure optimal performance. The plasma frequency will determine the operating frequency range of the antenna, while the collision frequency will influence the efficiency and effectiveness of wave propagation. Proper management of these parameters enables the creation of efficient and high-performance plasma-based antenna systems.

Understanding these interactions allows for the development of innovative antenna designs that leverage the unique properties of plasma for various applications in communications, radar, and other fields.

Drude Model for Plasma Antennas

To simulate the performance of a plasma monopole antenna, CST software, which utilizes the finite integral technique, is employed. The software models the behavior of plasma using the Drude dispersion model. This model describes the transport properties of electrons in materials, especially metals, and is based on kinetic theory.

The Drude model assumes that the microscopic behavior of electrons can be treated classically, resembling a pinball machine where a sea of constantly jittering electrons bounceoff heavier, relatively immobile positive ions.

Drude Model for Electrical Conductivity

The electrical conductivity ($\sigma(\omega)$) of a plasma according to the Drude model is given by:

$$\boldsymbol{\sigma(\omega) = (n_e * e^2) / [m_e * (\nu + i\omega)]}$$

where:

- $\mathbf{n_e}$ = Electron density (number of free electrons per unit volume)
- $\mathbf{e}$ = Elementary charge (approximately 1.602 x 10^-19 coulombs)
- $\mathbf{m_e}$ = Electron mass (approximately 9.109 x 10^-31 kg)
- $\boldsymbol{\nu}$ = Collision frequency (rate of collisions between electrons and other particles)
- $\boldsymbol{\omega}$ = Angular frequency of the incident electromagnetic wave ($\omega = 2\pi f$, where f is the frequency)

Complex Conductivity:

The conductivity is complex due to the presence of both real and imaginary parts:

$$\sigma(\omega) = \sigma'(\omega) + i\sigma''(\omega)$$

where:

- $\sigma'(\omega)$ = Real part of the conductivity (resistive losses)
- $\sigma''(\omega)$ = Imaginary part of the conductivity (reactive component)

Structure of a Plasma Antenna

A plasma antenna is composed of three main components:

1. **Enclosure:** The enclosure serves as the container in which the plasma is formed and maintained. It is typically made of a dielectric material such as glass or ceramic, which is transparent to the electromagnetic waves and does not interfere with the plasma's operation.
2. **Plasma Medium:** The plasma, or ionized gas, acts as the conductive medium in the antenna. This is the fundamental distinction between plasma antennas and traditional metallic antennas. The plasma’s ability to conduct electricity and respond to electromagnetic fields allows it to serve as the radiating element or transmission line.
3. **Coupler:** The coupler is a device used to connect external signals to the plasma medium. It ensures that the electromagnetic signals are efficiently transferred to and from the plasma. The coupler is essential for both transmitting and receiving signals through the plasma antenna. It is designed to interface with the enclosure and the plasma medium, facilitating the coupling of energy between the external circuitry and the plasma.

Design Produce

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Abstract - A plasma antenna, diverging from conventional metal conductors, operates using noble gases. This study encompassed simulations and experiments on both dipole plasma antennas and dipole metal antennas operating within the very high frequency (VHF) band. The plasma dipole antenna configuration comprises two specially designed plasma sources positioned as the arms of a standard metal dipole.

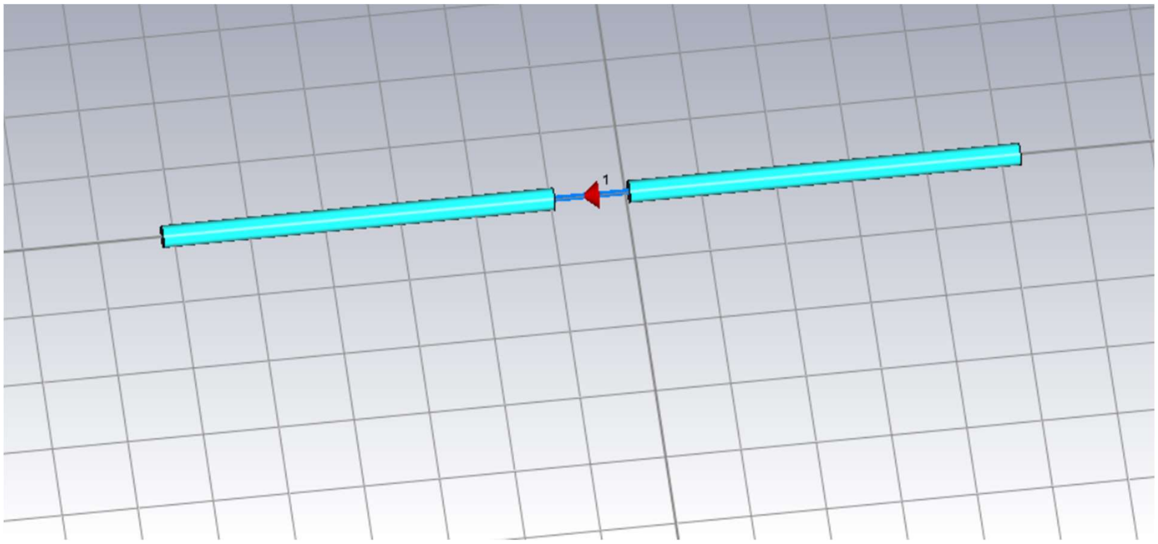
Initially, simulations were conducted to determine the plasma parameters and calculate the dielectric permittivity. The gas-filled plasma tube was energized by directly connecting it to the electrodes via an AC power supply (10 kV, 30 mA). Simulated results for return loss, gain, and impedance were presented for both the dipole plasma antenna and the dipole metal antenna.

The findings indicate superior impedance, voltage standing wave ratio (VSWR), and gain characteristics in the dipole plasma antenna compared with its metal counterpart. In addition, the rapid on/off functionality of plasma antennas, unachievable with metal antennas, renders them particularly appealing for stealth applications like radar systems.

SIMULATION MODEL

Design Summary:

- **Antenna Type**: Dipole Plasma Antenna
- **Dimensions**: Length = 104 cm, Radius = 1.5 cm
- **Frequency Range**: 100–125 MHz (VHF band)
- **Port Impedance**: 70 ohms
- **Port Location**: At z=0z = 0z=0 with a 10 cm gap
- **Plasma Conditions**: 1-torr pressure, 300-K plasma temperature
- **Excitation**: Discrete port between the two arms
- **Simulation Model**: Uniform dispersive Drude model
- **Materials**: Dielectric tubes filled with plasma, omitting metallic electrodes



Dielectric Properties of Gases in Plasma Antennas

For plasma antennas in the VHF band, the dielectric properties of the gases used are critical. These properties include the real part (ε'r) and imaginary part (ε"r) of the dielectric constant at specific frequencies:

- **Argon:**
  - **Frequency:** 107.72 MHz
  - **ε'r:** -1800.50
  - **ε''r:** 9800.35
- **Neon:**
  - **Frequency:** 110.26 MHz
  - **ε'r:** -35000.40
  - **ε''r:** 198500.75
- **Argon-Neon Mixture:**
  - **Frequency:** 109.42 MHz
  - **ε'r:** -27000.55
  - **ε''r:** 152000.60

The negative ε'r values indicate metallic-like behavior, while ε"r represents energy dissipation. These properties are essential for simulating plasma antenna performance.

Calculated Drude Parameters for Different Gases

The behavior of gases in plasma antennas can be characterized using the Drude model, which describes the electrical properties of materials. Two important parameters in this model are the plasma frequency (ω_p) and the collision frequency (V_p). These parameters help in understanding the conductive properties of the gases and their interaction with electromagnetic waves.

Below are the calculated Drude parameters for Argon, Neon, and an Argon-Neon mixture:

Argon

- **Plasma Frequency (ω_p):** 1.727×10^{11} rad/s
- **Collision Frequency (V_p):** 4.127×10^{9} 1/s

Neon

- **Plasma Frequency (ω_p):** 7.874×10^{11} rad/s
- **Collision Frequency (V_p):** 4.163×10^{9} 1/s

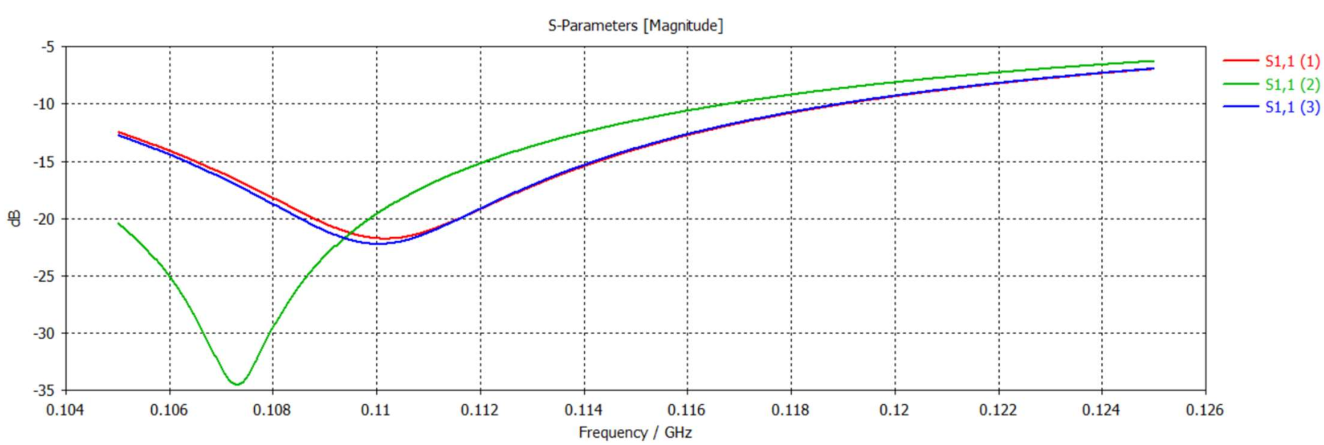
Argon-Neon Mixture

- **Plasma Frequency (ω_p):** 6.845×10^{11} rad/s
- **Collision Frequency (V_p):** 4.127×10^{9} 1/s

These parameters indicate the rate at which free electrons oscillate in the plasma and the frequency of collisions between these electrons and the gas molecules. Higher plasma frequencies suggest more rapid oscillations, while the collision frequency affects the rate of energy loss within the gas. Understanding these parameters is essential for designing and optimizing plasma antennas for various applications.

S-parameter

This plot shows the S-parameters (magnitude) in dB against frequency in GHz for three different gas environments:



1. **S1,1 (1)** - Red curve: Neon (Ne)

2. **S1,1 (2)** - Green curve: Argon (Ar)
3. **S1,1 (3)** - Blue curve: A mixture of 25% Argon (Ar) and 75% Neon (Ne)

Observations:

1. **Neon (Red Curve)**:

   - The S-parameter starts around -15 dB at 0.104 GHz and decreases steadily to about -20 dB at 0.110 GHz, after which it begins to increase again.
   - This indicates a dip in reflection at around 0.110 GHz.

2. **Argon (Green Curve)**:

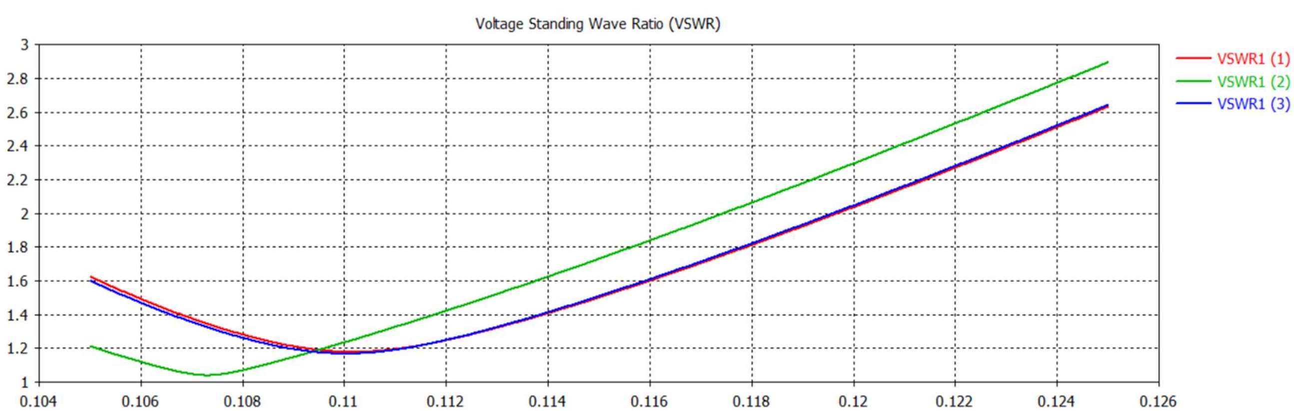
   - The S-parameter starts around -15 dB at 0.104 GHz, sharply dips to about -34.52 dB around 0.107 GHz, and then rises back up to around -20 dB at 0.116 GHz.
   - The deep dip suggests a significant reduction in reflection at around 0.104 GHz.

3. **Argon-Neon Mixture (Blue Curve)**:

   - The S-parameter follows a similar trend to Neon, starting around -15 dB at 0.104 GHz, dipping to around -22.24 dB at 0.109 GHz, and then rising again.
   - This indicates that the mixture's behavior is more similar to Neon than to pure Argon, but with slightly different attenuation characteristics.

VSWR

This plot shows the Voltage Standing Wave Ratio (VSWR) as a function of



frequency for three different gas environments:

1. **VSWR1 (1)** - Red curve: Neon (Ne)
2. **VSWR1 (2)** - Green curve: Argon (Ar)
3. **VSWR1 (3)** - Blue curve: A mixture of 25% Argon (Ar) and 75% Neon (Ne)

Observations:

1. **Neon (Red Curve)**:

   - The VSWR starts around 1.6 at 0.104 GHz and gradually decreases, reaching about 1.17 around 0.110 GHz. It then starts to increase again.
   - The lower the VSWR, the better the impedance matching, indicating less reflection at that frequency.

2. **Argon (Green Curve)**:

   - The VSWR starts around 1.6 at 0.104 GHz, drops significantly to about 1.038 at 0.107 GHz, and then increases sharply.
   - The dip at 0.107 GHz indicates excellent matching at this frequency, with minimal reflected power.

3. **Argon-Neon Mixture (Blue Curve)**:

   - The VSWR behavior is similar to that of Neon, starting around 1.6 at 0.104 GHz, with a minimum around 0.109 GHz at a VSWR of 1.167 (or 1.17).
   - This suggests the mixture has good matching characteristics close to those of Neon but slightly higher VSWR values.

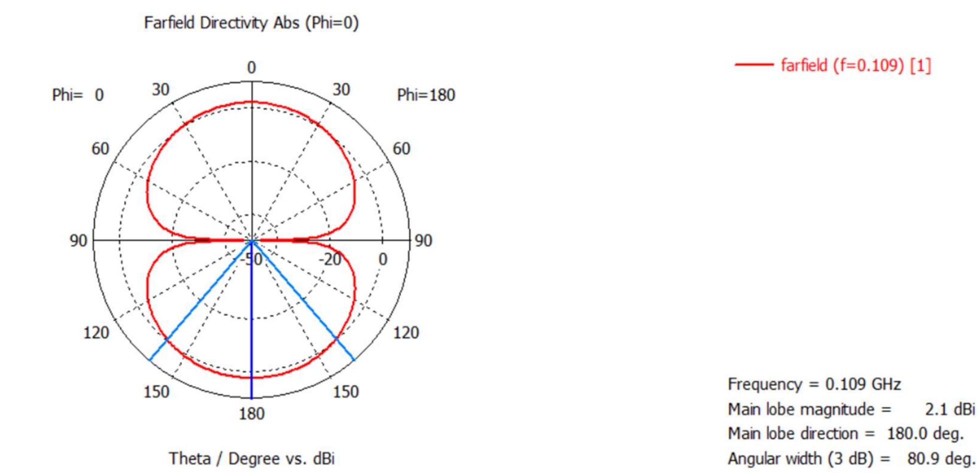
Gain Pattern

1. **Argon-Neon Mixture**

Directivity Plot:

- The plot represents the radiation pattern of the antenna in the far field, showing how the power is distributed with respect to angle (Theta) in the Phi = 0° and Phi = 180° planes.

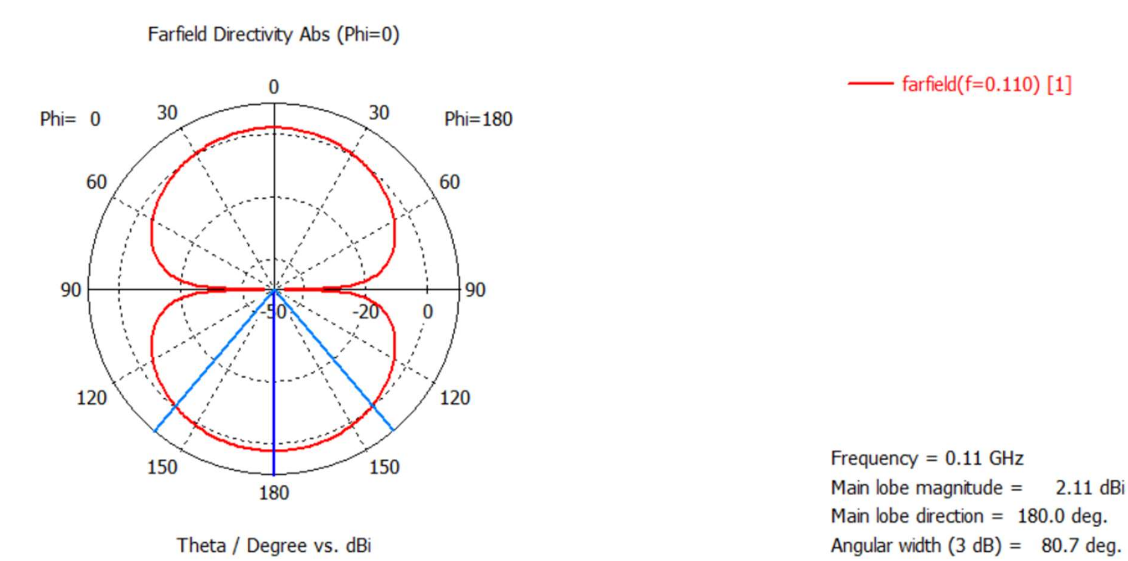
- The main lobe is directed at 180° with a magnitude of 2.1 dBi.



2. **Neon**

Directivity Plot:

- The plot represents the radiation pattern of the antenna in the far field, showing how the power is distributed with respect to angle (Theta) in the Phi = 0° and Phi = 180° planes.
- The main lobe is directed at 180° with a magnitude of 2.11 dBi.
- The angular width of the main lobe at 3 dB (half-power beamwidth) is 80.7

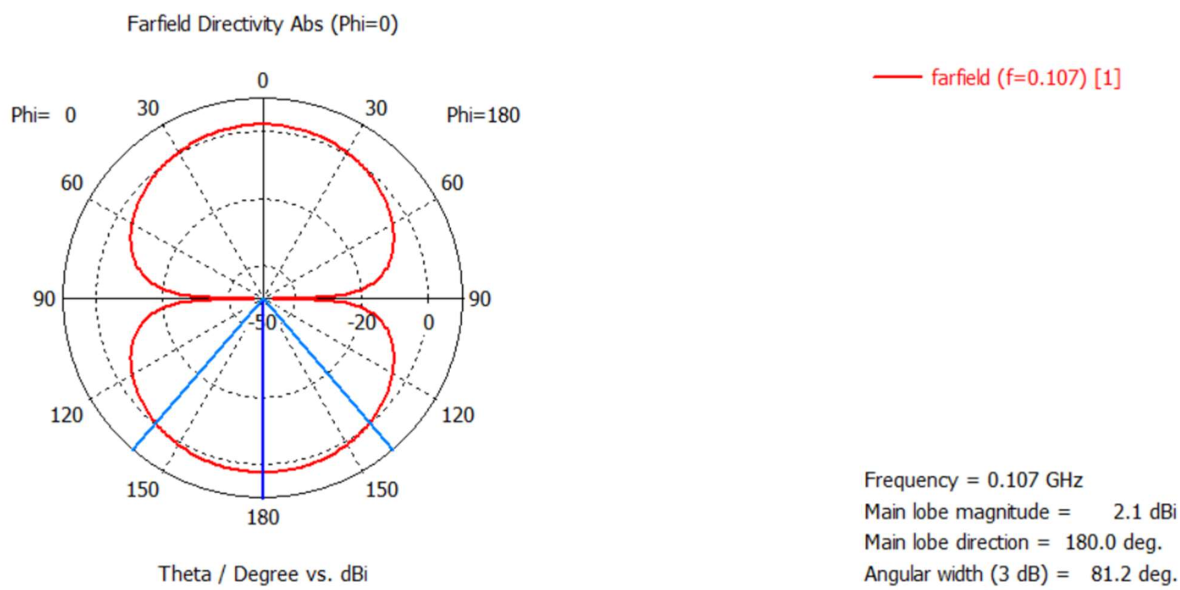


degrees.

3. Argon

Directivity Plot:

- The plot represents the radiation pattern of the antenna in the far field, showing how the power is distributed with respect to angle (Theta) in the Phi = 0° and Phi = 180° planes.
- The main lobe is directed at 180° with a magnitude of 2.1 dBi.



Conclusion

Plasma antennas, with their ability to serve as receivers, transmitters, and reflectors, offer significant advantages for electromagnetic communication applications due to their unique operational characteristics and reconfigurability. The analysis of S-parameters and VSWR reveals that plasma antennas using different gases such as Neon, Argon, and Argon-Neon mixtures exhibit distinct reflection and impedance matching properties. Argon shows excellent transmission and impedance matching around 0.107 GHz, while Neon provides optimal performance around 0.110 GHz, and the Argon-Neon mixture closely follows Neon's behavior. These findings highlight the versatility and adaptability of plasma antennas, making them ideal for applications requiring rapid reconfiguration and precise control over frequency ranges. Furthermore, the ability to reduce interference and the potential for stealth applications underscore their value in advanced communication and radar systems. The unique properties of plasma, such as its responsiveness to electromagnetic fields and the ability to rapidly switch states, enable innovative designs and advancements in telecommunications and other fields.

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