

---

# List of Figures

Figure		Page
<b>Chapter 3</b>		
3.1	Spectra of OFDM UWB systems compliant with the FCC's emission limit masks for indoor and outdoor UWB applications	30
3.2	FCC regulated spectral mask for various indoor and outdoor applications	34
3.3	Modern digital home equipped with various UWB devices	38
3.4	UWB devices (a) USB storage device (b) USB hub (c) USB 2.0 networking server (d) UWB HDMI Extender (e) UWB laptop (f) Audio video Extender (g) Multimedia transmitter (h) Computer to TV Wireless Connection Kit	49
3.5	Potential applications of the UWB system	39
3.6	Interference of WLAN with the UWB spectrum	42
3.7	Simulation setup for group delay measurement in face-to-face orientation	42
3.8	Co-axial feed monopole antenna with various shaped radiators	42
3.9	Microstrip and CPW fed monopole and slot antennas	47
<b>Chapter 4</b>		
4.1	Geometries of thin ground pentagonal monopole UWB antenna (a) Antenna 1 (b) Antenna 2 (c) Antenna 3	50
4.2	(a) Reflection coefficient of Antenna 1 for variation in ground height $h_1$ (b) Reflection coefficient of Antenna 1 and Antenna 2	52
4.3	Reflection coefficient of Antenna 3 with variation in ground height $h_1$	52
4.4	Reflection coefficient of Antenna 3 with variation in $w_f$	53
4.5	Simulated reflection coefficient comparison of monopole UWB Antenna 1 - 4 with variation in $w_f$ , $h_f$ and measured $S_{11}$ of the proposed PSCUMA with $w_f = 2.6$ mm	53
4.6	(a) Smith chart of PSCUMA (b) Current distribution of PSCUMA (c) Simulated and measured gain of PSCUMA and (d) Photograph of PSCUMA	55
4.7	Group delay for the face-to-face identical PSCUMA pair	55
4.8	(a) Impedance model for radiating element of UWB antenna (b) Equivalent circuit of UWB antenna	56
4.9	Interference of existing narrow bands with the UWB spectrum	57
4.10	Geometry of the 3.5 GHz band-notched monopole antenna (a) a pair of L-	59

	shaped slot and (b) Photograph of fabricated antenna ( $W = 32$ mm, $L = 22$ mm, $h_1 = 4.35$ mm, $w_f = 2.6$ mm, $g = 0.5$ mm, $S = 9.52$ , $p = 0.45$ mm, $s_1 = 0.64$ mm, $s_2 = 0.5$ mm, $l_1 = 1.85$ mm, $L' = 11$ mm and $w' = 2.45$ mm)	
4.11	(a) Comparison of simulated reflection coefficient of PSCUMA and band-notched PSCUMA with a pair of L-shaped slots	59
4.11	(b) Effect of the variation in ground slot length $L'$ on VSWR of PSCUMA with a single L-shaped slot	60
4.12	(a) Gain of the band-notched antenna with and without an L-shaped slot and (b) Surface current distribution at 3.5 GHz with a single L-shaped slot	60
4.13	VSWR comparisons for PSCUMA with a pair of L-shaped slot for band-notch at 3.5 GHz with variation in $L'$	62
4.14	Simulated and measured VSWR comparison for single and dual L-shaped slot	62
4.15	(a) Simulated and measured gain comparison for 3.5 GHz band-notched PSCUMA with a pair of L-shaped slots	62
4.15	(b) Group delay for the face-to-face oriented identical antenna pair	63
4.16	Radiation Pattern at (a) 3.1 GHz (b) 6.8 GHz (c) 9.0 GHz of 3.5 GHz band notched antenna	64
4.17	Equivalent circuit model for 3.5 GHz band-notched antenna (a) with quarter wavelength slot resonator (b) Lumped circuit model of band notched UWB antenna	65
4.18	Geometry of 5.2 GHz band-notched PSCUMA ( $W = 32$ mm, $L = 22$ mm, $h_1 = 4.35$ mm, $w_f = 2.6$ mm, $g = 0.5$ mm, $S = 9.52$ , $p = 0.45$ mm, $s_1 = 0.64$ mm, $s_2 = 0.5$ mm, $l_1 = 1.85$ mm, $l_2 = 7.15$ mm, $l_3 = 9.1$ mm, $l_4 = 7$ mm and $l_5 = 1.2$ mm)	66
4.19	Reflection coefficient of 5.2 GHz band-notched PSCUMA with and without $l_5$	67
4.20	VSWR of 5.2 GHz band-notched PSCUMA with (a) open-ended semi-spiral thin ground plane ( $l_2 + l_3 + l_4 + l_5$ ) and (b) parasitic stub $L'' = (l_3 + l_4 + l_5)$	67
4.21	Surface current distribution of 5.2 GHz band-notched PSCUMA with (a) open-ended semi-spiral thin ground plane ( $l_2 + l_3 + l_4 + l_5$ ) (b) parasitic stub $L'' = (l_3 + l_4 + l_5)$	68
4.22	Geometry of 7.5 GHz band-notched Pentagonal UWB monopole antenna ( $W = 32$ mm, $L = 22$ mm, $h_1 = 4.35$ mm, $w_f = 2.6$ mm, $g = 0.5$ mm, $S = 9.52$ , $p = 0.45$ mm, $s_1 = 0.64$ mm, $s_2 = 0.5$ mm, $l_1 = 1.85$ mm, $l_{f1} = 6.1$ mm)	69
4.23	Surface current distribution of the UWB antenna (a) without filter at 4 GHz (b) with a filter at 7.5 GHz	69
4.24	Equivalent circuit of the 7.5 GHz Band-Notched PSCUMA	69

4.25	(a) Effect of the distance $d$ on the VSWR	71
4.25	(b) Effect of the open ended slot width variations on VSWR	71
4.26	Comparison between gain with and without the filter	71
4.27	Radiation patterns of 7.5 GHz Band-Notched PSCUMA at (a) 3.5 GHz (b) 6 GHz (c) 9 GHz	72
4.28	(a) Geometry of Triple Band-Notched Compact UWB Monopole Antenna ( $W = 32$ mm, $L = 22$ mm, $h_1 = 4.35$ mm, $w_f = 2.6$ mm, $g = 0.5$ mm, $S = 9.52$ , $p = 0.45$ mm, $s_1 = 0.64$ mm, $s_2 = 0.5$ mm, $l_1 = 1.85$ mm, $L' = 11$ mm and $w' = 2.45$ mm, $l_2 = 7.15$ mm $l_3 = 9.1$ mm, $l_4 = 7$ mm and $l_5 = 1.2$ mm, $l_6 = 4.5$ , $l_{fi} = 6.1$ mm) (b) Photograph of the fabricated antenna	73
4.29	Measured and simulated reflection coefficient of triple band-notched compact UWB monopole antenna	74
4.30	Measured and simulated VSWR of triple band-notched compact UWB monopole antenna with slots in the patch and extended thin ground	74
4.31	Measured and simulated gain of the triple band-notched compact UWB monopole antenna	75
4.32	(a) Simulated group delay of triple band notched PSCUMA, (b) Current distribution at various notch frequencies	75
4.33	Measured radiation patterns of triple band notched PSCUMA (a) 3 GHz (b) 4.6 GHz, (c) 6.6 GHz and (d) 10.4 GHz in the E-plane and H-plane	77
4.34	Convex hexagonal shaped UWB antenna (a) Antenna geometry and (b) Fabricated antenna photograph	79
4.35	Simulated reflection coefficient of convex hexagonal shaped UWB antenna with and without extended thin rectangular ground plane	79
4.36	(a) VSWR curves at various values of the vertical extended thin ground (b) Simulated surface current distribution at 3.1 GHz for the UWB antenna with first stop band	80
4.37	(a) Simulated reflection coefficient $S_{11}$ of the proposed antenna for various distance $d_1$ at constant $d = 3.7$ , (b) Simulated VSWR for various distance $d$ at constant $d_1 = 1.3$ for the proposed dual band stop antenna	82
4.38	Simulated results for the surface current distributions of band-notched antenna at (a) 5.6 GHz (b) 7 GHz and (c) 9.6 GHz	82
4.39	(a) Simulated and measured VSWR of convex hexagonal shaped wide stop band antenna (b) Simulated group delay with and without stop band	82
4.40	Measured and simulated co- and cross- radiation patterns of the convex hexagonal shaped band - notched antenna at (a) 5.4 GHz in E-plane, (b) 5.4 GHz in H-plane, (c) 9.6 GHz in E-plane and (d) 9.6 GHz in H-plane	83

4.41	Measured and simulated gain of convex hexagonal shaped UWB antenna with and without vertical rectangular slot as the notch filter	83
------	---	----

## Chapter 5

5.1	Pentagonal slot antenna configuration (a) Side feed (b) Vertex feed	88
5.2	Simulated reflection coefficient of pentagonal slot antenna with various $p_2$ , at $W = L = 25$ mm, $p_1 = 10.5$ mm, $w_f = 1.6$ mm, $L_{off} = 1$ mm, and $l_f = 11.5$ mm	89
5.3	Simulated reflection coefficient of pentagonal slot antenna with different $p_1$ , at $W = L = 25$ mm, $p_2 = 5.5$ mm, $w_f = 1.6$ mm, $L_{off} = 1$ mm, and $l_f = 11.5$ mm	89
5.4	Simulated $S_{11}$ with variation in $l_f$ , at $W = L = 25$ mm, $p_1 = 11.5$ mm, $p_2 = 5.5$ mm and $w_f = 1.6$ mm	89
5.5	(a) Photograph of the fabricated vertex feed pentagonal slot antenna (b) Measured and Simulated reflection coefficient of the pentagonal slot antenna at $W = L = 25$ mm, $p_1 = 11.5$ mm, $p_2 = 5$ mm, $w_f = 1.6$ mm, $L_{off} = 1.25$ mm, and $l_f = 11.25$ mm	91
5.6	(a) Gain and radiation efficiency and (b) Simulated group delay of the pentagonal slot antenna	92
5.7	Measured radiation pattern at 3.5 GHz, 5 GHz and 6.8 GHz in the E-plane and H-plane for the pentagonal slot antenna	93
5.8	Structural development of the antenna (a) Rectangular ground plane antenna (Antenna I) (b) L shape ground plane antenna (Antenna II) (c) Mirror L shaped ground plane or Full band antenna (Antenna III) (d) Rectangular radiating patch slot antenna (Antenna IV) (e) Proposed triple band convex hexagonal shaped stub rectangular slot antenna (Antenna V)	96
5.9	Geometry and configuration of the proposed Antenna V (a) Rectangular C-shaped ground plane (b) Proposed Triple band rectangular slot antenna (c) Photograph of Triple band rectangular slot antenna	96
5.10	Simulated $S_{11}$ for Antenna (I), Antenna (II) and Antenna (III)	98
5.11	Comparison of measured and simulated 10 dB impedance curves of Antenna III, Antenna IV and Antenna V	98
5.12	Simulated current distributions for the proposed triple band Antenna V at (a) 2.4 GHz, (b) 5.2GHz	100
5.13	(a) Effect of length $l_{g3}$ on the VSWR of proposed antenna V and (b) Measured VSWR	100
5.14	Measured and simulated reflection coefficient ( $S_{11}$ ) curves for optimized parameter $L_{p1}$ , $w_g$ , $F_{sw}$ , and other parameter are $L = 22$ mm, $W = 40$ mm, $w = 24$ mm, $w_n = 6.4$ mm, $w_g = 2$ mm, $L_{p2} = 6.9$ mm, $l_{g1} = 2$ mm, $p = 0.45$ mm, $w_f = 2.8$ mm	102

5.15	Measured radiation pattern at 1.8 GHz, 3.5 GHz and 9 GHz in (a) E-plane and (b) H- Plane	102
5.16	(a) Measured gain and (b) Simulation group delay in face-to-face orientation of convex hexagonal shaped stub rectangular slot antenna	103
5.17	(a) Geometry of the proposed rectangular slot antenna with pentagonal shaped tuning stub (b) Photograph of the fabricated antenna	105
5.18	Simulated reflection coefficient $S_{11}$ curves for variation in $r_1$ and $s$ at $W = 42$ mm, $L = 32$ mm, $w = 33$ mm, $h_1 = 10.4$ mm, $h_2 = 7.5$ mm, $w_f = 3.16$ mm, $g = 0.22$ mm	107
5.19	Simulated reflection coefficient $S_{11}$ curves for variation in ground plane height $h_1$ at $W = 42$ mm, $L = 32$ mm, $w = 33$ mm, $r_1 = 6.8$ mm, $h_2 = 7.5$ mm, $w_f = 3.16$ , $g = 0.22$ mm	107
5.20	Simulated reflection coefficient $S_{11}$ curves for variation in ground plane height $h_2$ at $W = 42$ mm, $L = 32$ mm, $w = 33$ mm, $r_1 = 6.8$ mm, $h_1 = 10.4$ mm, $w_f = 3.16$ mm, $s = 1$ mm, $g = 0.22$ mm	107
5.21	Simulated reflection coefficient $S_{11}$ curves for variation in feed width at $W = 42$ mm, $L = 32$ mm, $w = 33$ mm, $r_1 = 6.8$ mm, $h_1 = 10.4$ mm, $h_2 = 5$ mm, $w_f = 3$ mm, $s = 1$ mm and $g = 0.3$ mm	108
5.22	Measured and Simulated reflection coefficient $S_{11}$ curves of the proposed antenna	108
5.23	Simulated VSWR curves of the proposed antenna	108
5.24	Surface current distribution of antenna at (a) 4 GHz, (b) 2.6 GHz (c) 5.1 GHz and (d) 8 GHz	110
5.25	Simulated group delay of the rectangular slot antenna with pentagonal shaped tuning stub	110
5.26	Measured gain of the rectangular slot antenna with pentagonal shaped tuning stub	111
5.27	Measured radiation pattern of the proposed triple band antenna at (a) 2.6 GHz (b) 5.1 GHz and (c) 8 GHz	111

## Chapter 6

6.1	Geometry of the EDG UWB Antenna	115
6.2	Development of the proposed EDG antenna (a) Antenna 1: semicircular base, (b) Antenna 2: single rectangular teeth, (c) Antenna 3: dual rectangular teeth, (d) Antenna 4: modified fork shaped proposed antenna	117
6.3	Equivalent circuit of the defected ground UWB antenna	117
6.4	Reflection coefficients of Antenna 1, Antenna 2, and Antenna 3	119
6.5	Current distribution of (a) Antenna 1 at 7.2 GHz, (b) Antenna 2 at 2.6 GHz,	119

---

	(c) Antenna 3 at 9.3 GHz and (d) Antenna 4 at 9.3 GHz	
6.6	(a) Reflection coefficient of the elliptically defected ground UWB Antenna with variation in parameter $A$ (b) Measured and Simulation reflection coefficient of Antenna 3 and the elliptically defected ground UWB Antenna	120
6.7	Measured and Simulation gain of the proposed elliptically defected ground UWB Antenna	121
6.8	Measured and Simulation E-Plane radiation pattern of the proposed defected ground UWB Antenna 4 (a) $f = 4$ GHz, (b) $f = 5.8$ GHz, (c) $f = 9.3$ GHz	121
6.9	Measured and Simulation H-Plane radiation pattern of the proposed defected ground UWB Antenna 4 (a) $f = 4$ GHz, (b) $f = 5.8$ GHz, (c) $f = 9.3$ GHz	122
6.10	Geometry of the miniaturised defected ground band-notched antenna (a) Radiating patch (b) Defected ground plane with elliptical and rectangular slit DGS (c) Photograph of Top view and (d) Back view of fabricated defected ground band-notched antenna	125
6.11	Comparison of the measured and simulated reflection coefficient of the miniaturised defected ground band-notch antenna with and without DGS	126
6.12	Simulated VSWR of the miniaturised defected ground 3.5 GHz band-notch antenna with variation in the DGS length $l$	126
6.13	Measured and simulated VSWR of the miniaturised defected ground band-notch antenna with variation in the radius $r$	128
6.14	Comparison of the Measured and simulated gain of miniaturised defected ground band-notch antenna	128
6.15	Simulated results of the surface current distribution for miniaturized defected ground band-notch antenna at (a) 3.5 GHz (b) 5.2 GHz	129
6.16	Measured radiation pattern of the miniaturized defected ground band-notch antenna in the E- and H-Plane at (a) 3 GHz (b) 6.5 GHz(c) 9.1 GHz	129
6.17	Simulation group delay of the defected ground band notched antenna	131
<b>Chapter 7</b>		
7.1	Iteration elements of the CPW feed inscribed pentagon fractal antenna	134
7.2	Geometry and configuration of (a) CPW feed inscribed pentagon fractal antenna (IPFA) (b) Photograph of the fabricated antenna	135
7.3	Simulated reflection coefficient of the fractal antenna with 1 <sup>st</sup> , 2 <sup>nd</sup> and 3 <sup>rd</sup> iteration	135
7.4	Simulated reflection coefficient of the fractal antenna with variation in feed width	137
7.5	(a) Comparison of reflection coefficient with variation in coupling gap $p$ and ground height $h_1$	137

---

7.5	(b) Simulated Smith Chart of IPFA	138
7.6	Simulated radiation patterns in the E- and H-plane at (a) 3.2 GHz and (b) 8.4 GHz and (c) 10.7 GHz	138
7.7	(a) Geometry and configuration of the CPW feed inscribed pentagon fractal radiating patch on the top (b) Electromagnetically coupled parasitic element on the bottom of substrate (c) Photograph of the fabricated antenna	141
7.8	Simulated and Measured reflection coefficient of the band-notched fractal antenna	141
7.9	Simulated and measured VSWR of the band-notched IPFA	143
7.10	VSWR Comparison of the band-notched IPFA for various side lengths of the parasitic patch	143
7.11	Gain of band-notched IPFA	145
7.12	Simulated Current distributions on the top view of the IPFA at 3.2 GHz (b) 6.8 GHz (c) 10 GHz and (d) 14 GHz	146
7.13	Simulated current distribution on the bottom view of the IPFA at notch frequencies (a) 5.6 GHz and (b) 9.3 GHz	146
7.14	Simulated and measured radiation pattern in the E-plane at (a) 3.2GHz and (b) 7.1 GHz (c) 10 GHz and (d) 15 GHz of the band notched fractal antenna	147
7.15	Simulated and measured radiation pattern in H-plane at (a) 3.2GHz and (b) 7.1 GHz (c) 10 GHz and (d) 15 GHz of band notched fractal antenna	147
7.16	(a) Simulation set up for group delay (b) Simulated group delay of fractal Antenna	148
E.1	Antenna radiation pattern measurement in Anechoic Chamber	163
E.2	Figure E.2 Anechoic chamber system for radiation pattern measurement	164
F.1	Single tetrahedral with component of the vector field	166