

# Construction of two VLF receivers to monitor Sudden Ionospheric Disturbances (SID) from Solar Flares

M. Marbouti<sup>1</sup>, M. Khakian Ghomi<sup>2</sup>, A.Zand<sup>2</sup>, A.Moridi<sup>2</sup>

Young Researchers Club, Central Tehran Branch, Islamic Azad University, Tehran, Iran<sup>1</sup>  
Amir Kabir University of Technology, 15875-4413, Tehran, Iran<sup>2</sup>

## Abstract

In this paper we discuss the construction of two VLF receivers built to monitor Sudden Ionosphere Disturbance (SID). The first VLF receiver was built at Tehran University, the second at the Amir Kabir University, Iran. Both receivers were tuned to the Naval VLF transmitter TBB, located at Bafa, Turkey. It took two attempts to come up with the final antenna and receiver design to filter out the large amount of urban noises, and to stabilize the receiver to the TBB Naval transmitter. The first antenna built was an octagon loop antenna 80 cm in diameter; the second antenna was a square loop of  $60 \times 60$ cm. Our first receiver relied on external capacitors at the octagon loop; the second receiver uses an internal capacitor and variable resistors part of the receiver design, which could be tuned specifically to the TBB transmitter. Our goal was to observe the X-ray solar flares as well as the effects of Sunrise and Sunsets in the region. So that, after receiving the TBB signal, we could compare the receiving signal's quality received of the octagon antenna and filter, to that of the receiver with the internal filter using the square loop antenna. Our future use of these VLF receivers will be to survey and study different phenomena such as earthquakes [Hayakawa, 2010] as well as SID events from solar flares. The original designs for both these receivers come from Percival Andrew's book '*How to build your own radio telescope*', 2007, and Lionel Loudet, 2011.

## Introduction

The ionosphere is the part of earth's atmosphere where molecules are ionized as the result of Ultra Violet (UV) radiation from the sun. During the day the ionosphere changes from one general night time layer into multiple layers due to the intensity and the power of UV solar radiation. The ionization rate during the day divides the ionosphere into different segments or regions called  $F_2$ ,  $F_1$ ,  $E$  and  $D$  layers. During the daytime hours the naval transmitter signal level is lower due to the presence of electrons (ionized) which saturate the  $D$  layer and attenuate the transmitter signal. However when there is a solar flare at the surface of the sun, these phenomena will cause an ionosphere disturbance with as much as a 100 fold increase in the re-ionization rate of an already UV ionized  $D$  Layer due to intense solar X-ray radiation [Loudet, 2009]. It is this re-ionization of the  $D$  layer which causes the characteristic sudden and abrupt ionospheric disturbance, or SID (see Figure 1).

The first step of our study was choosing a suitable naval VLF transmitter. We used the following criteria:

- 1) Demonstrate suitable power to deliver a strong signal during day time, such that the signal shows a distinct diurnal characteristic, and such that during the day time signal we can identify SIDs.

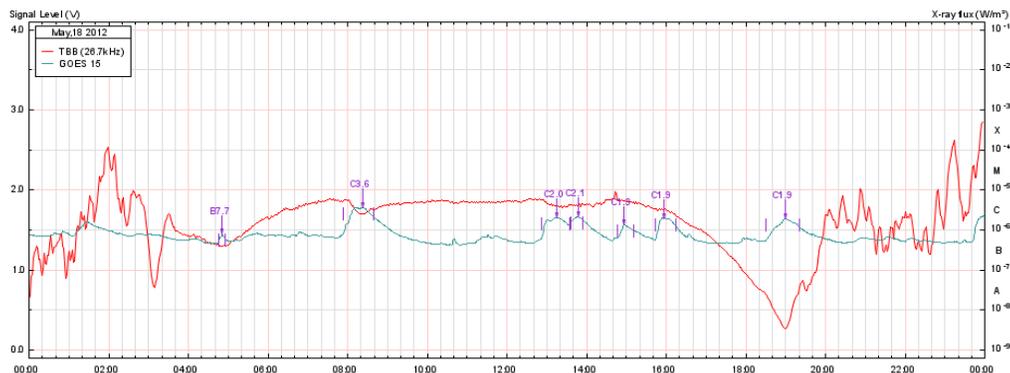


Figure 1 from Lionel Loudet's web site: <http://sidstation.loudet.org/data-fr.xhtml>

2) The ideal distance from the receiver should be from between 500 to 5000 km. From Tehran to Bafa Turkey the Naval transmitter is approximately 2000 km (see Table 4).



Figure 2 from Percival Andrews SSRT web site: <http://www.radiotelescopebuilder.com/network.htm>

After carrying out all necessary evaluations and studies, we reached the conclusion and understanding by using the 'Movable Type Scripts' software [8], that the TBB transmitter located in Bafa city of Turkey would be an appropriate naval transmitter for our objective. TBB has a working frequency of 26.7 kHz.

**Part I - The first receiver and octagon antenna were built by the faculty of electrical engineering collage at Tehran University.**



Figure 3 Different phases of building the octagon antenna:  
a. Building of the octagon wooden piece in the center of the loop shape antenna.  
b. Assembling and mounting the wood pieces around octagon loop shape.

- c. Building the supporting legs for antenna.
- d. Water resistant making of antenna against rain fall by coloring it.
- e. The final shape or view of looped antenna.

To test the octagon antenna we used a signal generator attached to a tuning coil placed next to the antenna at a distance of a few meters (see Figure 6). We connected the two, 'first and last wire ends' of the coil to signal generator. Then from the octagon antenna the two first and last wire ends were connected to the oscilloscope. With the oscilloscope and signal generator switched on, with frequencies of 1 kHz bandwidth, we tested the antenna while sweeping the oscilloscope. The receiving voltage values are noted and registered in Tables 1 and 2.

Antenna diameter(d)	Wire diameter (D)	L	C
80cm	0.55mm	38.24mH	919 pF

Induced frequency to coil through generator signal (kHz)	Receiving voltage by antenna and oscilloscope (V)	Induced frequency to coil through generator signal (kHz)	Receiving voltage by antenna and oscilloscope (V)
3	0.20	23	0.85
4	0.25	24	0.95
5	0.30	25	1.1
6	0.35	26	1.2
7	0.38	27	1.5
8	0.40	28	2
9	0.41	29	2.8
10	0.41	30	4.6
11	0.42	31	18
12	0.42	32	5.8
13	0.44	33	3
14	0.48	34	1.8
15	0.5	35	1.4
16	0.55	36	1.1
17	0.58	37	0.9
18	0.6	38	0.7
19	0.62	39	0.6
20	0.65	40	0.5
21	0.7		
22	0.8		

Table 1 and 2– Dimension of octagon loop and resonance frequency and receiving voltage with bandwidth of 1 kHz

It was observed that in 31 kHz frequency, a very high voltage is produced, hence, we noted that the antenna resonance frequency was around 31 kHz. We repeated the above steps to have higher degree of precision for bandwidth of less than 1 kHz (Table 3).

Induced frequency to coil through generator signal ( KHZ)	Receiving voltage by antenna and oscilloscope (V)	Induced frequency to coil through generator signal (KHZ)	Receiving voltage by antenna and oscilloscope (V)
31	18	31.5	12
31.1	19	31.6	10
31.2	20	31.7	9
31.3	19	31.8	8
31.4	16	31.9	6

Table 3 - Resonant frequency and receiving voltage in the bandwidth range of 0/1 kHz

In view of the above data the resonance frequency of antenna is 31.2 kHz. Now by noticing the relationship shown in the antenna theory (Balanis, [3] and Lionel Loudet [4]), we calculated the capacitance  $C'$ , to bring 31.2kHz into tune with TBB transmitter with a frequency of 26.7kHz, it was determined that a capacitor of about 239.1 pF should be mounted on antenna.

$$f' = 1/2 \times \pi \times \sqrt{LC'} \rightarrow 31200 = 1/2 \times \pi \times \sqrt{LC'} \rightarrow LC' = 2.6 \times 10^{-11}$$

$$\rightarrow 38.24 \times 10^{-3} \times C' = 2.6 \times 10^{-11} \rightarrow C' = 679.9 \text{ pF}$$

$$C = C' + C''$$

$$919 \text{ pF} = 679.9 \text{ pF} + C \rightarrow C = 239.1 \text{ pF}$$

### Designing and building the soundcard 'Amplifier Circuit'

The designed octagon loop antenna with capacitors receives 26.7 kHz frequency, which is the TBB naval transmitter frequency. For better reception of this frequency the signal from the antenna needs to be amplified. In fact, our circuit is comprised of two phases or stages of Op-Amp so that each of the stages performs amplification to 20dBm gain ( $20 \times 20 = 400$ ). This should be enough for our target to use first stage of 20 dBm gain.

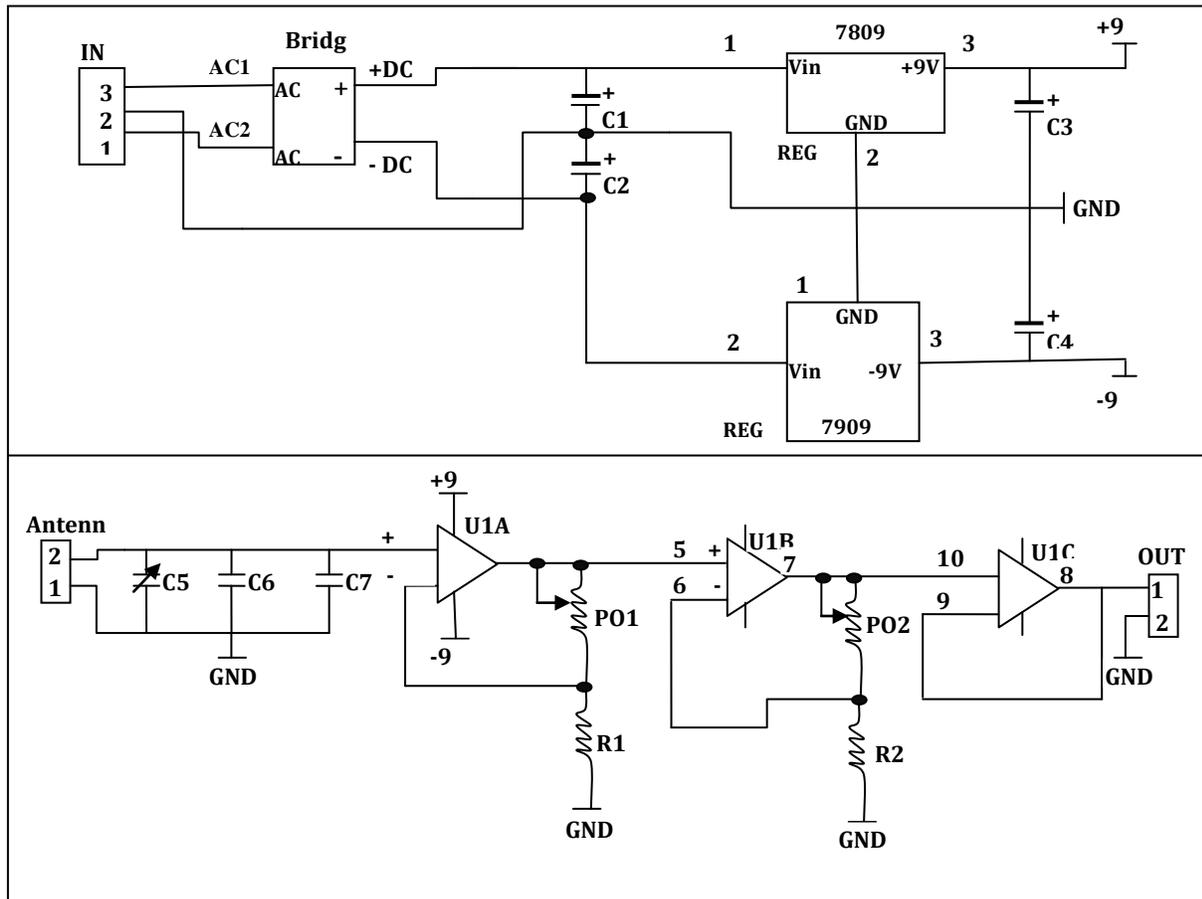


Figure 4 - Amplifying schematic circuit for octagon loop antenna

**Parts list for the amplifier circuit (Figure 4):**

Quantity	Description	Circuit
1	OP-AMP O74	U1A,U1B,U1C
1	2KBP08M	Bridge
3	Capacitor 1.0 $\mu$ f	C3,C4
2	Capacitor 470 $\mu$ f	C1,C2
1	Reg7809	Reg1
1	Reg7909	Reg2
2	Resistor4.7k $\Omega$	R1,R2
2	100K Linear Trim Pot	PO1, PO2
1	Capacitor Polyester(390PK)	C6
1	Capacitor Polyester(221JQ)	C7
1	Capacitor Polyester(100PF)	C5
1	Anti-Noise Aluminum Box*	
1	Anti-Noise Plastic Box**	
2	Military Socket 2pin	
1	Military Socket 3pin	
1	Trans 220v/12v	
sufficient	Audio Cable	
sufficient	Coax Cable 75 $\Omega$	

Tables 3 and 4 show the parts used to build the receiver for the octagon loop antenna  
 \*For amplifier circuit  
 \*\* The transformer is put in this box to be separated from amplifying circuit and to omit its noise effect on the device

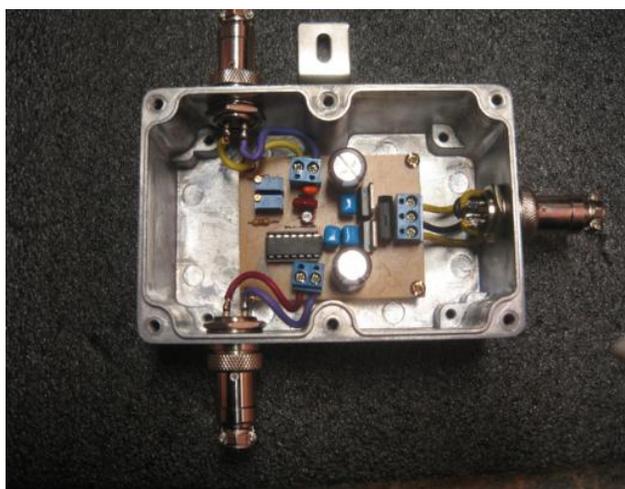


Figure 5 - Amplifier circuit is placed in a metal box general design from Percival Andrew, 2007

## Final testing of the connectivity of the amplifying circuit with the octagon antenna

In this stage, 26.7 kHz frequency was transmitted to designed antenna by the signal generator connected to a coil, so that we could observe the 'noiseless' signal on the oscilloscope



Figure 6 -Test through generator signal in laboratory

**First test of the amplifying circuit to antenna and its testing in the laboratory**

The final test was performed with the octagon antenna in open atmosphere, where we did receive the signal from the TBB naval transmitter.

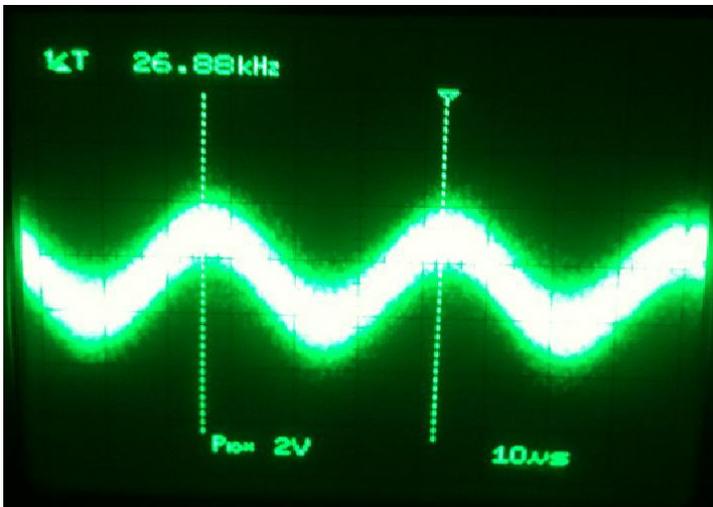


Figure 7 -Signal receiving on oscilloscope in open atmosphere

**To analyze the spectrum from the soundcard we used Spectrum Lab and SSRT Robot2 software (Percival Andrew, 2007).**

The antenna and amplifying circuit set was connected to 96 kHz soundcard through audio cable. After launching the receiver we noticed different peaks in Spectrum lab; some of them, such as 30 kHz were found to be from electricity objects and local radio frequency interference (RFI) around the antenna location, while other peaks such as 45.9 kHz, (NSY) Italy, and 16.3 kHz (VTX) India, were from VLF transmitters from of high transmitting power. Reception of signals from other VLF transmitters could also be seen in addition to the desired frequency of TBB (26.7 kHz).

Frequency	VLF transmitter	Transmitter location	Distance from Iran (Km)
16.3kHz	VTX	Vijayanarayanam ,South India	4046.8096
26.7kHz	TBB	Bafa ,Turkey	2158.2455
45.9KHZ	NSY	Nescimi ,Italy	3297.0614

Table.4 VLF transmitting stations, that the octagon antenna detected

### Project complications and their solution

After testing the receiver a few days with the octagon loop we came to know that due to local RFI and the use of external capacitors, we noticed a large amount of urban noise. We were asked to adjust the capacitors once every few days to tune the loop to various VLF naval transmitters (see Table 4). Re-setting the capacitors is a difficult job to perform, and caused interruption of the received data. We also found that we could not tune the octagon loop to receive the frequency of 26.7 kHz easily. After many tests and analysis, and correspondence with foreign expert friends such as, Rodney Howe, Percival Andrews and Lionel Loudet, we decided to design and build a SID receiver with an internal filter using a variable resistor. The following problems were identified at Tehran University:

1. Abundant urban noises
2. Electricity power cut off at the installation site
3. Lack of electronic parts in the Iranian market
4. Heavy snowfall and bad winter conditions at the time of our receiver and antenna was setting on the roof of Tehran University

**Part II - The second receiver was built in the facilities of electrical engineering and physics departments at Amir Kabir University.**

### Building a second SID receiver with internal protected capacitor and variable resistor used for tuning

General building phases of second receiver with internal capacitor filter are shown in the following picture (fig.8).

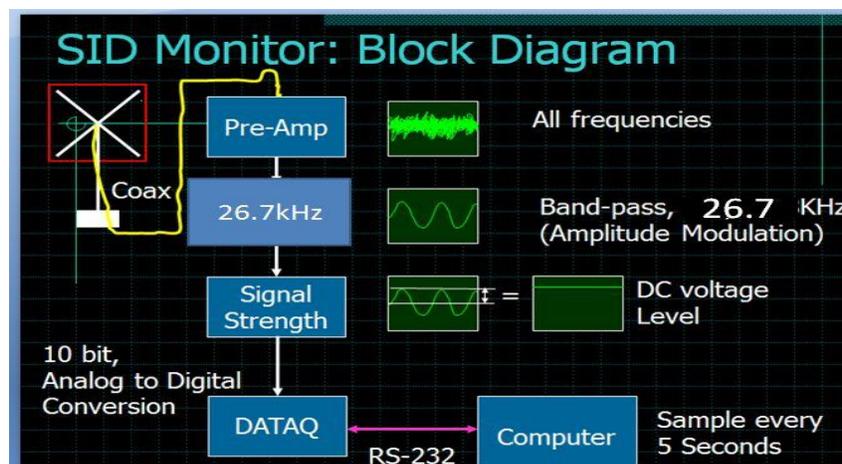


Figure 8– Block diagram of receiver with the internal capacitor/ resistor filter using the square loop antenna

## 'Square' looped antenna's building phases

To achieve our goal; that there should be no need to adjust or set the external antenna capacitors to receive the 26.7 kHz frequency. We would have to build a SID receiver with internally protected variable resistor and capacitors. This second receiver was designed to receive the required frequency with a tuning resistor inside the amplifier box. Designing the square antenna was easy and simple. The antenna included 45 winding rounds of copper wire wound around a  $60 \times 60$ cm square [3].

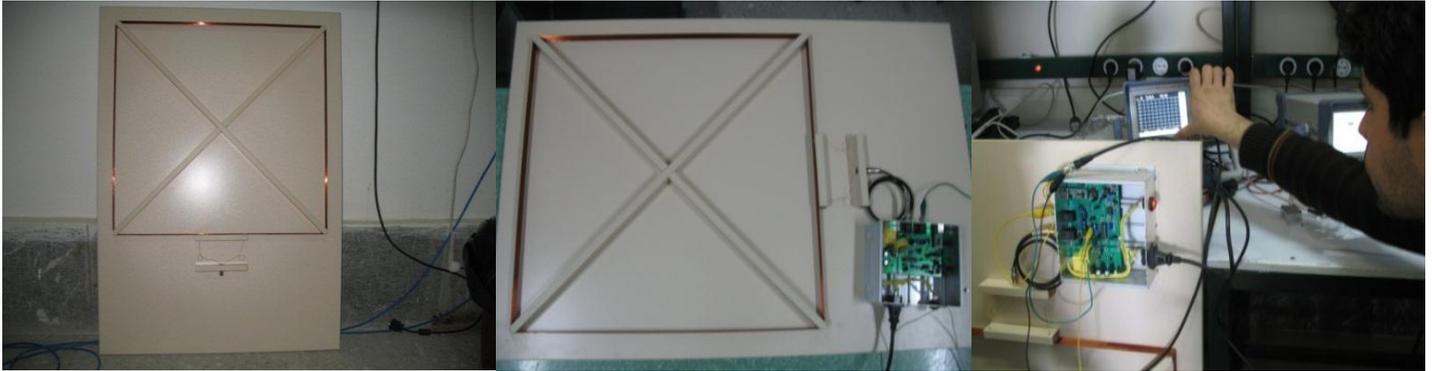


Figure 9 - Looped antenna (Square)

- a. A ( $70 \times 100$  cm) wooden form is prepared for this purpose
- b. Two wood pieces are affixed on the form surface (with square circumference of  $60 \times 60$  cm) in a cross shape.
- c. The copper wire is wound 45 times around the obtained square
- d. Finally, by mounting a connector, the 'Square' looped antenna is completed

## SID Receiver, antenna and receiver test for 26.7 kHz frequency

Figure 10 shows the **SID Receiver** circuit built with internal capacitor and variable resistor. After testing the connectivity of antenna and SID Receiver we set the SID receiver to receive the 26.7 kHz frequency. We prepared a table that would be appropriate to the frequency we want to receive from each VLF naval transmitter; which would show us where to tune the SID Receiver settings for TBB (26.7 kHz). After brazing and soldering the constant and variable resistor, we adjusted the turn setting of variable resistor; this was done in the antenna laboratory of electrical faculty of Amir Kabir University [4]



Figure 10 - SID Receiver circuit with internal capacitor and variable resistor

## Results

The aim in completing this project was to build a SID receiver system with capacitors attached to the antenna for tuning to various VLF naval transmitters. However, the first project was not so successfully carried out in our country, Iran. But, we did build and complete the SID receiver project. After conducting the large scale research work we came to know understand the possibility of a final SID receiver system with higher quality by using internal filter with a variable resistor, which allowed us to tune to various VLF naval stations. This is why we decided to build another second system with the internal filter.

## Acknowledgement

At last, it is necessary to thank Mr. Rodney Howe, who was always with me in all phases of my work. I am also thankful to Mr. Percival Andrews.

## References

1. Andrews, Percival, How to build your own radio telescope, 2007
2. Poole, Ian, Radio waves and the ionosphere, 1999, QST@ARRL
3. Balanas, **Antenna Theory: Analysis and Design**, ISBN 10: 047166782X/0-471-66782-X ISBN 13: 9780471667827 Publisher: Wiley-Inter science
4. Loudet, Lionel, SID Receiver Assembly Manual (SID Receiver V1.1), Copyright©2011 Lionel Loudet, Antenna Theory, <http://sidstation.loudet.org/antenna-theory-en.xhtml>
5. Singh, Vikram; Singh, Birbal; Scattering of VLF signals from localized perturbations in the lower ionosphere, Indian Journal of Radio and Space Physics. Vol.39, June 2010, pp.144-149
6. Loudet L., 2009, **Application of Empirical Mode Decomposition to the detection of Sudden Ionospheric Disturbances by monitoring the signal of a distant Very Low Frequency transmitter**,
7. HAYAKAWA, M, et al., SICE Journal of Control, Measurement, and System Integration, Vol. 3, No. 1, pp. 010–014, January 2010 **Sub-ionospheric VLF/LF Probing of Ionospheric Perturbations Associated with Earthquakes: A Possibility of Earthquake Prediction**
8. 'Movable Type Scripts' software: <http://www.movable-type.co.uk/scripts/latlong.html>

The following from Lionel Loudet's VLF Loop design <http://www.vlf.it/octoloop/rlt-n4ywk.htm> and <http://sidstation.loudet.org/antenna-theory-en.xhtml>

The frequency of (F) antenna resonance depends on inductance of (L) wire loop, and the capacitance capacity of total (c):

$$f = 1/2 \times \pi \times \sqrt{LC} \quad (1)$$

The inductance of a loop depends on using wire's thickness in antenna structure, its diameter and the number of wire rounds:

$$L = \mu \times r \times N^2 \times (\ln(8 \times r/R) - 1.75) \quad (2)$$

In view of this fact, that the VLF transmitter which will be used to receive frequency uses a transmitting frequency of 26.7 kHz, therefore, we put  $f = 26700 \text{ Hz}$  in relationship of (1):

$$\left. \begin{aligned} f &= 1/2 \times \pi \times \sqrt{LC} \\ f &= 26700 \end{aligned} \right\} \rightarrow LC = 3.55 \times 10^{-11}$$

Now we refer to relationship (2), and on the basis of the existing experience and the availability of the parts in market, arrange a, 0.55 mm diameter wire. We consider the radius of the antenna, about,  $N = 100$ ,  $r = 0.4 \text{ m}$  rounds, and substitute these values in relationship (2).

$$D = 0.55 \text{ mm} \rightarrow R = 0.275 \text{ mm}$$

So, we have:

$$\begin{aligned} L &= (4\pi \times 10^{-7}) \times 0.4 \times (100^2) \times [(\ln(8 \times 0.4)/(0.275 \times 10^{-3})) - 1.75] \\ L &= 38.24 \text{ mH} \end{aligned}$$

This 'L' value is reasonable to continue the assignment.

Now substitute  $L = 38.24 \text{ mH}$  in the result of (1) relationship, so we shall have the following:

$$LC = (3.55 \times 10^{-11}) \rightarrow 38.24 \times 10^{-3} \times C = 3.55 \times 10^{-11} \rightarrow C = 919 \text{ pF}$$

Considering the above calculations, the designed antenna will have the following specifications:

C is called total capacity of the capacitance

$$C = C' + C'' \quad (3)$$

Each antenna has a 'C', which is specific to the antenna itself. To find the 'C', we arrange a Coil of equal diameter to antenna, which has fewer rounds of winding (about 20 to 30 rounds)



Marjan Marbouti building the Octagon loop.