Study of Solar Radiation Effect on Radio Signal Using Plasma Antenna

A N Dagang¹, F S Azmi¹ and R Umar²

¹ Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
² East Coast Environmental Research Institute, Universiti Sultan Zainal Abidin, 21300 Kuala Nerus, Terengganu, Malaysia

Abstract. Plasma antenna can be formed by energizing glass tubes which are filled with neutral gases. It works similarly as metal antenna where it can transmit and receive wireless signal. This study aims to investigate the effect of weather focused on solar radiation towards the performance of plasma antenna represented by signal strength. Fluorescent lamp was set as plasma because it used ionized gas as its conducting element instead of metal. Execution of electrical properties measurements need to be done first, in order to obtain discharge current and voltage values, that need to be used into Glomac programming for the generation of electron temperature and electron density. Next, calculations of the plasma properties was performed to derive the value of plasma and collision frequencies. The plasma properties are important parameters to design and simulate plasma antenna using Computer Simulation Technology (CST). Antenna parameters in terms of return loss, gain, directivity and radiation pattern can be simulated using CST. Signal strength experiment was conducted to evaluate plasma antenna performance in terms of its capability to capture the signals and analyse the effect of solar radiation on that particular moment through the rate of power level over time versus solar radiation data. It was observed at the highest solar radiation rate which is 920 V/m, the power level recorded is the lowest value at -172.93 dBm. Therefore, the signal strength received by the plasma antenna shows remarkable changes under the influence of solar radiation.

1. Introduction
Plasma antenna is an alternative antenna that practically uses plasma as the conducting medium for signal transmission and reception. The applications of plasma in real life applications are circulating faster especially in semiconductor and communication system applications. Before plasma, metal is generally a famous option as conducting medium in an antenna. Naturally, metal have high electrical and thermal conductivities. Since the discovery of the electron in 1897 by J.J Thomson and Wiechert, it has been recognized that the electric current in metals is carried by electrons [1]. Therefore, recent findings have discussed the potential of using plasma medium in creating the next generation of smart antenna. A. C. Das [2] stated that plasma is defined as a collection of charged particles which in average, maintains the state of quasi-neutrality, that is, the number density of positively charged particles is almost the same as that of negatively charged particles. The possibility of using plasma medium in antenna structures are due to the electrical properties exist within it such as conductivity, electrical permittivity and magnetic permeability. With these parameters known, propagation of electromagnetic waves in plasma medium can be inspected thoroughly.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
To portray a simple model of plasma antenna, a fluorescent lamp is normally used. Within the glowing tube of the fluorescent lamp is plasma that contains argon and mercury ions, as well as many neutral particles. When the lamp is turned on, a high voltage between electrodes at the ends of the tube causes electrons to flow. These electrons ionize some of the atoms, keep the current flowing [3]. As the argon gas is energized to the plasma state, mercury vapour in the tube will be excited thus radiating ultraviolet rays. The UV rays then strike the layer of phosphor compound coated inside the tube, and the phosphor splits the UV rays into visible rays which mainly produce bright lights. Now, fluorescent lamp does not only acts as lighting source, besides it also can be run as an antenna.

One of the unique characteristics that differs plasma antenna from metal antenna is that the gas ionizing process can manipulate resistance [4]. This can be seen when deionizing process occurs, the gas has infinite resistance and does not interact with radio frequency radiation. Thus, the antenna will not backscatter radar waves and will not absorb high-power microwave radiation. When the plasma antennas are inactive the radars will find it difficult to find the antennas, as well as 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 [5]. Besides, another unique feature of plasma antenna is that, plasma antenna can be deionised reconfigurably after sending a pulse, thus able to eliminate ringing effect. Ringing effect is an associated noise of a metal antenna which limit the capabilities in high frequency short pulse transmissions. Hence, it is proven plasma antenna gives higher accuracy in signals detection and ease computer signal processing requirements, especially in high-speed digital communication.

Radio wave propagation is influenced by the properties of the earth and atmosphere. The curvature of the earth and the condition of the atmosphere can refract electromagnetic waves either in the direction of upwards, away from or downwards to earth’s surface. The approach used to explain the findings was based on ionosphere layer which reflects transmitted very low frequency (VLF) radio waves back to the Earth. Ionization of ionosphere by solar radiation determines the strength of transmitted VLF. This is because solar activities affect the total electron content of the ionosphere thus affect various radio frequencies used in telecommunications. Research done by Ezekoye and Obodo [6] on the effects of solar radiation on telecommunications, they stated that solar activity can make the telecommunications suffer of disturbances. Electromagnetic storms from the sun may wipe out the telephone lines, television signals and others [7]. Many WSNs (wireless sensor networks) and their applications are in use outdoors exposed to changing environment conditions. Weather particularly can have a significant impact on the performances of WSNs and therefore cannot be ignored. There have been numeral studies reported that temperature is the dominating factor affecting signal strength while others claim humidity is the main reason [8].

This research focuses on plasma antenna performance in the context of signal strength under severe weather influence which is specifically referring to variance in solar radiation. The signal strength is measured in unit of power level (dBm) using the Spectrum Analyzer (SA), while the frequency range is set from 1 GHz to 10 GHz.

2. CST Simulation Setup
Computer Simulation Technology (CST) was used to design and simulate the plasma antenna properties. In order to do so, few parameters from the plasma properties and physical dimension of the fluorescent lamp need to be clarified.

2.1. Electrical properties measurement
Electrical properties measurement was done by reading the discharge current produced by the fluorescent lamp as it is activated. To light up the fluorescent lamp, DC power supply with electronic ballast was essential to produce plasma through the fluorescent lamp. High voltage was required to
light up a commercial fluorescent lamp, thus the DC voltage need to be fed to the electronic ballast to amplify the voltage and control the current. The input voltage need to be adjusted accordingly to control and stabilize the output current connected to the fluorescent lamp. This output current from the ballast or discharge current for the lamp was measure via current probe and digital oscilloscope. Electronic ballast or inverter must be connected in between the DC power supply and the fluorescent lamp. A schematic diagram this for light up condition is shown in Figure 1 below.

![Figure 1. Connection diagram for electrical measurement](image)

2.2. Plasma properties calculation
Calculation of plasma parameters was done assisted by the Glomac programming and then calculated using formulas. The value of electrical parameters i.e., discharge current and voltage, together with the physical parameters of the fluorescent lamp i.e., length, radius, insert gas, gas pressure, will be inserted into Glomac programming. Glomac is a numerical model that can generate electron temperature, average gas density and average electron density [8]. This numerical model is based on diffusion equations formulated for low-pressure mercury discharge specifically for fluorescent lamp development purposes. Electron temperature and density generated by Glomac were used to calculate theoretically the plasma frequency and collision frequency. Since fluorescent lamp was set as the model for plasma antenna, Drude model was applied to graphically show the plasma behaviour. Thus, in Drude model, values of plasma frequency and plasma collision frequency was required. These values is obtained through calculation using equations 1 and 2 [10] as follow. From the calculation, the values of plasma frequency and collision frequency were obtained and used as input parameters in CST software for plasma antenna [11-12]. Plasma frequency, \( \omega_p \), was derived using equation 1 (where \( n_e \) is the density of the ionized electrons, \( e \) and \( m \) are electron charge and electron mass respectively), while collision frequency, \( \nu_c \), can be calculated using equation 2 (where \( n \) is gas density, \( \sigma \) is collision cross section and \( v_e \) is electron speed.).

\[
\omega_p = \sqrt{\frac{e^2 n_e}{\varepsilon_0 m}} \quad (1)
\]

\[
\nu_c = n\left\langle \sigma v_e \right\rangle \quad (2)
\]

2.3. Antenna properties simulation
In order to construct the virtual model of plasma antenna, it can be accomplished by using CST Microwave Studio (CST MWS) software. The design was carried out based on the actual fluorescent lamp used with the length diameter are 200 mm and 15 mm respectively. Plasma parameters were calculated using equations as shown above. The plasma antenna as a monopole type due to the
presence of actual tubular shaped fluorescent lamp. It was design by using copper as the coupling sleeve to simulate antenna parameters such as gain, return loss, directivity and radiation pattern.

![Figure 2. A complete model of plasma antenna.](image)

3. Signal Strength Measurement
The signal strength experiment was conducted at Balai Cerap KUSZA in Setiu, Terengganu by using fluorescent lamp as plasma antenna to receive radio signals radiated from area surroundings. In the experiment, the plasma antenna is strapped around a tripod in upwards position as the radiation pattern now identified as omnidirectional. A Lower Noise Amplifier (LNA) was placed next to the plasma antenna in order to lower the noise floor, hence peak value can be captured clearly by the spectrum analyzer. There was no specific range of frequency is set for the emitted radio signal as it comes from areas surrounding. However the range of frequency from 1 GHz to 10 GHz was set at the spectrum analyser to ensure the signal receive tally with the frequency range that was set during CST simulation previously. A simple diagram for signal strength measurement is illustrated in Figure 3.

![Figure 3. A connection diagram for signal strength measurement](image)

4. Results and Discussion
The results obtained from CST simulation of the plasma antenna is compared with the results of signal strength experiments in terms of antenna properties. The collected signal strength data is used to investigate the effect solar radiation itself by using plasma antenna.
4.1. CST Simulation Results

To match the results from simulation and actual experiment, the variable bring into comparison is the value of return loss or scattering parameter, S11. In both activity, the range of frequency were set similarly, from 1 GHz up to 10 GHz.

4.1.1 Electrical properties. DC power supply is used to supply voltage to the fluorescent lamp with assistance from Cold Cathode Fluorescent Lamp (CCFL) inverter. Thus the inverter function was initiated at the value of 0.16 A of current and 10.3 V of voltage. The average value that can be recorded was, the fluorescent lamp lighted up at 400 V of voltage supply, releasing discharge current at 0.064 A. Fluorescent lamp requires high voltage to light up because of the breakdown voltage needed to ionize the filling gas, as well as its physical dimensions. Since it was in long tubular shape, the distance between electrodes is long, therefore the particles inside need higher energy to be accelerated and causes high impact collisions.

4.1.2 Plasma properties. The value of current recorded which is 0.064 A was put into Glomac programming along with other properties such as tube radius at 7.5 mm, gas pressures at 10 Torr, gas fill temperature at 25 °C (at room temperature), and positive column length at 150 cm (assumed with electrode to electrode distance). Upon input data insertion, Glomac then run the data and generates output. The generated output value for electron temperature was equals to 11200.0 K or 0.965 eV. This value is relatively high due to high voltage supplied in order to light up the fluorescent lamp which exerted more heat on electrons. Meanwhile, the given value of average electron density from Glomac is $2.10 \times 10^{15} \text{ m}^{-3}$. There were high density of electrons in fluorescent lamp due to prominent amount of electrons produced. For plasma frequency calculation, taking in the average electron density into formula provided, the calculated value is $2.8432 \times 10^{10} \text{ rad s}^{-1}$. For collision frequencies, the calculated value is $1.1710 \times 10^{9} \text{ s}^{-1}$. These values were substituted into parameters of plasma material. Thus the values of plasma frequency and collision frequency calculated above were used to complete the antenna simulation (as plasma material) required for plasma antenna simulation afterwards.

4.1.3 Antenna properties. The simulation of plasma antenna, established the essential antenna parameters which are return loss, gain, directivity and radiation pattern. The values for each parameter are tabulated in Table 1 bellow.

| Antenna Parameters | Value          |
|--------------------|----------------|
| Return loss, $S_{11}$ | $-22.643358 \text{ dB}$ |
| Resonance frequency | 3.934 GHz      |
| Gain               | 2.788 dB       |
| Directivity        | 3.258 dB       |
| Radiation pattern  | Omnidirectional|

For radiation pattern observation, it was presented in 2-dimension (2D) in terms of E-plane as illustrated in Figure 4. As shown in the figure, the radiation pattern had main lobe magnitude at $-0.7\text{dBi}$ and 176.0 degree. Moreover, the presence of symmetrical radiation in both upper and lower planes hence shows the omnidirectional properties. The plasma antenna has a good return loss value as shown in Figure 5, indicated no significant amount of power was reflected by the antenna. Thus the antenna is said to match with the transmission line and able to work properly in both signal transmission and reception. Meanwhile, the figures of resonant frequency shows that the plasma antenna seemed to be the most effective in its functionality at 3.934 GHz. Moreover it is also a valid value since 3.934 GHz falls in the frequency range set earlier which in between 1 GHz to 10 GHz.
4.2. **Experimental Results**

The plasma antenna was attached to SA to capture radio wave in surrounding area whereas the weather station read the solar radiation data. Therefore, the observation done relied on the measurement of return loss, the power level versus peak frequencies and the power level at peak frequencies versus solar radiation rate over time.

**4.2.1 Weather Data of Solar Radiation.** All data from weather station was recorded in 1 minute interval starting from 10:43 am until 11:43 am. The manipulative variable taken into measurement is the solar radiation rate over the 1 hour period of time. Moreover, the weather data was measured at midday (noon) where the solar radiation is relatively high and causing the ionosphere region to be at the most ionized state. The recorded power level was in range from $-170$ dBm to $-176$dBm, whereas for solar radiation was in range from $570$ V m$^{-1}$ to $920$ V m$^{-1}$. The amount of solar radiation varies depending on many factors such as local geographical features, changing position of the Sun, changing atmospheric conditions, time and season. Normally, in the presence of bright sunlight exposure, the reading of solar radiation would be in the range of $5$ V m$^{-1}$ up to $900$ V m$^{-1}$. When reaching the dark,
starting from evenings and onwards, solar radiation rate decreases slowly to zero. Meanwhile in a cloudy state, less solar radiation is received as the distance for solar radiation to reach earth’s surface decreases by cover of clouds. From the recorded data, it shows the highest solar radiation rate is 920 V m\(^{-1}\) at 11:28 am. This is because the Sun is positioned high in the sky and the path of the Sun rays through the earth’s atmosphere is shortened. At 920 V m\(^{-1}\), the power level recorded by spectrum analyzer was \(-172.93\) dBm, indicated as the lowest or good value. High solar radiation rate greatly affects the wave propagation, thus lead to signal attenuation and resulted in low strength of signal received by antenna.

4.2.2 Power level and peak frequencies. The presence of visible peak frequencies detected in the range of frequency set before is represented in Figure 6. As can be seen from the graph, the peak frequencies recorded are at 675 MHz, 945 MHz, 1822.5 MHz, 2160 MHz and 2340 MHz, thus match with the designed plasma antenna frequency range. However when compared to the simulation results, the peak frequencies visible from spectrum analyser (SA) readings did not match with the simulation results. The peak frequencies captured match with range of ultra-high frequency (UHF). The source of signal recorded were from the earth ground which radiated from mobile telecommunication through cellular phones, GPS or UHF television. All of these spectrum user working in the range from 1GHz to 3 GHz only as it is the permitted band as according radio frequency bands defined by International Telecommunications Union (ITU). Therefore it explains the absence of signals that are higher than 3 GHz to be captured by SA.

![Power Level VS Frequency](image_url)

**Figure 6.** Graph plotted for power level versus peak frequencies

From the antenna simulation, the resonance frequency where the antenna should radiates was at 3.934 GHz. Conversely, in the signal strength experiment, the resonant frequency fall on 3.507 GHz. However, the difference could be considered small. However, the mismatch of resonant frequency between simulation and experimental results could be due to substrate selected may shows perfect material, however in commercially available material such as fluorescent lamp, there are variation in thickness, gas pressure or dielectric constant that produces dissimilarity of plasma material as compared to the simulation. Especially when the use of commercial lamp where some information was based on assumption. In simulation, the return loss value was \(-22.64\) dB at resonant frequency of 3.934 GHz meanwhile in experiment, the return loss value obtained was \(-17.82\) dB at resonant frequency of 3.507 GHz. It shows that the simulation result possess better return loss than experimental results.
4.2.3 Power Level and solar radiation. The data of signal strength was represented by the power level recorded by SA in the unit of dBm. For comparison, only three peak frequencies are chosen to be compared with effect of solar radiation level at a set time. Results of power level and solar radiation rate over time have been plotted to see the relationship between these two variables. Thus, the pattern of power level difference responds to the change of solar radiation rate over time was determined, and illustrated in Figures 7-9. From the figures, it show the signal strength or power level received by the plasma antenna responded accordingly to the solar radiation rate over time in negative correlation pattern. As solar radiation rate over time increased, the power level dropped. Likewise, when solar radiation rate over time was low, the power level was high. However, at several points, a linear relationship was also observed. Overall, the results comes to a good agreement where signal strength received by the plasma antenna was affected by the solar radiation factor. As mentioned earlier, the range of frequencies captured by the plasma antenna were all in the range of UHF which recorded as ground wave. They continually in contact with the Earth’s surface, hence do not make use of reflection from the ionosphere. The transmission of short distance and all UHF that sent by ground waves propagates through the troposphere layer are affected severely by the Earth’s electrical characteristics and by the amount of diffraction (bending) of the waves along the curvature of the Earth [13]. Troposphere is the lowest part of the Earth’s atmosphere and the distance from the surface of the Earth to an altitude which the layer typically extends is approximately 9 km at the poles and 17 km at the equator [14]. It consists of a boiler receiving heat from the solar radiation a cooling system emitting heat into space. When a radio wave travels and propagates through troposphere meets turbulences, there is sudden change in velocity that alters the amplitude and phase of the radio waves. Radio waves, the ultimate waves for communication, suffer a lot of disturbances as a results of irregular behaviour of the ionosphere attributed to erratic solar radiation from the sun [6].

Figure 7. Power level versus solar radiation rate at frequency of 945 MHz.
Figure 8. Power level versus solar radiation rate at frequency of 1822.5 MHz.

Figure 9. Power level versus solar radiation rate at frequency of 2340 MHz.

5. Conclusion
Simulation results shows good accuracy as compared with the real one. The range of frequency of plasma antenna is acknowledged, approximately up to 3.507 GHz. Moreover, the radiation pattern obtained gives information about the directivity of plasma antenna as it is omnidirectional, meaning it is able to pick up radio waves in its surrounding in all direction. For the signal strength experiment, it is noticed that solar radiation contributes to significant changes on signal strength. Based on data analysis, as solar radiation rate over time increases, the power level decreases. Signal attenuation is important in determining signal strength as a function of distance and with solar radiation is one of the
critical factors significantly affecting it, hence proving that radio signal suffers consequence from weather effect.

References

[1] Mott N F and Jones H 1958 The Theory of The Properties of Metals and Alloys (Dovel Publications Inc. New York)
[2] Das A C 2004 Space Plasma Physics: An Introduction (Narosa Publishing House, India)
[3] Hewitt P G 1998 Conceptual Physics. Eighth Edition (The Lehigh Press, Inc. United States)
[4] Ye H Q, Gao M and Tang C J 2011 Radiation Theory of The Plasma Antenna IEEE Transactions on Antennas & Propagation vol 59(5) pp 1497-1502
[5] Dheeraj R M 2017 Plasma antenna International Journal of Current Engineering and Scientific Research vol 4(11) pp 34-38
[6] Ezekoye B A and Obodo R M 2007 The Effects of Solar Radiations Telecommunications The Pacific Journal of Science and Technology vol 8(1) pp 109-117
[7] Roslan U, Shahirah S S, Atiq W A, Zainol A I, Wan Z A W M, Nor H S 2015 Radio Frequency Interference: The Study of Rain Effect on Radio Signal Attenuation Malaysian Journal of Analytical Sciences. Malaysia vol 19(5) pp 1093-1098
[8] Luomala J and Hakala I 2015 Effects of Temperature and Humidity on Signal Strength in Outdoor Wireless Sensor Networks Proceedings of the Federated Conference in Computer Science and Information System pp 1247-1255
[9] Lister G G and Coe S E 1993 GLOMAC: A One Dimensional Numerical Model For Steady State Low Pressure Mercury- Noble Gas Discharges Computer Physics Communications vol 75(1) pp 160-184
[10] Goebel D and Katz I 2008 Basic Plasma Physics. Fundamentals of Electric Propulsion: Ion and Hall Thrusters (John Wiley & Sons, Inc. New Jersey)
[11] Dagang A N, Kondo A, Motomura H, and Jinno M 2009 Mercury-free Electrodeless Discharge Lamp: Effect of Xenon Pressure and Plasma Parameters on Luminance J. Phys. D: Appl. Phys vol 42 p 095202
[12] Jaafar H, Ali M T, Dagang A N, Mohd Zali H, and Halili N A 2015 A Reconfigurable Monopole Antenna With Fluorescent Tubes Using Plasma Windowing Concepts for 4.9-GHz Application IEEE Transactions on Plasma Science vol 43(3) pp 815-820
[13] International Telecommunication Union 1998 The Ionosphere and its Effects on Radiowave Propagation (Radiocommunication Bureau)
[14] Cuesta J, Eremenko m, Liu X, Dufour G, Cai Z, Hopfner M, Von Clarmann T, Selitto P, Foret G, Gaubert B, Beekmann M, Orphal J, Chance K, Spurr R, Flaud J M, 2013 Satellite observation of lowermost tropospheric ozone by multispectral synergism of IASI thermal infrared and GOME-2 ultraviolet measurements over Europe Atmospheric Chemistry and Physics vol 13 pp 9675-9693