PREAMPLIFIER DESIGN FOR IMPEDANCE MATCHING AND AMPLIFICATION FOR MULTIPLE TURN RECEIVER LOOP ANTENNA

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ABSTRACT

The paper is aimed on the description of the design of a preamplifier circuit which works as a BALUN (Balanced – Unbalanced). This circuit can match antenna impedance to 50 Ω coaxial cable. Since output impedance of multiple turn loop antenna comes out to be very low, impedance matching is an issue. This circuit works at 3 KHz – 30 KHz frequency. Op-amp OP27 is used as it is easily available. Circuit has been implemented such that, it reduces input impedance of Op-amp and increases output impedance of the circuit to match with the impedance of coaxial cable. Loop antenna connected to the circuit is receiver antenna to receive Lightning flashes at very low frequency range. Actual design of this system includes orthogonal pair of loop antennas, each connected with the circuit and then to the receiver circuit. Preamplifier gives good gain, impedance matching and better SWR parameters. Setup is tested using Vector Network analyzer in the lab.

Keywords*: *BALUN, CG, TOA, VLF & VNA.

I INTRODUCTION

This antenna is designed for Lightning detection for Cloud-to-Ground (CG) detection in VLF frequency range. The project is based on Time of arrival (TOA) method [1], so is made to work in the whole frequency range from 3 KHz to 30 KHz. Many systems are already available with different types of antenna used as sensors which include ferrite antenna, electrical whip antennas, coaxial cable antennas and wire antennas. Purpose of the work done in this paper is to design a circuit which can help in matching output impedance of the antenna to the coaxial cable as well as provide good gain to the signals received. Loop antenna to receive magnetic field with multiple turns is used. Section 2 describes details about the antenna design for the application. Section describes preamplifier circuit design and its sub sections describe simulation and development of preamplifier circuit on PCB. Section 4 describes testing of PCB with VNA device. Section 5 gives details about the complete test set up of antenna with circuit used and test results achieved on VNA. Section 6 gives advantages and applications of this project in conclusion part. References used in the project work are listed at the end of the paper.

II ANTENNA DESIGN

Square shaped loop antenna is selected here in rhombic form which is connected to the next part of the project i.e. preamplifier at one of the corner. A wooden frame is made which two wooden cloves each of 20 mm * 20 mm width. One clove is made longer of 2 mtrs and another less ~1 mtr. Diagonal of frame is kept 1mtr and metal hooks are used to mark the distance of 1mts on both the cloves. The wire used for the project is 1 mm diameter general electrician wire. ~75 mtrs of wire is used to make an antenna with 24 loop turns. We can use more number of turns again to increase resistance of the antenna [2]. But this will increase inductance linearly. The wire used can be used with more thickness. In the similar way, changes can be made on umber of turns, area of the loop, wire diameter etc. The antenna can be seen in the below Fig. 1.

Figure 1: Loop antenna – Multiple turns

Two loop antennas are placed orthogonally to each other to cover 360˚ and receive em waves from maximum directions. Antenna is not tuned at any frequency to make to work for wide frequency range to obey TOA methodology. On the other side, untuned antenna has limited sensitivity. Antenna wire used for winding is shielded wire to make it highly directional and provide extremely sharp nulls to electric field components that reduces noise.

Initially, 18 numbers of turns are wound on one of the frame side and output impedance is measured using VNA. Antenna wire ends are connected to N-type connector. Impedance measured with this configuration gave a value of 2Ω. Another configuration with 24 numbers of turns is tried on the other plane of the frame. Impedance measured with this configuration gave a value of 4Ω. In both the cases, inductance increased linearly with frequency. We can also reduce number of turns but then we have to increase loop size which may convert it to a resonant loop antenna from small loop antenna [3].

For tuning of the loop antenna at a particular frequency, we can use capacitor from a low value may be in the range of 0 – 300 pF. It takes approximately 2 hrs to implement this frame loop antenna in-house.

For theoretical reference, few calculations are done by assuming few parameters. Basic equations of the loop antenna can be given as:-

$$\mathrm{Erad}(t) = \frac{\mu_0 V I\left(t - \frac{D}{c}\right)}{2\pi D} \quad \ldots\ldots\ldots. (1)$$

$$H(t) = \frac{\mathrm{Erad}(t)}{c} \quad \ldots\ldots\ldots. (2)$$

$V = 2\pi\mu 0NAH0f\cos\theta$ ………. (3)

$I = \frac{V}{\sqrt{(R2 + XL2)}}$ ………. (4)

Here, Erad (t) Radiated electric field;
D Distance of the lightning strike;
A Loop area;
f Frequency of antenna at the particular strike;
μ_0 Constant (permeability)
H(t) Magnetic field
c velocity of light
V Voltage
I Current
R Resistance;
X_L Inductance

Assume, D = 100 kms; $\mu 0 = 4\pi \times 10\text{-}7$; f = 10 KHz; A = 0.25

Below Tables give an approximate idea about the values voltage, current, electric field and magnetic field received at the antenna (theoretically) with assumed values.

Table 1: N = 16; R = 2.574 Ω & L= 0.586 mH

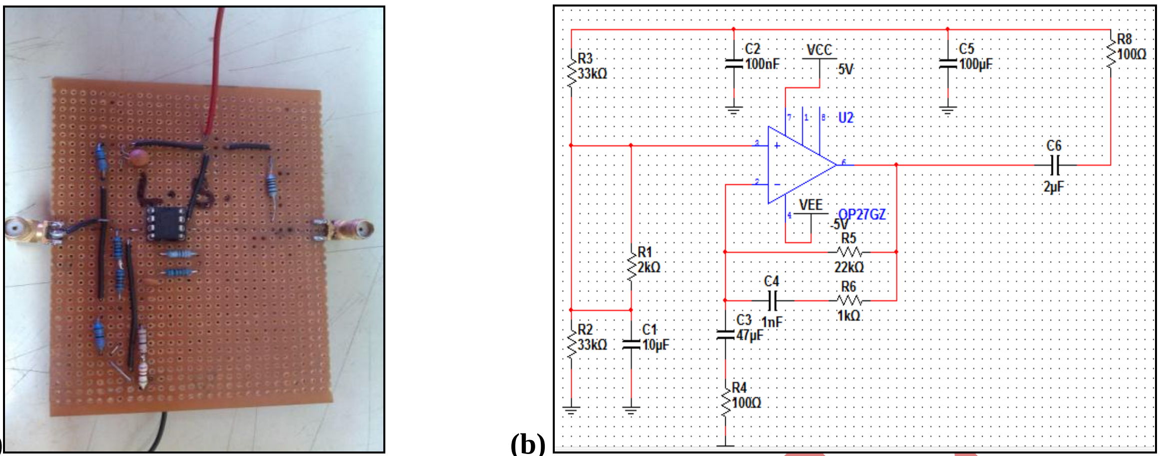
Assumed I	Erad(t) (V/m)	H(t) (nA/m)	V (nV)	I (nA)
5 KA	1	3.33	1.05	0.408
30 KA	6	20	6.31	2.45

Table 2: N = 24; R = 4.07 Ω & L = 1.3 mH

Assumed I	Erad(t) (V/m)	H(t) (nA/m)	V (nV)	I (nA)
5 KA	10	33.3	15	3.68
30 KA	60	200	94.7	23.26

III PREAMPLIFIER DESIGN & SIMULATION

Balun can be of various types employing functionality of amplification and impedance matching [4]. The preamplifier circuit uses low precision operational amplifier OP27 with 8 pins[5]. At the input and the output SMA connectors are soldered to be connected to the antenna and VNA device. R2, R3 and R8 play major role in the impedance matching and feedback network with R5, R6 and R4 work majorly for Gain of the operational amplifier. For external power supply we can use LC power divider circuit after R8 and C6. A resister before R3 and R2 network can be used in series with antenna to increase output impedance of antenna to further match the same with input of the preamplifier (resistive matching).



(a) (b)

Figure 2: (a) PCB design; (b) Multisim design of circuit

We can also calculate gain of the circuit using formulae's on feedback network. Gain calculations for the Opamp in above configuration can be done as:-

$$\frac{Vout}{Vin} = 1 + \frac{Rf}{R1} \quad \text{...} (5)$$

Here, R_f = 22 KΩ and R_1 = 100 Ω

$$\text{Gain} = 20\log\frac{Vout}{Vin} \quad \text{...} (6)$$

Gain = 47dB

This balun circuit is simulated on Multisim initially to find V-I characteristics and impedance of the circuit. Various components are modified and then used in the design to get the final design. This design considers a very low impedance value of antenna which has to be connected to the circuit. So, input impedance of circuit is made low to match with the antenna. Antenna matching transformer is then not used as it may load the antenna. At the output, circuit output is measured and made suitable to be connected to the receiver through coaxial cable.

PCB is then developed in the lab with components available. General purpose PCB is used with through hole components. Few capacitors which were not available in the through hole form, SMT capacitors are used instead, which are soldered at the backside of PCB. SMA female connectors are used at the input and output of the circuit to be connected to the Vector Network Analyzer (VNA) and antenna.

IV PREAMPLIFIER TESTING

This PCB is then connected to the VNA from both the ends. The VNA has to be calibrated first at the required frequency range. 2-port analysis is done using 1 mtr cable at port 1 and port 2. Port 1 is connected to the input of the circuit and port 2 is connected to the port 2. Setup can be seen as in below diagram:

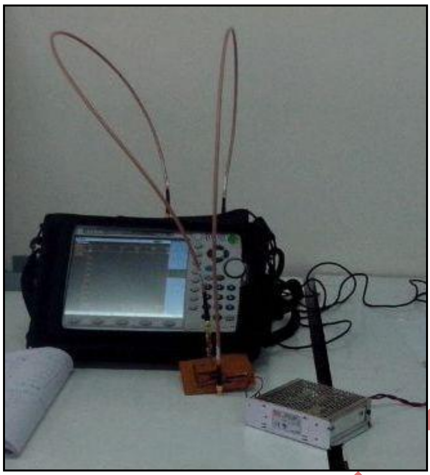


Fig 3: PCB two port analysis

Theoretical gain provided by the op-amp is calculated and is ~47db. Before connecting the circuit directly to the VNA, dc component of the circuit at the input and output should be 0V as it can make damages to the VNA device. For this purpose initially to capacitor values 0.1µF and 2µF are connected at the input and output of the circuit respectively to make DC voltage as 0V.

Gain measurement is tried n VNA for circuit and sometimes to prevent any damage to the device VNA, 40dB attenuators are used at the port for performing 2-port analysis as shown in the above Figure. Before performing any calculation, VNA ia calibrated at load, short and open ports. DC SMPS power supply is used to power the circuit externally. 1 mtr cables with SMA connectors are used for connection of circuit and VNA.

DC supply through SMPS (5V) is given to the circuit. Testing of circuit for dc components gives following details:

Configuration I: Input capacitor = 47µF Vdc = 2V

Output capacitor = 2µF Vdc = 0V

Configuration II: Input capacitor = 0.1µF Vdc = 0V

Output capacitor = 2µF Vdc = 0V

The circuit with capacitors changes to the below Fig.

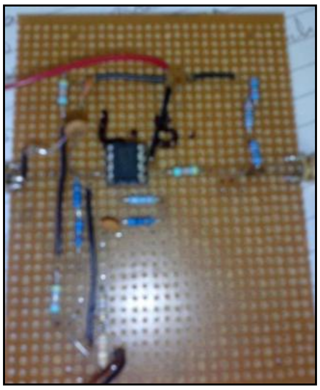


Fig 4: Input ceramic capacitor

After testing with VNA, the input capacitor is removed as later the circuit input will be connected to antenna and capacitor will tune antenna to specific frequencies.

V ANTENNA TESTING

After development of antenna and preamplifier circuit, final testing is done. Testing is done in the lab with an available transmitter loop antenna. Transmitter antenna used here is Passive loop antenna 20 Hz Model 6511. Steps followed for the setup and testing of the antenna can be written in points as:-

I. Calibrating VNA, Anritsu MS2026C for load, short and open configurations.
II. Putting markers for 5 KHz, 10 KHz, 15 KHz, 20 KHz, 25 KHz and 30KHz.
III. Placing test antenna and reference antenna at a distance for testing.
IV. Connecting port 1 of VNA to the output of preamplifier circuit. Pre-amplifier circuit input is connected to antenna output.
V. Connecting dc voltage source to the circuit (5V).
VI. Port 2 of the VNA is connected to the reference antenna.
VII. Pushing measure button and measuring s-parameters

5.1 Test Setup

As test s done in the lab environment, test antenna and reference antennas are placed. Test antenna is then connected to VNA directly and measurements are taken. For second configuration, Test antenna is then connected to circuit which is then connected to VNA. Same measurements are doe for both the configurations to find the differences. In the beginning, distance between both the antennas is kept very low (~1 mtr). Since the experiment is performed in the lab, results may vary for outdoor testing in the open environment. This set up is shown in below Fig:

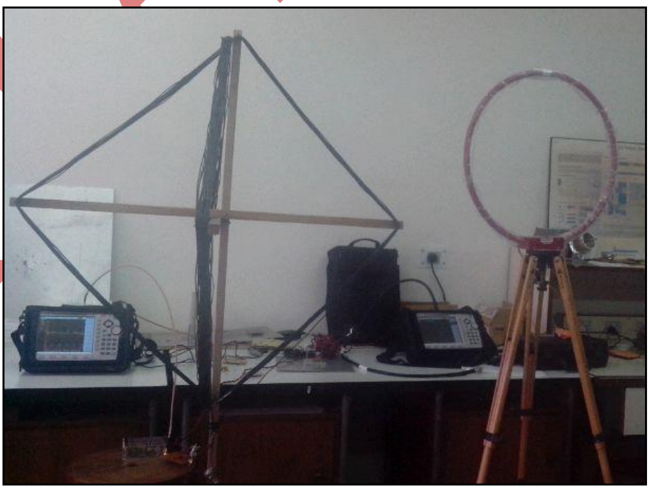


Fig 5: Set up of test antenna and reference antenna

5.2 Results

The graphs obtained after testing of antenna with/without circuit are shown below:

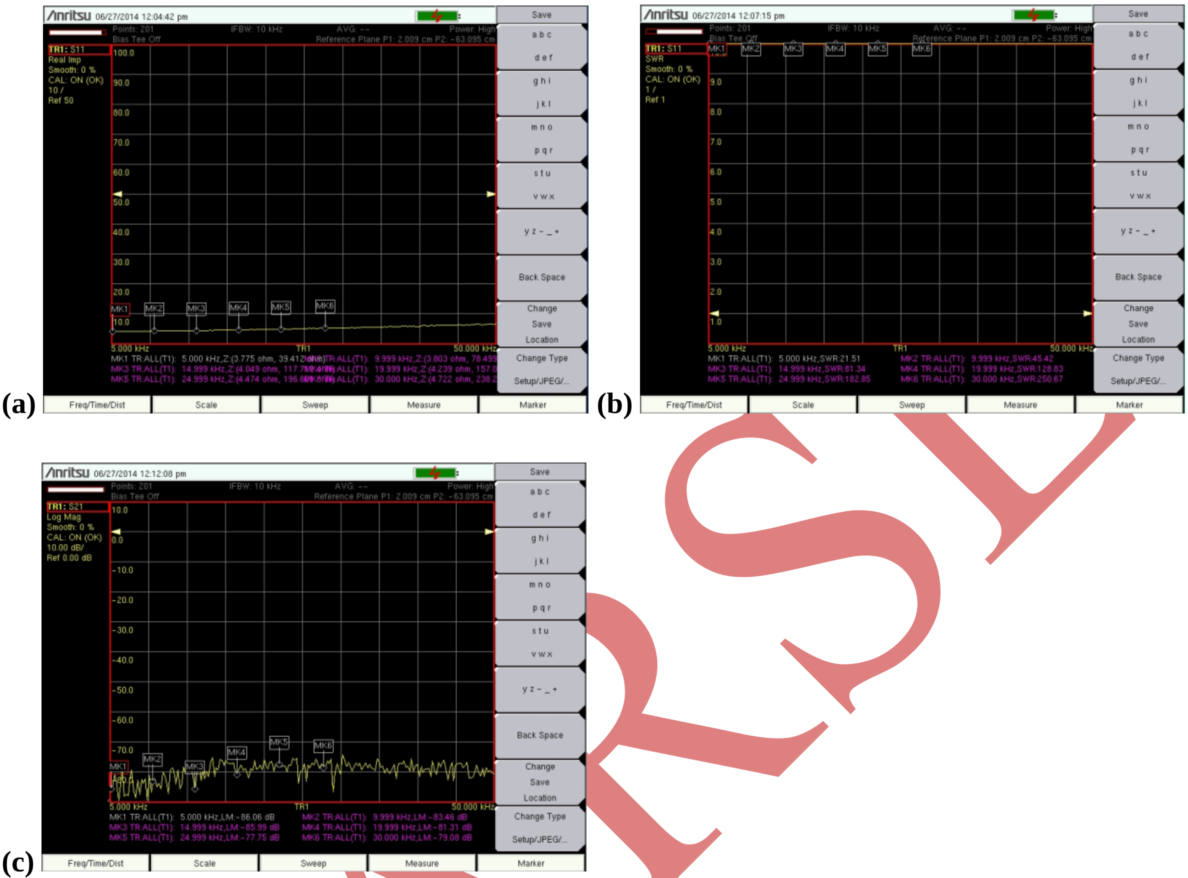


Fig 6: Antenna without circuit (a) Impedance; (b) SWR; (c) Return Loss

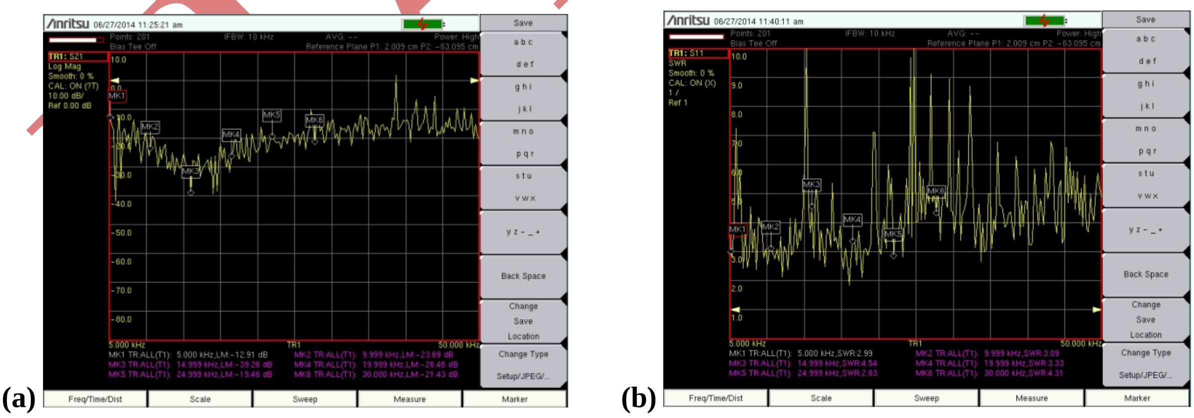


Fig 7: Antenna with circuit (a) Return loss; (b) SWR

The above graphs show the changes in antenna return loss and SWR values. Fr better understanding, below table is shown which gives the values of loss and compares them to get actual gain obtained by the circuit.

Table 6.1: Comparison Table for Return Losses of Antenna

	Frequency	Antenna without circuit	Antenna with circuit
S21	5KHz	-86	-13
	10KHz	-83	-23.69
	15KHz	-85	-39.26
	30KHz	-79	-21.43

Here, we can see the difference between return losses received by the antenna in two configurations:-

1. Without using preamplifier circuit
2. With using preamplifier circuit.

Above table clearly shows reduction in return loss with circuit and hence, increase in gain of the antenna.

VI CONCLUSION

A properly designed loop aerial system, with a low-noise preamplifier, is a useful part of the VLF-LF receiving equipment and can enable signals to be picked out from noise which otherwise overrides the signal from the wire aerial. It also provides a means to obtain good signal reception at VLF-LF without the use of a large aerial installation usually considered necessary for low frequency reception. Instead of magnetic loop antenna, electrical antenna can also be used to receive the signals. Due to few disadvantage related to electrical antenna for example sensitivity to noise and necessity of lightning protection circuitry, we usually prefer magnetic loop antennas. The signal level received from the loop aerial is low compared to the wire aerial and the signal-to-noise ratio can be limited by the noise generated in the first amplifier.

In this design there is no requirement of transformer to match impedance. Preamplifier circuit performs the function. This antenna was specifically designed to work in low frequency capture of Lightning locations. We can use this antenna near water bodies to as there is less effect of water on VLF range frequency signals.

REFERENCES

[1] Marek Loboda*, Hans D. Betz, Piotr Baranski, Jan Wiszniowski and Zdzislaw Dziewit , *New Lightning Detection Networks in Poland – LINET and LLDN*, The Open Atmospheric Science Journal, 2009, 3, 29-38.

[2] Egon Wanke, *A low cost Time of Arrival Lightning Detection and Lightning Location network*, www.blitzzortung.org, pp8-23, Dusseldorf, Germany, September 12, 2011.

[3] U. Finke, O. Kreyer, T. Hauf, *Lightning Detection and Location from Geostationary Satellite Observations,* Institut für Meteorologie und Klimatologie Universität Hannover.

[4] Bill Bowers, John Bryant, Nick Hall-Patch, *Impedance Matching Transformers for Receiving Antennas at Medium and Lower Shortwave Frequencies*, June /July 2003, VE7DXR.

[5] Jabbar S. Hussein, *Design of Active Loop Antenna for Multi-band Radio Reception*, Karbala University, Journal of Kerbala University , Vol. 10 No.1 Scientific . 2012.