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STUDY OF A FLUORESCENT TUBE AS PLASMA ANTENNA

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Abstract—The present paper is a work on fluorescent tube performing the function of a monopole plasma antenna. In the construction, the needed power supply to the fluorescent tube is controlled by an IC 555 timer. In the experiments the supply frequency varies from 25 Hz to 200 Hz. By using a vector network analyzer it is shown that the persistence of plasma developed inside the tube persists for longer duration with increase in supply frequency. It is also found that the stability of resonant frequency increases with the increase in frequency of the AC power supply measured up to 200 Hz. Result shows that the effective part of a fluorescent tube functioning as Monopole plasma antenna is about 60% of the total length of the tube.

1. INTRODUCTION

Plasma antenna is an agile antenna which hides itself from hostile radar in switch off mode and brought to functioning or switch on mode immediately when it is needed. Plasma antenna consists of glass tube filled with some neutral gases such as Argon energized by any non-thermal plasma generation method. Functioning of a plasma antenna largely depends upon the behavior of electromagnetic waves propagating in plasma. Previous works on plasma antenna have shown that plasma antenna is just as effective as a metal antenna [1] in which the length of the plasma column increases by the square root of the applied power [2]. The research work done on circular fluorescent tube in order to find out the gain shows that the average gain in the

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case of fluorescent tube functioning as a plasma antenna is 6 dB lower than its metallic counterpart with the same dimensions [3]. Also, DC biased plasma antenna has been studied, and it is found that the gain of a plasma antenna which consists of Ar-Hg vapour is particularly high at high frequency [4]. The fluorescent tube operates by the principle of electron flow and photo phosphoresces. When an AC voltage is applied across the filaments present at both ends of a tube, it provides an intense source of electrons. Each end acts as cathode for alternate halves of a voltage cycle. As this behavior of the electrodes is repeated, Argon gas is energized to the plasma state which excites Mercury vapour to radiate UV rays. These UV rays strike the layer of phosphorus compound coated inside the tube, and the phosphorus splits the UV rays into visible rays.

In the present work, a fluorescent tube of 20 cm length and 1 cm diameter is used to get the antenna effect. The operating circuit is made using an IC 555 chip which controls the voltage of the tube and maintains a consistence source of power to its electrodes. The frequency of the applied voltage is varied from 25 Hz to 200 Hz, and the return loss results have been observed on a vector network analyzer.

2. EXPERIMENTAL SETUP

plasma antenna has been constructed and tested for return loss characteristic, as shown in Figures 1 and 2. An Agilent PNA-L Vector Network Analyzer is connected between coupling sleeves over the fluorescent tube and the ground plane. An aluminum disc of radius 11 cm is used for the ground plane. The tube is 20 cm long and 1 cm in its diameter. 230 V AC is applied across electrodes of the tube.

The glow due to fluorescence indicates that the Argon gas inside

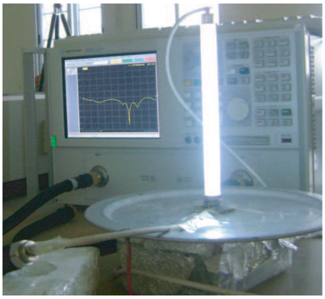

Figure 1. Experimental setup of plasma antenna for measuring return loss.

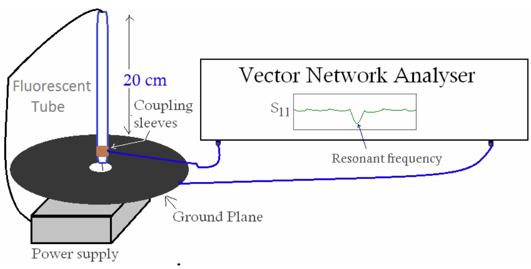

Figure 2. Experimental setup of plasma antenna for measuring return loss.

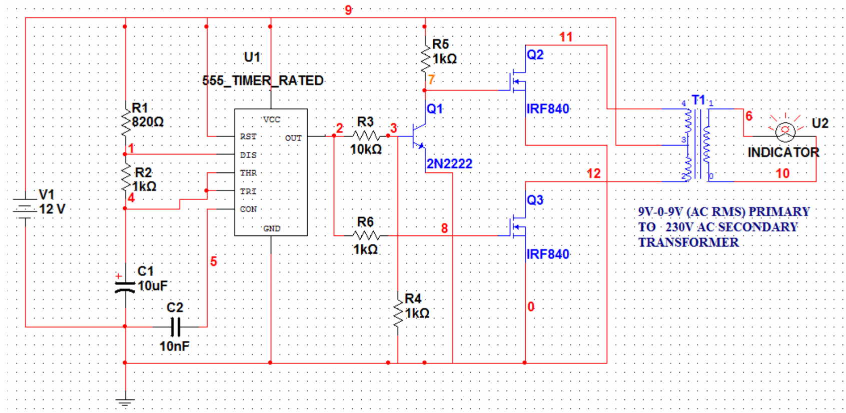

Figure 3. AC power supply using astable multi vibrator for 50 Hz supply frequency. Here in place of indicator we are using fluorescent tube and $V1$ is the variable DC power supply.

the tube changes into the plasma state and forms the plasma column. This plasma column behaves as a conductor and used as an antenna with the help of coupling sleeves. The return loss characteristics of plasma antenna in a frequency range of 10 MHz–900 MHz have been observed on the network analyzer. Figure 2 shows the schematic diagram of the experimental setup for this measurement.

An electronic circuit employing IC555 timer is used as an astable multi-vibrator, as shown in Figure 3. To obtain frequencies 25 Hz, 50 Hz, and 200 Hz we change the resistances of specific value. The output pulse at port 2 of IC 555 is used for switching the transistor Q1, which results in pulse from the MOSFETs.

Capacitance C_1 has a value 10 µF. The combination of R_1 and R_2 is used for varying the frequency of power supply. The frequency is given by the relation

$$f = \frac{1}{\ln(2) \times C_1 \times (R_1 + 2R_2)} \tag{1}$$

The capacitor C_1 is charged through R_1 and R_2, and discharged only through R_2 since the impedance between the discharge and ground-plane is low during the lower half of the output cycle. The timer produces square wave for all three frequencies and for these frequencies the output of whole circuit will also be a square wave. The combination of R_1 and R_2 used for varying the frequency of power supply according to Equation (1) has been tabulated in Table 1, which shows the resistance value in the circuit to generate the three different frequencies (25 Hz, 50 Hz, and 200 Hz).

Table 1. Table showing resistance values for corresponding frequencies.

Serial No.	Frequency	R_1 (kΩ)	R_2 (kΩ)
1	25 Hz	1.640	2.0
2	50 Hz	0.820	1.0
3	200 Hz	0.205	0.25

3. FORMATION OF PLASMA COLUMN

It has been shown that ionizing fluorescent tube by short burst of DC gives remarkable improvements in generating plasma inside it, so the fluorescent tube is used at frequencies ranging from 50 Hz to 60 Hz [1]. Formation of plasma column is characterized by a sudden fall in the AC voltage across the electrodes of the fluorescent tube as the input DC voltage of the multivibrator is increased. This happens because when the plasma inside the tube starts to form a conductive column, it increases the conductivity of the tube as a whole. This AC voltage becomes almost constant as soon as the DC voltage is increased to a particular value. In Figure 4 this behaviour in our plasma fluorescent tube is clearly shown at the frequencies of 50 Hz and 200 Hz. The figure shows that the sudden fall in AC voltage occurs at about 10 V of the DC supply. The figure also shows that at 14 V DC power supply, the AC voltage goes constant, and it shows a reading of 60 V. The results at these two different frequencies show the behaviour of plasma column formation and almost give the same behaviour at both the above mentioned different frequencies.

4. RESULTS AND DISCUSSION

4.1. Return Loss Measurement

The persistence of plasma and the antenna behavior of plasma can be enhanced by increasing the frequency of the applied AC voltage [1]. It is found that increase in frequency increases the duration of stable conductivity in the plasma column. This behavior can be studied with the help of a network analyzer which displays the return loss characteristics of plasma antenna. The return loss characteristics of the plasma antenna at varying supply frequencies (from 25 Hz to 200 Hz) are clearly shown by the Figures 5, 6, and 7. In all these results, the return losses observed through network analyzer range from 10 MHz to 900 MHz.

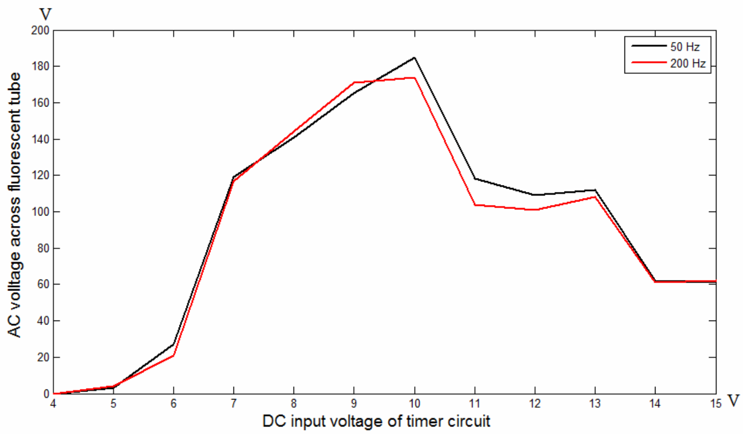

Figure 4. Plasma column formation characterization in the tube at different frequencies.

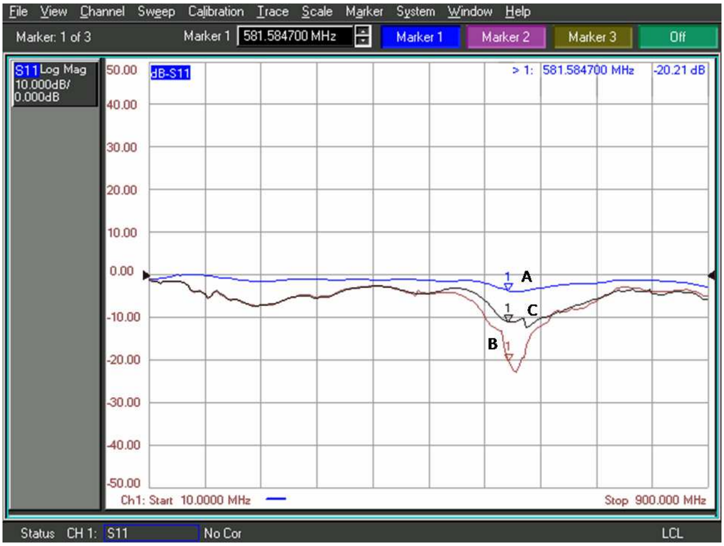

Figure 5. Response at 25 Hz AC voltage shows inefficient antenna characteristic.

It is very essential to observe and show the state of fluorescent tube functioning as plasma antenna in a switch off mode through the network analyzer. In order to calculate the actual return loss, observations are also taken through a network analyzer in a switch off mode. In this process we get a reference level of return loss

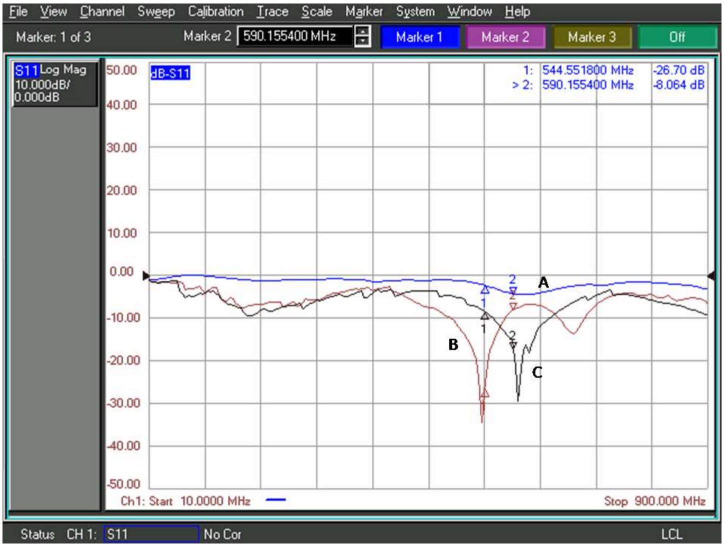

Figure 6. Response at 50 Hz AC voltage showing improved antenna characteristic but fluctuating resonant frequency.

characteristics in order to get the losses other than antenna losses (absolute loss in the switch on mode). These are also shown by Figures 5, 6, and 7 and marked as curve 'A' in these figures.

In a switch on mode, two most different fluctuating results on network analyzer are found, which explain the antenna loss characteristics of fluorescent tube as plasma antenna shown in Figures 5, 6, and 7 through the curves 'B' and 'C'. The antenna loss characteristics results are shown by using three supply frequencies, i.e., at 25 Hz, 50 Hz and 200 Hz, respectively.

It is found that at 25 Hz the return loss characteristics show the resonant frequency of about 585 MHz once, but so far no clear resonant frequency is found at 25 Hz. The return loss fluctuates around the resonant frequency which is between −10 dB and −20 dB, showing inefficient antenna characteristics.

4.2. Persistent Plasma and Improved Resonant Behavior

It is known that at a low frequency of AC supply, striation develops in the fluorescent tube [5]. This may introduce fluctuating resonant frequency and significant reduction in efficiency of plasma column functioning as an antenna. At lower frequencies, electrons move from one electrode to another, producing few secondary electrons, due to other collision with neutral atoms in the tube [6].

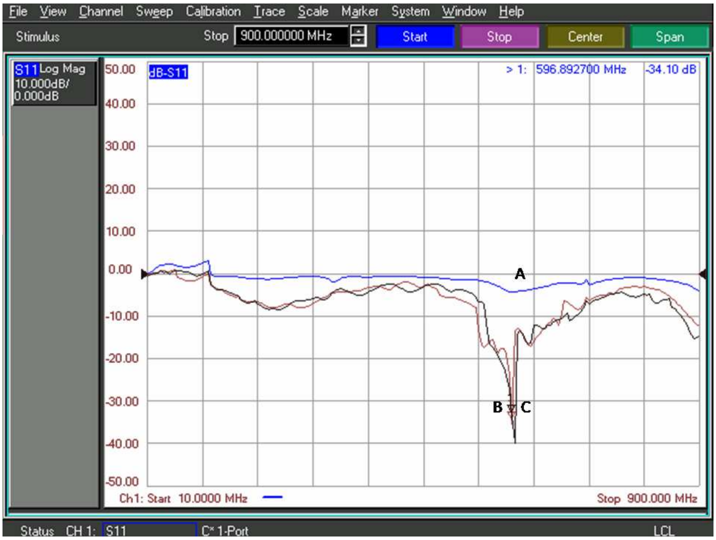

Figure 7. Response at 200 Hz AC voltage shows efficient antenna characteristics with sharply defined resonant frequency.

When the frequency is increased, the ions and electrons are unable to reach the electrode at the other side and keep on oscillating in a to and fro motion at their places. It results in the generation of large number of secondary electrons and ions, thereby persistent plasma evolves. Figure 6 shows the return loss characteristic at an AC voltage frequency of 50 Hz.

In the present work return loss characteristics is assessed at an AC voltage frequency of 50 Hz to check the efficiency of a fluorescent tube functioning as plasma antenna. At 50 Hz the fluctuation in return loss characteristics is still found to be prevailing, but it is different from what is observed at 25 Hz. At 25 Hz the return loss characteristic does not show any specific resonant frequency in most of the situations as shown in Figure 5. Curves B and C at 50 Hz supply frequency exhibit a return loss characteristic with fluctuating resonant frequency as shown in Figure 6. At 50 Hz supply frequency, fluctuation in resonant frequency is observed around the values of 540 MHz to 596 MHz in which return loss is around −25 dB, which shows a rise in the efficiency of a fluorescent tube functioning as plasma antenna. It is concluded that at 50 Hz, the fluorescent tube under experiment does not become an efficient antenna.

Further, the supply frequency is increased to a value of 200 Hz, and it is found that the variation in the resonant frequency is negligible as shown in Figure 7. In this situation the resonant frequency is observed at a value of 596.9 MHz with the return loss of −34 dB as shown by curve B in Figure 7. This certainly shows an increase in efficiency of antenna characteristics of the fluorescent tube. It is concluded that at 200 Hz supply frequency fluorescent tubes are capable to perform as an efficient antenna.

4.3. Effective Length of Plasma Antenna

The effective length of the monopole plasma antenna * radiating at 596.9 MHz is obtained by noting that $\lambda = \frac{c}{v} = (300 \times 10^8)/(596.9 \times 10^6)$, i.e., $\lambda = 50.26$ cm. Thus its effective length is $L_{eff} = \frac{\lambda}{4}$, or $L_{eff} = 12.565$ cm. The fluorescent tube is 20 cm long, and the effective length of plasma antenna is 62.825% of its physical length.

5. RADIATION PATTERN

The radiation pattern of the tube working as an antenna is measured by a standard transmitter-receiver system 'Signet Antenna Analyzing Equipment's (S-99R, S-99T, S-99V)' as shown in Figure 8. The schematic experimental set up for this purpose is shown in Figure 9. The radiation pattern is measured in the H plane (perpendicular to the antenna).

A 3 element Yagi antenna is taken as the transmitter to radiate at 590 MHz. The plasma antenna is mounted on the revolving machine and connected to the receiver. For each 1 degree, the receiver measures the power received by the plasma antenna in dB micro Volt (dBμV) and stores it in the internal array memory. Two such arrays (of

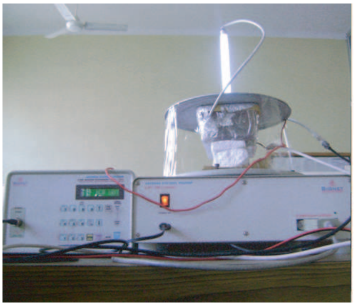

Figure 8. Picture of Plasma antenna on the Signet receiver.

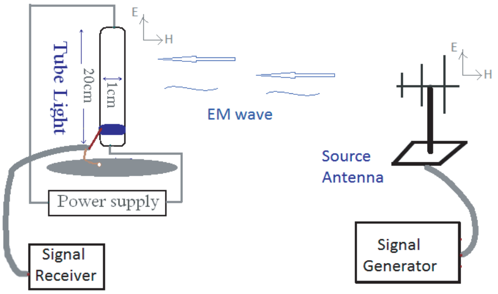

Figure 9. Schematic picture showing the antenna with respect to the Transmitting system in the co polar position.

360 points each) are provided. The observed pattern is shown in Figure 10 for frequency 590 MHz. Both curves are polar plots, showing angular variation of the normalized received power. The outer circle has a constant value 0 dB in this scale, and the inner circle has a value −10 dB. The measurement, with reference to Figure 9, is done for one particular polarization of the transmitter (or one particular transmitter) at a time, for a full rotation of 360 degree of the receiver. First measurement is referred to as 'Array 1', as shown on the upper left panel of Figure 10. We can mark two cursors on the Array 1 curve that show the received power in dBμV at those particular angle values, as shown on the lower left panel of Figure 10. In our measurement, Array 1 curve, marked 'A', is for co-polarization. The first cursor shows the maximum value of received power having a value 73.4 dB at 193 degree, while the second cursor shows the minimum value of received power having a value 59.0 dB at 24 degree. The second measurement referred to as 'Array 2' is for a cross polarization between the transmitter and plasma antenna, and this curve is marked 'B'. No cursors can be marked on this, as it has to be analyzed relative to the Array 1 results. Also, it can be seen from Figure 10 that from angle 0 degree to 60 degree, the received power values are approximately equal in both co- and cross-polarizations. This happens due to scattering of fields from the coaxial cable because it comes in between the transmitting and receiving antennas. This coaxial cable

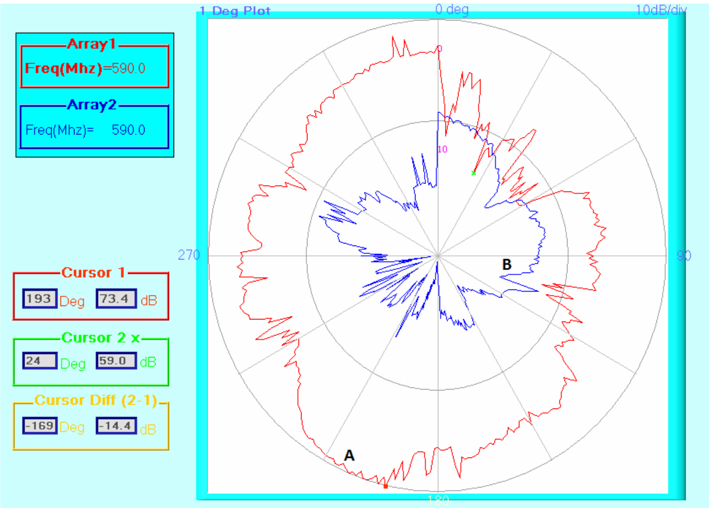

Figure 10. Radiation from the plasma antenna shows monopole patterns.

has been used for power supply to the upper electrode of the fluorescent tube.

6. CONCLUSION

The study of plasma antenna shows that a simple fluorescent tube, used for household applications can be used to work as a plasma antenna. This can be done by applying AC voltage of 200 Hz or more, across the electrodes of fluorescent tube. The performance of plasma antenna can be improved by increasing the frequency of applied AC voltage, so that the plasma persists inside the fluorescent tube for longer duration. Persistent plasma that results in an efficient antenna radiator can be obtained even at lower frequency of 200 Hz. This frequency can be achieved by using Astable multivibrator (fabricated from IC555 chip). The electronic ballast using IC 555 chip is much cheaper and easier to calibrate than RF power supply used for earlier plasma antennas. In the future, it is possible to have cheaper and more effective plasma antennas by using fluorescent tubes.

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