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Design and Simulation of a Square Loop Antenna for 920 MHz

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Abstract: *This study describes design and simulation of a loop antenna. A square loop antenna is designed for 920 MHz. The loop antenna is then modelled and simulated using 4NEC2 electromagnetic (EM) modeling software. 4NEC2 is a completely free numerical electromagnetic modeling code. It is based on method of moments technique to solve electromagnetic boundary value problem. The 4NEC2 simulation of the loop antenna design predicted antenna resonant frequency to be 920 MHz, Return Loss bandwidth of 130 MHz and input impedance of 50.14 -j0.30 Ohm. The antenna radiation pattern is then simulated at 920 MHz. The Return Loss, VSWR, Input Impedance and Radiation Pattern of the antenna predicated by 4NEC2 simulation are studied for the possible development of copper or aluminium tube based loop antenna.*

Keywords: Loop Antenna, Maxwell's Equations, Electromagnetic Simulation, 4NEC2, Method of Moments.

I. INTRODUCTION

Antennas are eyes and ears of wireless communication technology. Handheld units of mobile communication systems most often use the monopole type antenna element. Loop antenna element is inexpensive and easy to construct alternative to monopole element. The loop antennas being more immune to noise makes them more attractive for mobile communication systems. They are employed as transmitting and receiving antennas for mobile telephones. The loop antennas find applications in radio, pagers, underground communication, direction finding etc. Loop antennas are extensively used in the HF (3–30 MHz), VHF (30–300 MHz), and UHF (300–3,000 MHz) bands. Loop antennas can be of rectangular, square, triangular, elliptical, circular and many other shapes [1].

Loop antennas are broadly divided into electrically small and electrically large types. Electrically small loop antennas have overall length (circumference) less than about one-tenth of a wavelength ($C < \lambda/10$). Electrically large loops antennas have overall length (circumference) of about a free-space wavelength(C □ λ). Electrically small loop antennas have small radiation resistances and thus they are very poor radiators. They are not employed for transmission in radio communication. However, they are used as probes for field measurements and as directional antennas for radiowave navigation. The field pattern of electrically small loop antennas have a null perpendicular to the plane of the loop and with its maximum along the plane of the loop. The maximum of field pattern of electrically large loop antennas is perpendicular to the plane of loop [2].

The present work studies an electrically large square loop antenna for 920 MHz. The loop antenna is modelled and simulated using 4NEC2 electromagnetic (EM) modeling and simulation software. NEC2 is the U.S. Government developed numerical code for modeling wire antennas. 4NEC2 is a completely free numerical electromagnetic modeling code. It is based on method of moments technique to solve electromagnetic boundary value problem [3][4].

The loop antenna is first designed using the procedure outlined in [5]. It is then modelled and simulated in 4NEC2. The simulation output is studied for return loss (RL), voltage standing wave ratio (VSWR) and input impedance (Zin1) of antenna model. The antenna model is adjusted to get it resonant at about 920 MHz and achieve input impedance real near 50 ohm. The antenna radiation pattern is then simulated at this frequency. The RL, VSWR and ZIn1 of antenna predicated by 4NEC2 simulation are studeied for possible development of aluminium tube based loop antenna.

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II. METHODOLOGY

2.1 Antenna Design Simulation Setup

The first step is to design a resonant circular loop antenna to operate at 920 MHz whose radiation pattern maximum is along its axis. The design process involves the determination of the radius of the loop and that of the wire to be used, the axial directivity (in dB), and the selection of parallel lumped element that must be used to resonate the antenna at 920 MHz. The antenna radiation pattern maximum will be along the axis of the loop antenna when its circumference is large compared to the wavelength. The need for a resonating capacitor can be eliminated by selecting a circumference value where the loop antenna is self resonant. To satisfy these two requirements, the circumference of the loop should be 1.125λ and the ratio of radius of loop to the radius of wire should be 64.2077 [6]. The radius of loop is found to be a = 5.8370 cm and that of wire is b = 0.9 mm. The Axial Directivity for this design is approximately 3.6 dB according to [7]. Table 1 shows the calculated parameters for loop antenna to resonate at 920 MHz.

Table 1: Antenna Parameters

Antenna Parameter	Value	Antenna Parameter	Value
Resonant Frequency	920 MHz	Wire Radius **b**	0.9 mm
Wavelength **λ**	32.60 cm	Axial Directivity	3.6 dB
Loop Circumference **C**	36.675 cm	Input Impedance $\mathbf{Z_{in}}$	840 ohm
Loop Radius **b**	5.8370 cm		

The second step is to transform the circular loop antenna design into an equivalent square loop antenna. The circumference of the circular loop antenna is considered as the perimeter of the square loop. The circumference is therefore divided into four equal parts each of length 9.16875 cm. The radius of wire is kept at 0.9 mm. Table 2 shows the parameters for square loop antenna dervied from the starting circular loop antenna.

Table 2: Antenna Parameters

Antenna Parameter	Value	Antenna Parameter	Value
Resonant Frequency	920 MHz	Wire Radius **b**	0.9 mm
Wavelength **λ**	32.60 cm	Axial Directivity	3.6 dB
Loop Perimeter **C**	36.675 cm	Input Impedance $\mathbf{Z_{in}}$	840 ohm
Loop Side **L**	9.16875 cm	Height above ground	2.0 meter

The square loop antenna design described in Table 2 is converted into 4NEC2 model. The antenna is assumed to be in the vertical (YZ) plane. The antenna with voltage excitation at the centre of the bottom conductor is modelled using 4NEC2 commands in a NEC file. This NEC file is given below in Table 3. The detailed description of this NEC file is given below.

For NEC modelling of the square loop antenna, the actual values of wire length and wire radius are modified. The modified values are more practical and can be measured easily for antenna construction. The length of each side of loop is taken to be **L** = 9.1 cm, the radius of wire is **b** = 1 mm. Copper is selected as the wire material. The antenna is 2 meter above a realistic ground. Its dielectric constant is 13 and conductivity is 0.005 mho/m. The antenna is excited by a voltage source placed at middle of the bottom wire of square loop. Its peak value is 1 volt. The frequency of excitation is set to 920 MHz. Radiation pattern in vertical plane where theta varies from -90 to +90 and phi is 0 (XZ Plane) and horizontal plane where phi varies from 0 to 360 and theta is 90 (XY Plane) are requested. The length of antenna side, the radius of wire and the height above the ground are parameterized by the symbols L, b and h in the NEC file. These can be fine tuned to achieve the desired simulation results.

Table 3: Square Loop Bootom Fed NEC

Square Loop NEC file	
CM 30CM Rect Loop, bottom fed	
CM	
CM	
CE	
SY L = 0.091	'Length of square side in meter
SY h = 2.0	'Height of loop above the ground in meter
SY b = 0.001	'Radius of wire in meter

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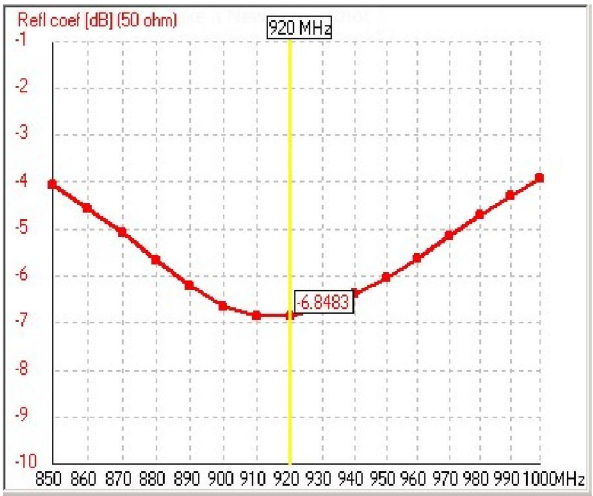
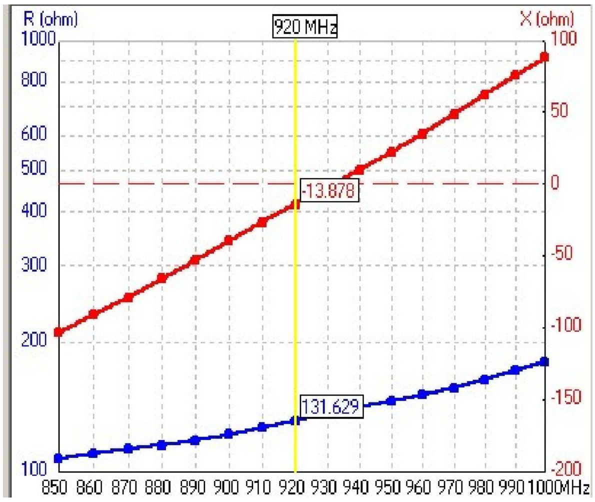
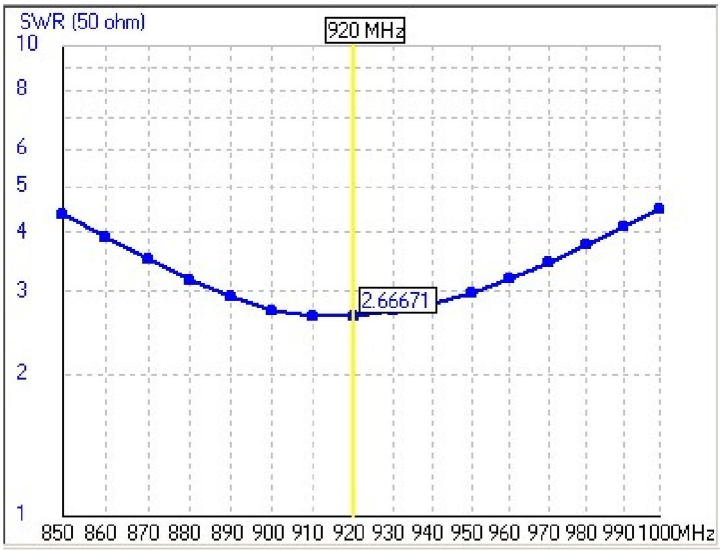
GW	1	11	0	-L/2	h	0	L/2	h	b
GW	2	11	0	L/2	h	0	L/2	L+h	b
GW	3	11	0	L/2	L+h	0	-L/2	L+h	b
GW	4	11	0	-L/2	L+h	0	-L/2	h	b
GE	1								
LD	5	0	1	36	58000000				
GN	2	0	0	0	13	0.005			
EK									
EX	0	1	6	0	1.0	0	0		
FR	0	0	0	0	920	0			
RP	0	1	361	1000	75.	0.	0.	1.	0.
EN									

3.2 Antenna Design Simulation Results

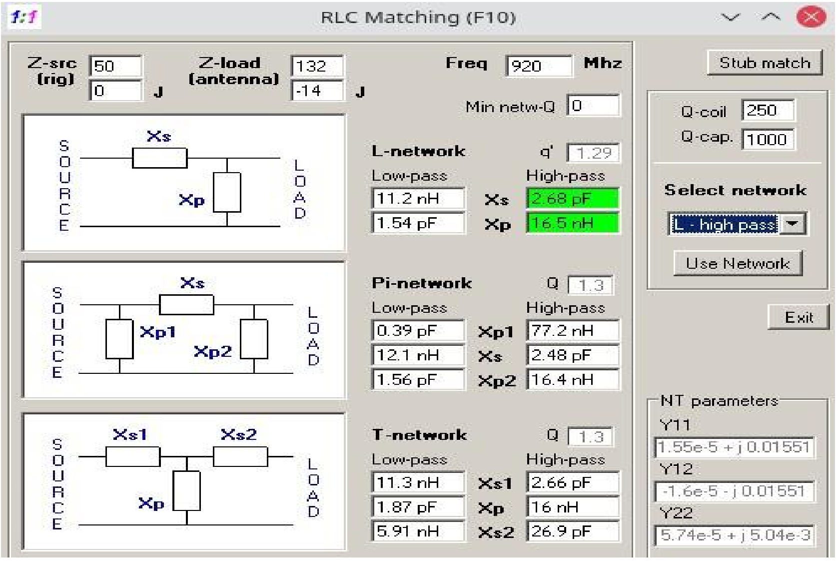
The above described loop antenna model NEC file is simulated by 4NEC2 . The reflection coefficient graph for the antenna shows a minimum reflection coefficient of nearly -7 dB at 920 MHz. The impedance graph shows that the antenna impedance is complex at 920 MHz being nearly 132 -j 14 ohm. The Voltage Standing Wave Ratio (VSWR) is minimum at 920 MHz having value 2.67.



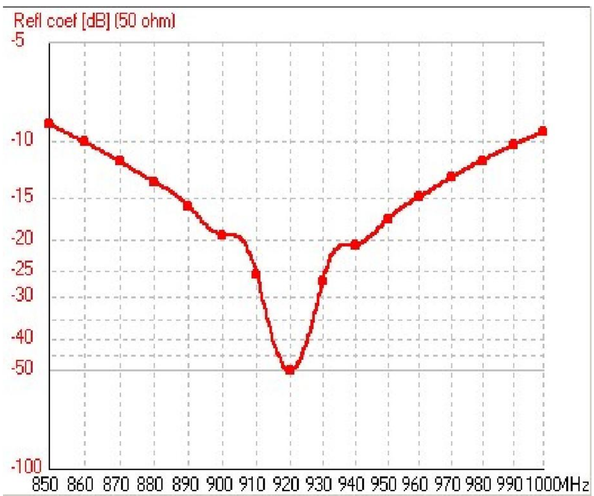


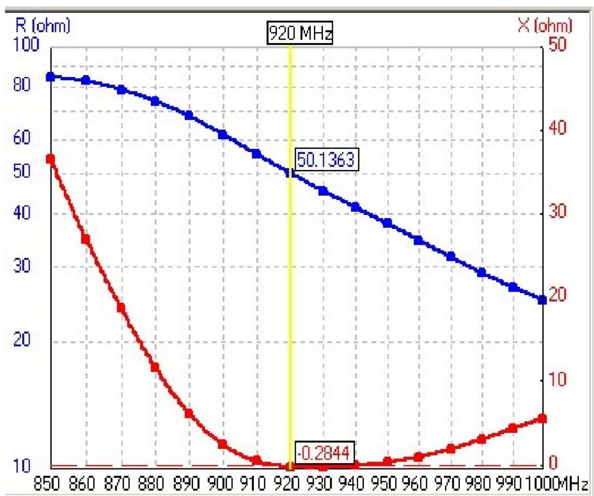


The antenna is usually fed by 50 ohm transmission line or coaxial cable. The antenna needs to be matched with the feeding transmission line. The transmission line impedance 50 + j 0 ohm has to be matched with the antenna impedance 132 -j 14 ohm. This can be achieved by connecting the antenna and transmission line through a high pass network. The 4NEC2 program provides a tool for the calculation of this high pass L type network as shown in the Figure 3.



The values for capacitor and inductor for the high pass network are found to be 2.68 pF and 16.5 nH. These values are used in the antenna model alongwith the transmission line. The new model is simulated by 4NEC2. The results for reflection coefficient, impedance and VSWR now shows from Figure 4 and Figure 5 that the antenna is resonant at 920 MHz with relection coefficient of -50 dB, the reflection coefficient is below -10 dB from 860 MHz to 990 MHz and VSWR is 1 at 920 MHz.





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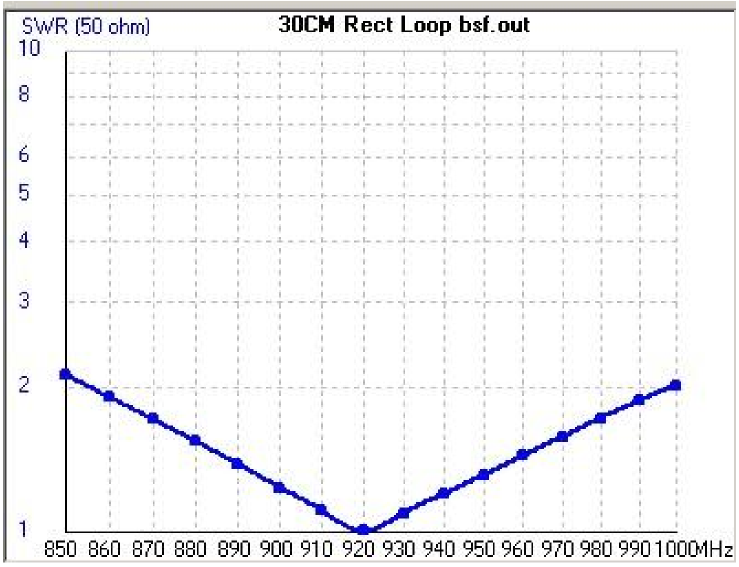
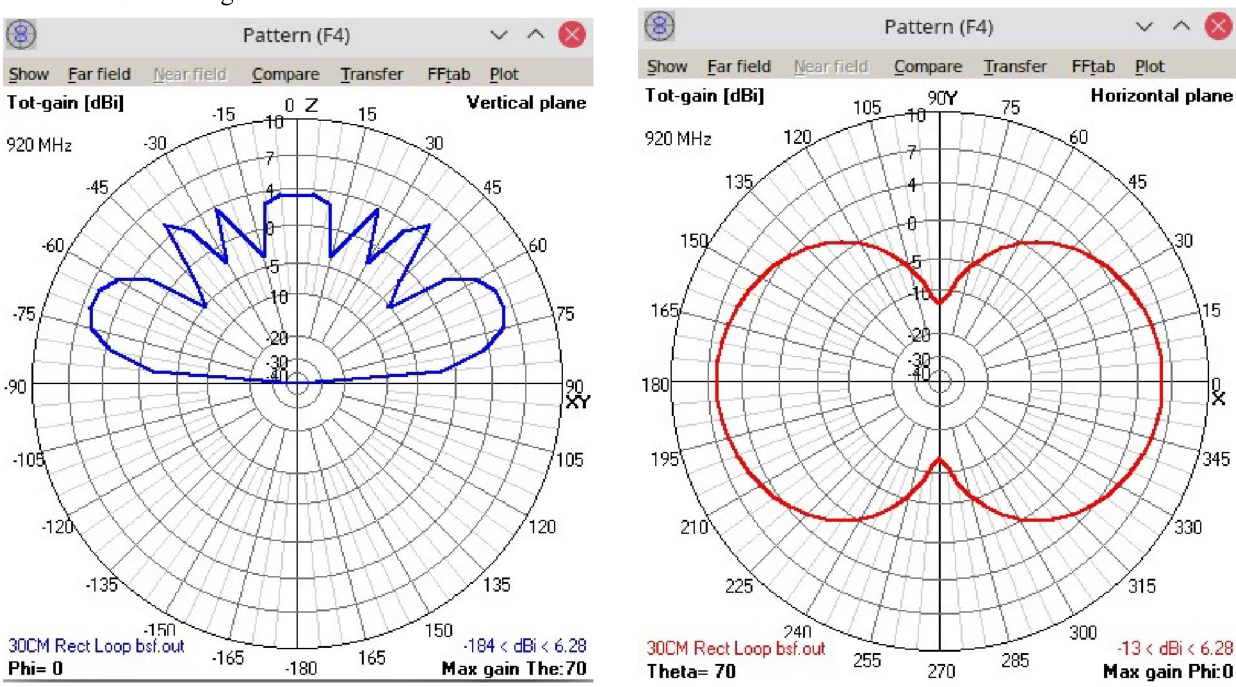


Finally, the antenna radiation pattern at 920 MHz is obtained in the vertical (XZ) and horizontal (XY) planes. The radiation pattern shows a maximum value of 6.28 dBi in total gain of antenna at theta equal to 70 degree. The radiation pattern is shown in Figure 6.



IV. RESULTS AND DISCUSSION

The 4NEC2 simulated values of Resonant Frequency, Return Loss bandwidth, minimum VSWR, VSWR bandwidth, input impedance of the square loop antenna model are shown in the Table 4. The radiation pattern in vertical and horizontal planes show that the antenna can be used in wireless transreceivers.

Table 4: 4NEC2 Simulation

Antenna Parameter	Simulation Predicted
Resonant Frequency	920 MHz
Return Loss Minimum	-50 dB
Return Loss Bandwidth	130 MHz
VSWR minimum	1.01

VSWR bandwidth	130 MHz
Input Impedance	50.14 -j0.30 Ohm

V. CONCLUSION

In this work a square loop antenna has been designed and modeled. 4NEC2 which is Method of Moments (MOM) based electromagnetic simulation software is used to model and simulate the antenna [8]. 4NEC2 is used to simulate the antenna model and obtain the predictions for antenna Return Loss (RL), the antenna VSWR and the antenna input impedance. The 4NEC2 simulation of antenna model predicted the antenna resonant frequency to be 920 MHz. The simulation predicted the Return Loss and VSWR bandwidths to be 130 MHz each after matching the antenna impedance to that of transmission line. Finally, the radiation pattern of the antenna is simulated at the resonant frequency 920 MHz.

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