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Design of an 868 MHz Printed S-Shape Monopole Antenna

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Abstract

The purpose of this work is to design and analyze an s-shaped printed circuit board (PCB) monopole antenna. The antenna was analyzed to operate at a resonance frequency band of 868 MHz; acceptable in 915 MHz as well. The s-shape is selected due to the need of reducing the overall size of the normal monopole antenna. The printed antenna was designed with an approximate overall size of 39 × 56 mm² of which the antenna's upper side is 26 × 39 mm² while its reference ground board was sized at 39 × 30 mm². The antenna is fed by a strip line of 3 × 1.5 mm², in series with a 4.4 pF capacitance and shunt with an 8.7 nH inductance for purpose of antenna's impedance matching with the input. A couple of existing publications showed that PCB antenna is not a new technology; however not an old technology for telecommunication industry. The raised problem by this work was duly solved with HFSS as a tool; excellent results are presented. After duly matching the antenna's impedance with 50 Ω microstrip feed-line, solutions for overall performance were analyzed and demonstrated optimal: radiation patterns were proven omnidirectional, antenna gain optimized. The present antenna prototype's overall dimensions can be readjusted according to any industrial and manufacturing requests.

Keywords

S-Shape, Printed Antenna, HFSS, Impedance Matching

1. Introduction

Most monopole antennas commonly refer to quarter wavelengths ($\lambda/4$); derivatives of dipoles where one element is folded into the ground (GND) and serves as the second radiator [1] [2]. The first derivatives of the monopole are the inverted-L and inverted-F antennas [3]-[6]. The antenna length is an important parameter and it is influenced by the dielectric constant of the material in the reactive near field. According to [2], calculation of the ef-

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fective dielectric constant (ε_{eff}) for both the half-wave dipole and the quarter-wave monopole is approximated in (1).

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \left[\frac{1}{\sqrt{1 + \frac{12 \times h}{W}}} + 0.04 \times \left(1 - \frac{W}{2}\right)^2 \right] \quad (1)$$

where h is the thickness of substrate or PCB material; W is the trace width of the dipole arms, decided to 2 mm in this case [7]-[11]. The working or effective wavelength (λ_{eff}) for most antennas is then given by the formula in (2), $\lambda_{eff} = \frac{\lambda}{\sqrt{\varepsilon_{eff}}}$ (2); knowing the free space wavelength, $\lambda_0 = \frac{c}{f}$ (3); whereby $c = 3 \times 10^8 \text{m} \cdot \text{s}^{-1}$ is the speed of light and f is the working frequency in Hertz (Hz).

2. The Proposed s-Shape Monopole Antenna Structure

As per Equations (1)-(3), normal monopole antennas to work with industrial, scientific and medical (ISM) band of 868 MHz and 915 MHz would be presenting the length sizes according to **Table 1**.

Nonetheless, irrespective of the calculated lengths in **Table 1**, the proposed s-shape antenna will utilize almost half of the overall length. It is to note that s-shape, snakelike shape as well as Meander shape are interchangeable names [2] [7]. The proposed s-shaped monopole antenna's design model is illustrated in **Figure 1**.

3. The Antenna Design, Analysis and Discussions

The software tool that was utilized for the design tasks is Ansoft HFSS [2]. According to the necessary problem solving steps, the solution type for the present model is set to driven terminal. It normally calculates the terminal-based s-parameters of multi-conductor transmission line ports. The s-shaped monopole antenna element together with the feed-line as well as the ground boards (top and bottom) are all assigned with finite conductivity boundary. It is one of the advanced boundary conditions. The rectangular port designed at 0.8 × 1.5 mm^2 is assigned the lumped port excitation.

Table 1. Theoretical monopole lengths.

$\varepsilon_{eff} = 2.9931$ **on a 0.8 mm thick FR-4 PCB,** $\varepsilon_r = 4.4$				
Frequency (MHz)	λ_0 (mm)	λ_{eff} (mm)	$\frac{\lambda_{eff}}{4}$ (mm)	$\frac{\lambda_{eff}}{2}$ (mm)
868	345.6	199.7	50	100
915	327.8	189.5	47.4	94.8

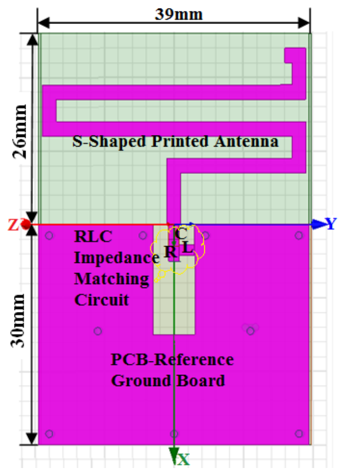


Figure 1. The proposed antenna structure.

3.1. Design Results

3.1.1. The Antenna's Return Loss (RL)

As a measure of the reflected energy from a transmitted signal, **Figure 2** illustrates the maximum RL of −7.76 dB at 868 MHz.

It is practically known that the bigger the value of RL, the much less energy reflected back; the main reason of this kind of loss is due to mismatch conditions of the antenna with the input impedance. For that reason, the impedance matching will be applied which will reach to optimization results.

3.1.2. The Antenna's Impedance

The impedance analysis by Smith Chart in **Figure 3** results in mismatch where the point m_1 is very far from the matching point.

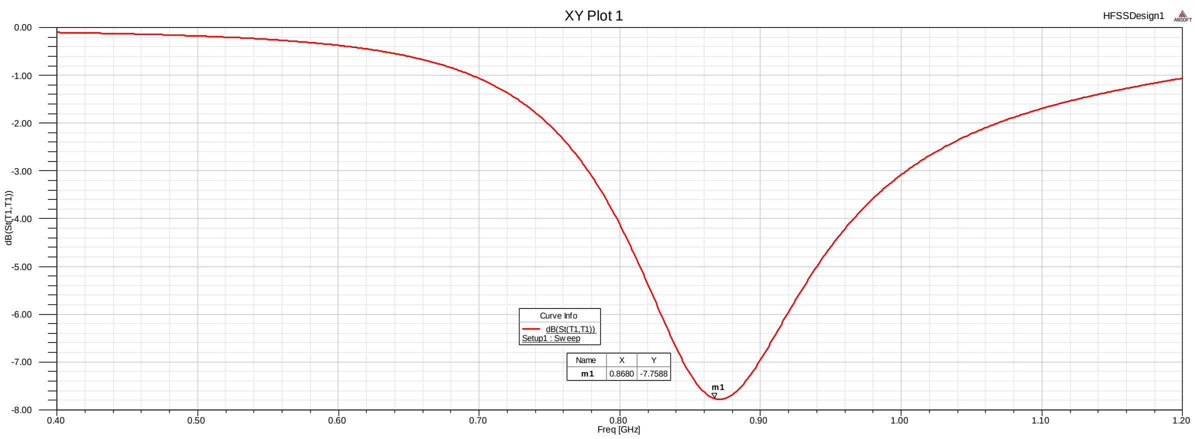


Figure 2. The return loss (RL) before impedance matching, resonance at 868 MHZ.

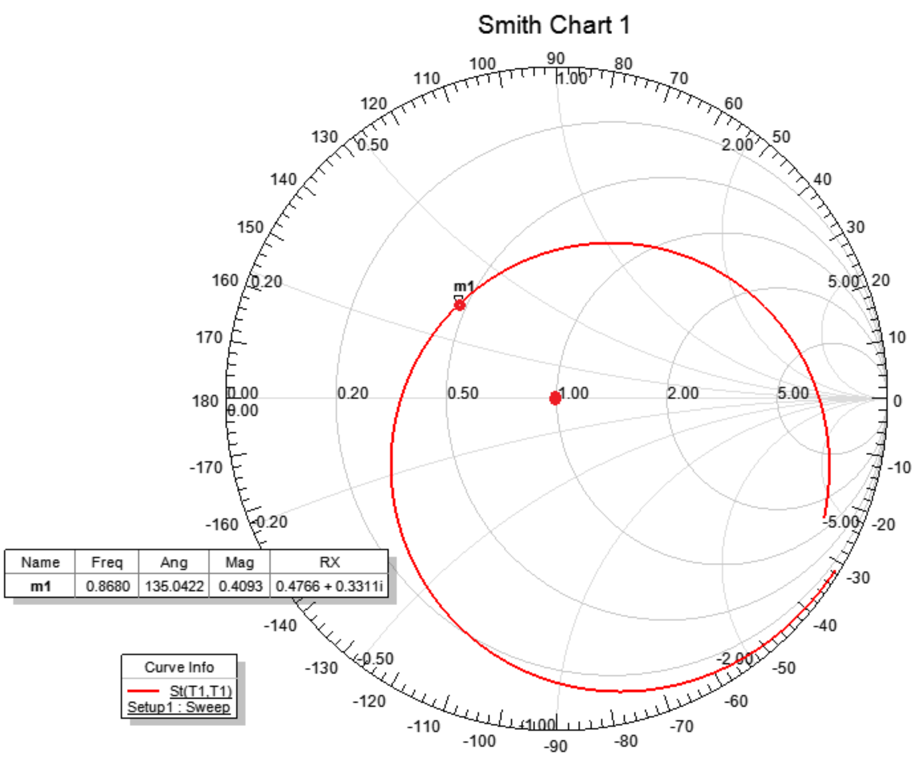


Figure 3. Smith chart impedance analysis.

Reading the current Smith Chart in **Figure 3**, the actual antenna impedance is given by the calculation of the normalized input impedances, Z_{in}, such that $Z_{in} = (0.4766 + 0.331)*50 = 23.83 + j16.5$; which give us values for the real and imaginary parts to be used during the Smith Chart impedance matching in **Figure 4**.

3.2. Impedance Matching

The Smith Chart impedance matching data points 1, 2 and 3 respectively, in **Figure 4(a)**, were obtained by fixing a central frequency of 868 MHz, thus generating point 1; then by drawing a series capacitance from point 1 to point 2 and finally drawing a shunt inductance from point 2 to point 3. This means the pulling of antenna's impedance to the central matching point. Under such conditions, the Smith chart system calculates the matching series capacitance to 4.4 pF while the shunt inductance is 8.7 nH as shown in **Figure 4(b)**. The values are then implemented into the 3D model of **Figure 1** as R-L-C impedance matching circuit, R = 50 Ω being the strip feed-line's resistance.

3.3. Optimization Results

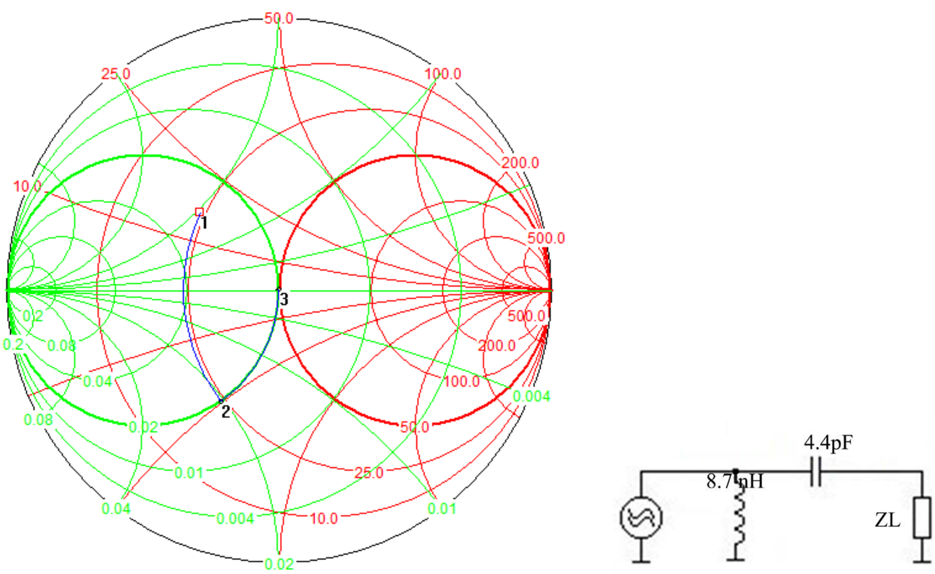
After building the matching circuit as shown in **Figure 1**, the new simulation results were considered optimal as presented in **Figures 5-9**. Those are Smith Chart impedance, radiation patterns, return loss and PCB fields overlay respectively. Regarding the capacitance and inductance sizes, the real implementation would adopt the standard manufacturing smaller sizes of such valued capacitance and inductance.

3.4. Discussions

According to the standards [8]-[11], the impedance matching [12] [13] brings a big improvement. For example, due to that impedance matching in our model, the return loss shifts from −7.76 dB to −16.5 dB. Another proof is the measurement by Smith Chart in **Figure 5** which show the very big difference between unmatched conditions illustrated in **Figure 3**. Observing the return loss behavior in **Figure 8**, the 6.15 dB bandwidth is estimated to (0.915 - 0.826) MHz = 0.089 MHz; while for the 16.5 dB bandwidth is estimated to 0 MHz.

4. Conclusion

The PCB monopole s-shaped antenna design and simulation have been so successful that the obtained results are excellent, notably the omonidirectional radiation patterns shown in **Figures 7-9**. Due to the folding of the normally



(a) (b)

Figure 4. (a) Smith chart impedance matching; (b) Smith chart impedance matching schematic diagram.

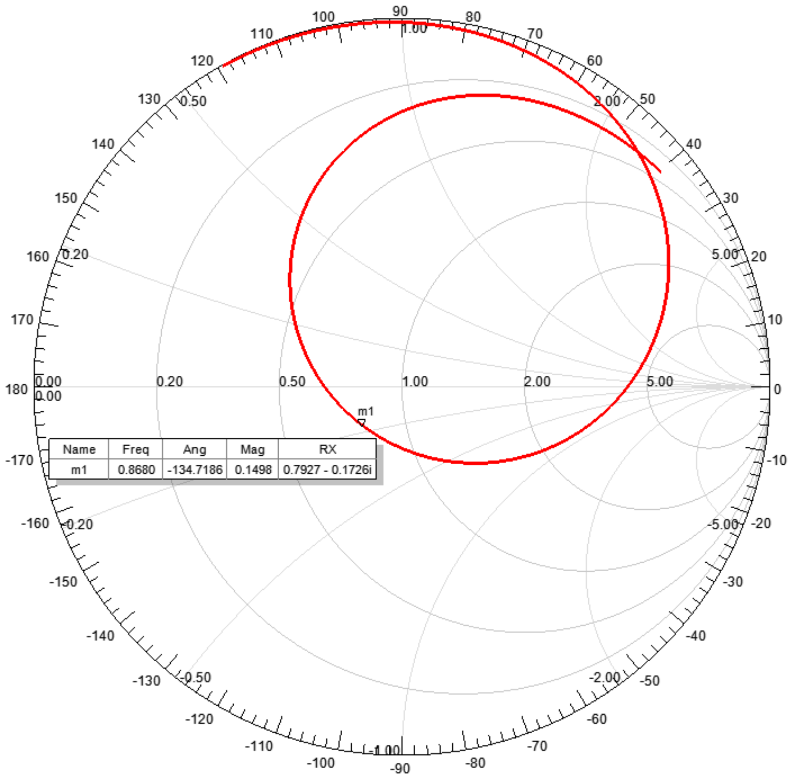


Figure 5. Impedance measuring by smith chart.

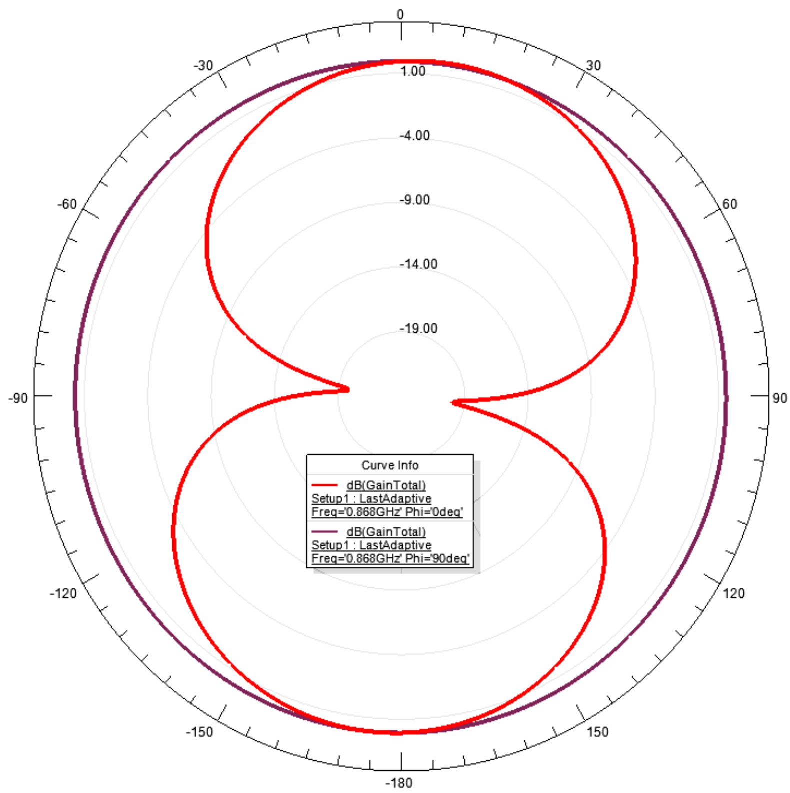


Figure 6. EH plane radiation pattern.

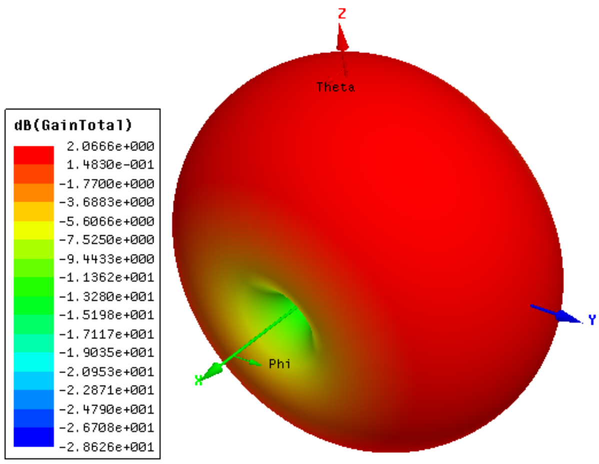


Figure 7. 3D radiation pattern.

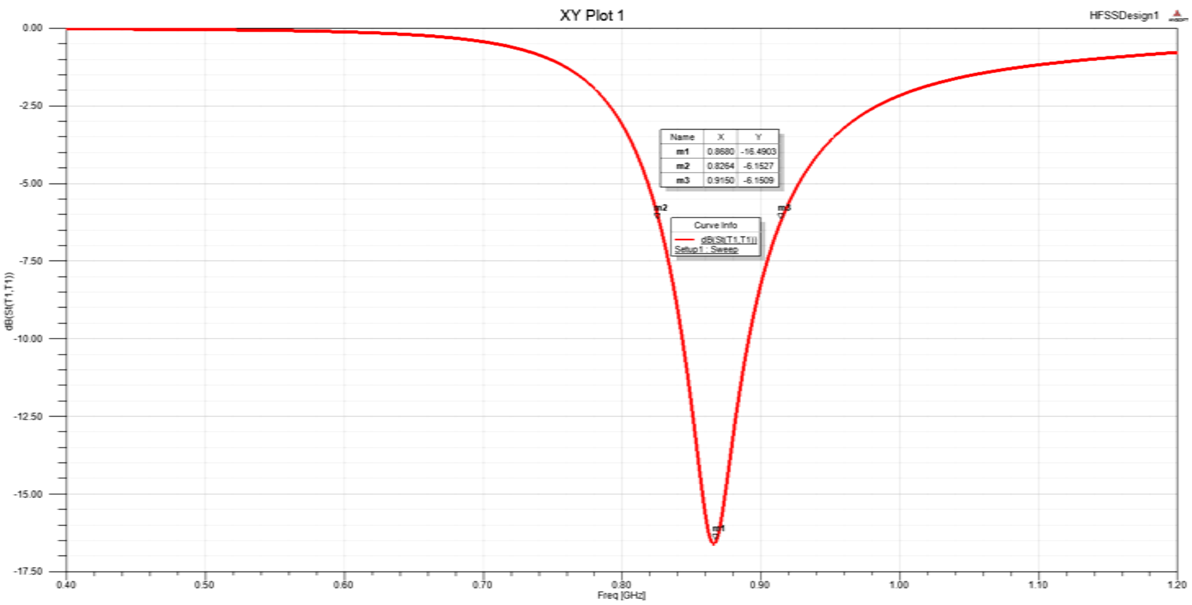


Figure 8. Return loss.

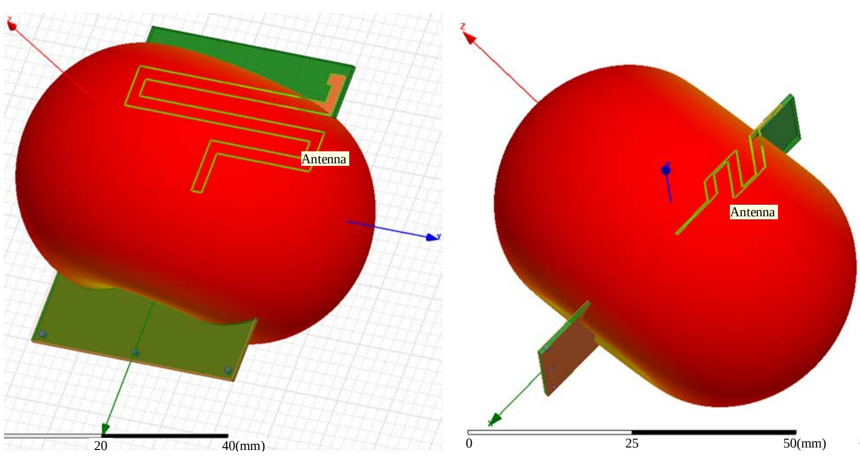


Figure 9. The PCB fields overlaying in two different view positions.

known monopole antenna into a snakelike shape, the antenna has reached to a reduced size that can be easily implemented in all miniaturized transceivers and receivers operating in ISM 868MHz as well as in ISM 915 MHz with less return loss.

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