Optimization of the Ground Plane by Size Variation of E-shaped Patch Antenna for Energy Harvesting at GSM-900

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Abstract: The optimization of ground plane by size variation of E-shaped patch antenna for RF energy harvesting system is presented and discussed in this study. The variation of this ground plane by size variation was tested to demonstrate the effects of return loss and impedance bandwidth on the patch antenna to enhance its RF energy reception capabilities. The antenna was modeled and simulated in the ADS 2009 environment for downlink radio frequency band of GSM-900, showed an impedance bandwidth of 30.26% (285 MHz) and return loss of -39.99 dB at 941.7 MHz.

Keywords: Downlink, energy harvesting, ground plane, GSM-900, impedance bandwidth, radio frequency, return loss

INTRODUCTION

An impedance bandwidth of 22% at 5 GHz centre frequency was obtained using an unequal patch sizes and without an air region separation on the triple patch antennas (Bulja and Syahkal, 2006). The impedance bandwidth of 19.8% at 2.378 GHz centre frequency was obtained (Chair *et al*., 2005) using shorted wall loading and introducing multi resonance in the low profile E shaped patch antenna. Proposed two closely staggered resonant modes to achieve an impedance bandwidth of 13.3% at 900 MHz centre frequency using two unequal arms of the U-shaped patch (Guo *et al*., 2002). The impedance bandwidth was enhanced to 44% (Guo *et al*., 1998) by increasing the thickness of the substrate and with the addition of second U slot over the main U shaped patch. Introduced U shaped slot in the rectangular patch was able to achieve an impedance bandwidth of 10-40% (Huynh and Lee, 1995). Designed E-shaped patch antenna (Kavuri *et al*., 2012b) for 377 Ω impedance with optimized partial ground plane, which operates in the impedance bandwidth range of 850 to 1135 MHz (285 MHz) and achieved return loss of 39.99 dB. Designed Rectangular Stepped Patch Antenna at GSM-900 for 377 Ω impedance with optimized partial ground plane, obtained an impedance bandwidth of 32.7% (310 MHz) at 947 MHz centre frequency with return loss of -28.12 dB (Kavuri *et al*., 2012a). Three different types of feeding techniques were employed at the centre frequency of 3.3 GHz and able to achieve an impedance bandwidth in the range of 17.1-24% (Kumar and Gupta, 1985). A rectangular

micro strip antenna with a foam layer thickness of around 10% of the wavelength using L shaped probe feed achieved an impedance bandwidth of 35% at frequency range of 3.76-5.44 GHz (Luk *et al*., 1998). Broadband impedance matching (Pues and Van de Capelle, 1989) was proposed using Fano's theory where an impedance bandwidth of 12% at 3.34 GHz centre frequency was obtained. The effect on bandwidth using variation in substrate thick ness and its permittivity (Schaubert *et al*., 1989) showed that erratic result was obtained for substrates thicker than about 0.02 λ_0. The design in Shackelford *et al*. (2003) combined the wideband U-slot and L-probe-fed patch with the addition of a shorting wall and shorting pin techniques, obtained an impedance bandwidth of 20% at 3.755 GHz centre frequency. Implemented a square patch antenna with a cross shaped slot on the surface through an aperture coupling (Vera *et al*., 2010) achieved a return loss of -14 dB at 2.45 GHz. Used two U-shaped parasitic elements along the radiating edges of a probe fed rectangular patch antenna to achieve the impedance bandwidth of 27.3% at the centre frequency of 5.5 GHz (Wi *et al*., 2007). Chip resistor loading technique was implemented and achieved an impedance bandwidth of 9.3% at the centre frequency of 710 MHz (Wong and Lin, 1997). Impedance bandwidth of 19.8% at 2.378 GHz centre frequency was obtained (Xiong *et al*., 2008) using shorted wall loading and introducing multi resonance in the low profile E shaped patch antenna. The technique of L shaped probe feed implemented on a thick substrate achieved an impedance bandwidth of 30.3% at the frequency range of 1.9 to 2.4 GHz (Yang, *et al*., 2001).

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In this study a novel optimized ground plane for E-shaped patch antenna (Kavuri *et al*., 2012a) was designed with 377 Ω impedance, which operates in the impedance bandwidth range of 850 to 1135 MHz (285 MHz) and return loss of 39.99 dB. This work has achieved the requirement for the wideband antenna to RF energy harvesting at GSM-900 band. The discerning feature of this design is especially in the optimization of the ground plane, which differs from all the previous published works.

Antenna design: The antenna design with optimized partial ground for wide band 377 Ω E-shaped patch antenna is shown in Fig. 1. The topology of the antenna is designed on an FR-4 substrate with 1.6 mm thickness and dielectric constant ϵ_r of 3.9. The antenna consists of a larger patch, followed by a Pi matching network, a smaller patch which serves as the feed line and a partial ground plane.

The patch antenna's basic width and length are denoted by W and L is formalized (Balanis, 2005) by the Eq. (1) and (2):

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \tag{1}$$

$$L = \frac{\lambda}{2} - \Delta L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\,\Delta L \tag{2}$$

The size of the ground plane is the vital factor in the present design of antenna for the required application. As the size of ground plane is reducing successively from the full to one-tenth the area of patch, the capacitance of the antenna is gradually reduced and the antenna become more inductive. This reduction enables the antenna to maximize the pick-up capability of the magnetic field from the free space.

METHODOLOGY

The optimized design of antenna ground plane is too complex to obtain by any analytical methods. Hence in this study the antenna model was performed using a CAD design tool. The simulations were performed for various dimensions of the size of the antenna ground plane through electromagnetic simulation software environment (Agilent, 2009). The Model of partial ground plane for antenna structure is shown in Fig. 1, where G_W represents the width of the ground plane and L_W represents the length of ground plane. The other dimensions of the antenna geometry were unaltered. To start with ground plane was extended to the full width of antenna structure and recorded the results of return loss, values of complex impedance and impedance bandwidth at the resonance
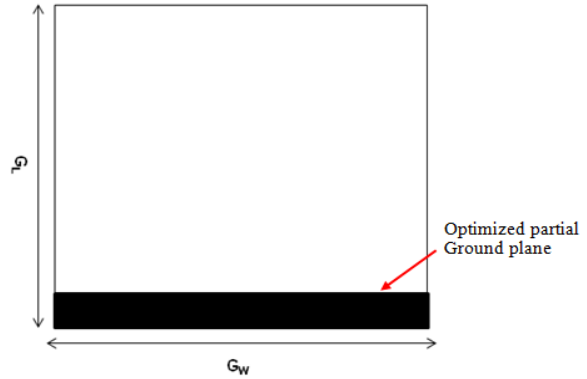

Fig.1: Model of partial ground plane for antenna structure

frequency. The procedure was repeated for many cases by gradually reducing the size of the width (G_W) of the ground plane and recorded the effect of ground plane on the performance of desired requirement. Finally four cases are selected for reduction in size of width (G_W) for ground planeie full ground plane, extended up to the end of the slots, up to the matching network and up to the feeding edge of the antenna.

RESULTS AND DISCUSSION

The investigations were focussed on the effect of the size of the ground plane and the performance of the following parameters: return loss better than -20 dB at resonance frequency, real and reactive part of the impedance match close to 50 Ω and to 0 Ω, respectively. Impedance bandwidth (-10 dB) greater than 150 MHz. Several cases were carried out in the simulation, but four cases are presented and discussed in this study.

Case studies for the effect on ground plane:
Case 1: E-shapedpatch antenna structure with full ground plane.

The model antenna structure is shown in Fig. 2 and itsdimensions are shown in Table 1.

The results obtained for return loss and complex impedance from the Smith chart for case 1 are shown in Fig. 3 and 4. From Fig. 3 it is observed that the antenna structure is resonating at 950 MHz with the return loss of -5.47 dB. Figure 4 shows the real and reactive part of impedances at resonannce and they are 110.65 and 71.35 Ω, respectively. This results indicates the antena is inductive and hence it led to theimpedance mismatch from the load to the source which resulting to large return loss. This case results are not suitable for the application even though the resonance frequency is with in the frequency band.

Case 2: E-shaped patch antenna with partial ground plane extended up to the first non-radiating slot.

Table 1: Dimensions of antenna geometry for case 1

Basic configuration	E-shaped patch antenna						Pi matching network						Feed line		Ground plane	
			S_1		S_2		L_1		L_2		L_3					
Variable	W	L	W	L	W	L	W	L	W	L	W	L	W	L	G_W	G_L
Dimensions (mm)	85	106	79	2	81	3	2	10	13	8	2	20	8	3	120	110

Table 2: Dimensions of antenna geometry for case 2

Basic configuration	E-shaped patch antenna						Pi matching network						Feed line		Ground plane	
			S_1		S_2		L_1		L_2		L_3					
Variable	W	L	W	L	W	L	W	L	W	L	W	L	W	L	G_W	G_L
Dimensions (mm)	85	106	79	2	81	3	2	10	13	8	2	20	8	3	116	110

Fig. 2: Model of antenna structure for case 1
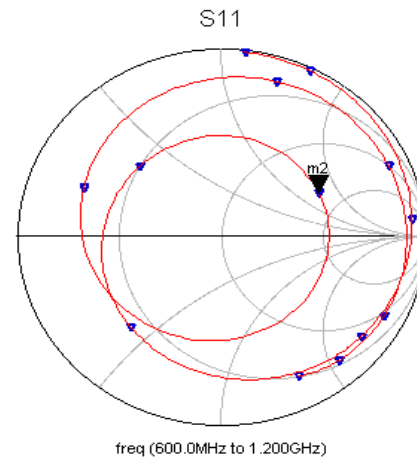

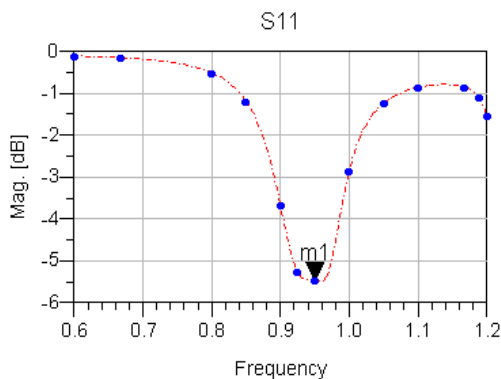Fig. 4: Results of complex impedance on Smith chart for case 1

Fig. 3: Results of return loss for case 1

Fig. 5: Model of antenna structure for case 2

The model of the antenna structure is shown in Fig. 5 and its dimensions are shown in Table 2.

The results of the return loss and complex impedance from the Smith chart obtained for the case 2 are shown in Fig. 6 and 7. From Fig. 6 it is observed that the structure is resonating at 1005 MHz with return loss of -9.266 dB. The resonant frequency is shifted beyond the upper range of required frequency band, the reas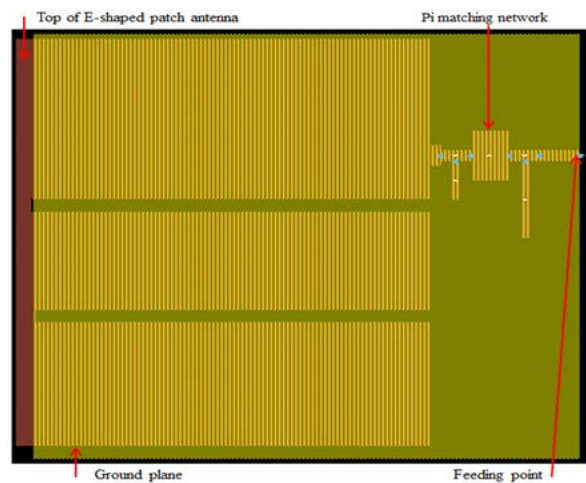on behind is the reduction of capacitance in the antenna structure that led to the higher resonance frequncy. Figure 7 shows the real and reactive part of impedances at resonant frequency 100.5 and 12.3 Ω, respectively and is capacitive. This shows an impedance mismatch from the load to the source. Further refinement is required.

Table 3: Dimensions of antenna geometry for case 3

Basic configuration	E-shaped patch antenna						Pi matching network						Feed line		Ground plane	
			S_1		S_2		L_1		L_2		L_3					
Variable	W	L	W	L	W	L	W	L	W	L	W	L	W	L	G_W	G_L
Dimensions (mm)	85	106	79	2	81	3	2	10	13	8	2	20	8	3	35	110

Fig. 6: Results of return loss for case 2

Fig. 9: Results of return loss for case 3

freq (600.0MHz to 1.200GHz)

Fig. 7: Results of complex impedance on Smith chart for case 2

freq (300.0MHz to 1.200GHz)

Fig. 10: Results of complex impedance on Smith chart for case 3
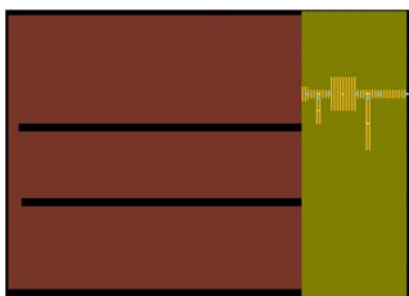

Fig. 8: Model of antenna structure for case 3

Case 3: E-shaped patch antenna with partial ground plane extended up to the matching network.

The model of the antenna structure is shown in Fig. 8 and its dimensions are given in Table 3.
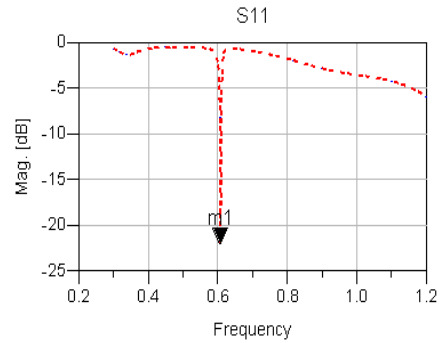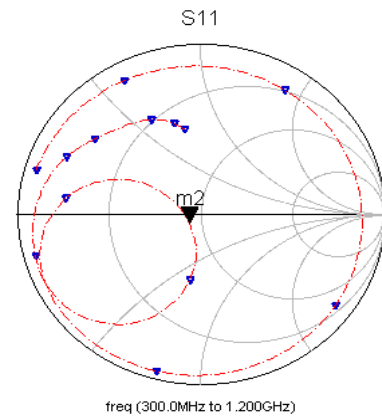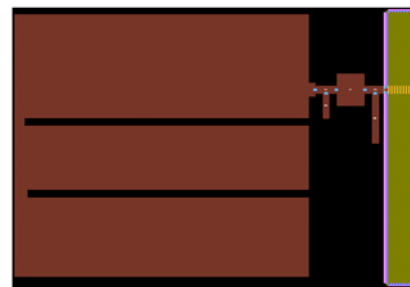

Fig. 11: Model of antenna structure for case 4

The results of return loss and impedance from Smith chart obtained for case 3 are shown in Fig. 9 and 10. Figure 9 shows that the antenna structure is resonating at 606.5 MHz with return loss of -22.056 dB. The frequency is shifted below the lower end of required frequency band. The drop in resonance frequency is due to the increase of electrical length of the antenna. From Fig. 10 it is observed that the real

Table 4: Dimensions of antenna geometry for case 4

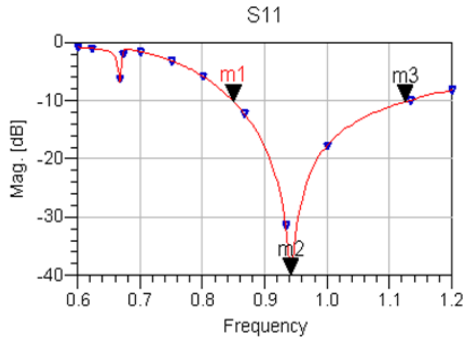| Basic configuration	E-shaped patch antenna						Pi matching network									
			S_1		S_2		L_1		L_2		L_3		Feed line		Ground plane	
Variable	W	L	W	L	W	L	W	L	W	L	W	L	W	L	G_W	G_L
Dimensions (mm)	85	106	79	2	81	3	2	10	13	8	2	20	8	3	8	110

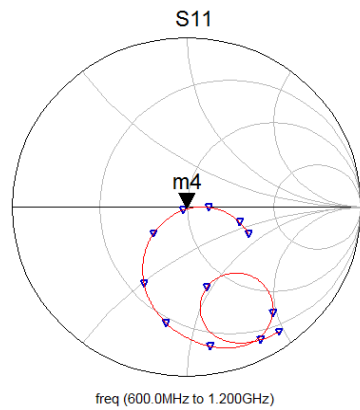Fig. 12: Results of return loss for case 4

Fig. 13: Results of impedance on Smith chart for case 4

and reactive part of impedances at resonant frequency was 44.25 and 4.7 Ω, respectively and is capacitive in nature. It shows that the impedance mismatch from the load to the source. Hence not satisfing the stated required specifications.

Case 4: E-shapepatch antenna with partial ground plane at the feeding edge.

The model of the antenna structure is shown in Fig. 11 and its dimensions are shown in Table 4.

The results of return loss and impedance from the Smith chart obtained for case 4 is shown in Fig. 12 and 13. From the Fig. 12 it is observed that the structure is resonating at 941.7 MHz with return loss of -39.99 dB. The resonant frequecy is close to the centre frequency of the required radio frequency band. Figure 13 the real and reactive part of impedances at resonant frequency are 54.3 and 0.1 Ω, respectively and is capacitive. The real part of impedace at the resonant frequency 941.7 MHz is close to 50 Ω and the reactive part of impedance is almost negligible. This result shows best

impedance match from the load to the source out of several case studies. Hence results of this case satisfing the stated required specifications. Antenna is purely resistive. This is the desired result.

CONCLUSION

The technique of size reduction to optimize the size of ground plane was successes full in achieving very low return loss of -39.99 dB at 941.7 MHz (close to the center frequency 947.5 MHz of GSM-900 band) is in the range of GSM-900 band. This method also shrunk the ground plane from the initial size of 110×120 mm to the size of 110×8 mm, which is about 10 times less than that of the size of the patch antenna. Compared to the established performance characteristics of the wide band micro strip patch antennas, the presented antenna has a novel feature of achieving a wide impedance bandwidth for matching to free space impedance 377 Ω. This shows that the proposed antenna has all the capabilities for use in energy harvesting at GSM-900 band.

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