Performance Evaluation of Turnstile Antenna for Weather Satellite Application

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Abstract- In this work, a crossed-dipole turnstile antenna is designed for weather satellite application. The turnstile antenna is able to receive the Automatic Picture Transmission (APT) from the National Oceanic and Atmospheric Administration (NOAA) satellites. The turnstiles antenna is modeled and simulated using Computer Simulation Technique Microwave Studio (CST) software. Through this method, the free space reflection, S_{11} and the radiation pattern are obtained. This turnstile antenna was then measured and the S_{11} reading and the radiation pattern were recorded and calculated. The Voltage Standing Wave Ratio (VSWR) of both methods was presented. The simulation results were then compared with the measurement results where good agreements are observed. The antenna shall be receptive toward NOAA satellites transmitted frequency range, approximately from 137 MHz to 138 MHz with a peak response at 137.5 MHz.

Keywords: Turnstile Antenna, Dipole, Resonant Frequency, Very High frequency (VHF)

1.0 INTRODUCTION

Modern communication systems require radio frequency (RF) and microwave signals for the wireless transmission of information. The transmitter communicates with the receiver via antenna placed on each side [1]. Antenna is the most crucial element that can make or break a video downlink system. Antenna act as an interface between electronics circuit at the outer space as it transforms motion of electrons into electromagnetic wave.

There are many antenna designs in the world of communication today but there are only a few that has been developed for omni-directional VHF communication. One of them is the turnstile antenna that is known as the simplest antenna design that demonstrates radiating behaviour. Turnstile antenna is widely use for VHF application as it transmits signal uniformly in all direction [2].

Turnstile antenna is made up of two coplanar resonant dipoles placed at right angles to each other and having a 90° progressive phase shift [3]. The turnstile antenna is one solution to the occasional need for an omni-directional, horizontally polarized antenna [4]. Besides its simplicity in the design and assembly, the cost for the construction of the turnstile antenna is also low.

The turnstile antenna in this project is designed to receive the APT image from the NOAA satellites. Preliminary study indicates that one of the types of antenna widely use for APT receiving station is the turnstile antenna. The NOAA is a series of polar orbiting metrological satellites that have been continuously imaging the earth using the onboard Advanced Very High Resolution Radiometer (AVHRR) instruments. Operationally, NOAA satellites are transmitting the APT data at frequencies between 137 and 138 MHz [5].

In this project, the turnstile antenna was modeled using CST MWS. CST MWS is software for electromagnetic analysis and design in the high frequency range. This program is design to suit to the fast, efficient analysis and design of components and since the underlying method is a general 3D approach, CST MWS has the ability to solve virtually any high frequency field problem [6]. The CST MWS come with three different simulation techniques since no method works equally well in all application domain. The transient solver was used in this design as it can solve the widest range of electromagnetic field problems and is the most suitable solver for the dipole antenna. The entire broadband frequency behaviour of the simulated device was obtained by using the transient solver and it was done for only one calculation run.

2.0 THEORY

Figure 1 shows the basic half-wavelength dipole.

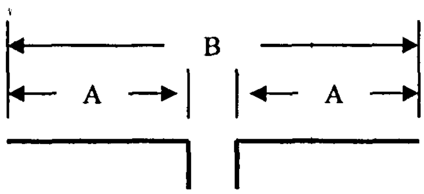


Figure 1: Basic half-wavelength dipole

It consists of a half-wavelength radiator ('B') that is cut into sections ('A') which are each a quarter-wavelength long. The feed point is the middle of the half-wavelength and the dipole makes a good match to 75 ohm coaxial cable.
The element lengths (in meters) of the half-wavelength dipole would normally be found from $150/F_{\mathrm{MHz}}$ for the overall length and $75/F_{\mathrm{MHz}}$ for each quarter-wavelength segment. However, because of the velocity factor effects of the length-diameter ratio (which is high for wire HF antennas) and the capacitive end effects, a small foreshortening occurs, making actual lengths closer to [7]:

$$B_{\mathrm{meters}} = \frac{143}{F_{MHz}} \text{ meters} \quad (1)$$

$$A_{\mathrm{meters}} = \frac{71.5}{F_{MHz}} \text{ meters} \quad (2)$$

However, in this particular design, the tubing was use for the construction of the main antenna elements instead of the wire. For tubing element, the length of the elements can be theoretically derived from the basic equation as follow:

$$\lambda = \frac{C}{f} \quad (3)$$

Since each dipole consist of two quarter-wave elements, the equation become

$$L = \frac{C}{4f} \quad (4)$$

where;

C = speed of light
f = center of transmitting frequency
λ = frequency wavelength
L = length of dipole element = $\frac{\lambda}{4}$

In space, wave is traveling at a speed of light, C. However, it speed decreases in medium such as aluminum tube. Therefore, the effective traveling speed of wave in material is denoted by the velocity factor of that material. In this case, the aluminum material has 0.98 velocity factor. The equation will then become

$$L = \frac{0.98C}{4f} \quad (5)$$

The near field distance of the antenna is given by [8]:

$$r_{\min} = \frac{2d^2}{\lambda} \quad (6)$$

where,

$r_{\min}$ = the near field distance
d = the largest antenna dimension
λ = wavelength of the radiated signal

Standing Wave Ratio (SWR) can be defined in terms of reflection coefficient [9]:

$$VSWR = \frac{1+S_{11}}{1-S_{11}} \quad (7)$$

Figure 2 below shows the wiring method for the turnstile antenna [4].

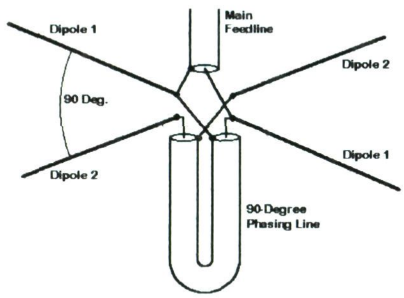


Figure 2: Wiring method of turnstile antenna

3.0 MODELING AND MEASUREMENT

3.1 Modeling with CST MWS

The modeling of turnstile antenna was carried out by the following steps:

1. Select a template Antenna (in Free Space, waveguide)
2. Units, background, working plane properties and frequency range were defined.
3. The first dipole were created using the cylinder tool with the radius, a = 0.5 cm and height, h = 63.4 cm at the Z-axis. The material of the dipole is aluminum.
4. Define the box structure at the center of the dipole with the dimensions of 10 cm x 10 cm x 10 cm.
5. Boolean subtract the box from the cylinder resulting in two quarter-wave length dipoles.
6. Use the same steps (3 to 5) to create the second dipoles.
7. Create the main feed line using the cylinder structure. The feed line is a coaxial cable consists of two conductors. The inner conductor material is perfect electric conductor (PEC) and the outer conductor is copper. The dielectric that separates the conductors is the paraffin wax with the permittivity of 2.25.
8. Connect one of the dipoles to the main feed line as shown in Figure 3.
9. To achieve 90 degrees phase shift, another feed line was created. This phase line will connect the first dipole to the second dipole as shown in Figure 4. Thus, the complete turnstile antenna is obtained.
10. Field monitor and port were defined.
11. The turnstile antenna is then simulated using the Transient Solver.
12. The simulation using different type of material for the dipole are also been conducted.

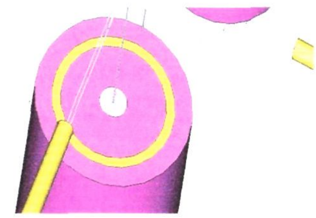


Figure 3: Connection of the dipoles to the main feed line

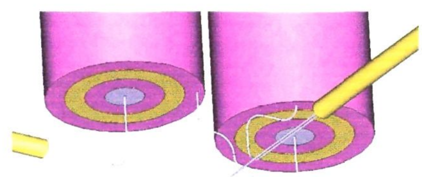


Figure 4: Connection of the dipoles to the phase line

3.2 Measurement Setup

The first procedure is to check the ability of the antenna to act as a receiver. The antenna was connected directly to a spectrum analyzer and the signal received is identified.

The second procedure is to identify the resonance frequency of the antenna. This process is to ensure that the antenna is operating at the desired frequency which is 137.5 MHz. Measurement for identifying the value of the return loss; S_{11} was carried out by using Hewlett Packard 8757D Scalar Network Analyzer (SNA) and Hewlett Packard 83640B Signal Generator as shown in Figure 5. The SNA and signal generator were calibrated by using a few standards namely, a short and open circuit also a through connection connected to each port before both equipments were connected to the turnstile antenna. The values of the S_{11} were recorded. The antenna height from ground was also varied and the S_{11} values obtained were tabulated.

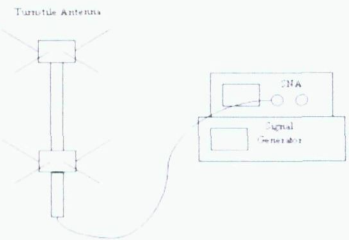


Figure 5: Connection for S_{11} measurement

The next procedure is to obtain the radiation pattern of the turnstile antenna. The measurement was carried out in the communication lab since there was no anechoic chamber available. Two antennas were used in this measurement. The RF generator was connected to the loop antenna that acts as a transmitter while the signal generator was connected to the turnstile antenna that acts as a receiver. The antenna was manually rotated and readings were taken for every 10° rotation.

4.0 RESULTS

4.1 Simulation Results

Figure 6 shows the turnstile antenna that has been designed using the CST MWS.

Figure 6: Turnstile antenna

Figure 7 indicates the results for the S_{11} obtained from the simulation using the CST MWS. The result shows that the antenna operated successfully at the desired frequency of 137.5 MHz with the S_{11} value at -37.36 dB.

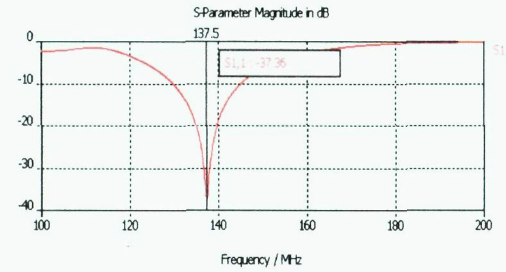


Figure 7: S_{11} value at 137.5 MHz

Figure 8 and 9 display the 3D radiation pattern obtained from the simulation of the turnstile antenna using the CST MWS software. It can be seen that the high radiation indicated by red color focused on the dipole that was connected directly to the main feed line. The radiation pattern is approximately closed to the theoretical pattern except that the classic figure '8' did not appear correctly at the second dipole that is not connect directly to the main feed line.

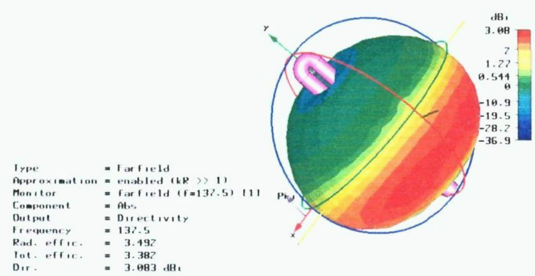


Figure 8: Far field at f = 137.5 MHz for turnstile antenna

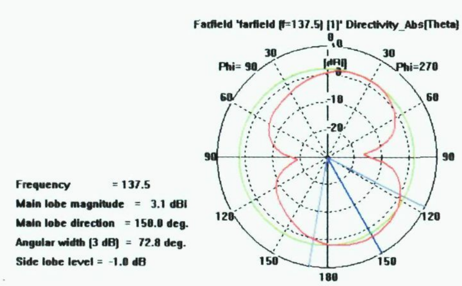


Figure 9: Radiation pattern for the turnstile antenna

Table 1 below shows the comparison of the simulation result for the turnstile antenna with different dipole material.

Table 1: Simulation results using different materials

MATERIAL	S_{11} VALUES (dB)	RESONANCE FREQUENCY (MHz)
Aluminum	-37.36	137.5
PEC	-37.28	137.5
Copper	-37.26	137.5
Gold	-37.26	137.5
Brass	-37.25	137.5
Tin	-37.24	137.5
Zinc	-33.02	135.3

4.2 Measurement Results

From the measurement carried out it can be observed that the turnstile antenna is capable to receive signal at 137.5 MHz. Figure 10 shows the signal receives by the turnstile antenna approximately at 137.5 MHz.

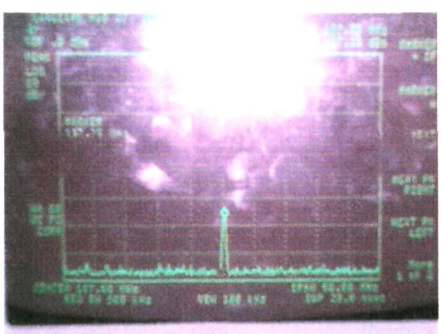
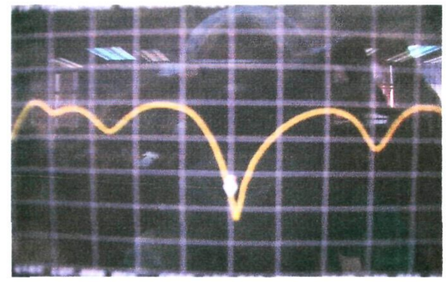
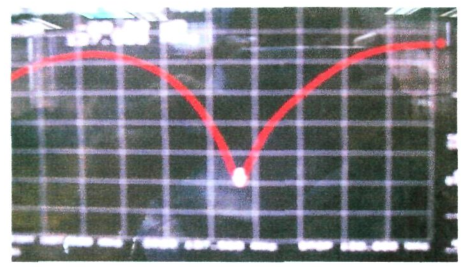


Figure 10: Signal receives by the turnstile antenna

The result for the measured S_{11} is shown in Figure 11. Figure 11(a) shows the response before the signal was span where the frequency resonates at 137.505 MHz. While Figure 11(b) shows the response of the S_{11} after the signal was span at 50 MHz. which shows the frequency resonates at 137.510 MHz.



(a)



(b)

Figure 11: Simulation result for the S_{11}
(a) before signal span, (b) after signal span at 50 MHz

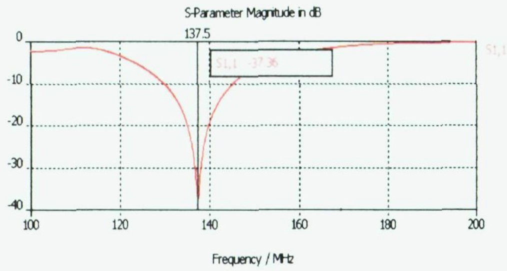
Table 2 indicates the S_{11} value obtained from the measurement as the height of the antenna from ground was varied.

Table 2: Results from S_{11} at different height

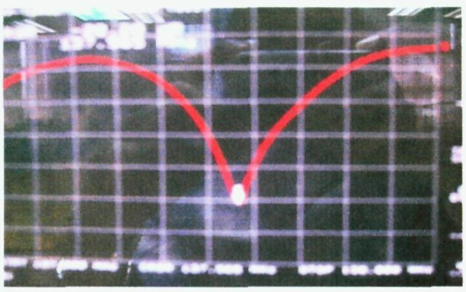
HEIGHT (meter)	RESONANCE FREQUENCY (MHz)	S_{11} RESPONSE (dB)
2.5	137.505	-33.51
2.43	137.510	-32.60
2.02	137.529	-32.00
1.92	137.530	-31.80
1.85	137.550	-31.20

4.3 Comparison of the S11 value

Figure 12 shows the results for the S_{11} from both the simulation and measurement that have been carried out. Both results are compared and it shows that the antenna was operating successfully at the desired frequency of 137.5 MHz.



(a)



(b)

Figure 12: (a) simulation result, (b) measurement result

5.0 DISCUSSION

Several problems were encountered in designing the turnstile antenna. Since the turnstile antenna has two feed line namely; main feed line and phase line, the connection between each dipoles became more complicated as we have to ensure that the connecters do not overlap with each other. The most difficult part was to design the phase line due to its shape. The size of the feed line is bigger than usual as it was the only way to enable the CST MWS to simulate the results due to the four layer construction of the main feed line. The accuracy level used in the transient solver was -40 dB in order to obtain the accurate far field result. The feed line was match to the 75 ohm impedance. The 75 ohm is suitable impedance matching for the dipole and turnstile antenna while the 50 ohm is a good impedance matching for the monopole antenna [10]. The radiation pattern of the antenna is approximately close to the omni-directional pattern. By referring to Figure 9, the radiation pattern radiates more at the dipole which is connected directly to the main feed line. The waveguide that go through the phase line was not strong enough to radiate the second dipole to the maximum. This is why the second dipole cannot radiate the signal to the maximum. The dipole material was varied to see the effect of different metal to the antenna's response. It has been proved that almost all the metals gave the same result, where, they have the same operating frequency but with different S_{11} value. All the metals are good electrical conductors but the most common metal use in the construction of the antenna is the aluminum because it is cheaper and easier to construct.

Several limitations occurred during the measurement of the antenna. To obtain the radiation pattern, the measurement should be carried out in the anechoic chamber as this will give more accurate result. In this project, the measurement was only done in the normal lab as there is no anechoic chamber available. Thus, the measurement was exposed to the noise and other interference that affected the overall results. Another limitation was the equipments available in the lab were not suitable to conduct the radiation pattern measurement. Due to all the limitations, the radiation pattern from the measurement could not be obtained.

The signal was not span during the first measurement resulting in interference from other frequencies. To get the best result at the desired frequency, the signal was span so that any other signals that interfere will disappear. The signal was span at 50 MHz and its result in the resonance frequency of 137.510 MHz. The frequency did move forward as the span stretched the signal to eliminate the other interference signal.

The S_{11} result for the simulation is -37.36 dB while in the measurement; the S_{11} is equal to -33.51 dB. The S_{11} is the return loss of the antenna. The -37.36 dB reading from the simulation indicates that the entire signal is being transmitted successfully and no signal is reflected to the system. The S_{11} measurement result is approximately at 137.510 MHz. The difference for the resonant frequency gained from both simulation and measurement is about 0.01 MHz and the difference in the S_{11} is 3.85 dB. The discrepancy in the results were possibly due to the interference that occurred at the time the measurement took place and other equipments in the lab such as the computer, light and cell phone.

The heights of the antenna from the ground were also varied accordingly. From Table 2, it can be seen that the S_{11} value decreased as the height of the antenna decreased. This occurred because the measurement took place in a normal lab where other electrical equipment might affect the performance of the antenna. This is not the best place to conduct the measurement as some energy may be wasted because of absorption by nearby objects [9].

The values of the VSWR for both simulation and measurement were calculated. From Equation 7, the calculated value of VSWR for simulation was 1.000367 while for the measurement the value was 1.000892. Both values indicate that all the signals were transmitted and there was no reflection occurred [8].

6.0 CONCLUSION

A turnstile antenna is designed to operate as a VHF antenna at the frequency of 137.5 MHz. It is shown that the return loss, S_{11} of the antenna is almost the same for both the simulation and the measurement. The antenna is working properly as it can transmit almost all the signals that it receives. The radiation pattern of such an antenna obtained from the simulation is closed to the omni-directional pattern. The height of the antenna from ground also affect its performance as decreasing the height will at the same time decreasing the S_{11} value.

7.0 FUTURE DEVELOPMENT

Preliminary study indicates that there is another antenna that exhibits the omni-directional characteristics which are the Quadrifilar Helical (QFH) antenna. It has a slightly better performance but it is difficult to assemble. The performance of both antennas can be compared.
Other way to give the 90°progressive shift can be investigated to facilitate the design and simulation using the CST MWS.

ACKNOWLEDGEMENT

The author would like to thank the following individuals for their support, helps and guidance in completing this project; Pn Noor Hasimah Baba, En Fadhil Sayuti, Dr. Zaiki Awang, En Kamaruzzaman Md. Nor, En Azman Misroo, Muhammad Zahiruddin Bin Mohd Zahari and Norlia Bt. Ahmad Suhami.

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