

List of Tables

Table No.	Table Captions	Page No.
1.1	Attributes of electronic switching elements	6
2.1	Design specifications of the base antenna	24
2.2	Measured and simulated parameters of the base antenna	25
2.3	Optimized slot dimensions of the modified patch antenna	28
2.4	PIN diode states and corresponding frequencies with measured directivity and gain	32
2.5	Comparison of the proposed antenna with previously reported recent works of frequency reconfigurable antenna	36
3.1	Antenna design parameters	49
3.2	Reconfigured beam direction and beamwidth for Sq 0 – Sq 4	52
3.3	Combinations of PIN activation sequence from set A and C	55
3.4	Beam direction and beamwidth for Sq 5 – Sq 8	56
3.5	Beam direction and beamwidth for Sq 9 – Sq 14	56
3.6	Measured antenna parameters for sequences Sq 0 – Sq 14	59
3.7	Beam pattern statistics for some of the selected combinations	61
3.8	Comparison of the proposed antenna with previously reported recent works of pattern reconfigurable antenna	63
4.1	Contact angle measurement data	78
4.2	Resonating frequency, percentage bandwidth and gain at different substrate structure configuration	83
5.1	Antenna design parameters	99
5.2	Electromagnet switching with position of FF and switching state	100
5.3	Beam direction and beamwidth for sequence Sq 0 – Sq 2	101
5.4	Beam direction and beamwidth for sequence Sq 3 – Sq 4	103
5.5	Antenna performance parameters for the reconfigured sequences	106

List of Figures

Figure No.	Figure Captions	Page No.
2.1	(a) Agilent VNA and (b) Antenna Measurement System showing the reference horn antenna and automated turn table for the test antenna mounting	22
2.2	Schematic representation of a rectangular patch antenna. $L = 8.38$ mm and $W = 11.52$ mm	24
2.3	Measured and simulated S11 plots for RMA fabricated on FR-4 substrate	24
2.4	Measured and simulated radiation patterns of RMA fabricated on FR4 substrate (a) XZ plane, (b) YZ plane. Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	25
2.5	Schematic diagram of the meandered slot microstrip patch antenna	26
2.6	Schematic diagram of slot optimization scheme and corresponding S11 plots. Solid lines shows the present configuration while dotted lines shows the previous configurations.	27
2.7	Schematics illustrating the simulated frequency reconfiguration with corresponding plots. The dotted line represent all the accessible frequency bands and the solid red line represents the frequency of the corresponding configuration.	29
2.8	Schematics of the (a) Designed antenna and (b) Fabricated antenna	31
2.9	(a) Measured and (b) Simulated S11 parameters. Solid lines in (a) represents measured result and dotted lines in (b) represents simulated results.	32
2.10	Surface current distribution: (a) Mode 1, (b) Mode 2, (c) Mode 3 and (d) Mode 4	33
2.11	Measured and simulated radiation patterns in XZ plane (a) Mode 1, (b) Mode 2, (c) Mode 3 and (d) Mode 4. Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	34
2.12	Measured and simulated radiation patterns in YZ plane (a) Mode 1, (b) Mode 2, (c) Mode 3 and (d) Mode 4. Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	35

Figure No.	Figure Captions	Page No.
3.1	Schematic diagram of the proposed antenna. $W = 11.52$ mm, $L = 8.38$ mm and A, B, C, D represents the position of the parasitic	46
3.2	(a) Representation of the gap optimization process along X axis and (b) corresponding S11 plots	47
3.3	(a) Representation of the gap optimization process along Y axis and (b) corresponding S11 plots	48
3.4	Schematic diagram of the antenna with optimized position of the elements	49
3.5	(a) Schematic diagram of the proposed antenna (b) schematic with detailed labelling of elements (c) fabricated antenna and (d) magnified view of the backside of the antenna showing the rf block inductors	50
3.6	Measured and simulated -radiation patterns (a) in XZ plane (b) YZ plane (c) S11 parameters without activating any directing element	51
3.7	Radiation patterns in both XZ and YZ plane for sequences given in Table 3.2. Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	53
3.8	Surface current distributions and corresponding simulated radiation patterns for Table 3.2 sequences	54
3.9	Radiation patterns in both XZ and YZ plane for sequences in given in Table 3.4. Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	57
3.10	Radiation patterns in both XZ and YZ plane following sequences in Table 3.5 Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	58
3.11	Surface current distribution and corresponding simulated radiation patterns	60
3.12	(a) Measured and (b) simulated S11 plots for sequences Sq 0 – Sq 14	61
3.13	Simulated 3-D radiation patterns for activated set (a) B, (b) C, (c) D, (d) AB, (e) DC and (f) BD	62

Figure No.	Figure Captions	Page No.
4.1	(a) XRD diffractogram of Fe ₃ O ₄ (FFT smoothed), (b) Raman spectra of Fe ₃ O ₄ nanoparticles	73
4.2	(a) TEM images of Fe ₃ O ₄ nanoparticles, (b) Hysteresis loop of Fe ₃ O ₄ nanoparticles	74
4.3	(a) Real part of complex permittivity, ϵ'_r and (b) loss tangent $\tan \delta$	75
4.4	(a) Real part of permittivity and (b) loss tangent of FF and ISPW solution	76
4.5	Sequential image analysis of the fluid transmission process. During the actuation a portion of FF (black fluid) covers a distance of ~ 12.00 mm in 108.29 milliseconds and completely shifts to the new position in 358.19 milliseconds.	77
4.6	Contact angle images of ferrofluid on (a) non-coated and (b) oleophobic solution coated FEP surface	78
4.7	Schematic diagram of the substrate modification in sequences (a) to (e) and (f) fluidic channel with injected liquids	79
4.8	Fabrication scheme of the proposed antenna (a) Stacking of various layers (b) Final prototype with marked channel position (dotted lines) (c) Fabricated antenna with three different viewing angle	80
4.9	A depiction of the method that reconfigures the antenna resonant frequency: (a) Top view of the antenna with patch and channel dimension marked (b) Enlarged view showing the position of channels under the patch (c) Back view (ground plane) of the antenna showing the position of the electromagnets with patch position in dotted lines (d) Status of electromagnets and corresponding positioning of liquids (grey colour indicating FF and white colour ISPW).	81
4.10	Two distinct frequency responses illustrating the frequency reconfigurability of the antenna between two modes. Responses of a standard RMA and antenna with air filled channels are also noticed. Solid symbol represents measured data and half-filled symbol represents simulated data.	82
4.11	Radiation pattern in XZ plane (a) measured and (b) simulated and in YZ plane (c) measured and (d) simulated at resonant frequencies for different substrate structure	84

Figure No.	Figure Captions	Page No.
5.1	Schematic diagram of the constructed microfluidic channel. LC = 10.38 mm, DE = 0.9 mm, DI = 0.8 mm, LNaCl = 8.38 mm and LFF = 2.00 mm	94
5.2	Proposed actuation mechanism of microfluidic channel. In (a) EM 1 is ON, EM 2 is OFF and FF is positioned at the far end, while in (b) EM 2 is ON, EM 1 is OFF and FF is shifted to the middle of the channel.	95
5.3	Schematic diagram of the proposed antenna showing the constituent elements	96
5.4	Optimization of channels position in X axis along with S11 plot	96
5.5	Optimization of channels position in Y axis along with S11 plot	97
5.6	Simulated radiation pattern for single vs. paired channels. For single channel beam direction is 358° and 4° in XZ and YZ plane respectively. With paired element it is shifted to 352° and 10°.	98
5.7	(a) Schematic diagram of the optimized antenna, (b) fabricated antenna and (c) magnified image of the backside of the antenna showing electromagnets (EM) covered and separated by mu metal	98
5.8	Illustration of the reconfiguration sequences. (a) EM 1 is OFF and EM 2 is ON, (b) EM 1 is ON and EM 2 is OFF. Shaded red and green colour rectangles shows the position of the EM at the back side of the antenna (ground plane).	99
5.9	Measured and simulated (a) XZ plane, (b) YZ plane radiation patterns and (c) S11 parameters with all the directing elements in void state. Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	100
5.10	Radiation patterns in XZ and YZ planes for sequences Sq 1 and Sq 2. Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	102
5.11	Surface current distribution and 3 - D radiation pattern plots for sequences given in Table 5.3	103
5.12	Radiation patterns in both XZ and YZ plane for sequences Sq 3 and Sq 5. Solid black and red line shows measured and simulated co-polar plots. Dotted black and red lines shows the corresponding cross-polar plots.	104
5.13	Surface current distribution and 3 - D radiation pattern plots for sequences given in Table 5.4.	105
5.14	(a) Measured and (b) simulated S11 plots for sequences Sq 0 - Sq 5	105

List of symbols and abbreviations

RA	Reconfigurable Antenna
MIMO	Multiple Input Multiple Output
RF-MEMS	Radio Frequency Microelectromechanical Systems
FRA	Frequency Reconfigurable Antenna
VNA	Vector Network Analyzer
RMA	Rectangular Microstrip Patch Antenna
TLM	Transmission Line Model
ω	Angular frequency
ϵ_{eff}	Effective permittivity
ϵ_r	Relative permittivity
ϵ'_r	Real part of complex permittivity
ϵ''_r	Imaginary part of complex permittivity
$\tan \delta_e$	Dielectric loss tangent
c	Velocity of light in free space
λ_0	Free space wavelength
λ_g	Guided wavelength
Ω	Ohm
θ	Theta
°C	Degree Celsius
f_r	Resonant frequency
S_{11}	Scattering parameter (reflection)
NRE	Non-radiating edge
XRD	X-ray Diffraction
TEM	Transmission Electron Microscope
SEM	Scanning Electron Microscopy

FF	Ferrofluid
ISPW	Isopropanol deionized water solution
N	Normal
E	Electric field vector
H	Magnetic field vector
GHz	Giga Hertz
MHz	Mega Hertz
mm	millimeter
nm	nano meter
A	Ampere
dB	Decibel
dB _i	Decibels relative to isotropic
Wt.	Weight
rf	Radio frequency
dc	Direct current
nH	Nanohenry
pF	Picofarad