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Electrically Small Rectangular Patch Antenna with Slot for MIMO Applications

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Abstract This article addresses the design and optimization of electrically small antenna suitable for MIMO (multiple input multiple output) applications. A MIMO transmission is one of the promising antenna technologies used for wireless communication. When the transceiver uses more than one antenna, the antennas must be placed at least half of the carrier wavelength apart, in order to transmit/receive uncorrelated signals. Such antenna systems are required to fit within the hand-held (mobile) terminal which occupies a small size (typically not more than 60x100 mm^2). Since antenna integration and miniaturization are two major challenges in MIMO systems, we propose a slot loaded electrically small rectangular patch antenna that operates in the 0.8GHz to 2.6GHz band which is suitable for most of the commercial wireless applications. The proposed antenna has an operating frequency of 1.7GHz with impedance bandwidth of 105%, and the total size of 20x40 mm^2. Measured results agree with the simulated values.

Keywords: *MIMO, microstrip antennas, long term evolution (LTE), wideband antennas*

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1. Introduction

The integration of more than one antenna (multiple input multiple output (MIMO) system) in each mobile terminal is a challenging task. Electrically small antennas are the right candidates for these applications. There are several works on electrically small antennas [1,2,3] and MIMO antennas [4,5,6,7,8] available in the literature. Meander line antennas are typical electrically small antennas which are being preferred in MIMO systems. For example in [4], a meander line antenna (MLA) that has a resonant frequency of 1 GHz was presented. The equations presented there will give a prohibitively large antenna if used for the 800 MHz band. While in [5] a spiral-like printed antenna that was electrically small was proposed to operate in the 700 MHz range with a size of 40x40 mm^2. The antenna had an extremely narrow bandwidth that will not be suitable for the application at hand that requires at least 40 MHz of bandwidth to cover the downlink and uplink in LTE channels. A multi-band printed bow-tie antenna was proposed in [6] to cover the 800 MHz and 1.9 GHz bands. The size of such an antenna will occupy the whole mobile terminal size since it covers a board area of 130x77 mm^2. While in [7] a dual band ESA was proposed that covered 800MHz and 2GHz bands with a size of 25x43 mm^2. The antenna suffers from narrow bandwidth in both bands. Thus, previous work shows that the proposed antennas will not be suitable for LTE mobile terminals due to their large size or narrow operating bandwidth.

In this paper we propose an electrically small antenna with center frequency around 1.7GHz, has very high bandwidth (105%) in comparison with bandwidth reported in [8] which has 59.9%. Although, the proposed antenna in this paper works on the similar principle of work reported in [8], has much simpler geometry, less number of optimization parameters and has better performance (nearly twice the impedance bandwidth reported in [8]). Section 2 presents the basic geometry [8]. Proposed geometry is presented in section 3 followed by conclusions in Section 5.

2. Basic Geometry

A meander line antenna shrinks the electrical length of a regular monopole or dipole antenna by folding its length back and forth to create a structure with multiple turns. This method has advantages when antennas with low frequency of operation are of interest as it will reduce the size of the antenna significantly. The geometry of meander antenna structure is shown in Figure 1 [8]. The dimensions of the antenna as reported in [8] are L=43mm, W=23.5mm, L_g=16.2mm, W_1=15.5mm, W_2=16.5mm, W_3=W_4=W_5=1mm, L_1=12.27mm, and L_1=5.93mm and the antenna was simulated as suggested there. These characteristics are depicted in Figure 2 and radiation patterns in two planes are presented in Figure 3.

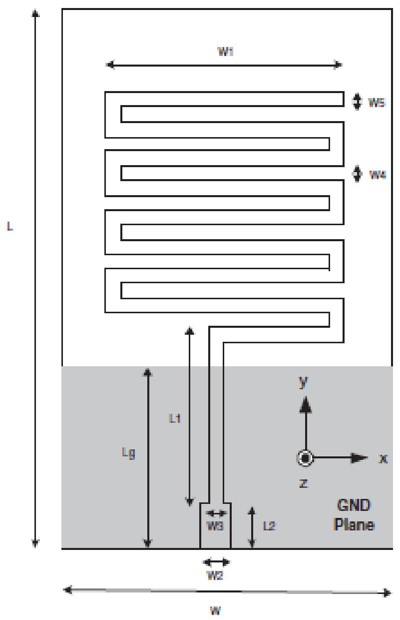

Figure 1. Basic geometry of MLA [8]

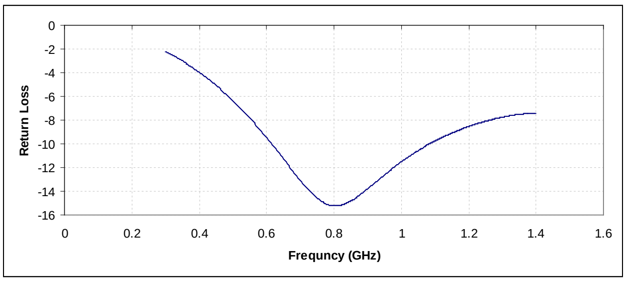

Figure 2. Simulated return loss of MLA shown in Figure 1

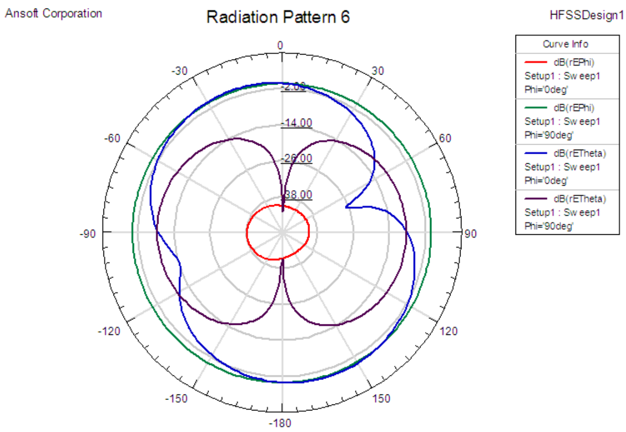

Figure 3. Radiation patterns of antenna shown in Figure 1

3. Modified Geometry

Figure 4 shows the geometry of modified antenna. In modified antenna meandered structure is replaced by rectangular patch. Antenna dimensions were optimized using Ansoft HFSS. An optimized set of dimensions for the proposed antenna design are listed in Table 1. The effects of key design parameters (L, W, and a diagonal slot) on the return loss and bandwidth of this antenna are investigated in the following paragraphs by numerical simulations.

The substarte used in simulations is FR4 with relative dielectric constant of 4.4 (loss tangent=0.01) and hieght of the substrate equal to 1.56mm. The design starts with the selection of patch dimensions. Initially, the length and width of rectangular patch are chosen equal to that of total area below the meander structure. A diagonal slot has been introduced to enhance the impedance bandwidth [9].

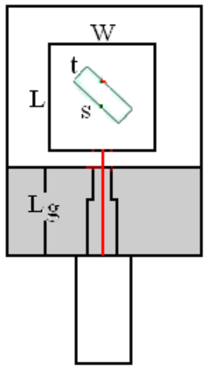

Figure 4. Geometry of the modified antenna

Table 1. Optimized dimensions of the modified antenna

Parameter	Value
Length of Rectangular patch(L)	17.0mm
Width of Rectangular patch(W)	15.5mm
Length of ground (Lg)	16.2mm
Length of slot (s)	6.0mm
Width of slot (t)	2.0mm

3.1. Effect of Patch Width (W)

In this study patch width was varied by keeping patch length (L=17mm) constant. Patch width was varied in steps of 1mm. All the results are presented in Table 2. Return loss characteristics for all the cases studied are depicted in Figure 5. From the Table 2 it may be noted that W=15.5mm case proves to be the best one. Hence in the patch length optimization, W=15.5mm has been used and kept constant while varying the patch length.

Table 2. Design parameters for various curves presented in Figure 5 showing the effects of the width of patch antenna

Curve No	Width of patch (W)	Length of patch (L)	RL Freq. Range	%Bandwidth
1	18.5mm	17mm	0.8-2.4GHz	100.0
2	17.5mm	17mm	0.85-2.3GHz	92.0
3	16.5mm	17mm	0.85-2.3GHz	92.0
4	15.5mm	17mm	0.8-2.6 GHz	105.8
5	14.5mm	17mm	0.85-2.7GHz	104.2
6	13.5mm	17mm	0.9-2.8GHz	102.7

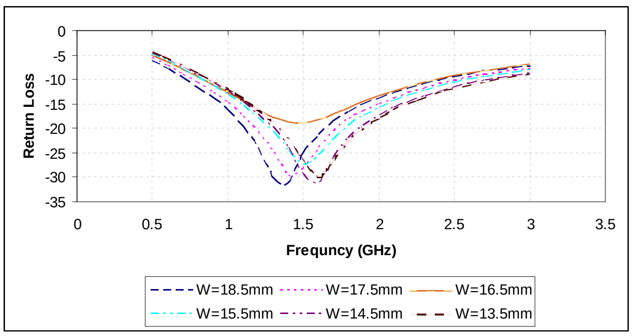

Figure 5. Return loss characteristics for different values of W

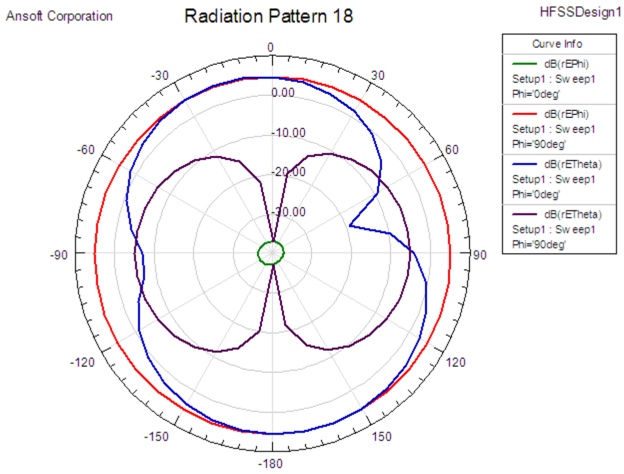

Figure 6. Radiation pattern of modified antenna

3.2. Effect of Patch Length (L)

As explained in Section 3.1, here the patch length was varied by keeping patch width (W=15.5mm) constant. Patch length was varied in steps of 1mm. All the cases are presented in Table 3. Return loss characteristics for all these values of patch length are depicted in Figure 7. From the Table 3 it may be noted that L=17.0mm case provides the highest bandwidth among all cases considered. Hence the optimized patch dimensions are L=17mm and W=15.5mm.

Table 3. Design parameters for various curves presented in Figure 6 showing the effects of the length of patch antenna

Curve No	Width of patch (W)	Length of patch (L)	RL Freq. Range	%Bandwidth
1	15.5mm	15mm	0.9-2.55GHz	95.6
2	15.5mm	16mm	0.85-2.56GHz	100.2
3	15.5mm	17mm	0.8-2.6 GHz	105.8
4	15.5mm	18mm	0.85-2.4GHz	95.3
5	15.5mm	19mm	0.8-2.4GHz	100.0

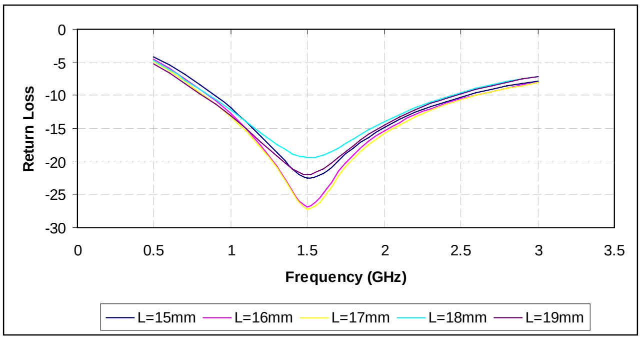

Figure 7. Return loss characteristics for different values of L (in mm)

3.3. Effect of Slot Dimensions

In order to tune the resonant frequency and slightly enhance the impedance bandwidth a slot was introduced with dimensions length (s) and width (t) as shown in Figure 1. Slot length was varied in steps of 1mm and it was observed that center frequency may be tuned up to 10%. This is basically due the fact that a slot introduces the reactance to the patch element. The effect of slot length variation is shown in Figure 8. Also, an effort has been made to vary the slot width, however no significant changes were observed.

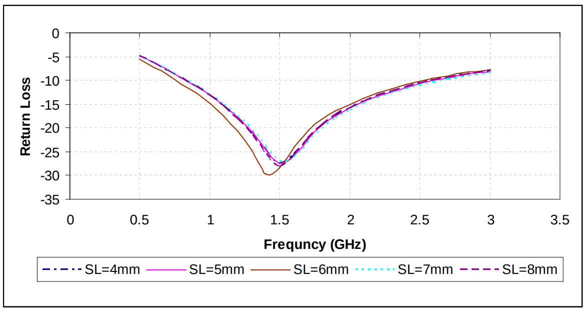

Figure 8. Effect of variation of slot length s

4. Experimental Results and Discussions

The antenna presented in Figure 1 was fabricated and tested. The photograph of the fabricated prototype is shown in Figure 9. The substrate used is the glass epoxy material with dielectric constant (ε_r) of 4.4, loss tangent (tanδ) of 0.001 and height of the substrate equal to 1.6mm.

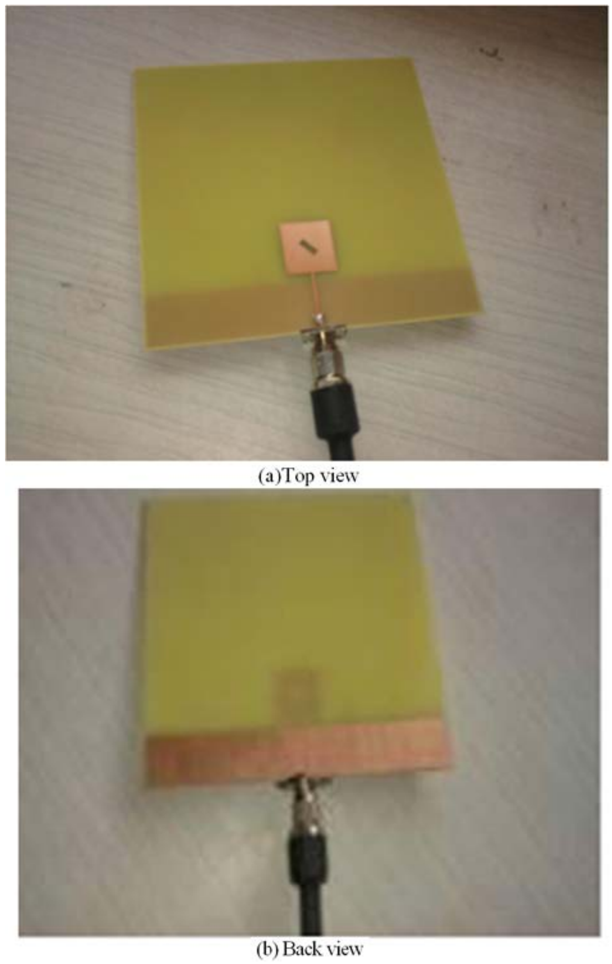

Figure 9. Fabricated prototype of the antenna geometry shown in Figure 4

The pin of the SMA connector is soldered to test the prototype. This prototype antenna was tested for S_{11} using VNA (Voltage Network Analyzer). As shown in Figure 100, the measured return loss (S_{11}) is better than -10dB for frequencies in the range of 0.9-2.5 GHz. This corresponds to a percentage bandwidth close to 100%. The slight difference between the simulated and measured results may be attributed due to fabrication inaccuracies.

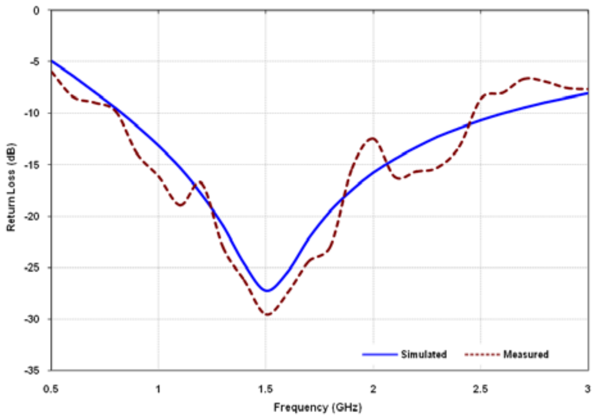

Figure 10. Experimental validation of antenna

5. Conclusions

A rectangular monopole patch antenna with a slot embedded in it has been proposed here after designing the basic geometry reported in literature having narrow bandwidth. The impedance bandwidth of the proposed design is above 100% in all the cases studied with good radiation characteristics. Also, the proposed design requires a very less number of parameters to optimize the geometry in comparison with the meander line antennas. The measured results agreed with the simulated values. The antenna presented here proves to be electrically small and is the best candidate for MIMO applications.

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