
List of Figures

| Figure No. | Caption of Figures | Page No. |
|---------------------|--|-----------|
| Figure 1.1: | (a) SISO system, (b) SIMO system, (c) MISO system, and (d) MIMO system..... | 5 |
| Figure 1.2: | Schematic and front view of the PIFA..... | 7 |
| Figure 1.3: | (a) Electric field distribution along patch resonant length and (b) Quarter wave patch, shorted at one end..... | 11 |
| Figure 1.4: | Planar monopole antenna inside portable devices..... | 13 |
| Figure 1.5: | (a) Quarter wave monopole antenna and (b) Equivalent half wave dipole antenna..... | 13 |
| Figure 1.6: | Different DGS geometries: (a) Dumbbell-shaped, (b) Spiral-shaped, (c) H-shaped, (d) U-shaped, (e) Arrow head dumbbell, (f) Concentric ring shaped, (g) Split ring resonators, (h) Meander line, (i) Cross-shaped, (j) Circular head dumbbell, (k) Square heads connected with U-slots, (l) Open loop dumbbell, (m) Fractal, (n) Half-circle, and (o) V-shaped..... | 17 |
| Figure 1.7: | Neutralization line between multi antenna systems..... | 18 |
| Figure 1.8: | EBG structure between MIMO antenna elements..... | 19 |
| Figure 1.9: | Loading of dielectric wall between MIMO antenna for isolation..... | 19 |
| Figure 1.10: | External feed network for isolation improvement (a) Decoupling network, and (b) Branchline decoupling feed network..... | 20 |
| Figure 2.1: | A typical Rayleigh fading envelope..... | 42 |
| Figure 2.2: | Spherical coordinates in mobile radio environments..... | 43 |
| Figure 2.3: | Incident radio wave arriving at the receiving antenna in multipath environment..... | 47 |
| Figure 2.4: | Gaussian distribution model of incident waves..... | 74 |

| | | |
|---------------------|---|-----------|
| Figure 2.5: | Probability for different number of branches of an M -port antenna system and diversity gain definition for $M = 2$ | 51 |
| Figure 2.6: | The illustration of SPLSR..... | 56 |
| Figure 2.7: | Total power radiated from antenna..... | 57 |
| Figure 3.1: | Proposed antenna (a) without folded shorting strip, and (b) with folded shorting strip..... | 61 |
| Figure 3.2: | (a) 3-D view of single antenna element, (b) Unfolded planar structure of single antenna element, and (c) Optimized dimensions of (b) in mm..... | 61 |
| Figure 3.3: | (a) Effect of different configurations on reflection coefficient, and (b) Effect of folded shorting strip on S -parameters..... | 63 |
| Figure 3.4: | Variation of S -parameters with (a) slot length (l_s), (b) slot width (w_s), (c) side arm length (l_a), and (d) folded shorting strip length (l)..... | 65 |
| Figure 3.5: | (a) Prototype of proposed antenna (size compared with Samsung Galaxy S GT I9000), and (b) Simulated and measured S -parameters of proposed structure..... | 66 |
| Figure 3.6: | Far field radiation patterns (a) Simulated 3D at 2.45 GHz and 5.5 GHz, and (b) Measured 2D at 2.45 GHz and 5.5 GHz..... | 67 |
| Figure 3.7: | Variation of measured peak realized gain and calculated total antenna efficiency..... | 69 |
| Figure 3.8: | (a) Surface current distribution at 2.45 GHz, (b) Surface current distribution at 5.5 GHz, (c) Vector surface current flow on folded shorting strip at 2.45 GHz, and (d) Vector surface current flow on folded shorting strip at 5.5 GHz..... | 69 |
| Figure 3.9: | Variation of ECC with frequency..... | 70 |
| Figure 3.10: | Configuration of mobile environment with MIMO antenna..... | 73 |
| Figure 3.11: | Effect of mobile environment on S -parameters of | 73 |

| | | |
|---------------------|--|-----------|
| | MIMO antenna..... | |
| Figure 3.12: | Distribution of energy over human head phantom, (a) Average SAR over 1g and (b) Average SAR over 10g.... | 75 |
| Figure 4.1: | (a) Antenna configuration with zoomed structure of single antenna element and fabricated antenna, (b) Unfolded planar structure of single antenna element, and (c) Optimized dimensions of (b) (unit in mm)..... | 80 |
| Figure 4.2: | Effect of different configurations on reflection coefficient..... | 81 |
| Figure 4.3: | Effect of slot length (S_l) on S -parameters..... | 83 |
| Figure 4.4: | Effect of slot width (S_w) on S -parameters..... | 83 |
| Figure 4.5: | Effect of length of the side arm 1 (L_{s1}) on S -parameters.. | 84 |
| Figure 4.6: | Effect of width of the side arms (W_{s1}) on S -parameters... | 84 |
| Figure 4.7: | Simulated and measured results of S -parameters in Free Space..... | 84 |
| Figure 4.8: | Configuration of the mobile phone with user proximity.. | 86 |
| Figure 4.9: | Variation of S -parameters without folded shorting strip in different environment, (a) S_{11} and (b) S_{21} | 86 |
| Figure 4.10: | Variation of S -parameters of the proposed antenna in different environment..... | 87 |
| Figure 4.11: | Surface current distribution (with and without folded shorting strip) when Ant. 1 is excited while Ant. 2 is matched terminated with 50Ω load..... | 88 |
| Figure 4.12: | (a) Simulated 3D far field radiation patterns at different resonance frequencies and (b) Measured 2D far field radiation patterns at different resonance frequencies..... | 90 |
| Figure 4.13: | (a) Variation of measured peak realized gain and (b) Total antenna efficiency with frequency..... | 91 |
| Figure 4.14: | Variation of ECC and EDG with frequency..... | 92 |
| Figure 4.15: | SAR simulation setup according to CTIA..... | 94 |
| Figure 4.16: | Distribution of energy over human tissue, (a) Average SAR over 1g and (b) Average SAR over 10g..... | 94 |

| | | |
|---------------------|--|------------|
| Figure 5.1: | Configuration of proposed antenna with fabricated prototype..... | 102 |
| Figure 5.2: | (a) 3-D view of the single antenna element, (b) Detailed dimension of proposed patch unfolded into a planar structure, and (c) Detailed dimension of added resonating arm..... | 102 |
| Figure 5.3: | Evolution of antenna element and respective reflection coefficient..... | 103 |
| Figure 5.4: | Surface current distribution on the antenna at 5.25 GHz..... | 103 |
| Figure 5.5: | Variation of S -parameters with slot shape parameters, (a) x_1 , (b) y_1 , and (c) W_s | 105 |
| Figure 5.6: | Variation of S -parameters with antenna shape parameters, (a) G_a , (b) L_a , and (c) W_{a1} | 106 |
| Figure 5.7: | Variation of S -parameters with antenna shape parameters, (a) W_{a2} and (b) W_{sh} | 107 |
| Figure 5.8: | S -parameters of the proposed MIMO antenna..... | 108 |
| Figure 5.9: | (a) Simulated 3D far field radiation patterns for the MIMO antenna at 1.575 GHz, 2.62 GHz, 3.35 GHz, and 5.25 GHz and (b) Measured 2D far field radiation patterns at 1.575 GHz, 2.62 GHz, 3.35 GHz, and 5.25 GHz..... | 110 |
| Figure 5.10: | Variation of measured peak realized gain and total efficiency with frequency..... | 111 |
| Figure 5.11: | Variation of ECC and EDG with frequency..... | 111 |
| Figure 5.12: | Mobile phone configuration with antenna elements..... | 114 |
| Figure 5.13: | Model of antenna elements locations of (a) SAM Head and PDA Hand (Talk mode), (b) PDA Hand (Data mode), and (c) Dual Hand (Read mode)..... | 115 |
| Figure 5.14: | Variation of S -parameters in mobile environment..... | 116 |
| Figure 5.15: | Variation of S -parameters of PIFA in the presence of user proximity (a) Talk mode, (b) Data mode, and (c) Read mode..... | 117 |
| Figure 5.16: | (a) Total efficiency, (b) ECC, and (c) multiplexing Efficiency of the SAM Head and PDA Hand (Talk | |

| | | |
|---------------------|---|-----|
| | mode) for PIFA..... | 119 |
| Figure 5.17: | (a) Total efficiency, (b) ECC, and (c) Multiplexing efficiency of the PDA Hand (Data mode) for PIFA..... | 121 |
| Figure 5.18: | (a) Total efficiency, (b) ECC, and (c) Multiplexing efficiency of the Dual Hand (Read mode) for PIFA..... | 121 |
| Figure 5.19: | Variation of power loss in user proximity at different frequencies for PIFA, (a) 1.575 GHz, (b) 2.62 GHz, (c) 3.35 GHz, and (d) 5.25 GHz..... | 124 |
| Figure 5.20: | SAR simulation setup according to CTIA..... | 125 |
| Figure 6.1: | (a) Front and rear view of the proposed antenna, (b) Detail dimensions of the single antenna element, and (c) Fabricated prototype..... | 133 |
| Figure 6.2: | (a) Effect of different configurations on reflection coefficient, (b) Surface current distribution for different cases..... | 135 |
| Figure 6.3: | Variation of reflection coefficient with various shape parameters (a) l_2 (b) w_1 , and (c) w_2 | 137 |
| Figure 6.4: | Variation of reflection coefficient with various shape parameters (a) w_3 and (b) l_2 | 138 |
| Figure 6.5: | Effect of protruded ground plane on S -parameters..... | 139 |
| Figure 6.6: | Simulated and measured S -parameters of the proposed planar monopole MIMO antenna..... | 140 |
| Figure 6.7: | (a) Simulated 3D and (b) Measured 2D far field radiation patterns at 0.777GHz, 1.9GHz, and 2.5GHz..... | 141 |
| Figure 6.8: | Variation of calculated total efficiency and measured peak realized gain with frequency..... | 142 |
| Figure 6.9: | (a) Actual mobile environment with antenna elements and (b) Effect of mobile environment on S -parameters.. | 146 |
| Figure 6.10: | Model of antenna elements locations of (a) SAM Head and PDA Hand (Talk mode), (b) PDA Hand (Data mode), and (c) Dual Hand (Read mode)..... | 146 |
| Figure 6.11: | Variation of S -parameters of PMA in the user proximity (a) Talk mode, (b) Data mode, and (c) Read mode..... | 148 |

| | | |
|---------------------|---|------------|
| Figure 6.12: | (a) Total efficiency, (b) ECC, and (c) Multiplexing efficiency, of the SAM Head and PDA Hand (Talk mode) for PMA..... | 149 |
| Figure 6.13: | (a) Total efficiency, (b) ECC, and (c) Multiplexing efficiency, of the PDA Hand (Data mode) for PMA..... | 151 |
| Figure 6.14: | (a) Total efficiency, (b) ECC, and (c) Multiplexing efficiency, of the Dual Hand (Read mode) for PMA..... | 152 |
| Figure 6.15: | Variation of power loss in user proximity at different frequencies of PMA (a) 0.777 GHz, (b) 1.9 GHz, (c) 2.1 GHz, and (d) 2.5 GHz..... | 154 |