Design and Fabrication of Magnetic Loop Antenna for 5MHz

Anvesh Inamdar, G. S. Mundada

Abstract*: *In the short-wave range, size of the antenna become large and therefore is a major constraint. Magnetic Loop Antenna provides an advantage over other antennas in terms of a smaller size, higher quality factor and better signal to noise ratio. It works on the principle of resonance with the inductor provided by loop and external tuning capacitor operating like a tank circuit. The tunable magnetic loop antenna is designed to work in the high frequency range. The antenna consists of a circular hollow copper pipe, an inductive loop feed and a variable tuning capacitor. The antenna is tuned using variable 9-140pF capacitor paralleled with 150pF capacitor. The designed antenna is simulated using 4NEC2 software. The simulated antenna has high efficiency and quality factor of more than 1000. The real time testing show great result at 5.45MHz with bandwidth of 8KHz.

Keywords: Magnetic loop antenna, High frequency, Resonance, small loop, gain.

I. INTRODUCTION

A Magnetic Loop Antenna is a closed circuit antenna composed of one or more turns with its ends joined together. The loop antenna is circular in shape and broadly can be classified into two types based on its dimension and size. The first type is the one in which the total length of the conductor must not be greater than 0.1 λ where λ is the operating wavelength of antenna. The phase and amplitude of the current distribution will remain same at every single point in the loop at any given instant of time. The second type is the one in which the antenna length is comparable with wavelength. And its other loop dimensions have close resemblance in size as compared with the wavelength. At which it is working with its amplitude and phase being different at different points in the antenna at the same instant of time [1]. The magnetic loop antenna is a small length antennas used for the communication within the short wave range. As we move higher into the frequency of operation in GHz range, the size of the antenna to be used decreases considerably. As size of the antenna gets smaller, the complexity gets higher. The increase in the complexity in turn makes the design more sophisticated and also increases the chances of error during the process of fabrication [2]. The antennas used for MHz range operating are generally the dipole antennas. The dipole antenna has high gain factor but one needs to make trade-off in its size when the operating frequency has low range as of 1 – 100 MHz. The antenna operating on low frequency can result into dipole of almost 50 meters in length which makes it very difficult to port from one point to another. And also is not feasible in aspect of cost and application to construct an antenna of such magnitude. The magnetic loop antenna provides a solution in this case with a considerably smaller size requirement for the same frequency operation. The magnetic loop antenna due to its high quality factor is a highly tuned resonant frequency antenna with high signal to noise ratio and narrow bandwidth thereby increasing the quality of reception [3]. As this antenna does not use the line-of-sight principle, it can be used for both long and short distance communications. It works on the principle of reflection from the ionization layer in the atmosphere thereby making a single pair of antenna possible to communicate all around the globe. The simple design and high cost effectiveness comparatively makes it more favorable than conventional dipole antennas. The generic magnetic loop antenna is strictly designed to resonate at a particular frequency based on the tank circuit as shown in equation.

$$F = {}^{1}/_{2\pi\sqrt{LC}} \quad (1)$$

The magnetic loop antenna is basically a tuned circuit with the inductor formed by a loop of wire consisting of circumference measured less than 1/4 wavelength and resonated to the operating frequency with a capacitor. As the antenna has low radiation resistance and large circulating current, the loop must be constructed of a low resistance large outer diameter conductor for best efficiency. Generally, magnetic loop antennas are made up of coaxial cable, hard-line, or solid copper or aluminum tubing or ribbon.

These antenna loops also have a very narrow bandwidth, which requires a variable capacitor for tuning loop to operate antenna on particular frequency. As voltages develop across the capacitor is in the order of thousands of volts, air variables or vacuum variable capacitors are used. To maintain the lowest series circuit resistance, the connections are mostly soldered and a split-stator or "Butterfly" type capacitor is preferred. Most of the parts required to build the antenna are inexpensive and easy to find and a typical construction of Magnetic loop is as shown in figure 1, (The figure 1 shown below is a reference figure to construct the actual loop antenna)

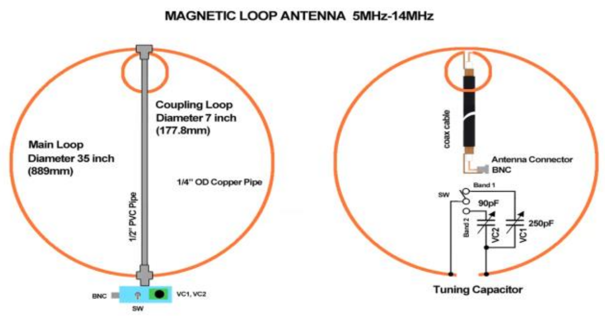

Figure 1 – Construction of Magnetic Loop Antenna

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In the following, section II presents the design of magnetic loop antenna at 5MHz operating frequency. Section III introduces the antenna simulations done on 4NEC2 software. In section IV the antenna hardware test results is given, and in section V our conclusions.

II. DESIGN OF MAGNETIC LOOP ANTENNA

The equivalent circuit diagram of the loop antenna is shown in figure 1. The magnetic loop antenna acts as a tank circuit in which loop of the antenna provides inductance and the tuning capacitor is to set frequency. As we are designing small loop antenna the length of the loop or antenna height is kept constant, future we find out inductance and capacitance of mag loop antenna.

A. Inductor

As we are designing a small loop antenna we have kept the antenna height constant, where the diameter of magnetic loop is considered to be 'D'- 0.9 meter (35.43 inch) and the width of copper hollow pipe is 'd'- 6.35 millimeter (0.25 inch). To find out inductance of this loop we use following equation,

$$L = 0.005p\ \{[7.353x(\log(8x\tfrac{D}{d})] - 6.386\} \qquad (2)$$

$$= 0.17715 \times \{[7.353 \times 3.054] - 6.386\}$$

$$L = 2.847\ uH$$

As we know,

$$X_L = 2\pi\ FL \qquad (3)$$

$$X_L = 89.441$$

B. Capacitor

The capacitor is important aspect of a magnetic loop antenna, as the length and height of loop are kept constant. So to vary the operating frequency of antenna the capacitor is essential. We are designing this antenna at 5MHz and to resonate loop at that frequency tuning capacitor is determined through following equations,

$$C_S \sim 0.2103 \times D \qquad (4)$$

$$C_S \sim 7.45\ pF$$

Therefore,

$$C = {10^6}/{(2\pi\ \mathrm{Fmax\ XL})} - Cs \qquad (5)$$

$$= 355.88 - C_S$$

$$C = 348.43\ pF \approx 350pF$$

So for matching the magnetic loop and to obtain the desired 5 MHz tunable frequency we need almost the matching capacitor of 350 pF.

The formula used for above calculations are taken from Ted Hart [8] and modified according to specifications of parameters available.

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III. ANTENNA SIMULATION

The magnetic loop antenna is designed and simulated using 4NEC2 software. This 4NEC2 is specialized simulation software used only for magnetic loop antennas. Figure 2 and 3 show the construction of magnetic loop with respect to the field. In the simulation design the magnetic loop antenna is taken 10 meters above the ground.

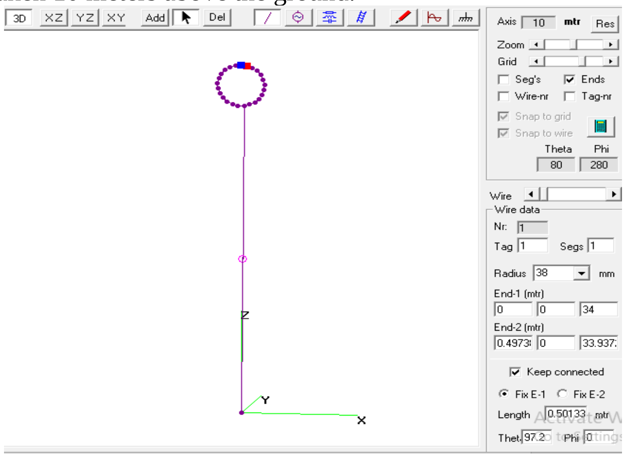

Figure 2 – Simulation of antenna.

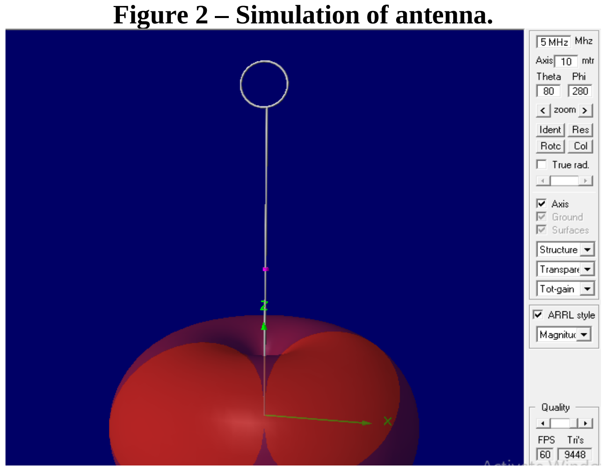

Figure 3-Simualtion of antenna with 3D field pattern.

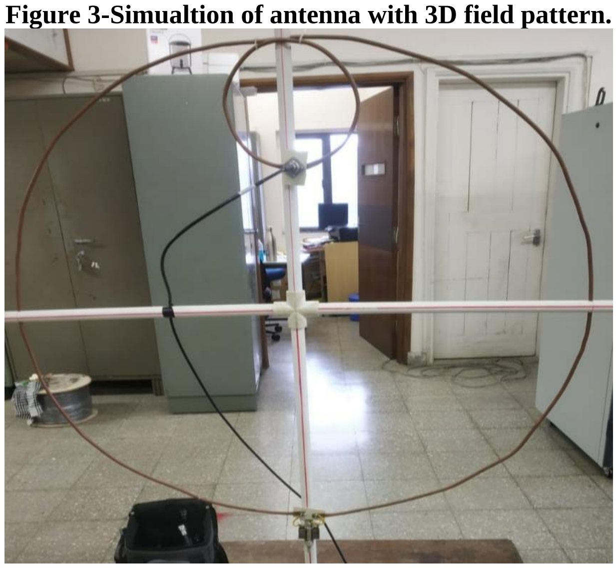

Figure 4-Actual magnetic loop antenna.

The antenna is taken 10m above the ground in simulation so as to reduce the effect of ground reflection which affects reception of antenna causing noise. The above figure 4 shows actual construction of the magnetic loop antenna. In which the outer loop is made up of copper and has diameter of 0.9 meters (35.43 inch) with width of copper pipe of 6.35 millimeters (0.25 inch).

The practical magnetic loop antenna also consists of a coupling loop to increase efficiency, where the diameter of coupling loop is 18 centimeter (7 inch) and has same width as of larger loop both are made up of copper hollow pipe. The actual antenna has a frame of PVC pipe to give circular loop rigidness. The capacitor connected to the outer loop is 9-140pF air variable capacitor paralleled with 150pF capacitor to get same result like 350pF tuning capacitor, as 350pF air variable capacitor is hard to get.

IV. RESULT AND DISCUSSION

The design of magnetic loop antenna to be fabricated is first simulated in 4NEC2 software. The simulation results obtained are verified against the design specification of antenna. The figure 5 shows the total gain response of antenna in simulation.

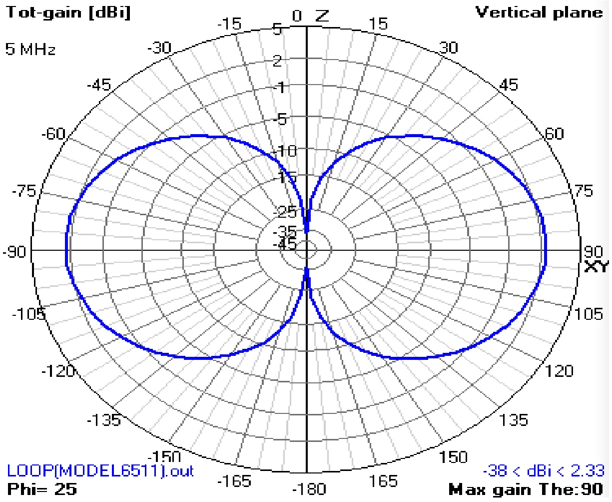

Figure 5- Total gain response.

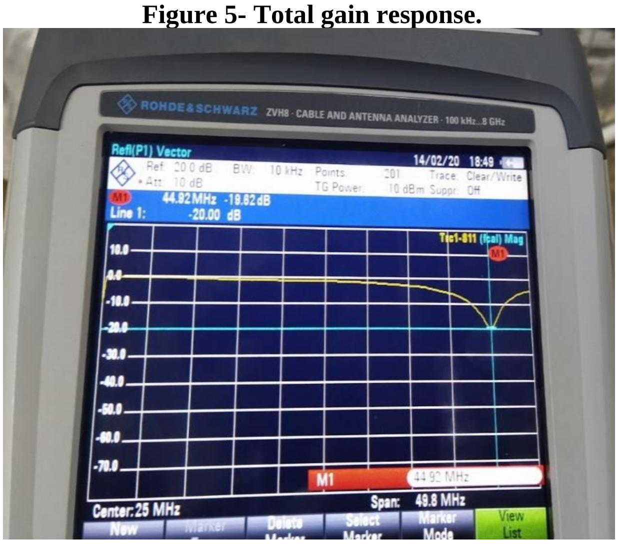

Figure 6- Antenna response (Tuned at 44.92 MHz)

The figure 6 shows the actual response of our designed magnetic loop antenna. The observations are measured by using Rohde & Schwarz cable and antenna analyzer (ZVH8). In which the measuring equipment is first calibrated and then used for obtain observations. Here we can see the antenna response which is at 44.92 MHz as we haven`t connected the matching capacitor (tuning capacitor) to antenna. That is the antenna is not tuned yet. In the graph the Y-axis represents attenuation in signal and on X-axis we have the frequency. The antenna is said to good when the return loss observed is less than -10dB. And in the antenna which we design shows almost -20dB of return loss, to be precise return loss is -19.62dB at 44.92MHz.

Figure 7 - Antenna response (Tuned at 5.45 MHz)

The figure 7 also shows actual response of antenna when the tuning capacitor is connected. The return loss of antenna when tuning capacitor is connected is -23.48dB at 5.45MHz, with bandwidth of 8KHz. The antenna which is fabricated thus provides a very good signal reception with low noise and also high signal quality.

V. CONCLUSION

In this paper, the magnetic loop antenna is successfully designed and fabricated for 5MHz operating frequency. Initially antenna was designed using theoretical equations keeping length and height of antenna constant and then simulated it using 4NEC2 software. The software design provided exact dimension required for fabrication of antenna. The values obtained were further optimized. The antenna is then fabricated depending on simulation results of same. To get specified frequency of 5MHz the tuning capacitor of 350pF (140pF paralleled with 150pF) is used. As result shows simulated and actual responses are in close range, where we got better results at 5.45MHz. Then the final setup is tested in real time.

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