

Development of Low Cost HF Antenna for Amplitude Observation at Equatorial Region

J. Talib¹, A. Taat², A. N Dagang¹, M. H Jusoh², R. Umar³ and W. H Wan Hassan¹

¹*School of Ocean Engineering, Universiti Malaysia Terengganu (UMT).*

²*Applied Electromagnetic Research Group (AERG), Universiti Teknologi MARA (UiTM) Shah Alam.*

³*East Coast Environmental Research Institute (ESERI), Universiti Sultan Zainal Abidin (UNiSA).*

Uk33887@student.umt.edu.my

Abstract—In this paper the development of low cost antenna for High Frequency (HF) has been proposed. The proposed antenna is designed to operate from 3 MHz until 30 MHz for space weather observation. The antenna consists of small loop with primary and secondary loop. The primary and secondary purpose for radiating element while a lumped element being placed in series with the secondary loop for frequency tuning. Circumference size is taken from the 1/10 or 10% of wavelength, with circumference of 2.14 M and diameter of 0.64 M and able to capture the frequency at 15.21 and 15.34 MHz respectively. 4nec2 software has been used to bear out the simulation results. The antennas prototype has been designed, constructed and measured. The return loss measurement of antenna is -30dB, at 14 MHz. An omni directional radiation pattern measurement has been carried out at 15 MHz for signal transmitting.

Index Terms—High Frequency; Loop Antenna; Space Weather.

I. INTRODUCTION

Solar phenomena is a natural phenomenon that occurred on the surface of the sun. Example of this phenomena such as solar flares, solar wind and coronal mass ejection (CMEs) happen unexpectedly, absorbing strong electromagnetic waves of assorted wavelengths (from gamma rays and X-rays to radio wave) as well as high-energy particles and agile radiation [1]. Solar phenomena such as CMEs, solar flares and associated recombination events are one of the driving factors in space weather and the solar wind intensity. Even though it is located at such a great distance from our nearest star, the Earth and its associated satellites are still directly affected by variances in these space weather phenomena [2]. The massive incident of a solar phenomenon occurred on March 13, 1989 where the entire province of Quebec, Canada suffered an electrical power blackout. Despite the fact that hundreds of blackouts occur in some part of North America every year, the Quebec Blackout was considered unique, because it caused by a solar storm and lead to extensive damage to the power grid system. These unwanted incidents due to solar phenomenon can be avoided and precautions method can be taken if we are able to estimate the time of impact. The impact time can be estimated by monitoring the changes of amplitude in HF signal and compare to the earth magnetic data. The comparison is possible due to the fact that the earth magnetic is also related with the changing of electron density in ionosphere. Due to spectral variability of the solar radiation and the density of various constituent in the atmosphere, there are layers created within the ionosphere, called the D, E and F-layers. The solar phenomena affect the charging of ionosphere. Since the huge amounts of ionization is caused by solar irradiance, the night-

side of earth and the pole pointed away from the sun (prior to season change) have much less ionization than the day-side of the earth, and the pole pointing towards the sun. Figure 1 shows the different layers of ionosphere.

Vertical Ionospheric Sounding (VIS), is the measurement techniques based on sending pulse of energy at different frequencies towards the ionosphere region also measuring the backscattered echo delay to specify the position of ionospheric layers. It consists of the transmitter (Tx) and receiver (Rx) antenna. This instrument is capable to perform such a measurement called “ionosonde” and can be considered as the radar’s “ancestor”, but at the price of a high cost. Thus, the main objective of this project is to develop a low-cost HF antenna receiver to observe the amplitude of the HF frequency in equatorial region during quiet and disturb geomagnetic disturbance.

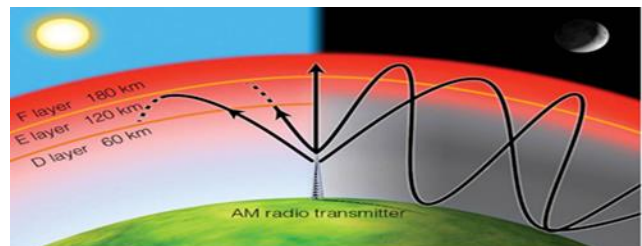


Figure 1: The different layers of ionosphere [4]

II. RELATED WORKS

HF radio waves reflected by the ionosphere can provide a relevant amount of information with the composite received signal. Ionospheric layer can be measured through the technique known as vertical sounding technique [5]. This technique able to evaluate the positions of the ionospheric layer resulted in the height and electron density of ionosphere. Furthermore, the virtual height in kilometer KM (PVH) and power observation of the small-scale disturbance (SD) effect on signal fading at ionospheric region also can be determined using Vertical Ionospheric Sounding (VIS) technique [6]. VIS is a consolidated technique that was first applied nearly a century ago to unveil the existence of the ionosphere, i.e. the density and altitude of the ionospheric layers. Nowadays advance digital sounders are used in the VIS technique for observation that provide detailed information about the structure and dynamics of the bottom side ionosphere. HF radio that propagates through ionosphere region can be disrupted through disturbed ionosphere conditions [3]. This is because of a variety space weather

events that affect strongly on the HF communications, particularly in equatorial and polar region. Beside space weather events, the ionosphere also response to the eclipse [7] and to evaluate the ionosphere conditions, a HF oblique sounding data is used throughout the eclipse events.

III. ANTENNA DESIGN

This section presents the methodology in the development of a small loop antenna. Figure 2 illustrates the steps taken in the development process which started with modelling of HF loop antenna follows by parameter validation via a simulation, then, hardware development and finally, field test measurement. The proposed design of a loop antenna is in accordance to the design of a small loop antenna shown in Figure 3. The small loop antenna is often viewed as a very large resonant circuit (Figure 4) due to a large single turn inductor exists in the circuit. Therefore, the small loop antenna tends to be highly inductive in its resistance. Normally, the values of inductive reactance closer to 100 Ω, but the value of 1000 Ω is not usual too. Since of this inductive reactance, the small loop antenna is tuned by one or more series capacitors. The following subsection shows the block diagram of the desired loop antenna.

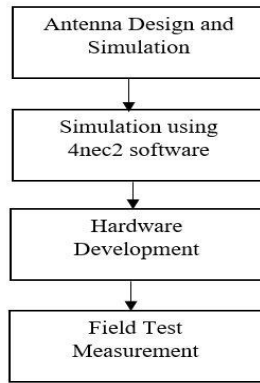


Figure 2: Block diagram of antenna development

A. Calculation of HF Loop Antenna

This subsection calculates the required parameters in modelling the HF loop antenna as specified in Table 1. The desired resonance frequency, f_o for this proposed HF receiver antenna is set at 14.05 MHz, which is defined by Equation (1) as,

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

where:

- f_o : The resonance frequency
- L : Inductance of the loop
- C : Capacitance of the loop

The circumference of the antenna, U, is determined by,

$$U = \frac{\lambda}{10} \quad (2)$$

where:

- λ : Wavelength of f_o
- U : Set to one tenth of λ because if it is made larger than about one tenth wavelength it will no longer be classified a small loop and its radiation pattern will begin to change

Since $\lambda = \frac{c}{f}$ (c = speed of light), U can be rewrite as follows:

$$U = \frac{c}{10f} = \frac{3 \times 10^8}{10 (14.05 \text{ MHz})} = 2.14 \text{ (M)}$$

Therefore, the desired circumference of antenna U is set to be 2.14 M. Next, to find the capacitance, the inductance of the loop can be calculated according to the following formula:

$$L = \mu\alpha [\ln(8a/b) - 2] \quad (3)$$

where:

- μ : Permeability of copper
- a : Diameter of antenna circular loop
- b : Radius of the copper tube

$$L = 0.68\mu \left[\ln \left(\frac{8 \times 0.68}{0.005} \right) - 2 \right] = 4.266 \mu\text{H}$$

Since the inductance has been obtained, the capacitance of the antenna can be calculated. Because this is a loop antenna, a variable capacitor is required to be attached across the copper tube. The capacitor is used as a lumped element to reduce mismatched loss. The value of the capacitance is given by:

$$C_{RES} = \frac{1}{\omega^2 L} = \frac{1}{(2\pi \times 14.05 \text{ MHz})^2 \times 4.266 \mu\text{H}} = 30 \text{ pF} \quad (4)$$

The output from the antenna in future then will be connected to the pre-amplifier using RG58, 50Ω coaxial cable to amplify the receive signal. All the calculated parameters are shown in Table 1. The diagram of the small loop antenna indicated in Figure 3 and the equivalent circuit prior to the calculation of the antenna is represented in Figure 4.

Table 1
The Parameter of the Antenna

Parameters (unit)	Value
Length of Conductor (antenna "circumference")	2.14 m
Diameter of the antenna, a (m)	0.64 m
Radius of the copper tube, b (m)	0.005 m
Resonance Frequency, f_o	14.05 MHz
Capacitance of the antenna loop, (F)	30 pF
Inductance of the antenna loop, (H)	4.266 μH

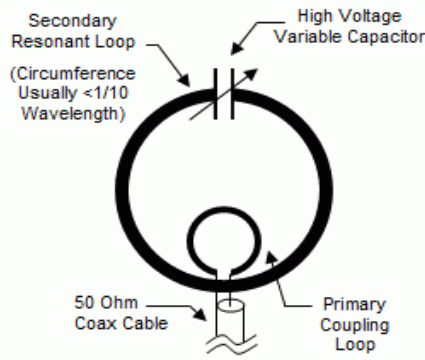


Figure 3: Diagram of small loop antenna [8]

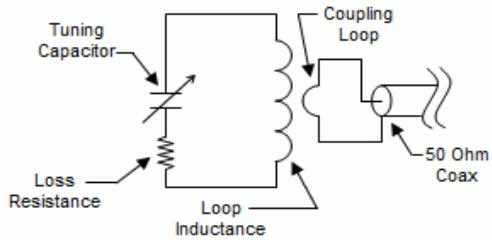


Figure 4: Equivalent circuit of small loop antenna [9]

B. Simulation of HF Antenna

Simulation is conducted after all the calculation parameters are obtained. The proposed antenna has the advantage of frequency and radiation pattern. Simulation results have been obtained from commercially by 4nec2 software. Figure 5 shows the parameter set up of the circular loop antenna for the simulation. The simulation results indicated that the efficiency of the antenna is 71.51%, the radiation efficiency is 78.74% and radiation power is 71.51W. Figure 6 show the Standing Wave Ratio (SWR) and reflection coefficient. The signal indicated a significant drop at 14.05 MHz prior to parameter settings in initial values. The reflection coefficient value is at -0.2215 dBi (isotropic decibel). Figure 7 shows the antenna radiation pattern. The radiate pattern is weak at 0 and 180 degree and the total gain (dBi) is from -7.8 until 0.63. Noted that some simulation values differ from the calculation values due to the effect of free space condition set in the simulation.

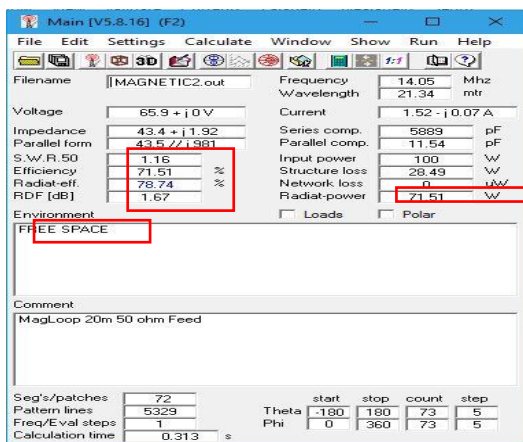


Figure 5: Parameter for antenna simulation

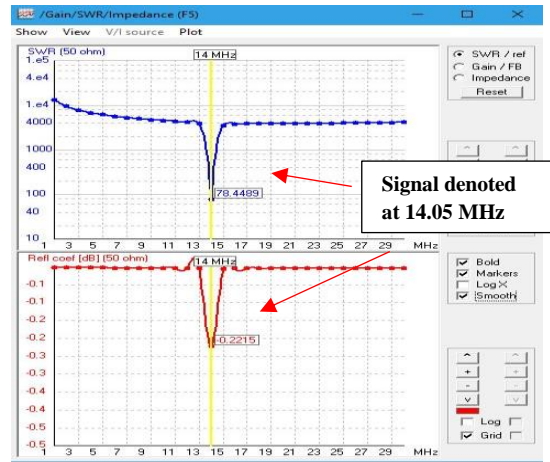


Figure 6: SWR and reflection coefficient of antenna

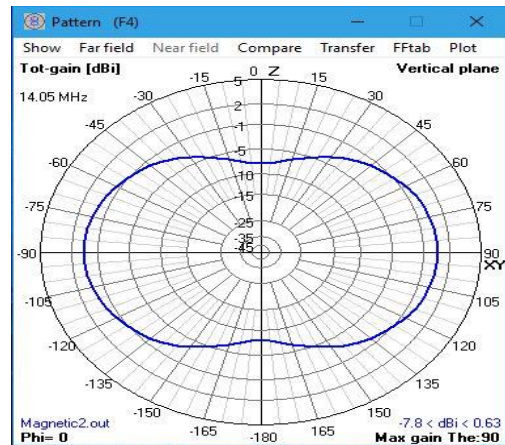


Figure 7: Radiation pattern

The following subsection shows the hardware development of small loop antenna prototype.

C. Simulation of HF Antenna

This subsection focuses on developing the hardware of a small loop antenna. The preferred material for this antenna is either copper or silver in order to minimize the resistive loss. In this work, a 1cm diameter of copper tube is utilized and the length of the copper tube per the circumference of antenna. An appropriate capacitor value is selected to ensure it will resonate the loop to the desired frequencies of operation. The variable capacitor within range from 23pF to 77pF is placed in series along the copper tube. Next, for the holder of the antenna, a non-conductive material is emphasized, in this case, PVP pipe is utilized since it is low cost and durable.

The small loop antenna is constructed following the design shown in Figure 5. Primary loop, also known as Electrostatically Shielded Loops is placed almost to the middle of secondary loop. Its purpose is to maintain a loop balance with respect to ground, by forcing the capacitance between all portions of the loop and ground to be identical. This loop generally takes the form of tube around the winding, made up of a conductive but non-magnetic material (such as copper or aluminum). Figure 8 presents the circular loop antenna that have been developed. In order to test the antenna, a field measurement is carried out and the results are discussed in the next section.

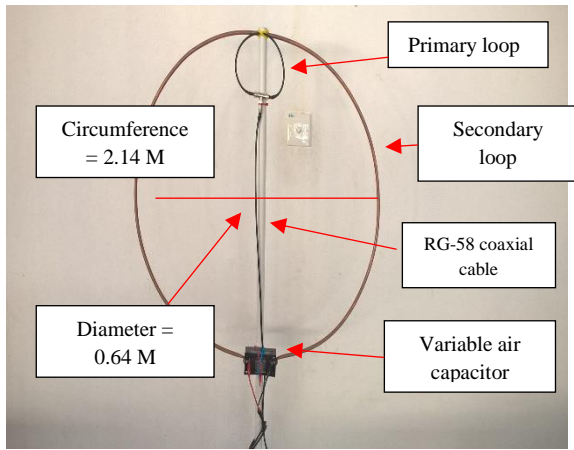


Figure 8: Circular loop antenna

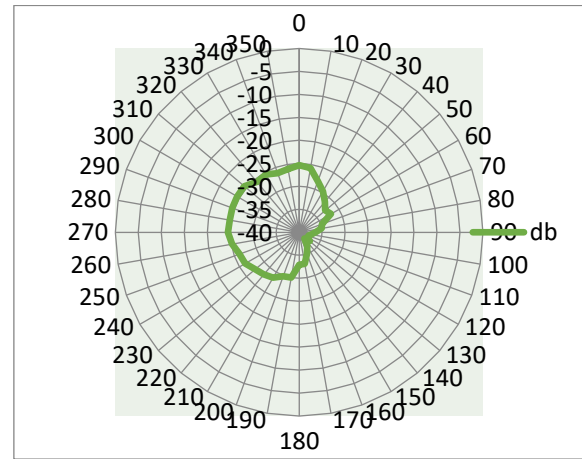


Figure 10: Radiation pattern of antenna

IV. RESULTS AND DISCUSSION

Spectrum analyzer is used for the measurement. Measurement was conducted at the ESERI laboratory, Universiti Sultan Zainal Abidin, Kuala Terengganu. The first measurement is to find the return loss of the antenna. In practice, the most commonly quoted parameter in regard to antenna is S_{11} . S_{11} represents how much power is reflected from the antenna, and hence is known as the reflection coefficient (sometimes written as gamma, Γ or return loss). If $S_{11}=0$ dB, then all the power is reflected from the antenna and nothing is radiated. If $S_{11}=-10$ dB, this implies that if 3 dB of power is delivered to the antenna, -7 dB is the reflected power. The remainder of the power was "accepted by" or delivered to the antenna. Return loss is related to both standing wave ratio (SWR) and reflection coefficient (Γ). Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss. This accepted power is either radiated or absorbed as losses within the antenna [10]. Since antennas are typically designed to be low loss, ideally most of the power delivered to the antenna is radiated. Figure 9 shows the measured return loss of antenna result, which is at -30 dB.

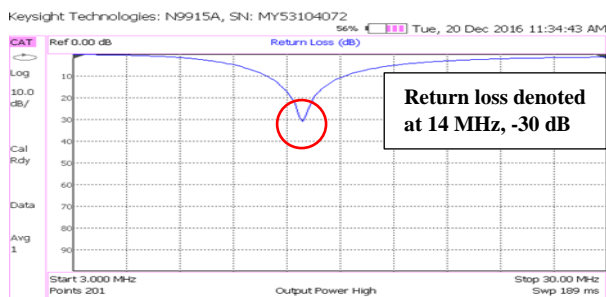


Figure 9: Measured return loss of antenna

Next, the radiation pattern of the antenna is measured. The measurement is conducted in the microwave laboratory, Universiti Teknologi MARA, Shah Alam, using signal generator that drove the HF signal and the antenna captured the signal while keep rotating every 10° to observe the change of gain. Figure 10 shows the radiation pattern of the antenna, measurement and simulation which being supplied with 15 MHz frequency.

The receiving signal from the signal generator is weak because the antenna is directly connected to a spectrum analyzer without using pre-amplifier. Therefore, the loss is noted high in this measurement. In comparison to the simulated radiation pattern, the radiation pattern quantification showed immensely colossal different in pattern and in dB. This is because the antenna that connect to the signal generator is equipped with the conventional AM/FM radio, thus the mismatch of signal and loss in radiating occurred contiguous towards the receiver antenna. This radiation pattern shows that the small loop antenna is able to capture the signal but with a massive loss of dB, around -30dB. As a solution, the transmitting antenna needs to use the loop antenna to avoid the mismatch and signal loss while radiating the frequency. Figure 11 shows the frequency captured by spectrum analyzer at 15MHz with -62 dBm. From the radiation pattern measurement, it is shown that the antenna is able to capture a HF signal, ranges from 3 MHz until 30 MHz.

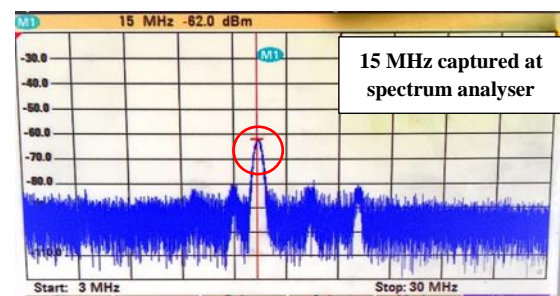


Figure 11: 15 MHz frequency captured by spectrum analyzer

The next measurement involves outdoor antenna measurement using spectrum analyzer to capture any random available HF band signal. Figure 12 verifies the antenna is able to capture two HF signals at 13 and 15.21 MHz respectively. It is understood that the design of the antenna is prior to one resonance frequency of 14.05 MHz, but the result in spectrum analyzer shows that an Intermodulation Distortion (IMD) occurred. IMD is the amplitude modulation of signals containing two or more different frequencies, caused by nonlinearities in a system, for this case, the antenna [11]. The intermodulation between each frequency component will form additional signals at frequencies that are not just at harmonic frequencies (integer multiplies) of either, like harmonic distortion, but also the sum and difference frequencies of the original frequencies and at multiples of

those sum and different frequencies. Intermodulation is also rarely desirable in radio, as it creates unwanted spurious emissions, often in form of sidebands. For radio transmission, intermodulation increases the occupied bandwidth, leading to adjacent channel interference, which can reduce audio clarity or increase spectrum usage.

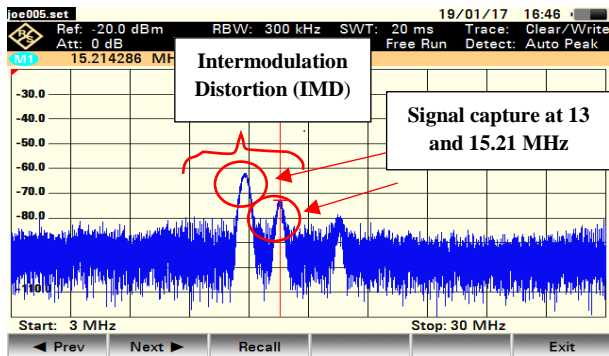


Figure 12: Signal captured at 13 and 15.21 MHz

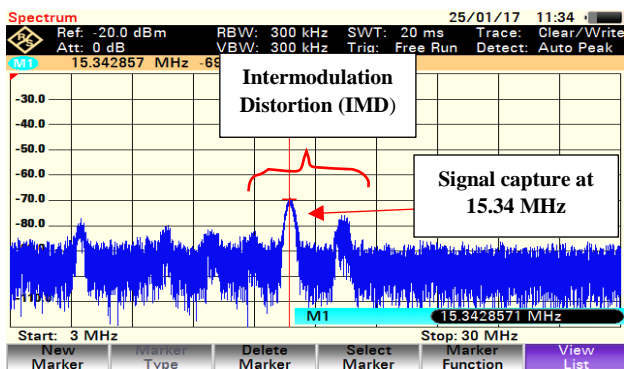


Figure 13: Signal captured at 15.34 MHz

V. CONCLUSION

The developed small loop antenna able to capture the HF frequency even there is loss in estimate about -30dB at the receiving part. The small loop antenna development can only have two significant parameters, either small size, efficiency or broadband. Ingenuously, small loop antennas sacrifice's bandwidth for small size and efficiency. The more efficient they are, the narrower the frequency range in which they can operate. If the antenna is build a wide bandwidth, small antenna then it cannot have good efficiency. In this paper, the proposed of low cost HF antenna for amplitude observation have been shown and proven simulated and measured results. Good agreement has been obtained between both of results. For a future work, it is proposed to incorporate a pre-amplifier to improve the signal strength. These proposed antennas can

be applied in future such as in astrophysics and in space weather observation.

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