Modeling of Magnetic Loop Antenna for an Improved Rockets/Spacecraft Communication Operation

M.E. Emetere[1], T.V. Omotosho[1], J.S. Mandeep[2] and M. Abdullah[2]
[1]Department of Physics, Covenant University, Ota, Nigeria
[2]Institute of Space Science,University Kebangsaan Malaysia 43600 UkmBangi, Selangor DarulEhsan, Malaysia
moses.emetere@covenantuniversity.edu.ng, omotosho@covenantuniversity.edu.ng, mandeep@eng.ukm.my, mardina@ukm.edu.my

***Abstract*—the magnetic loop antenna (MLA) is a compact HF antennas used transmitting signals within a fairly long distance. Its shape and size had metaphorsize from the usual analogue to a digital device-which is now used for experiments in space. In this paper, the resolution of the bearing angle errors of the antennas on a rocket or spacecraft was proposed to enhance improved application in signal transmission. A new concept was introduced -angular displacement theory which was used to mitigate fading in multipath propagation especially from Rocket or spacecraft orbits**

Keywords- magnetic loop antenna; functionality; ground plane; ultra wide band; radiation pattern.

I. INTRODUCTION

Several improvements have been made on the functionality of the MLAs. The useable frequency was improved upon from 20 KHz to 55 MHz by the introduction of an amplifier to separate the magnetic loops and the introduction of an electrically small material to the near-field of the electrically small radiator. That type of MLA (figure 1) was referred to as the magnetic EZ antenna which has been proven to operate at 100MHz [1]. Recently, the MLA application can be found in plasma physics i.e. heating and ionization for processing plasmas, laser-plasma interactions, plasma opening switches, and active experiments in space, excitation of large amplitude whistler modes in magnetized plasmas. Synthetic-aperture radar (SAR) is a special sensor located either in rockets or spacecraft which uses the motion of the SAR antenna over a target region to provide spatial resolution (see red arrow in figure 2). It has been established that the spatial resolution is finer with conventional beam-scanning radars. This feat is achieved when successive pulses of radio waves are transmitted to "illuminate" a target scene. The reflected echo of each pulse is received and recorded using a single beam-forming antenna, with wavelengths used anywhere from a meter down to millimeters. The bearing angle error of the beam-forming antenna and SAR antenna calls for attention. The MLA is presently used for space communication to minimize the bearing angle error. Certainly there are more to its functionality than already known. In this paper, we propose a magnetic loop antenna (MLA) – suitable for mitigating fading in multipath propagation by applying the angular displacement theory on the slots of a ground plane

II. THEORETICAL BACKGROUND

The time- independent Schrödinger equation and the Maxwell equation was modeled to open up the electron dynamics [2] and its effect on radio propagation from spacecraft or rockets (figure 2). The Euler-Lagrange equation associated to the function $S = S(E_r, E_z, B_r, B_z, r, \theta, z)$ was adopted to generate the governing equation i.e.

$$\frac{\partial}{\partial t}E_z = \frac{\partial}{\partial t}E_z e_z e^{-j\beta r}(sin\theta + cos\theta) \quad (1)$$

III. EXPERIMENTAL ARRANGEMENT

For the purpose of this study, we shall be concentrating on Equation [18] of Ref [3] which expresses the functionality of the antenna. We propose an introduction of a varactor diode of capacitance range between 25 to 0.5 pF to be installed at either the front open port or alongside the variable capacitor. The varactor is used to limit the absorption at the resonance by the help of a high series resistance. A series inductor (L) and protection resistor (R) of respective rating 1Ω and 5.5μH are expected to allow only direct current (dc) and truncate the alternative current flow. The type of coil used for this model is not specified largely due to constraints of access to materials and the flexibility to incorporate recent discoveries in material science, though; we acknowledge that coil material is the source of discrepancy between measured and simulated radiation patterns.

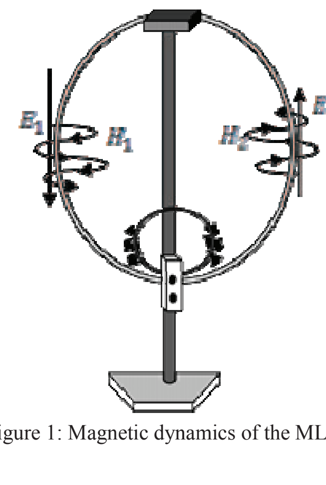

Figure 1: Magnetic dynamics of the MLA

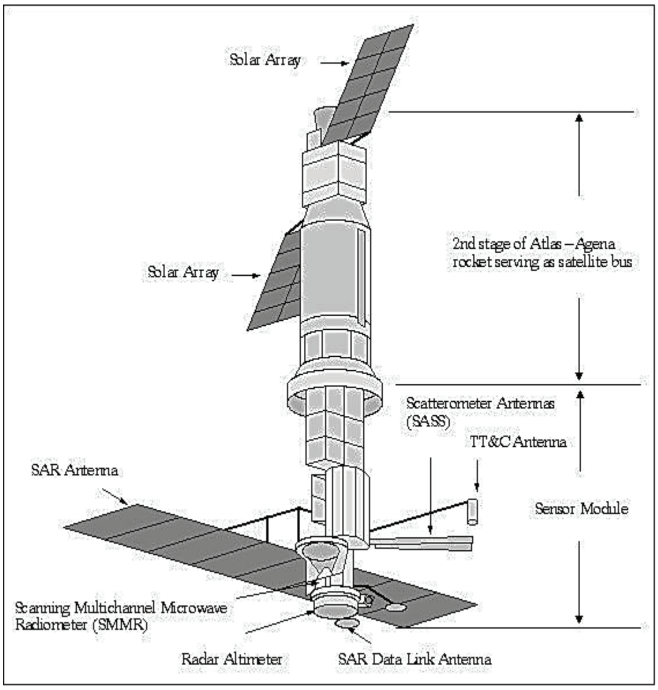

Figure 2: Antenna application to spacecraft [6]

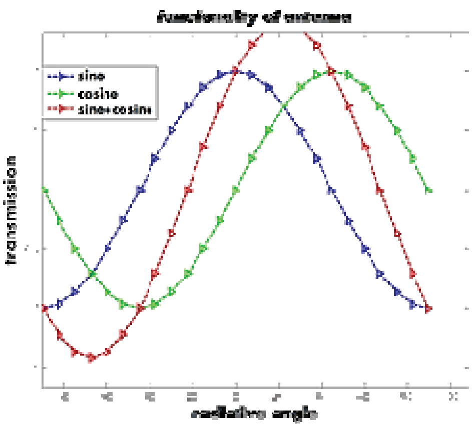

Figure 3: The functionality of the MLA with or without slot

IV. RESULTS AND DISCUSSION

The radiational angular displacement theory is all about substituting the slots on the ground plane with the radiation angle which had been properly accounted for in section II. From equation (2) drawn from Ref [2-5],

$$\frac{\partial}{\partial t}E_z = \frac{\partial}{\partial t}E_z e_z e^{-j\beta r}(sin\theta + cos\theta) \qquad (2)$$

Slot with higher width is represented by the sine of the radiation angle; slot with lower width is represented by the cosine of the radiation angle. The sum of both cosine and sine of radiation angle represents the MLAs without slot. We simulated the relationship between the radiation angle and its effect on the functionality of the antenna as shown in Figure [3].

Though the radiation patterns of the MLA with and without slots on the ground plane are very similar but the performance of the MLA differs at various conditions. First, the slot with higher width was more effective on the ground plane to minimize the ground plane effects on planar UWB magnetic loop antenna. The slot with lower width was less effective. This concept is in agreement with the experimental discoveries made in the past. The new discovery is that the MLA is functionally active when a slot-less ground plane is angularly displaced. This idea was applied to slot of higher width (sin(x)-cos(x)) and the slot of lower width (cos(x)-sin(x)) as shown in figure [4], It improved the functionality as the transmission increased considerably to the magnitude of the MLA without slot.

Another discovery was the reversal of functionality betwwen slots of varying widths i.e. slot with lower width was more active than slot with higher width.The frequency variation of the MLA as shown in figure [5], suggest that MLA can cover the entire ultra wide band (UWB) with a reflection coefficient of about -2dB. The integration of the varactor diode into the mechanism of the MLA enables the impedance matching which is dependent on the slot of antenna at lower frequencies. Again, the MLA with and without slot was tested, the reflection coefficient was better than -2dB over the entire UWB with significant difference between MLA with and without slot.

In figure [6], the MLA without slot – under the angular displacement theory was tested under different low frequencies i.e. 1.3MHz, 2MHz, 2.5MHz, 5MHz. The lower the frequency was confirmed to favor impedance matching.

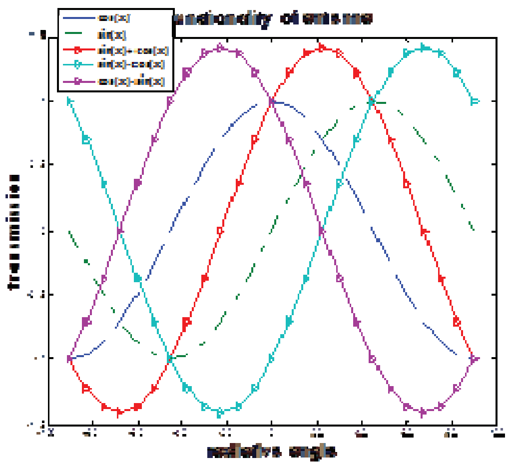

Figure 4: Verification of the angular displacement theory on the functionality of the MLA

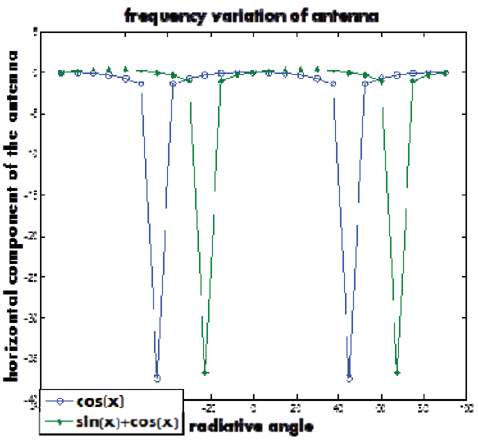

Figure 5: Frequency testing of MLA with and without slot

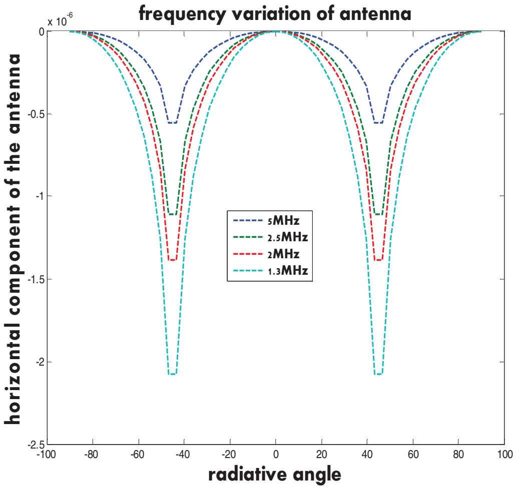

Figure 6: Frequency tuning of MLA without slot

The multipath fading is caused by largely meteorological factors e.g. reflection and refraction in the ionosphere, atmospheric ducting e.t.c. Hence, the changing radiative angle as shown in figure (6), reduces the changing signal strength over short distance. For example, between -50^o and +50^o, the possibility of changing signal strength via $\theta = \sin(\omega t)$ within short time is minimal. Also, figure (6) portrays a reduced possibility of random frequency modulation which are common to varying Doppler effects along the transmission paths. Figure (5) shows a two scenario to investigate the time dispersion of the multipath propagation delays. The time dispersion between a ‘coherent’ multipath (i.e. cos (x)) and the ‘incoherent multipath (i.e. cos (x) and sin (x)) is moderate. These results further affirm the efficiency of the modified loop antenna for rockets or spacecraft communication operations. However, the physics of $\frac{\partial}{\partial t}E_z = \frac{\partial}{\partial t}E_z e_z e^{-j\beta r}(sin\theta + cos\theta)$ in a remodified MLA cannot be underestimated in planning either the uplink or downlink efficiency during signal propagation.

V. CONCLUSION

The MLA has shown additional functionality i.e. UWB by incorporating a varactor diode to the front open port. The radiational angular displacement theory supports the MLA without slot. The MLA covers the entire ultra wide band (UWB) with a reflection coefficient of about -2dB. Therefore MLA was used to resolve the bearing angle errors for utmost enhancement of finer spatial resolutions. This makes the MLA applicable in greater interest for commercial and military wireless technologies if improved-upon.

ACKNOWLEDGMENT

The authors appreciate the unflinching support of Covenant University

REFERENCES

[1] Richard W Ziolkowski, Chia-Ching Lin, ean A Nielsen, Minas H Tanielian, Christopher L Holloway. “Design and Experimental Verification of a 3D Magnetic EZ Antenna at 300 MHz”. IEEE Antennas and Wireless Propagation Letters. 2009; 8: 989-993.

[2] Uno E. Uno and Moses E Emetere “The Physics Of Remodeling The Transmitting Loop Antenna Using The Schrodinger-Maxwell Equation” Journal for Asian scientific research vol 2(1), pp 14-24, 2011

[3] Moses E Emetere “Theoretical Modeling Of A Magnetic Loop Antenna for Ultra wideband (UWB) Application”. TELKOMNIKA Indonesian Journal of Electrical Engineering, vol 12 (10), pp7076 – 7081. 2014

[4] M.E. Emetere, M.L. Akinyemi, U.E. Uno, A. O. Boyo (2014) “Lightning Threat Forecast Simulation Using the Schrodinger-Electrostatic Algorithm”. IERI Elsevier Procedia, vol 9, pp 53 – 58, 2014

[5] M.E. Emetere, “Investigations of the Sheath Effect on the Resultant Magnetic Field of a Cylindrical Monopole Plasma Antenna”,Plasma Science and Technology, 17(2), 153-158.

[6] Earth Observation Portal, https://directory.eoportal.org/web/eoportal/satellite-missions/s/seasat (accessed on 2015)