Declaration

I, Khairnar Vikas Vishnu, hereby declare that this thesis entitled "Design and Development of Linearly and Circularly Polarized Pattern Reconfigurable Antennas" submitted by me under the guidance and supervision of Prof. Ramesha C. K. and Prof. Lucy J. Gudino, is a bonafide research work. I also declare that it has not been submitted previously in part or in full to this University or any other University or Institution for award of any degree.

Signature of the Student :

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Reg. No : 2013PHXF0409G

Date : 30/01/2020

Abstract

Next-generation wireless communication systems need antennas with multi-functionality, adaptability, and flexibility to provide efficient utilization of power and electromagnetic spectrum. Reconfigurable antenna can fulfill these demands by delivering multiple functionalities in a single antenna structure. These antennas can dynamically adapt to changing system requirements by altering their operating parameters. Reconfigurable antennas are classified as frequency, pattern, polarization and compound reconfiguration. Compound reconfigurable antenna involves simultaneous reconfiguration of two or more parameters such as frequency and pattern, frequency and polarization, pattern and polarization and frequency, pattern and polarization. This dissertation presents design and development of linearly polarized and circularly polarized pattern reconfigurable microstrip parasitic antennas.

The antenna designs presented in this thesis includes a) Pattern reconfigurable antenna with continuous beam scanning in H-plane, b) Pattern reconfigurable antenna with capabilities of complete azimuthal beam scanning and beamwidth variability in both the principal planes with linear polarization and c) Independent pattern and polarization reconfigurable antenna along with beamwidth reconfiguration for dual orthogonal linear polarization. The proposed reconfigurable antenna designs have the following characteristics a) Electrically reconfigured by incorporating varactor diode as switching element, b) Operating frequency of all the antennas is chosen as 2.45 GHz and c) Working on the principle of microstrip Yagi and tunable parasitic patch size method.

A reconfigurable microstrip Yagi antenna is proposed to realize continuous and improved beam scanning from $-40°$ to $40°$ in the H-plane. This antenna is designed using a square-shaped driven patch and two hexagonal slotted tunable parasitic elements placed in the H-plane. Tunable parasitic element shows dual resonance characteristics, and hence its effective electrical size can be changed by varying the capacitance of varactor diodes. Mutual coupling between the driven and tunable parasitic elements is controlled by changing the capacitance of varactor diodes loaded in the hexagonal slot. The relative lead and lag of current due to change in the dimension of tunable parasitic patch causes phase distribution across the elements resulting in continuous scanning of the main beam. It is observed that the antenna radiates with a maximum steered angle when the size of a tunable parasitic element is close to the driven patch size. Effect of varactor diode capacitance on the mutual coupling is studied by calculating current ratios in all three operating modes, namely Reflector-Director (RD), Director-Reflector (DR), and broadside. Performance of the proposed pattern reconfigurable antenna is measured in RD, DR, and broadside operating

mode. In RD and DR mode, the main beam is continuously scanned from 14.4° to 40° and −14.4° to −40°, respectively. The main beam is directed to 0° in the broadside mode with a gain of 3.36 dBi.

1-D continuous beam scanning principle is then extended to achieve increased diversity in terms of radiation characteristics. A reconfigurable cross parasitic antenna is proposed to realize complete azimuthal beam scanning and tunable beamwidth in the E-plane (xz-plane) and H-plane (yz-plane). This antenna consists of a square-shaped driven element and four size-tunable parasitic elements placed on each side of the driven element. Radiated beam of the cross antenna is continuously scanned in the elevation plane from θ = 0° to 10.8°, 0° to 32.4°, and 0° to 40° in ϕ = (0°, 180°), (45°, 135°, 225°, 315°), and (90°, 270°) planes respectively. Moreover, the 3-dB beamwidth of the cross antenna is continuously tuned from 65° to 152° and 64° to 116° in the E-plane and H-plane respectively. Performance of the antenna is experimentally verified in broadside direction and ϕ = (0°, 45°, 90°) plane. The beamwidth reconfiguration characteristics are also experimentally verified in E-plane and H-plane.

A RA design is proposed to achieve independent pattern and polarization reconfiguration along with beamwidth reconfiguration at an operating frequency of 2.45 GHz. This antenna consists of a dual-feed square-shaped driven patch surrounded by four tunable parasitic elements placed in the E-plane and H-plane. Each tunable parasitic element consists of a square-shaped slot loaded with four varactor diodes. A reconfigurable feeding network is developed using a 3-dB quadrature hybrid coupler, one SP4T switch, and two SPDT switches to generate orthogonal linear (LVP, LHP) and circular (LHCP, RHCP) polarization. For each polarization state, the main beam of the antenna is continuously scanned in the elevation plane and provide complete 360° azimuth coverage. In LP operating mode, main beam is continuously scanned from θ = 0° to 11°, 0° to 32°, and 0° to 40° in ϕ = (0°, 180°), (45°, 135°, 225°, 315°), and (90°, 270°) planes respectively. In CP operating mode, main beam is continuously scanned from θ = 0° to 30° in ϕ = (0°, 180°), (45°, 135°, 225°, 315°) and (90°, 270°) planes respectively. This antenna shows excellent cross-polarization characteristics, and it is observed that the axial ratio is less than 3 dB in all the beam scanning directions. The 3-dB beamwidth of the proposed antenna can also be continuously tuned in both the principal planes either individually or simultaneously with LVP and LHP polarization states. The result shows that 3-dB beamwidth in the E-plane, H-plane, and both the planes can be continuously tuned from 66° to 152°, 60° to 108°, and 78° to 120° respectively.

Full-wave simulation of the proposed reconfigurable antenna designs has been performed using commercial software Ansys HFSS. The antenna designs presented in this thesis are validated by simulation as well as measurement. Reflection and radiation performance of the fabricated antennas show good agreement with the simulation results.

Acknowledgements

I would like to acknowledge my deepest regards, sincere appreciation, and heartfelt thanks to my supervisor Prof. Ramesha C. K. and co-supervisor, Prof. Lucy J. Gudino, for their kind supervision and guidance. I would also like to thank the committee members for my thesis, Prof. K. R. Anupama and Dr. Narayan S. Manjarekar, for taking the time and effort to review the progress of my research work and providing me with their insightful comments.

I thank Prof. Sauvik Bhattacharya, Vice-Chancellor, BITS Pilani, Prof. G. Raghurama, Director, BITS Pilani-K. K. Birla Goa Campus, Prof. K. E. Raman, Former Director, BITS Pilani-K. K. Birla Goa Campus, Prof. Srinivas Krishnaswamy, Dean, AGSRD, Prof. Bharat M. Deshpande, Associate Dean, AGSRD, Prof. Prasanta Kumar Das, Prof. Sunil Bhand, Dean, SRCD and Prof. D. M. Kulkarni, Dean, Administration, BITS, Pilani - K. K. Birla Goa Campus, for allowing me to carry out research studies at the institute and also by providing necessary infrastructure and facilities to carry out my work.

I would extend my sincere thanks to Prof. Abhijit Pethe, HOD of the EEE Department, for his constant support and encouragement at various levels. I want to acknowledge Prof. M. K. Deshmukh and Prof. A. Amalin Prince, former HOD of the EEE Department, for their continuous support and motivation throughout my research work. I also extend my sincere thanks to Dr. Nitin Sharma, DRC Convener, for his support and motivation. I acknowledge with due gratitude to the faculty members of the EEE department Dr. Gautam Bacher, Dr. Pravin S. Mane and Dr. Sarang C. Dhongdi. I am thankful to Prof. Raghunath Ratabole for his help during the initial phase of my research work. I am grateful to Mr. Anil Lamani, Mr. Sameer Chodankar, and Mr. Vijay Patil, lab technicians, for their constant help during my research work.

My heartfelt thanks to Mr. Bhushan V. Kadam, Mr. Abhishek D. Joshi, Mr. Shamanth Nagaraju, Dr. Rajalekshmi Kishore, Mr. Praveen G. B., Dr. Saif Nalband, Mr. Athokpam Bharatbushan Singh, Mr. Gibin Chacko George and Mr. Swadesh S. Dixit for their moral support and motivation.

Finally, I would like to express sincere respect and gratitude to my mother, Smt. Saguna Vishnu Khairnar for her patience and blessings. I am extremely grateful to my sisters Archana, Manisha, Vaishali, and Seema for taking care of our mother in my absence. I am also thankful to my nieces Hrutuja, Nikita, Samruddhi, and Anushka and nephew Pratik, Pranav, Atharva, Prathamesh, and Archit.

Khairnar Vikas Vishnu

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Abbreviations

Abbreviation	Description
AR	Axial Ratio
AUT	Antenna Under Test
CP	Circular Polarization
CSRR	Complementary Split Ring Resonator
DoA	Direction of Arrival
DR	Director-Reflector
DRA	Dielectric Resonator Antenna
EBG	Electromagnetic Band Gap
EMI	Electromagnetic Imaging
ESPAR	Electronically Steerable Parasitic Array Radiator
FEM	Finite Element Method
FET	Field Effect Transistor
FSS	Frequency Selective Surface
HFSS	High Frequency Structure Simulator
HIS	High Impedance Surface
IoT	Internet of Things
LHCP	Left-Hand Circular Polarization
LHP	Linear Horizontal Polarization
LOS	Line-of-Sight
LP	Linear Polarization
LVP	Linear Vertical Polarization
LWA	Leaky Wave Antenna

ME	Magnetoelectric
MEMS	Micro-Electro-Mechanical Systems
MIMO	Multiple Input Multiple Output
NLOS	Nonline-of-Sight
PRA	Pattern Reconfigurable Antenna
PRS	Partially Reflecting Surface
RA	Reconfigurable Antenna
RD	Reflector-Director
RF	Radio Frequency
RFN	Reconfigurable Feeding Network
RHCP	Right-Hand Circular Polarization
SDR	Software Defined Radio
SIW	Substrate Integrated Waveguide
SLL	Side Lobe Level
SMA	Sub Miniature version A
SNR	Signal to Noise Ratio
SPDT	Single Pole Double Throw
SP3T	Single Pole Three Throw
SP4T	Single Pole Four Throw
UAV	Unmanned Aerial Vehicle
VNA	Vector Network Analyzer
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network
XPD	Cross-polarization Discrimination
1-D	One-Dimensional
2-D	Two-Dimensional
3-D	Three-Dimensional
5G	Fifth Generation

Symbols

Symbol	Description	Unit
f	Frequency	Hz
λ	Free space wavelength at the lowest cut-off frequency	m
λ_0	Free space wavelength at an operating frequency of 2.45 GHz	m
λ_g	Guided wavelength at an operating frequency of 2.45 GHz	m
X, Y, Z	Coordinates in a Cartesian coordinate system	-
θ, ϕ	Angular coordinates in the spherical coordinate system	degree
ϵ_r	Relative dielectric constant	-
h	Substrate thickness	mm
$tan\delta$	Dielectric loss tangent	-
R	Resistance	Ω
L	Inductance	H
C	Capacitance	F
Z	Impedance	Ω
G_{mes}	Measured gain	dBi
D_{sim}	Simulated directivity	dB
η	Radiation efficiency	%
$\|S_{11}\|$	Reflection coefficient	dB
$\|S_{12}\|$	Transmission coefficient	dB
$\Delta\phi$	Phase difference	degree
τ	Tilt angle	degree
α	Amplitude of mutually coupled field	dB
β	Phase of mutually coupled field	degree

In memory of my Father

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Dedicated to my Mother