PLASMA ANTENNA

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Abstract
The plasma antenna is an emerging technology and is a type of radio antenna currently in development in which plasma is used instead of the metal elements of a traditional antenna. A plasma can be used for both transmission and reception. Although plasma antennas have only become practical in recent years, the idea is not new; a patent for an antenna using this concept was granted to J. Hettinger in 1919. Early practical examples of the technology used discharge tubes to contain the plasma and are referred to as ionized gas plasma antennas. Ionized gas plasma antennas can be turned on and off and are good for stealth and resistance to electronic warfare and cyber attacks. This paper comprises the discussion of basic theory, operations of plasma antenna, features, advantages etc.

Keywords : Wi-Gig – Wireless Gigabit Alliance, RF – Radio Frequency, EM – Electro Magnetic, Wi-Fi – Wireless Fidelity, DC – Direct Current, CCTV – Closed Circuit Television.

I. UNDERSTANDING THE PLASMA

Now, before talking of a plasma antenna, we should understand the term plasma. There are five states of matter known to this date, namely, solid, liquid, gas, plasma and supercooled solid as shown in Fig. 1. Plasma is the fourth state of matter. The story of plasma starts with gases. A substance is said to be a gas if its boiling point is below room temperature under atmospheric pressure. More specifically, the intermolecular forces of attraction existing amongst the molecules are almost negligible. So that means higher the boiling point, higher the intermolecular forces of attraction.

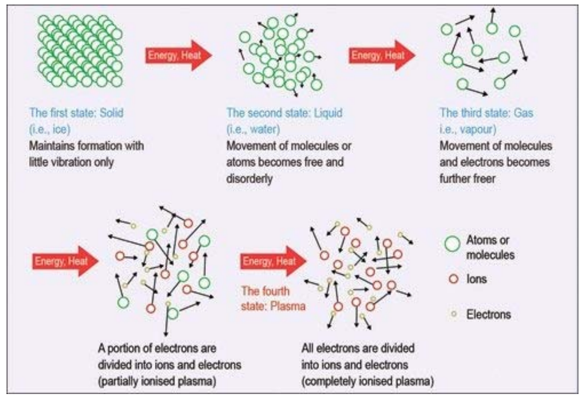

Fig. 1. Different States of Matter

Talking of electrical property of gases, we can say they are generally insulators. Now what happens when we supply thermal energy to the gases is that the heat absorbed is used to cut off the intermolecular forces. By applying more heat energy to the gases, we can convert them into a plasma state. Overall, this process is known as ionisation, i.e., the conversion of atoms to ions and electrons. For plasma to exist, ionisation is necessary. The term plasma density is a synonym to electron density.

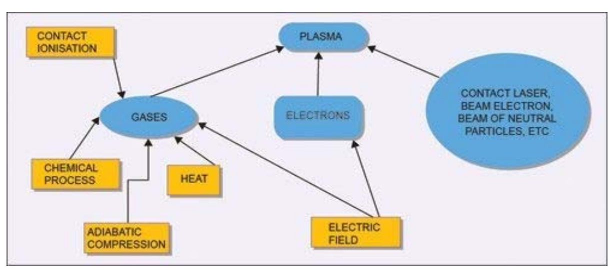

Fig. 2. Plasma Generation Technique

Definition: Plasma can be defined as a set of quasineutral particles with free electric charge carriers which behave collectively. In this definition, two terms are very important:

1. Quasi-neutral: Meaning that there is the same quantity of positive and negative particles so, as a whole, it behaves as a fluid without net charge.

2. Collectively: Meaning that plasma as a whole is capable of carrying out processes that generate electric and magnetic fields to which it can react. This is one of the most important properties that lead to some unparallel characteristics.

II. PRODUCTION OF PLASMA

Basically, plasma is produced when enough atoms are ionised to significantly affect the electrical properties of a gas under normal conditions. It is not any alien form but only a state of ionisation, a state of matter. There are eleven elements that exist as gas under normal conditions. Out of these, group 18 elements are of prime importance (if we are analysing discharge tubes) as they are inert. Plasma is much visible matter in the universe, being about 99 per cent of all the matter. Besides astronomical plasma, we can distinguish two main groups of plasma from laboratory point of view:

1. Thermal plasma: Here electrons and ions are at thermal equilibrium. But for this thermal equilibrium to exist, very high temperatures are required, specifically in the range of 4000K-20,000K. But this equilibrium makes this kind of plasma to be unfit for the antenna system application (welding, plasma torches, sintering and etching).

2. Non-thermal plasma: Here ions and neutral particles are at lower temperature as compared to electrons, or we can say that the electrons are somewhat hotter than ions. This fits for the antenna system application.

Fluorescent lamps and neon signs are examples of plasma states. In case of lamps, the extra electrons added at the electrode ionises the gas with the help of mercury atoms and the result is ionised state of plasma.

The most common way of generating a low-temperature plasma is by applying electric field to a neutral gas. The neutral gas always contains a few electrons and ions. When an electric field is applied to it, these free carriers are accelerated and they collide with atoms and molecules. This is similar to an avalanche breakdown, that is, a large number of charge carriers are formed at the loss of old carriers, and so there is a balance in carrier generation. In this way, steady-state plasma is developed.

Consider DC discharge system for a rough idea. If we subject the gas to high pressure, there would be a highcollision rate and this could produce thermal plasma. But DC discharge system requires non-thermal plasma, so we will pressurise the gas at low pressure to produce a low-collision rate. A high electric field is applied to the electrode plates and the phenomena stated above takes place. Following this pattern, if we apply more voltage, we will get more plasma density. But if we apply electric current in microsecond pulses, we can obtain high plasma density at the same input power. This can be advantageous as the voltage requirements of the system are determined by the nature of gas, electrode material, current density and length of the tube.

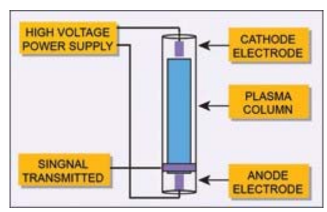

Fig. 3. Generating a low-temperature plasma with electric field application

Earlier, the DC discharge systems were very bulky but now engineers have been able to reduce their size. but the ionisation instrument is still bulky and hence it limits its universal application.

III. INTERACTION OF PLASMA WITH EM WAVES

As we are interested in designing antenna systems, the interaction and behaviour of plasma with EM waves must be investigated for better understanding. As per some theses, various relations are set up (qualitatively) to study their interaction. Plasma contains quasi-neutral particles, which means they are highly conductive. For analysing interaction with EM waves, four important parameters are conductivity, electrical permittivity, magnetic permittivity and propagation constant. Qualitatively, the interaction of plasma with EM waves can be formulated as:

1. Plasma with high-collision frequency behaves as a lossy medium: This is due to the reason that with increase in plasma pressure and electron density, the rate of collision increases, so considerable amount of energy will be lost. (This is the reason why thermal plasma is unfit to be used in antennae.)

2. If W is greater than Wp: EM wave frequency is greater than plasma frequency (an inherent property of plasma), so wave propagates in plasma and the plasma has dielectric properties which are electrically controllable.

3. If W is less than Wp: The propagation constant is imaginary. The wave is vanishing with the plasma medium. The wave can be absorbed or reflected depending on the collision frequency.

4. Effect of magnetic field: The plasma can be shaped into specific geometry to match the needs of intended application. This is done by applying magnetic field which will make a cyclic motion of the charged particle. This is also an important property as it frees the traditional image of antennae in our mind, although geometries are limited.

IV. THE PLASMA ANTENNA

Antenna is a matching section between two output terminals of a transmitter and space, or between space and two input terminals of a receiver. Radiation is simply the transfer of energy through a medium. So a plasma antenna is a type of transmission and reception device that makes use of plasma medium rather than metal components.

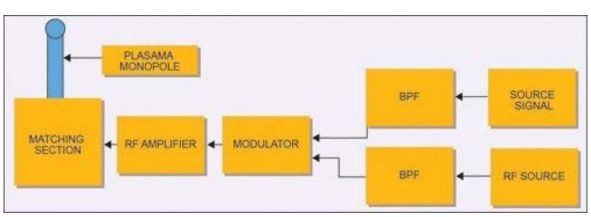

Fig. 4. Block Diagram of Simple Monopole Plasma Antenna

The electron behaviour of plasma antenna is completely different from that of metal antenna. In the plasma antenna, the functioning concept is altogether different. It is due to electrons in free space rather than electrons moving freely. The design allows for extremely short pulses that are very important to many forms of digital communication and radars. One fundamental distinguishing feature of a plasma antenna is that the gas ionising process can manipulate resistance. When de-ionised, it has infinite resistance and hence it does not react with RF. when ionised, it will have some resistance due to which it will react with EM waves. In plasma antenna, ionized gas is being enclosed in the tube and the gas acts as the conducting material of the antenna. When this gas is ionized to a plasma state it becomes conductive replacing the metals which were used in traditional antenna. The plasma antenna generates localized concentrations of plasma to form a plasma mirror which deflects a Radio Frequency (RF) beam. The plasma can be freely moved to the desired geometry of the reflector by plasma diode which enables the beam to be steered quickly without the need for mechanical motion. When the gas is not ionized, it allows other antennas to transmit and receive without any interference which is a very useful feature.

V. PLASMA REFLECTOR

Plasma behaves as a reflector if the frequency is lower than the plasma frequency. The reflection occurs at a critical surface inside of the plasma. The interesting of this is the rapid inertialess two dimensional scanning, frequency selectivity and potential wideband frequency performance. Plasma reflectors can be created using laser and optics using a sequence of line discharges forming a sheet of plasma.

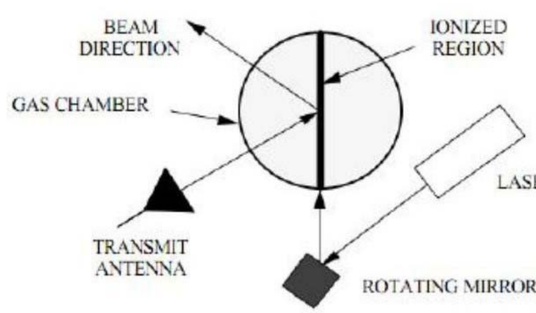

Fig. 5. Plasma Reflector Using Laser

VI. METHODS OF PRODUCING RADIATIONS

A. There are two methods of producing radiation

1. m-radiation method: In this method, the radiation is produced by current oscillations on the surface of a metal and by disturbing current on the interface between plasma and medium. (Example is surface wave-driven plasma antenna.)
2. d-radiation method: In this method, the excitation is applied to the interface which disturbs current between plasma and medium and radiation takes place. It is just like the radiation in dielectric antennae.

B. Plasma antennae are of two types

1. Gas chamber: In this type, we use the DC discharge system with a very high-voltage source applied to cathode and anode, and then the signal is superimposed on it (a plasma column). This is a primitive implementation of plasma antenna.

2. Solid-state semiconductor type: The concept of this type of plasma antenna is that the charge carriers in metal and semiconductor behave similar to those in gas plasma. The medium properties will vary as per constructions. However, the interaction of EM waves with charge carriers will have very similar properties to that of quasi-neutral particles.

The semiconductor having enough free carriers to interact with EM waves is called semiconductor plasma with very high electron density that can be obtained by heating, current injection or by optical excitation.

VII. FEATURES

Ringing effect which was a problem associated with a regular antenna is due to the traditional metal elements which reduces its capabilities in high frequency short pulse transmission. But in plasma antenna the antenna gets deionized by sending a pulse and thus the problem of ringing effect is overcome. Another feature of plasma antenna is that it can easily communicate signals in very short pulses and also it has the ability to focus a single beam. This feature is useful in areas of digital communication and radar.

VIII. APPLICATIONS

Plasma antennas find its applications in variety of fields due its unique properties, characteristics and advantages over traditional metallic antennas.

1. Military applications: Invisibility to radar means that signals sent by plasma antennas are very difficult to be detected by any outsider and as military needs to send and receive top secret information without any outside interception plasma antennas have qualities and potential that can be used to develop and produce equipments in military applications within foreseeable future.
2. Faster internet: Plasma antennas can provide a faster rate of data transmission and hence can be used to provide high speed internet like Wi-Gig (Wireless Gigabit Alliance) which is faster than Wi-Fi.

3. Public safety networks: Public safety networks like

CCTVs are used to prevent crimes, track down criminals and also may be accepted as video evidence in court. If these devices are tampered or damaged by criminals then it is possible to for a handler from safety department to diverge or reroute the traffic using plasma antennas.

4. Radio and television broadcasting: Signal strength of signals emitted by plasma antennas is relatively stronger than traditionally used normal metal antennas hence it lasts longer without damping and being extinguished hence broadcasting companies may require less relay stations and repeaters to relay signals to further areas and hence it may bring down cost of the broadcasting system for service provider companies.

5.Space communications: Plasma antennas are relatively lighter than normal antennas and hence can used as communication devices in spacecrafts like jet planes, commercial planes, even in space shuttles and also in unmanned air vehicle sensor antennas.

IX. ADVANTAGES

The plasma antenna has many advantages over current conventional antennas which make them suitable for military and commercial use.

1. Invisible to Radar: Plasma antennas are invisible to antennas. When the plasma antennas are inactive the radars will find it difficult to find the antennas. Also when the antennas are active the radars will have to look for antennas in the plasma frequency, they will be invisible to signals above plasma frequency. Hence these signals will be invisible to detectors other than the intended receivers. This advantage of plasma antennas make them suitable for military use.

2. No Ringing Effect: There is no ringing effect in plasma antenna as it allows extremely short pulses, which a metal conductor doesnt allow. When there is sudden change in input a burst of electricity flow through the metal conductor for a short time, this is ringing effect. This wastes energy and produces unwanted electromagnetic waves.

3. More efficient: Plasma antennas can be designed smaller, lighter and more efficient than the traditional antennas. Plasma antennas are made more portable by replacing metal conductors with semi-conductor chips or gases.

4. Dynamically reconfigurable: The gain, frequency, polarization, power, etc. of the plasma antenna can be changed by the handler of the antenna. A single plasma antenna can do work of multiple normal antennas thus reducing the space and cost required for operation.

5. Fast Transmission: By using plasma semiconductor antenna the electromagnetic waves produced can be focused to form a beam which travels faster than wave when certain diodes are activated.

X. DISADVANTAGES

Use of plasma makes the design of antenna complex. It has other disadvantages too.

1. Cannot Penetrate Walls: The semi-conductor plasma antenna developed by the inventors was limited to high frequency hence their use also gets limited. Also the signal from these antennas couldnt penetrate the walls. This can resolved by using reflectors to make waves reach the destination.

2. More Power: More power is used to ionize the gas, hence ionizer increases power consumption of the antenna.

3. Stable and repeatable plasma volumes: Not all of the gas is ionized to become plasma, some parts remain unionized. Thus the volume of the plasma formed during each time should be same to generate stable electromagnetic waves. This can be achieved by keeping the current flowing through it constant, which will excite the same amount of particles.

XI. CONCLUSION

The principle behind the working of the plasma antenna is same as the normal conventional antennas. Only the solid metal conductor is replaced with the plasma. This plasma gives it many advantages over the current antennas. It is more efficient, fast and also can be manufactured cheaply. There might be some disadvantages associated with plasma antennas but those can be overcome. It will take some time for plasma antennas to be commercially available, but it will change the landscape of antennas when it is available for use.

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