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Efficient Design and Implement a Small HF Antenna

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Abstract

HF small antennas are widely applied in military, mobile, radar and marine activities. In the design of electrically small antennas, there is a tradeoff between its size and parameters. In this paper, an electrically small monopole HF antenna with the height of 116cm, the diameter of 19cm and weight of 7kg, covering 1.5 to 30MHz selective was designed, simulated and implemented. The method used in the paper is a capacitive top and inductive center loaded. Suitable resonance at operation frequencies, with desired performance, was achieved. Because of operating at the low frequencies, the bandwidth and radiation efficiency were degraded. These were improved using the lossy and large diameter of the material.

Keywords: *HF antennas, Electrically small monopole antenna, Capacitive top loading, Inductively center loading*

1. Introduction

The electrically small efficient antenna can be used in the mobile, radar, and marine applications. Short vertical monopole antennas are a good candidate to design in HF bands. It is worth noticing that the frequency band 1.5 to 30MHz, i.e., the wavelength of 10 to 200m, will possess a monopole with non-feasible dimension of 2.5 to 50m. Small electrical antennas are designed with inexpensive and portable devices and involve easy implementation. In the design of electrically small antennas, there is a tradeoff between size and quality [1]. It is important to note that the criterion of the electrically shorted antenna, i.e., $ka \leq 0.5$, according to Chu relation, has been satisfied [4]. In recent years, different methods have been proposed to reduce sizes at the low frequencies. A shortening technique using different loadings to improve its performance in mid and high HF band can be used [2]. The method of the maximum volume in space in terms of different shapes at a single frequency is limited by the shortening standards that can be used in radar applications and submarines [3, 5]. In this work, an efficient and very small antenna was designed, simulated and implemented to have optimized return loss and radiation efficiency. In the second section, problem, challenges, the method of loading and the matching technique will be described. In the third section, the simulation and measurement results will be presented and discussed.

2. Design methods

Two steps have been used to design an efficient small HF antenna. The first step is capacitive top for tuning the resonance frequency and increasing radiation efficiency. Furthermore, an inductive center loading, which would compensate negative capacitive reactance to resonate at operation frequencies, has been used. The second step is designing an impedance matching for maximum power

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delivery. Using lossy materials and increasing metal diameters, the bandwidth and radiation efficiency could be improved.

2.1. Capacitive top and inductive center loading

As can be seen in Fig. 1, in the initial design, the antenna with the height of 50cm and diameter of 8cm was considered. The results showed that the antenna would have no resonance in the band of 1.5 to 30MHz, because of high negative reactance resulting from capacitive mode between the shortened metal antenna and the ground plane, as can be observed in Fig. 2. The capacitance of a vertical monopole antenna shorter than one-quarter wavelength is given by [6]:

$$C_A = \frac{17L}{[(\ln\frac{24L}{D})-1][1-(\frac{f_0 L}{234})^2]} \qquad (1)$$

and its reactance is:

$$X_A = \frac{10^6}{2\pi f_0 C_A} \qquad (2)$$

Capacitive reactance can be eliminated by creating the positive inductive reactance using connecting coil in center of antenna. The loading coil inductance, required to resonate antenna, is given by:

$$L_c = \frac{10^6}{4\pi^2 f_0^2 C_A} \qquad (3)$$

Table 1 indicates the primary parameters of the design. The radiation efficiency increases when the loading coil moves up on the antenna. We can see in table 2, the required parameter values of capacitance, reactance, and inductance of the coil at the selected frequencies. By increasing the frequency, the reactance will reduce. Furthermore, the capacitive top loading is used in the design for the capacitance to increase without changing its dimension by setting the capacitive hat. The hat increases the electric field intensity resulting in higher radiation resistance, with another result being tuning resonance frequency.

2.2. Impedance Matching Circuit Design

As can be noticed in Fig. 3, a simple design, but the really useful matching circuit for non-matched loads can be L-Network. This circuit is usually used for only a single resonance frequency, although multiband frequency can be made with switching networks as well. To determine circuit parameters, the antenna input as a load as well as transmission line as a source must be known. The advantage of L-Network is the linearity in frequency response and simplicity in the implementation. Table 3 illustrates the values of impedance matching parameters.

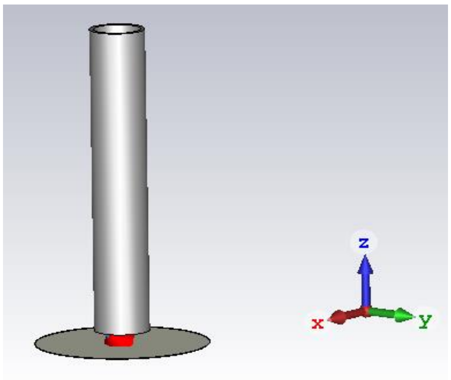

Figure 1: Aluminum monopole antenna with circular ground plane

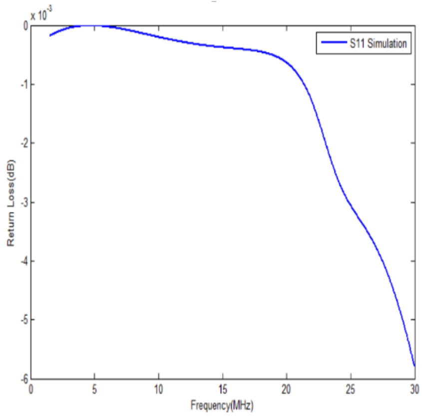

Figure 2: Simulated return loss of the initial monopole antenna.

2.3. A Procedure to Implement Antenna

Figure 4 shows electrically small monopole HF antenna with the height of 116cm, the diameter of 19cm and weight of 7kg covering the frequency band 1.5 to 30MHz. Each section can be described as:

2.3.1. An aluminum ground plane as an artificial negative pole with the diameter of 25cm has been implemented. In fact, the earth is known as a physical ground for vertical monopole antennas.

2.3.2. Two pieces of aluminum with dimensions of 36 and 22cm have been used. By increasing metal diameter, the bandwidth and radiation efficiency could be enhanced.

2.3.3. The copper coil as an inductive loading with the inductance of 583µH and height of 56cm and diameter of 19 cm was applied. Using this coil, the negative reactance could be canceled.

2.3.4. An aluminum circular plane as a capacitive hat with the width of 1mm and diameter of 27cm has been used, which would improve the radiation efficiency and frequency tuning.

2.3.5. To feed antenna to the transmission line, an SMA connector was used.

Table 1: description of the primary parameters.

sign	description
f_0	design frequency (MHz)
C_A	capacitance antenna (pF)
L	antenna height (feet)
D	diameter of radiator (inches)
L_c	inductance of loading coil (µH)

Table 2: design parameters.

f_0(MHz)	C_A(pF)	X_A (ohms)	L_c (µH)
1.5	19.32	5490.2	583
4.7	19.35	1750	59.2
6.9	19.38	1189.9	27.45
15	19.61	540.9	5.74
26.2	20.55	258.2	1.37

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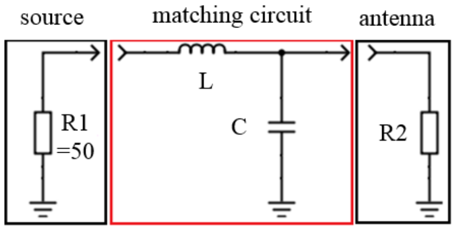

Figure 3: Simulated return loss of the initial monopole antenna.

Table 3: the value of impedance matching parameters.

f_0 (MHz)	R2(ohms)	L(μH)	C (pF)
1.52	224	9.83	878
4.74	104	1.76	338
6.95	95	1.09	229
15	112	0.591	105
26.2	107	0.324	60.6

3.Results

According to Fig. 5, in the first step, after determining the parameters, the antenna has been simulated in CST Microwave Studio. Far-field absolute directivity with the value of 1.68dBi at 15MHz is presented as shown in the figure. Moreover, the radiation pattern, the same as a monopole antenna, is omnidirectional. As clear in figure 6, by increasing frequency, the gain has developed, -14.6, -4.83 and 1.1dBi in 1.5, 6.87 and 15MHz respectively. The maximum gain was achieved at 90degrees.

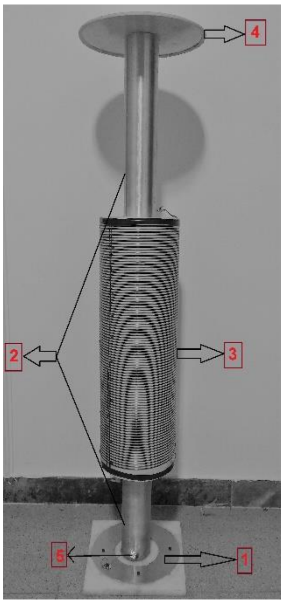

Figure 4: Implemented HF antenna.

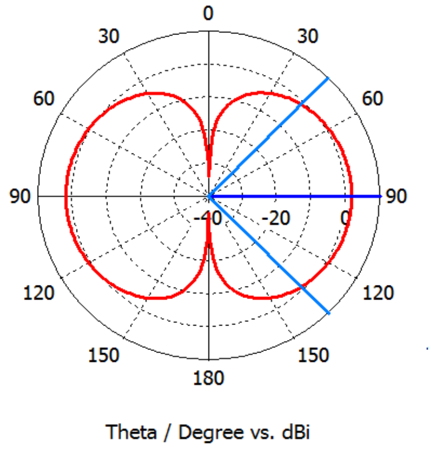

Figure 5: Farfield directivity radiation pattern at 15MHz.

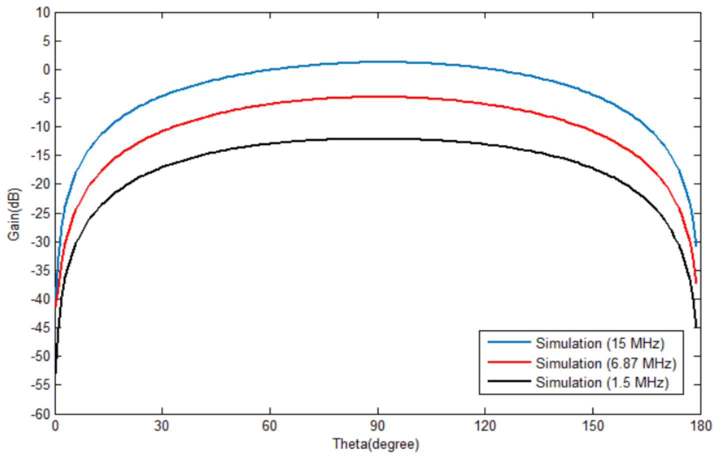

Figure 6: Gain comparison.

Fig. 7 presents simulation and measurement results. As can be seen, the return losses at 1.52, 4.74, 6.87 and 15MHz are -12.5, -17.6, -12.9 and -19.7dB, respectively. The experiment set up using the network analyzer, to measure 1.5 to 30MHz, is presented in Fig 8.

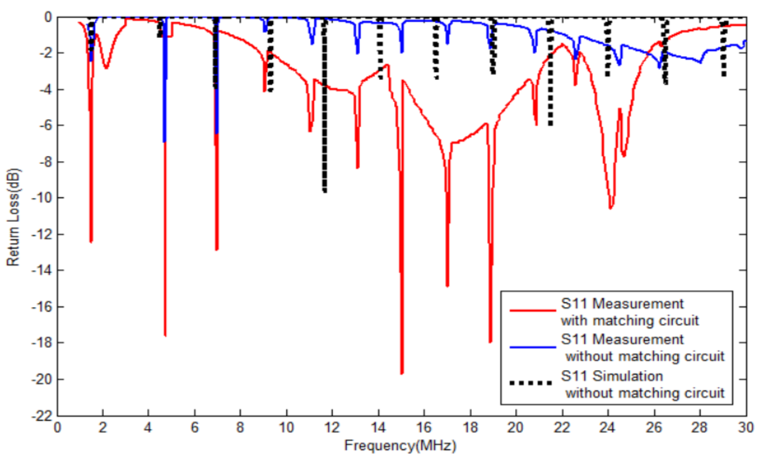

Figure 7: Return loss comparison in three situations.

Using the proposed matching network, the input resistance and reactance are listed in table 4. Corresponding standing wave ratio (SWR) was calculated and reported. As can be observed, SWR at 1.52MHz is 1.61. Table 5 illustrates, the bandwidth based on SWR 2:1 criterion. The minimum radiation efficiency is 9% at 1.52MHz.

Table 4: the value of impedance matching parameters.

f_0 (MHz)	Input resistance (ohms)	Input reactance (ohms)	SWR
1.52	69.3	-21	1.62
4.74	60.2	-10	1.3
6.95	43	-20	1.58
15	57	-8	1.23
17	39	+12	1.43
19	53	+12	1.29
24.1	67	+31	1.87

Figure 8: Measurement of the return loss.

Table 5: values of radiation efficiency and bandwidth.

f_0 (MHz)	Radiation efficiency (%)	Bandwidth (KHz)
1.52	9	70
4.74	24	20
15	48	17
24.2	76	1000

CONCLUSION

In this paper using a new method, the capacitance reactance was canceled with inductive center loading and L-Network matching circuit. The antenna was resonated at selected frequencies. The capacitive hat could enhance radiation efficiency. Resonance frequencies were tuned using the lossy material and increasing the diameter of metals. In this way, the electrically small monopole HF antenna with the height of 116cm, the diameter of 19cm and weight of 7kg covering a frequency band range from of 1.5 to 30MHz selective was successfully designed, simulated and implemented. The results of Simulation and measuring showed that by increasing the frequency from 1.5 to 30MHz, the gain enhanced from -14.6 to +1.1 dB and the radiation efficiency from 9% to 76%. In addition, the bandwidth grew from about 17KHz at 15MHz to 1MHz at 24.1MHz supporting some radar application and voice communication. It should be considered, the radiation efficiency and bandwidth, in actual fact, are low small HF antenna.

It was decided to implement these antennas at lower frequencies with efficient size and desired performance to reach more promising results.

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