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Multi-Function Adjustable Antenna using Plasma Radiation for Weather Monitoring

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Abstract: ***Plasma is the fourth state of matter. It is a common state of matter where almost of the universe in a plasma state and it can be found on earth naturally or artificially. The advantages of using plasma antenna are it is invisible to radar, no ringing effect, more efficient, dynamically reconfigurable and has fast transmission. The aim for this study is to investigate the effect of winds and humidity on radio signal using plasma antenna as an alternative to the conventional metal antenna. This research used two different type of commercial fluorescent lamps which are tubular (cylinder) and 2U-shape as plasma antenna. Thus, this kind of antenna can be considered as multi-function as it is originally a light source. The plasma antenna parameters such as return loss, gain and radiation pattern were characterized. In order to realize that, plasma parameters i.e., plasma and collision frequencies need to be obtained. The electrical properties measurement need to be done to record the values of current and voltage, then were used in GLOMAC programming to calculate the plasma parameters. The next stage was the simulation of plasma antenna using CST software. The last stage is signal strength experiment to get the value for radio signal strength received by plasma antenna. Then, the value of radio signal strength in against time was recorded. From the results, as the wind speed over time decreases, the power level decreases and vice versa. From the simulation results, the radiation pattern for tubular and 2U can be categorized as omni-directional pattern. Generally, good correlation was accomplished to prove the wind speed and humidity effect on radio signal using plasma antenna.***

Index Terms**:** ***CST, humidity, plasma antenna, radio signal, wind speed***

I. INTRODUCTION

Currently, radio wave has been used in many ways of communication from satellite communication to the mobile phones application. Wireless communication becomes more important for data as demonstrated by the rapid growth of Wi-Fi application [1]. Radio waves are important as they conquer the information in telecommunication technology and has the longest wavelength in the spectrum. Nowadays, it will be difficult to create new technology without using radio waves as it is a good delivery medium.

Plasma antenna is a type of radio antenna which is currently become popular. Both of transmission and reception can use plasma antenna. This idea is not new as J Hettinger has patent granted for an antenna using the concept in 1919 [2]. In early method, discharged tube has been used to place the plasma which is referred to ionized gas plasma antenna. Ionized gas plasma antenna can be switch on and off, has resistance to electronic warfare and cyber-attacks. In order to make the ionized gas plasma to be nested, the plasma antenna with higher frequency are placed inside the lower frequency. Ionized gas plasma antenna with greater frequency can transmit and receive through smaller frequency ionized gas plasma antenna [3]. Plasma has very high electrical conductivity, thus it is possible for radio frequency signals to travel through them and act as a driven element to radiate or receive radio waves. As the plasma properties can be controlled from the type of gas, its pressure, input current, etc, which can lead to manipulate plasma parameters such as density and temperature, the resonance frequency can be adjusted accordingly.

Weather condition in the atmosphere can cause disruption in radio signal. Radio waves sometimes can bounce from the Earth and the atmosphere. During the peaks of the solar cycle, the ionosphere will become increasingly ionized by solar photons and cosmic rays, it will affect the propagation of radio waves that can either facilitate or hinder communications [4]. The changes in solar output can also affect the maximum usable frequency which is limit on the highest frequency usable for communication. The importance of doing this is to make sure that it can operate during extreme environment, for example is rain [5].

Plasma antenna has brought a lot of benefit to wireless communication application. The previous research has discovered more advantages of using plasma antenna than metal antenna. As the antenna is commercial fluorescent lamp, it can be used as a light source and also as an antenna at the same time. In this study, the tubular shape and 2U shape were used as antenna to investigate the effect of the performance and the signal strength.

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It has been proved that a simple fluorescent lamp tube can be used to work as plasma antenna. By using the plasma element inside the commercial fluorescent lamp, it can improve antenna gain and overcome the problem occurred in conventional antenna.

From this study, as antenna's resonance frequency can be adjusted by manipulating the plasma parameters, as it is also a light source, a frequency adjustable multi-function antenna can be develop.

II. METHODOLOGY

A. Electrical Parameters Measurement

The values of current and voltage of each lamp need to be measured. These values are needed in order to simulate plasma parameters such as electron density and electron temperature using GLOMAC programming. Plasma parameters such as plasma frequency and collision frequency can be calculated theoretically using formulae. In simulation, fluorescent lamps were designed using the collision frequency and plasma frequency as a Drude model through CST (Cmputer Simulation Technology) Microwave Studio software. Electrical properties such as discharge current and voltage were recorded and measured by using digital oscilloscope. The measurement of current was done after the value is stable via current probe. Measurement diagram is shown in Fig. 1 below. Electronics ballast was needed to amplify the voltage and control the current for stable discharge.

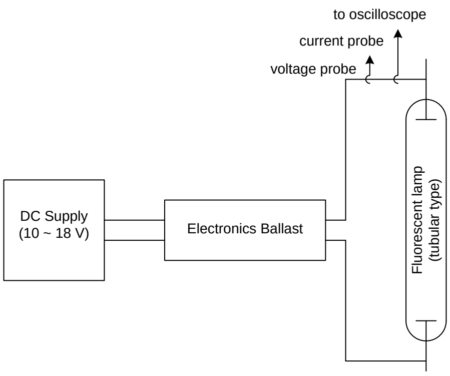

Fig. 1. Connection diagram for electrical measurement

Plasma Parameters Calculation

In this stage, 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 [6]. 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. An example of parameters needed to run Glomac is as Table-I below.

Table-I: Example of Glomac input data

No.	Parameters	Value
1	Tube radius (cm)	0.85
2	Discharge current : I_{min} , I_{max}, dI (A)	0.016 0.016 0
3	Gas pressure : P_{min}, P_{max}, dP (Torr)	10
4	Gas fill temperature (^{o}C)	27

Plasma frequency, ω_p, was calculated by 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, ν_c, can be obtained using equation 2 (where n is gas density, σ is collision cross section and v_e is electron speed.). The plasma frequency is based on the electron number density, and collision frequency is related to the electron temperature, those obtained from Glomac programming. From the calculation, the values of plasma frequency and collision frequency were obtained and used as input parameters in CST software for plasma antenna [7-8].

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

$$\nu_c = n\langle \sigma v_e \rangle \quad (2)$$

B. Simulation of Plasma Antenna

The simulation software, i.e., CST Microwave Studio is a commercially available electromagnetic simulator based on finite difference time domain technique. In the CST software, the behavior of the plasma is given by a Drude dispersion model which describes the transport properties of electrons in materials especially metals. This Drude model is basically an application of kinetic theory, which assumes that the microscopic behavior of electrons in a solid may be treated classically and looks much like a pinball machine, with a sea of constantly jittering electrons bouncing and re-bouncing off heavier, relatively immobile positive ions [9]. The plasma frequency, ω_p and the collision frequency, ν_c is the so called Drude parameters. First, the difference between the plasma frequency and operating frequency of the plasma antenna must be identified. The plasma frequency is a measure of the amount of ionization in the plasma while the operating frequency of the plasma antenna is the same as the operating frequency of a metal antenna [10]. Design for each type of lamps are shown in Figs. 2 and 3. The signal can be transmitted or received using coupling sleeve connected to the SMA connector. The coupling sleeve is act as an input terminal which is used to connect the fluorescent tube with external signals and measuring equipment. In addition, the frequency is focused in the range of 1 GHz to 10 GHz for all designs in this work.

The tubular shape lamp with the length of 54.9 cm (Fig. 2) and 2U shape lamp with the length of 9.2 cm (Fig. 3) are design and constructed in CST Microwave Studio 2012.

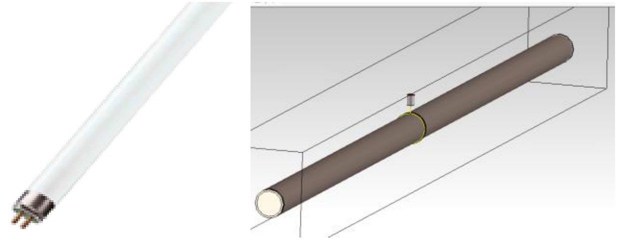

Fig. 2. Actual lamp and design for tubular shape in CST

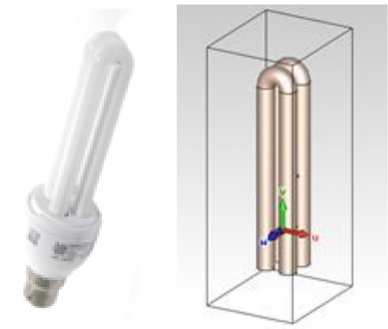

Fig. 3. Actual lamp and design for 2U shape in CST

D. Signal Strength Experiment

The signal strength experiment was conducted at East Coast Environmental Research Institute (ESERI), Universiti Sultan Zainal Abidin using proposed plasma antenna as a receiver of radio signal from surrounding area. The plasma antenna was connected to the Lower Noise Amplifier (LNA) in order to amplify a very low-power signal without significantly degrading its signal-to-noise ratio. A DC power supply was used in order to light up the fluorescent lamp with utilizing CCFL Inverter (electronic ballast) as shown in Fig. 1. The range frequency of the SA (spectrum analyzer) was set from 100MHz to 10 GHz, and the radio signal strength received can be displayed and mattched with the range set previously in CST simulation. During the recording data from the SA, the plasma antenna (fluorescent lamp) was activated from the DC power supply to light it up so that the radio signal emitted from the surrounding area can be received. As the peak of radio signal strength (dBm) can be captured its proves that the antenna is working properly as signal receiver.

III. RESULTS AND DISCUSSION

A. ELECTRICAL PROPERTIES

The result of current and voltage from the electrical properties are shown in Table II. From the results, the minimum voltage needed to light up the tubular lamp was 300 V and the discharge current was 16 mA, whereas the minimum voltage for 2U lamp was 320 V and the discharge current was 15 mA. Due to the physical difference of these lamps, it could be the main reason why the difference of the minimum needed voltage was occured. The length of the tubular lamp was 52.9 cm while the 2U lamp was 9.2 cm respectively. The 2U fluorescent lamp needs high amount of energy due to its curved shape than tubular fluorescent lamp. The higher amount of power is needed to accelerate particles due to the curved shape that could produce high resistance.

Table-II: The results from electrical measurement

Shape	Current, I (mA)		Voltage, V (V)	
	Min	Max	Min	Max
Tubular	16.0	16.0	300	308
2U	14.0	15.0	320	332

B. PLASMA PROPERTIES

The electrical properties obtain from the simulation were inserted into Glomac programming as explained above. Output values, i.e., electron density and electron temperarure from Glomac were used to calculate plasma properties. The value of the electron temperature was 8880.3 K or 0.765 eV for tubular lamp and 9697.4 K or 0.836 eV for 2U lamp. The value is high due to the high voltage needed to lighten the tubular lamp and 2U lamp. It can be thought, that the amount of heat energy released upon light up of the lamp is proportional to the value of the input voltage across the fluorescent tube's electrodes. Meaning the higher the input voltage, the higher the heat energy released. Table III shows the values of plasma frequency and collision frequency. As mentioned above, the values of plasma frequency and collision frequency were needed in the design and simulation stage where they are inserted into the parameters of plasma material under the option of Drude model.

Table-III: The calculated values of plasma properties

Lamp	Plasma frequency	Collison frequency
Tubular	1.1873×10^{10} rads^{-1}	7.48×10^{6} s^{-1}
2U	1.828×10^{10} rads^{-1}	8.74×10^{6} s^{-1}

C. SIMULATION RESULTS

The frequency ranges for the tubular lamp works best is at 3 GHz to 4 GHz in Fig. 4 while in Fig. 5 the 2U lamp works best in the range of 4 GHz to 5 GHz. The plasma parameters such as return loss, gain, directivity and radiation pattern obtained from the simulation is shown in Table IV. The return loss of the tubular lamp was -26.5844 dB and -17.1591 dB for 2U lamp. The return loss must be lower than -10 dB so that it can work functionally. The gain produced was related on how good the antenna can change the input power to radio waves. For the value of the directivity recorded was 2.941 dB for tubular lamp and 2.864 dB for 2U lamp showed the plasma antenna produced low directivity to collect signal from all direction.

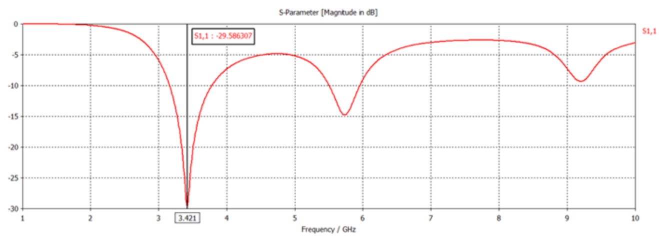

Fig. 4. The return loss, (S_{11}) and resonant frequency values for tubular lamp

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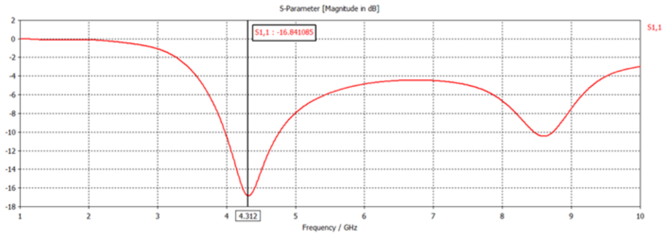
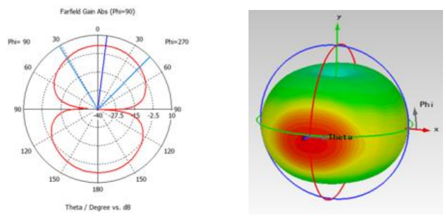


Fig. 5. The return loss, (S_{11})and resonant frequency values for 2U lamp

Table-IV: The return loss, gain and directivity result for tubular and 2U fluorescent lamp.

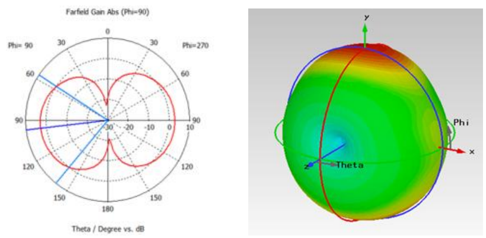
Shape	Frequency, GHz	Return Loss, S_{11}, dB	Gain, dB	Directivity, dBi
Tubular	3.45	-26.5844	2.933	2.941
2U	4.34	-17.1591	2.852	2.864

Figs. 6 and 7 show the radiation pattern in 2-dimension (2D) in term of E-plane for tubular lamp and 2U lamp. The radiation pattern of the tubular lamp has the main lobe magnitude of 2.9 dB at 76.2˚ while for 2U lamp has the main lobe magnitude of 2.8 dB at 97.0˚. The pattern shows that it has symmetry for upper and lower plane which make the radiation was omnidirectional.



(a) (b)

Fig. 6. The radiation pattern for Tubular lamp (a) 2-dimension pattern and (b) 3-dimension pattern.



(a) (b)

Fig. 7. The radiation pattern for 2U lamp where (a) 2-dimension pattern and (b) 3-dimension pattern

D. EXPERIMENTAL RESULTS

Data from weather station was collected with the time interval of 1 minute for 1 hour long. The radio signal strength, wind speed and humidity values over the given time was taken at ESERI, Unisza as the manipulative variables. The first day was on noon January 29, 2019, followed by next day at approximately the same time as previous experiment day. Table V shows the summarized detected peak frequencies for each conditions. The radio signal strength that has been detected was identified as mostly came from mobile phones, Philippine long distance telecommunication company (PLDT) Malaysia Sdn. Bhd., satellite and radio astronomy.

Table-V: The detected peak for each condition

Date	Lamp	Peak detected (MHz)
29/1/2019	Tubular	877.5, 945, 1822.5, 2137.5, 2362.5, 2632.5
29/1/2019	2U	877.5, 945, 1822.5, 1867.5, 2137.5, 2632.5
30/1/2019	Tubular	877.5, 945, 1822.5, 2137.5, 2362.5, 2632.5
30/1/2019	2U	877.5, 945, 1822.5, 2137.5, 2677.5, 3625

Figs. 8 and 9 below show the peaks frequencies detected during two experiment days with two types of lamp. From the figures, it can be seen that this two types of plasma antenna can detect almost the same frequency. However, there is slightly different in terms of level of detected signal where 2U shape give higher power level.

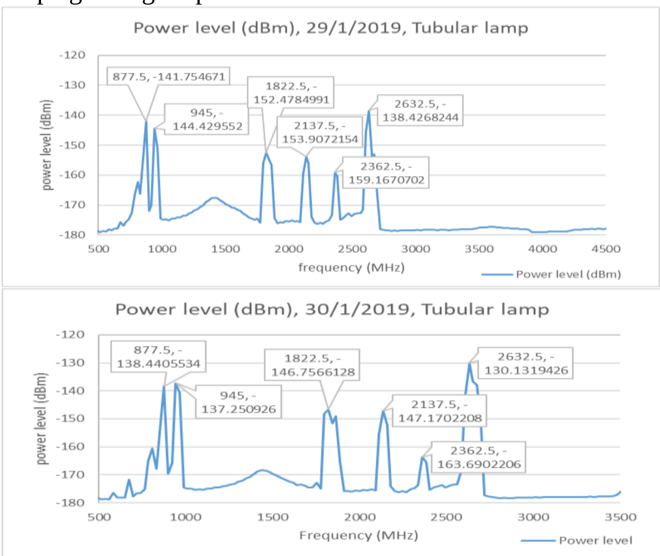


Fig. 8. Power level versus peak frequencies for tubular lamp for two consecutive days

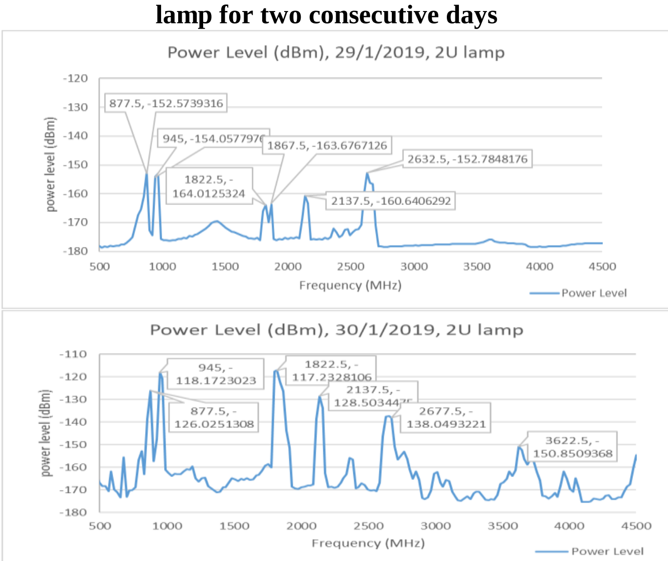


Fig. 9. Power level versus peak frequencies for 2U lamp for two consecutive days

The results of 1 hour of each lamp measuring the wind speed and humidity with the average of power level were analyzed. Figs.

10 and 11 show the results of power level and wind speed versus time for tubular and 2U shapes respectively. Power level went up and down along the time, the same trend with the value of wind speed. Figs. 12 and 13 show the results of power level and humidity versus time for tubular and 2U shapes respectively. The trend can be considered similar with the wind speed where when humidity increases, the power level also increases. The both conditions show that there is a significant effect on power level when wind speed and humidity changed.

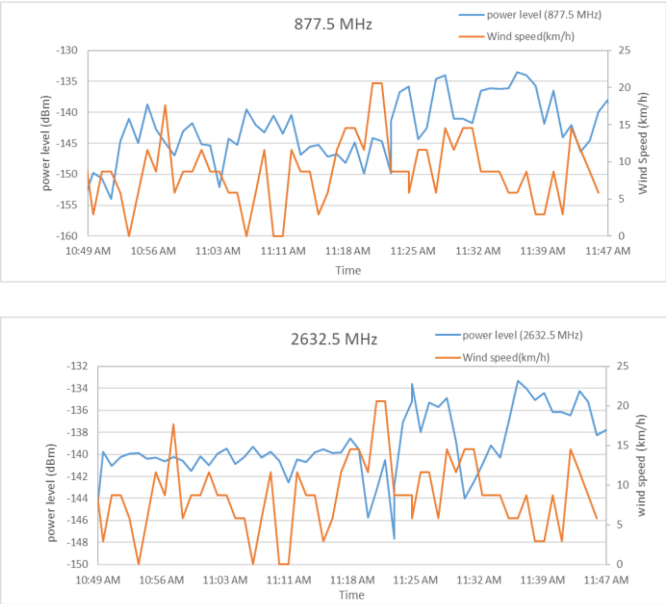


Fig. 10. Power level and wind speed against time at frequency of 877.5 MHz (min) and 2.63 GHz (max) for tubular lamp

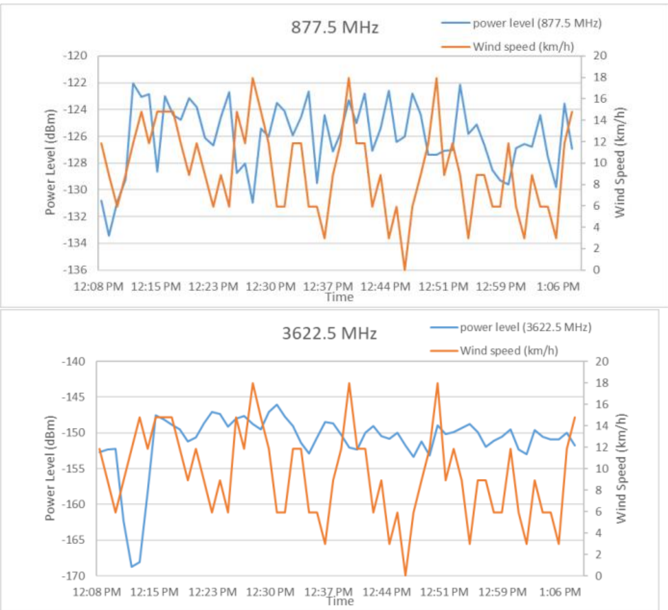


Fig. 11. Power level and wind speed against time at frequency of 877.5 MHz (min) and 3.62 GHz (max) for 2U lamp

Fig. 12. Power level and humidity against time at frequency of 877.5 MHz (min) and 2.63 GHz (max) for turbular lamp

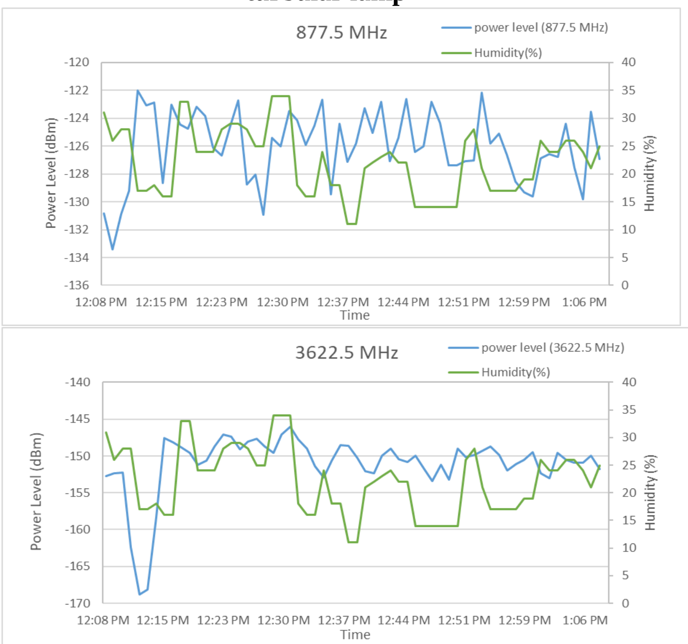


Fig. 13. Power level and humidity against time at frequency of 877.5 MHz (min) and 3.62 GHz (max) for 2U lamp

I. Frequency Comparison

The frequency range for simulation work best at from 3 GHz to 4 GHz where 3.4 GHz for tubular lamp and 4.3 for 2U lamp. The frequency detected during the experiment was below the optimum frequency as obtained in simulation. The highest frequency detected for tubular and 2U lamps were 2.63 GHz and 3.62 GHz respectively, where both conditions are nearly 1 GHz different to the frequency obtained in simulation. The value for simulation and experiment was not matched well due to the tolerance in plasma parameters that has been calculated, the actual value could be slightly difference. The value generated from Glomac is very important to get an accurate output.

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As the lamp used were commercial one, some of the parameters need to be put into Glomac were based on assumption, especially on the filling gas and its pressure inside the tube. Thus, this will affect the calculated value of plasma frequency and collision frequency. A custom-made tubes should be considered for future improvement.

II. Effect of Wind and Humidity

From wind speed results, the power level increases as the wind speed increases. From the results, even though there is a difference in the power level for each difference of wind speed, it shows that wind give significant effect to the transmitted radio wave. Strong wind contains a lot rainwater due to the high rain rate and humidity, especially for the weather condition in Malaysia. The absorption of radio signal can disrupt by the water content [11]. It was observed that power level increases as the humidity decreases and vice versa from the signal strength carried out. The increases in relative humidity has great impact on the signal strength negatively and this is could be as a result of the water particulate content of the atmosphere which may cause diffraction, reflection and scattering and consequently attenuate the radio signal [12]. It can be concluded that the wind speed and humidity can affected the radio signal strength. The humidity contains high condense of water that can cause the unpredictable changes in signal strength. Therefore, humidity may have the indirect effect on radio signal [13].

IV. CONCLUSION

As an alternative to the conventional metal antenna, the proposed plasma antennas had showed their capabilities to detect the radio signals. From the manipulation of the plasma properties and the used of commercial lamp, an adjustable and multi-function antenna can be realized. As far as the functionality of plasma antenna is concern, form the results, it has been proved by simulation that the antenna be designed accordingly, and from the experimental results the data recorded is considered acceptable. Future work could be the optimization of plasma parameters

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Roslan UMAR earns his PhD from Universiti Malaya (UM), Malaysia in the field of Radio Astronomy. His interest in exploring universe begin from his bachelor degree internship program, when he attached to Malaysia National Planetarium. After he finished his MSc, Dr. Roslan begin his academic career at Universiti Sultan Zainal Abidin (UNISZA) and appointed as Head of Astronomy Unit at UNISZA Observatory. He is currently holds a dual appointment: a senior lecturer, teaching Cosmology and Introduction to Astronomy and at the same time a research fellow at East Coast Environmental Research Institute (ESERI), UNISZA. Dr. Roslan research interest is in the field of electromagnetic, radio frequency interference, radio astronomy and environmental study.

Nor Hazmin SABRI is a senior lecturer in School of Fundamental Science, University Malaysia Terengganu (UMT). Her career as an academician begin in 2004 when she first enter Physics Department, Faculty of Science and Technology, Universiti Pendidikan Sultan Idris (UPSI) at Tanjong Malim, Perak.

She has joins UMT in December 2007, fell in love with the ocean and never left. She obtains her bachelor degree with honours and master degree in physics from Universiti Kebangsaan Malaysia (UKM) in the field of Theoretical and Simulation Physics (Quantum Physlet). Her interests in theories and computational physics has never fade. She is then obtained her PhD in Theoretical Physics (Quantum Optics) from University of Malaya (UM).