Design and Characterization of a 2MHz Loop Antenna for its Application in Radio Emission Investigation of High Energy Showers

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Abstract

In this paper design and calibration of a 2 MHz loop antenna is presented for detection of radio emission due to high energy cosmic showers. The tuning measurement of the antenna is carried out by a HAM radio set. Free space radiation pattern measurement is carried out at the tuning frequency of 1.999 MHz (≈ 2 MHz). The power and field strength calibration graph is plotted which shows the potential of its use as a receiver for the required purpose.

***Keywords*:** Loop; callibration; tuning

Introduction

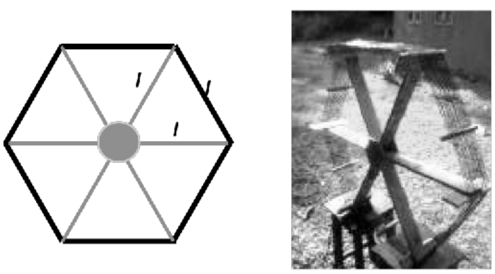
With the advent of new technologies for meeting the day to day requirement a trend of shifting to the higher side of the frequency spectrum as observed. But in certain applications such as detection of radio emissions from air showers initiated by high energy cosmic ray particles, antenna operating at low frequencies is required. The radio emission mainly ranges from 50 KHz to 520 MHz [1, 2]. For detection and investigation of such low frequency radio emission a loop antenna is designed and characterized. Loop antenna mainly falls in the category of wire antennas used for low frequency applications [3]. Loop antennas have low radiation efficiency so it is mostly used at the receiving end because of its directional properties as well as compact in nature. Work on loop antennas can be traced back to as early as 1915 used for communication purpose [4]. In the current work, a loop antenna is designed to operate at 2 MHz and characterized for investigating radio emission. Radiation pattern measurement is carried out along with the calibration observations done with HAM radio set.

Antenna Design

Loop antennas are designed mostly because of its versatility and compactness in nature that are used for detecting lower frequency band. In most of the cases the circular geometry is adopted because of simplicity in fabrication. However, designing loop antenna with more than a number of turn and maintaining the pitch difference one has to have a supporting base. Based on ease of fabrication a hexagonal loop antenna is designed without much compromising the loop area than a circular one. The design parameters of the hexagonal loop is shown in table I along with the schematic and the fabricated loop in figure 1 (a & b).

Table I: Designed parameters

Operating frequency	2 MHz
Wavelength (λ)	150 m
Arm length (l)	0.5m
Wire in SWG	14 ($r \approx 2.14$ mm)
Number of turn (N)	17
Spacing between winding (c)	4 mm
Wire material	Copper (Cu)
Conductivity (σ)	$5.7 \text{ X } 10^7 \Omega^{-1}\text{m}^{-1}$



(a) (b)

Figure 1: (a) Schematic diagram of the hexagonal loop
(b) Fabricated loop antenna

Measurements, Calculations and Results

A. Loop sensitivity

For a tuned loop oriented to give maximum signal (that is, its plane in line with direction of signal source) the loop sensitivity can be defined as follows [5]: $E_s/e=(2\pi NAQ)/\lambda$ (1.1)

where

E_s = output voltage from loop

e = field strength in volts per meter

N = number of loop turns

A = loop area in square meters

Q = loop Q factor

λ = wavelength in meters

The Q factor of the designed loop antenna can be found out from the relation [5]:

$$Q=\omega L/R_{ohmic} \quad (1.2)$$

where L is the inductance of the loop which is measured with an LCR bridge. The Q factor value comes out to be around 236 (assuming the proximity effect to be absent).

By putting the overall calculated values in the right hand side of equation (1.1) yields the loop sensitivity to be of 109 approximately.

B.Tuning measurements

The tuning measurement of the loop antenna is carried out with the help of HAM radio set. Different frequencies allotted in the HAM are transmitted where the signal received by the designed antenna is measured from a CRO. Table II shows the measured receiving voltage of the loop antenna for different incoming frequency signal of equal power. Figure 2 shows the graph of the data shown in table II.

Table II: Measured receiving voltage for different transmitting frequencies

T_x *frequency (MHz)*	R_x *voltage* (V_{p-p})
1.80	3.0
1.85	3.5
1.90	4.0
1.95	4.5
1.99	5.0
3.40	---
14.4	---

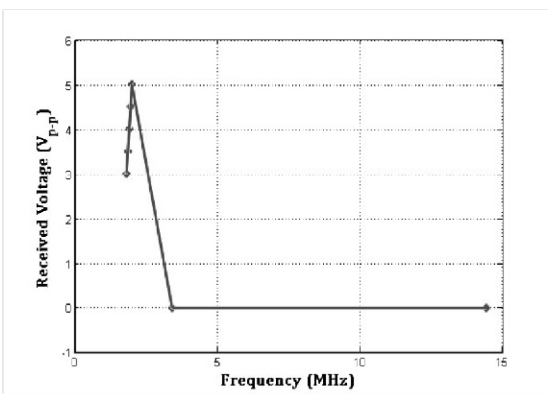


Figure 2: Transmitting frequency versus receiving voltage

As can be seen from figure 2 the loop antenna receives a maximum signal of 5 V_{p-p} at a frequency 1.99 MHz (≈ 2 MHz) amongst the transmitting range of frequencies having constant power.

C. Radiation pattern measurements

Free space radiation pattern measurement is carried out for the designed loop antenna for its highest tuning frequency by changing its orientation for a full 360° rotation with a distance separation of 30m between the transmitting and the receiving end. Figure 3 shows the measured radiation pattern plot of the loop antenna which shows a doublet pattern with its maximum at 0°.

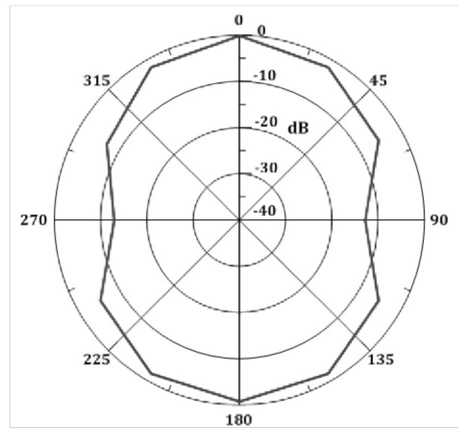


Figure 3: Measured radiation pattern of the loop antenna at 1.99 MHz

D. Power and field strength calibration

The power calibration is done by changing the transmitting power of the transmitter and observing the received power by the loop antenna for a given distance of separation (8m). This power calibration curve is very much essential in determining an unknown source power by observing the voltage response at the output. Also the field strength calibration curve (which will be received by the antenna) is plotted by calculating with respect to the loop sensitivity as found from equation (1.1). Table III shows the measured received voltage by the loop antenna for corresponding transmitted power from the transmitter along with its respective field strength (F.S.) for the given frequency of 1.99 MHz (≈ 2MHz).

Table III: Measured received voltage and equivalent field strength (F.S.) for corresponding transmitted power

T_x power (W)	***R_x voltage (V_{p-p})***	***Equiv. F.S.***
0.0	0.0	0.0
5.0	2.0	0.018332
10.0	3.2	0.029331
15.0	4.5	0.041247
20.0	5.5	0.050412
25.0	6.8	0.062328
30.0	7.8	0.071494
35.0	9.0	0.082493
40.0	10.0	0.091659
45.0	10.0	0.091659
50.0	10.0	0.091659

Figure 4 shows the power calibration curve of the designed loop antenna where the plot is between transmitted power and the received voltage. The field strength calibration curve is shown in figure 5 which is the plot between the received voltage and the equivalent field strength.

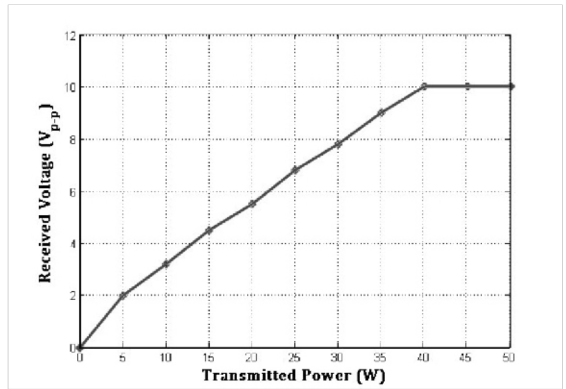


Figure 4: Power calibration curve

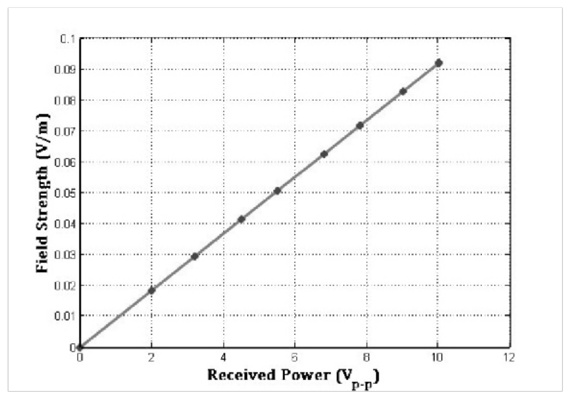


Figure 5: Field strength calibration curve

As can be seen from the power calibration curve the values saturates after a certain receiving voltage of 10 V_{p-p}. This occurs due to the saturation characteristics of the loop antenna itself where it reaches the maximum voltage it can induce. Moreover, the field strength calibration curve shows a good linearity that might enable to predict the value of an unknown emission to its nearest approximation.

Conclusion

The work and measured results presented in this paper confirms the loop antenna to be a potential design for it use in low frequency reception of secondary emission resulting from high energy cosmic showers. The antenna designed here resonates at a frequency of around 2 MHz as required for the targeted application. A doublet pattern is observed for the loop antenna, if required the antenna can be shielded in one side for a unidirectional reception. The calibration curves show a promising linearity which can be used for detecting unknown source to its nearest approximation.

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