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A Miniaturized Non-ResonantLoaded Monopole Antenna for HF-VHF Band

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Abstract—In this paper, a new technique for wideband impedance matching of short monopole antennas in the HF-VHF bands is proposed. This technique is motivated by the challenge of obtaining low VSWR values in small and low frequency antennas. The proposed network topology consists of two lumped elements: an inductor cascaded with a transformer. An analytical model is provided to obtain the proper values of these lumped elements. The small monopole antenna is designed, fabricated, and tested in the HF-VHF band and a good agreement between the simulated and measured results is achieved. Moreover, it is also shown that a critical improvement of the antenna matching is obtained by adding a pure resistor in the middle of the antenna, without significantly reducing the antenna gain.

Index Terms—loaded monopole antennas, impedance matching, small antennas.

1 INTRODUCTION

Engineers have had a great challenge to design desired matching circuits to match a non-resonant (i.e., relatively short) monopole or dipole antenna over a wide frequency bands. Small antennas are being widely used in many applications [1] specifically in monopole and dipole antenna [2].For instance, in low-frequency links, where robustness with respect to blockage and multipath is more important than large data throughputs [3]. In some papers metamaterials are used to design VHF antenna but these type of the antennas cannot handle high RF power. Current impedance matching techniques involve modifying the antenna structure. Although this is quite popular, such antennas are sometimes complicated to design, build, and analyze. Some designers use helix antennas to obtain wideband frequency responses [4-6], but these structures cannot be used in VHF or HF band. The common way to compensate for the capacitive behavior of short antennas is using passive elements with inductive behavior. Standard narrowband impedance matching techniques include introducing some sections of reactive lumped circuit elements, which are cascaded with some resistive elements. However, typically this is not sufficient to obtain VSWR values below 3.5 and these standard approaches are not applicable when the bandwidth required is 20% or higher. This paper attempts to solve the problem of wideband matching for short non-resonant monopoles by using lumped element matching networks, which we believe would minimize the complexity. This approach could also serve as a basis for constructing appropriate matching networks that modifies the antenna response dynamically. The standard narrowband impedance matching techniques include some sections of reactive lumped circuit elements which are cascaded with some resistance elements [7-9]. Former circuits are not applicable when the bandwidth required is 20% or higher. In general, matching circuits can be classified into two groups. Passive circuits and active or switching circuits [10,11]. In passive circuits, the analytical approach requires an approximation of the antenna's input impedance (the load), but it has been developed for simple load circuits only. A thorough treatment of the analytical approach for different types of load is available in [12]. The Carlin's RFT gain-bandwidth optimization approach is a numerical technique that does not require a load model. Since the main radiation of monopoles is fixed at λ/4, end loading is a well-known and very common technique that has been employed to reduce the resonant length of antennas [13,14]. We sidestep these two approaches and prefer to introduce the equalizer topology up front: the equalizer's first section is the section with two inductors. This section is adopted from the analysis of whip monopoles. This section is cascaded with a high-pass -section comprising a shunt inductor and two capacitors, intended to broaden the narrowband response of the section. This matching network topology can be used for all dipole-like antennas. In this paper a simple monopole antenna has been divided in two sections and to improve the matching response, a resistor has been embedded between two upper and under rods as well as an external matching circuit is added. This antenna can handle high RF power (about 80 Watt) because there is no active element for the matching network and may find its application in the design of small and low frequency antennas.

2 ANTENNA SCHEMATIC OVERVIEW

In Figure 1 the schematic diagram of the frequency reconfigurable antenna is depicted.

As shown in Figure 1, two section monopole antenna have been mounted on a square ground plane with dimensions of

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0.5meter. A lumped element connects two sections of the monopole antenna. From the beginning to end of the story dimensions of the two sections of the monopole and the resistor value are main purpose to design.In this paper we use a matching circuit to improve antenna matching (see Figure 2) and the final value of the antenna dimensions are mentioned in Table 1.

TABLE 1. PHYSICAL PARAMETERS AND DIMENTIONS OF SHORT MONOPOLE PRESENTED IN FIGURE 1

Parameter	L1	L2	L3
Value (mm)	1650	20	450
Parameter	L4	L5	2a
Value (mm)	120	500	10

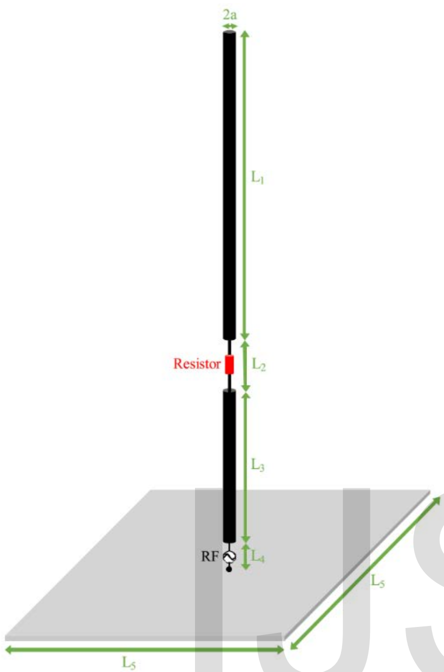

Figure 1. Geometry of the proposed non-resonant short monopole with lumped element

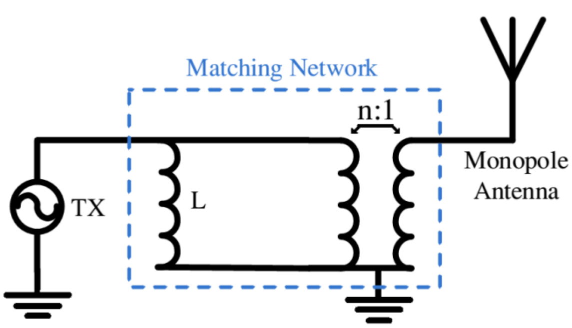

Figure 2. The schematic model of the monopole antenna with proposed wideband matching network

For small antennas capacitor behavior should be compensated and inductor matching circuit is used. We describe how chose values for the inductor and transformer as follows. At the first glance it is clear that how matching circuit improved the VSWR. From 50MHz to 80MHz and 30MHz to 35MHz the VSWR is improved dramatically.

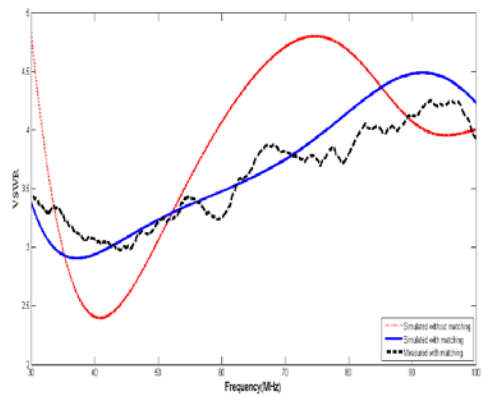

Figure 3. Simulated and measured reflection coefficient with/without matching circuit

3 ANTENNA DESIGN PROCEDURES

For a wire or strip dipole, the input impedance can be approximated with a high degree of accuracy as

$$Z_A = R_{ant}(\omega) + jX_{ant}(\omega) \quad (1)$$

Every antenna has an input impedance or admittance which is dependent on the operating frequency of the antenna. The imaginary part of a short monopole input impedance is negative (capacitive behavior), so we can use the inductor for eliminating capacitive properties of short wire antenna. As it shown in Figure 2, parallel inductor delivers positive reactance to the antenna in low frequencies because in higher frequencies impedance of the inductor is very high and does not significant effect on the antenna. If we used a series inductor it had a significant effect on higher operation frequencies and it was not proper for the antenna matching. To compensate the difference level of impedance between the antenna and transmission line a RF transformer is used. Using the RF transformer can increase degree of freedom to get the best result. After some mathematical calculation the $R_{in}(\omega), X_{in}(\omega)$ of the monopole antenna with the matching circuit in Figure 2 are given by the following equations.

$$Z_{in} = j\omega L \| (n^2 (R_{ant} + jX_{ant}) \quad (2)$$

$$R_{in} = \frac{\left(\frac{\omega L}{n}\right)^2}{R_{ant}^{\ 2} + (X_{ant} + \frac{\omega L}{n^2})^2} \quad (3)$$

$$X_{in} = \frac{\omega L\left(\left(R_{ant}^{\ 2} + X_{ant}^{\ 2}\right) + \frac{\omega L}{n^2} X_{ant}\right)}{R_{ant}^{\ 2} + (X_{ant} + \frac{\omega L}{n^2})^2} \quad (4)$$

Therefore, the real part of output impedance of matching network should be equaled to 50Ω and the imaginary part of it should be equaled to zero to achieve perfect matching. The following equation must be satisfied.

$$\begin{cases} R_{in} = Z_0 \\ X_{in} = 0 \end{cases} \quad (5)$$

After some mathematical calculations the values of inductance and transformer turns are derived. It is obvious that the values of them versus frequency can be obtained from the $R_{ant}(\omega), jX_{ant}(\omega)$ matrixes which have been calculated by CST software. It is interesting to mention that we cannot obtain constant values for L and n because the R_{ant} and $X_{ant}$are not constant versus the frequency operation. Therefore, they have been plotted at the first step.

$$L = \frac{-Z_0 R_{ant}}{\omega . X_{ant}} \quad (6)$$

$$n = \sqrt{\frac{Z_0 R_{ant}}{(R_{ant}^{\ 2} + X_{ant}^{\ 2})}} \quad (7)$$

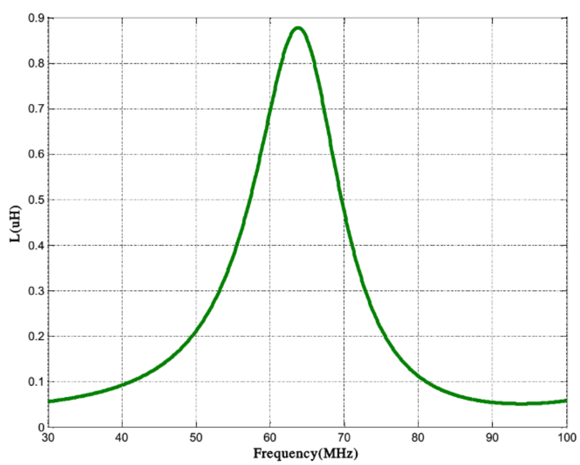

Figure 4. Different values of matching circuit inductor for perfect matching parameters versus frequency.

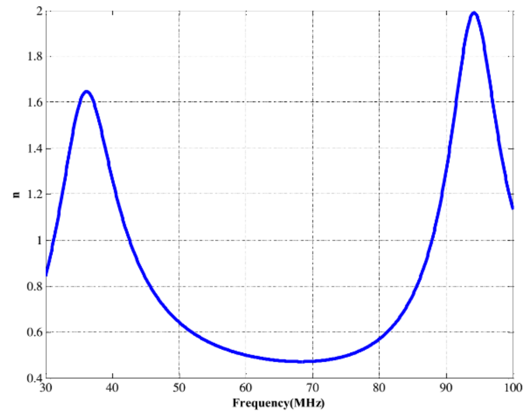

Figure 5. Different values of the ferrite (n: 1) transformer turns for perfect matching parameters versus frequency.

In this step of designing procedure, we should choose the proper values of transform turns and matching inductance from the obtained diagrams, which have been presented in Figure 4 and 5. In these diagrams the values of L and n for perfect matching condition are illustrated. It is important for a designer to choose anappropriate value to reach the final purposes. In this paper, good matching at the middle of the band has taken priority over the other frequency band. Then, with respect of the transformer turns diagram (Figure 5), the transformer turn value can be chosen between 0.4 to 0.6 (at the range of the frequencies between 50MHz to 80MHz). Theaverage value of 0.4 and 0.6 is 0.5, which is applied for our design. Fortunately, the standard transformers at this ranges are available. In this step we should choose a proper transformer to match the antenna with line. At first transformer should be able to handle high RF power. About 80Watt RF power is transferred by the transformer, therefore the Quality Factor (Q) of the transformer must be high. Second, frequency bandwidth is another important factor for choosing RF transformer. Third, transformer size can be considered since very large transformers are not practical. In this matching circuit, ADT2-1T-1P transformer has been utilized.

4RESULTS ANALYSIS

To measure the antenna radiation pattern, we installed the monopole antenna and receiver antenna mounted on the special tower. This is often done for very large antennas or at low frequencies (VHF and below, <100 MHz) where indoor measurements would be intractable. The source antenna (the monopole) is not necessarily at a higher elevation than the test antenna, but it is better to set on higher elevation to get pattern higher than 90° in elevation plane (E-Plane). The source antenna must be placed in the far field of the test antenna. The reason is that the wave received by the test antenna should be a plane wave for maximum accuracy. The photo of the fabricated antenna prototype and matching circuit is shown in Figure 7 and Figure 8, respectively. As shown these radiation patterns are almost omnidirectional

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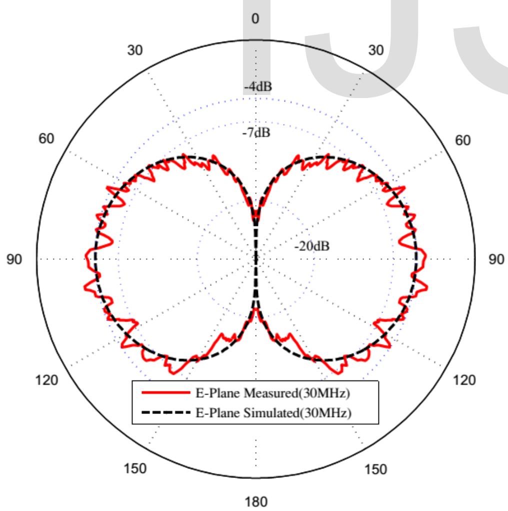
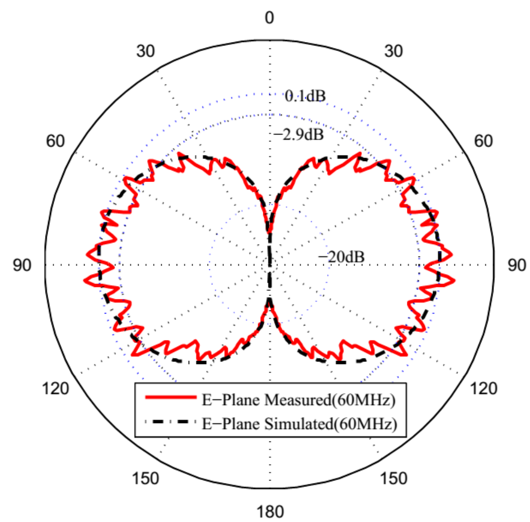
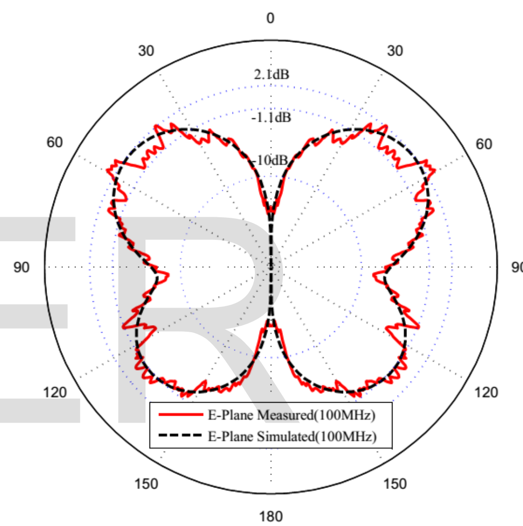
and there is no deep null inside them. When the operation frequency increases the main beams trend to turn upward because as the length of the dipole increases beyond one wavelength (l/λ) the number of lobes begin to increase. In upper frequency band (100MHz), radiation pattern shape is like a butter fly. The minimum value for the null is about -5dB (see Figure 6(c)). This value is acceptable for a short monopole antenna. The resistor in the antenna has not intensive effect on the antenna gain since the current pick on the monopole antenna is not on the resistor location. The maximum value for antenna gain can be achieved at higher frequencies and in this case at 100MHz. As shown in Figure 6(c) the maximum gain is 2.1dB. At lower frequencies (about 30MHz), antenna gain is -4dB. The main reason for low antenna gain at lower frequency band is radiation resistance value. Size of the antenna for lower frequencies is small and cannot be cover by even λ/8 operation frequency current. Then, it is normal to have antenna gain lower than 0dB. This antenna is used for portable applications. Therefore, it should be installed on the roof of the cars or truck bodies. It is clear that the ground plane for the antenna will be increased when antenna ground is connected to cars body. So, the main lobs at upper frequency band are pulled up. Therefore, the lower lobs will be vanished. At lower frequency band, moving of the main lobs happens, but the movement is negligible. The reason is that at lower frequency, vehicle body length is about one or less than wavelength.



(a)



(b)



(c)

Figure 6. The radiation pattern of the antenna at the three frequency bands. Simulated and measured antenna realized gain (a) 30MHz (b) 60MHz (c) 100MHz.

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Figure 7. Photo of the fabricated antenna prototype

5 Conclusion

To sum up, in this paper a novel simple matching circuit, which can be applied for every short antenna, is designed and fabricated. Because of capacitive behavior of short monopole and dipole antennas, matching network with inductor and RF transformer is practicable. By the use of the analytical solution and calculation of obtained graphs, the appropriate values of lumped inductor and transformer have been gained. The values of these elements can be achieved for other antennas conveniently. Also, to improve VSWR of proposed antenna a resistor is located in somewhere between the two parts of the antenna. The simulated and measured results showed good agreement.

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