Radiation characteristics and electromagnetic compatibility of 5-20 KHz ac plasma antenna

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Abstract. In order to meet the needs of engineering, plasma antenna must meet the requirement in terms of gain, bandwidth, noise, electromagnetic compatibility (EMC) and so on. A plasma antenna prototype was established by 5-20 KHz high voltage ac power, whose radiation characteristics and electromagnetic compatibility was tested and analyzed. Results show that 5-20 KHz ac plasma antenna is of broadband impedance characteristics. Compared with 50 Hz ac plasma antenna, the noise reduces and the gain increases from 150 MHz to 350 MHz. When plasma antenna connected to radio is on, the radio can receive signals. The interference to radio is much lower than RF surface wave plasma antenna and 50 Hz ac plasma antenna. It is of a certain electromagnetic compatibility.

1. Introduction
Plasma antennas are usually radio-frequency (RF) antennas using the plasma column instead of metal conductors or other dielectric materials as elements [1-3]. They are constructed by insulating tubes filled with low pressure gas. Over decades, plasma antenna has attracted much attention since they have numerous advantages over conventional metal antenna [1, 3-6]: its parameters can be reconfigured conveniently by changing discharge power, which makes it possible for it to be used at wide waveband and to simplify the matching network; plasma can be rapidly created and destroyed by applying an electrical pulse to the discharge tube, hence a plasma antenna can be rapidly switched on and off. When it is on, it exhibits a high conductivity, providing a conducting medium for the applied RF signal. When it is off, it is non-conducting and invisible to electromagnetic (EM) radiations, the radar cross section (RCS) close to 0. So plasma antenna can provide an integral and most important part in both communication and plasma stealth technology.

So far many theoretical and experimental works including impedance, gain and radiation characteristics have been conducted on this subject [1-12]. But few papers concern investigation of their electromagnetic compatibility (EMC). It has been reported that 50 or 60 Hz ac plasma antenna is of very high noise [9], moreover, the antenna efficiency and gain are not satisfactory. In the past decades, the vast majority of plasma antennas have been produced by RF power, which is called surface wave (SAW) plasma antenna and is proved to have a certain gain and low noise [9]. However, the bandwidth of such antenna is limited to the pumping RF frequency, and the cost of pumping RF generator is also high [10, 11]. Electromagnetic interference (EMI) between excitation and signal channels seriously affected the normal work of antenna and other instruments. Hence, the problems of...
EMC, if not addressed, not only can’t make the antenna to meet the engineering requirement, but also likely to cause greater losses. Here 5-20 KHz ac power supply is employed to produce plasma antenna, such structure is characterized as square-loop plasma antenna in an experiment and this paper is aimed at presenting the experimental investigation and analysis of the EMC.

2. Antenna structure and experimental setup

2.1. 5-20 KHz ac plasma antenna

Figure 1 shows the home-made 5-20 KHz ac plasma antenna, the main body of which was a commercially available tube with an inner diameter of 10 mm, an outer diameter of 12 mm and a length of 1200 mm. The system was filled with argon and mercury, at a working pressure about 5Torr. The structure of the tube was characterized as square-loop, with two electrodes inserted in an insulating box. A 5-20 KHz ac adjustable power supply was also installed in the insulating box. The capacitive coupling model was applied to the signal coupling system. A capacitive coupler of width 30 mm was placed around the tube and shielded by a well-sealed shielding box (100 mm×60 mm×60 mm) made of cast aluminium. The coupler was connected to transmission line to apply the useful signal. The distance between the center of the coupler and the electrode was longer than 200 mm.

![Figure 1. 5-20 KHz ac plasma antenna.](image)

2.2. Experimental setup

To investigate the wireless communication capability and EMC for radio frequency range (100-400 MHz) of 5-20 KHz ac plasma antenna, an experimental setup was constructed and dedicated experiments were carried out to characterize it. A schematic of the experimental setup for 5-20 KHz ac field produced plasma, which acts as a plasma antenna, is shown in figure 2. 5-20 KHz ac power supply could be operated between 5-20 KHz up to 500 W. In the experiment, discharge frequency was 10 KHz. The discharge power of fluorescent was measured with a digital fluorescent oscilloscope. The input impedance was measured with a vector network analyzer which was calibrated. The output impedance of RF port of network analyzer is 50 Ω, which is equal to characteristic impedance of the transmission line. A matching network with variable inductors and capacitors was used to maintain the 50 Ω impedance for transmitting antenna. Then, we collected it to a radio directly. Our aim was now to investigate the radiation characteristics and to analyze the EMC of plasma antenna. In addition, we compared it to 50 Hz ac plasma antenna, 40.68 MHz surface wave plasma antenna and metal antenna in terms of radiation characteristics and EMC.
3. Results

3.1. Input impedance of plasma antenna

It is measured and calculated that the discharge power of 5-20 KHz ac plasma antenna is 6.2 W, which is nearly equal to that of 50 Hz ac plasma antenna (5.8 W) and much lower than that of surface wave plasma antenna (29 W). Figure 3 shows experimental data input impedance $Z_i = R + jX$ for a 5-20 KHz ac square-loop plasma antenna driven at 10 KHz. The solid and dashed lines represent resistance and reactance respectively. It is easily found that in a wide frequency range, the resistance components are close to 50 and the reactance ones to 0. It is obvious that 5-20 KHz ac plasma antenna has broadband impedance characteristics.

Figure 3. Input impedance of 5-20 KHz ac plasma antenna.

Figure 4. Input impedance of 50 Hz ac plasma antenna.

Figure 4 shows the impedance characteristics of 50 Hz ac plasma antenna. These results display that this antenna also has broadband impedance characteristics, very similar to 5-20 KHz ac plasma antenna. But the difference is that the impedance curves of 50 Hz ac plasma antenna are relatively rough compared with the 5-20 KHz one due to larger disturbance of plasma produced by 50 Hz ac
power supply. Because of strong coupling between the two circuits: signal and excitation, we can’t measure input impedance of 40.68 MHz surface wave plasma directly.

3.2. Gains and pattern of 5-20 KHz plasma antenna

Figure 5 displays the relative gains of 5-20 KHz ac and 50 Hz ac plasma antennas. In the experiment, the EM waves are imposed with a frequency ranging from 150 to 400 MHz, in this scope the VSWR is lower than 2. It is shown from the results that fluctuation of the value of 50 Hz ac plasma antenna is very large with the frequency changing. In contrast, 5-20 KHz plasma antenna has ideal gains in a wide frequency range. Moreover, varies of value are smaller than 50 Hz plasma antenna. Figure 6 displays radiation pattern in horizontal plane of 5-20 KHz plasma and metal antennas working at 200 MHz, where the VSWR is about 1.2. Because of impacts by shielding layer inside the insulation box, the pattern has directionality. It is obvious that, the two patterns are very similar, and the gain of plasma antenna is a little smaller than that of metal antenna.

3.3. EMC analysis of plasma antenna

Figure 7 is the frequency spectrum of signals measured by spectrum analyzer (N9010, Agilent). The output power of signal source is unchanged -10 dBm (0.1 mW). We choose signal of 100 MHz in this experiment to test disturbance of plasma to signals. 50 Hz ac plasma antenna, 5-20 KHz ac plasma antenna, 40.68 MHz surface wave plasma antenna and metal antenna are used in the experiment. High-pass filter is connected between spectrum analyzer and surface wave plasma antenna to prevent the 40.68 MHz signal from damaging spectrum analyzer. It is so clearly that 50 Hz ac plasma has large disturbance to signal so that the noise level is much higher than other antennas. Besides, the signal level is lower. The gains of 5-20 KHz ac and surface wave plasma antenna are nearly the same, a little lower than conventional metal antenna. And the noise levels of the two antennas are also nearly the same. For a uniform plasma density, the wave vector along plasma column \( \beta \) can be determined from [8]:

\[
\varepsilon_r T_0 J_1(T_p a^r) K_0(T_p a^\ell) + T_p K_1(T_p a^r) I_0(T_p a^\ell) = 0
\]

(1)

Where \( T_p^2 = \beta^2 - \varepsilon_r k_0^2 \) and \( T_0^2 = \beta^2 - k_0^2 \), \( a \) is plasma column radius, \( k_0 \) is free-space wave vector = \( \frac{\omega}{c} \) and \( \varepsilon_r \) is plasma dielectric constant. \( K' \)'s and \( I' \)'s are Bessel function. The plasma dielectric constant can be expressed as:

\[
\varepsilon_r = 1 - \frac{\omega^2_{pe}}{\omega(\omega + iv)}
\]

(2)
Where $v$ is electron-neutral collision frequency, electron plasma frequency can be written as

$$\omega_{pe}^2 = \frac{n_e e^2}{m_e \varepsilon_0}$$  \hspace{1cm} (3)

When the EM waves propagate in plasma produced by 50 Hz ac power supply, the unstable plasma leads to changes in the wave vector $\beta$ constantly. In addition, the reflection coefficient is constantly changing. Hence, the measured curves such as impedance and spectrum of 50 Hz ac plasma antenna are unstable. In contrast, there’re much smaller changed in parameters of 5-20 KHz ac and surface wave plasma antennas, and the changes of values are relatively small with time.

![Figure 7. Signal spectrum of plasma antenna.](image)

**Table 1.** A table with headings spanning two columns and containing notes.

| Radio frequency of Dalian (MHz) | 99.1   | 100.8  | 105.7  | 106.7  |
|--------------------------------|--------|--------|--------|--------|
| 50 Hz ac plasma antenna        | Signal strength: 40%, large noise | Signal strength: 40%, large noise | Signal strength: 40%, large noise | Signal strength: 40%, large noise |
| 5-20 KHz ac plasma antenna     | Signal strength: 80%, a little noise | Signal strength: 80%, a little noise | Signal strength: 60%, a little noise | Signal strength: 60%, a little noise |
| Surface wave plasma antenna    | Unable to work | Unable to work | Unable to work | Unable to work |
| Metal antenna                  | Signal strength: 100%, small noise | Signal strength: 100%, small noise | Signal strength: 100%, small noise | Signal strength: 100%, small noise |
A radio is also used in the experiment to analyze communication properties and EMC of antennas. Table 1 shows the working abilities of radio connected to 50 Hz ac plasma, 5-20 KHz ac plasma antenna, surface wave plasma antenna and metal antenna. Though there is a filter connected between plasma antenna, the EMI is still exist, especially in the system of surface wave plasma antenna. When plasma is on, the radio connected to surface wave plasma antenna cannot work normally. The signal strength is relatively low when the radio connected to 50 Hz ac plasma antenna. And the noise is very large so that we cannot hear the broadcast normally. If the radio is connected to metal antenna, there is very strong signal and low noise. When connected to 5-20 KHz ac plasma, the noise is a litter higher than metal antenna, but much lower than the 50 Hz one. Besides, signal strength is close to metal in relatively low signal frequency. This antenna maintains a certain EMC.

4. Conclusion
We have presented measured results of input impedance, radiation characteristics and analyzed the EMC of 5-20 KHz plasma antenna. Compared with 50 Hz ac plasma, 40.68 MHz surface wave plasma antenna and metal antenna, it has a certain EMC and ideal gains for relative low signal frequency. Although surface wave plasma can also maintain a certain gain, the strong electromagnetic interference of exciting port lead to bad EMC. Both 50 Hz and 5-20 KHz plasma antennas have broadband impedance characteristics, but the unstable plasma in 50 Hz lead to changed results and larger noise.

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