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4-Port 2-Element MIMO Antenna for 5G Portable Applications

HASSAN TARIQ CHATTHA, (Senior Member, IEEE)
Department of Electrical Engineering, Faculty of Engineering, Islamic University of Madinah, Medina 41411, Saudi Arabia
e-mail: chattha43@hotmail.com

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ABSTRACT In this paper, a compact, low-profile four-port, two-element antenna for the 5G Internet of Things (IoT) and handheld applications with height $h = 3.0$ mm is presented. The antenna structure contains two planar inverted-F antenna (PIFA) elements having the same shapes. Each antenna element has two feeding plates placed at the right angle to each other to make them cross-polarized for the exploitation of polarization diversity, whereas spatial diversity is employed by positioning two antennas diagonally on opposite sides of the antenna structure. For reducing mutual coupling, the etching of rectangular slots on each side of the ground plane beneath the top plate of each element has been done to stop the flow of current between two ports of the same antenna element. Maximum isolation achieved among ports is less than −25 dB, and envelope correlation coefficient is below 0.009 in bands of interest. The minimum frequency range covered by the four ports of this antenna is from around 2.7 to 3.6 GHz for $S_{11} < -10$ dB, thus covering expected future 5G band (3300–3600 MHz), and may be used for small portable and handheld the IoT and cellular applications as a diversity/MIMO antenna.

INDEX TERMS Antennas, planar antennas, PIFA, diversity, MIMO, mutual coupling, isolation.

I. INTRODUCTION

With the fast pace evolution happening in wireless communication systems, there is an ever-increasing need for high performance of portable handheld applications which mainly include very high data rates. 5G, the next generation telecommunication standard is expected to have data rates of tens of megabits per second, i.e. up to 10 Gbps [1], [2]. Multiple-Input Multiple-Output (MIMO) means that two or more antennas are used simultaneously for transmission as well as for reception over a radio channel. MIMO technology uses multipath to achieve higher data rates simultaneously increasing reliability and range without using extra bandwidth, thus improving spectral efficiency to cope with the need of high data rates for different services [3]. The technique used to handle multipath fading in no clear Line-of-Sight (LOS) radio channels, called antenna diversity is employed by different schemes such as spatial, pattern and polarization diversities or a combination of these. To obtain diversity gain, one or more of these diversity methods can be implemented considering different factors which include the environment, interferences and available space [4], [5].

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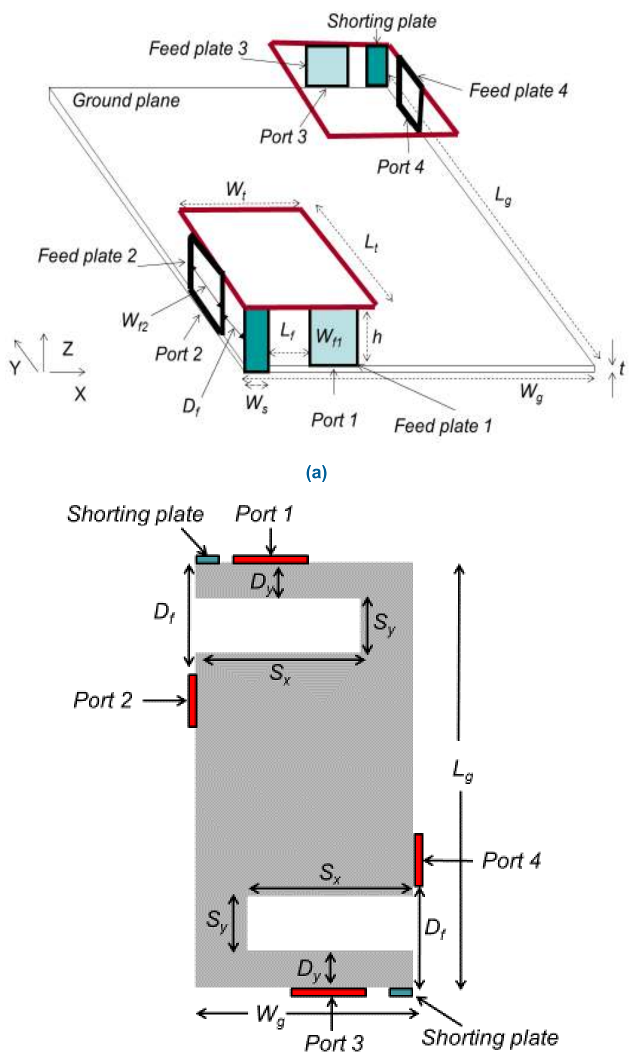
Numerous two-port, two-element MIMO antennas are found in literature using mainly space diversity to achieve diversity gain [7]–[10]. However, a less attention is given to the antennas having two or more ports connected to a common radiating element for diversity/MIMO applications using polarization and/or pattern diversities [11]–[13]. The reason of this fact is the difficulty to isolate the ports placed very close to each other. In case of four-port MIMO antennas, there are mainly 2D printed antennas found in the literature with omnidirectional radiation patterns having lower gain [14], [15]. There are also available some four-port four-element MIMO antennas having 3D antenna structure which takes too much space to accommodate four antenna elements using only spatial diversity technique [16], [17]. But there does not exist in the literature any 3D MIMO antenna structure having four-ports using only two antenna elements which would save space and cost.

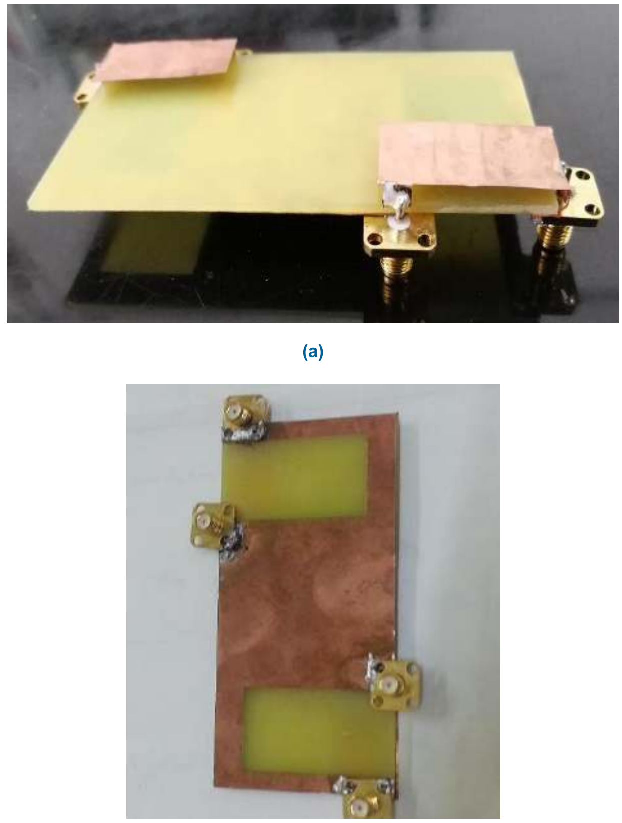
This paper presents a 4-ports 2-element antenna for $h = 3.0$ *mm* using Planar Inverted-F Antennas (PIFAs) as antenna elements. Having attractive features such directional radiation pattern and high gain, PIFA is an extremely bright candidate for Internet of Things (IoT) and handheld portable applications [18]. Each element of PIFA has two feeding ports connected to the common radiating plate using polarization



(a)

(b)

FIGURE 1. Structure of the four-port, two-element antenna (a) 3-D view and (b) back view.



(a)

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FIGURE 2. Fabricated four-port, two-element antenna (a) 3D view and (b) bottom view.

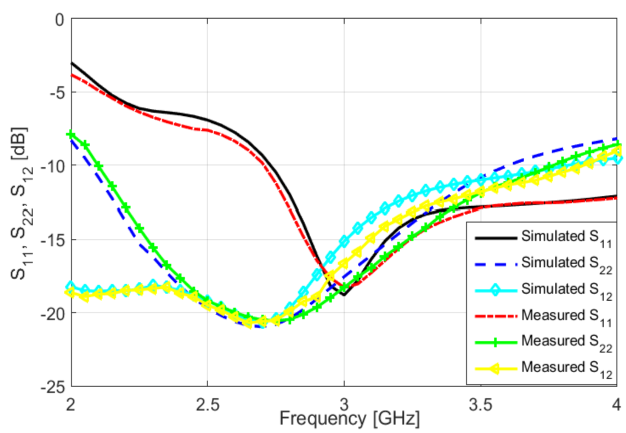

FIGURE 3. Measured and simulated S_{11}, S_{22} and S_{12} [dB] of four-port antenna.

and pattern diversities as the two feeding plates are at right angle to each other. In addition to polarization and pattern diversities, spatial diversity is also exploited between two PIFAs as the two antenna elements are positioned diagonally opposite ends of ground plane.

II. DESIGN CONFIGURATION

Four-port two-element MIMO antenna is shown in Fig. 1, with a ground plane having dimensions $W_g \times L_g$ *(50 mm × 100 mm)*. FR-4 material is used as dielectric substrate having relative permittivity $\varepsilon_r = 4.4$ and thickness $t = 1.5$ *mm*. The two PIFAs are positioned on opposite diagonal ends of ground plane. Both elements of PIFA are identical where each PIFA consists of a top radiating plate having dimensions $W_t \times L_t$ where width and length of the top plate are $W_t = 16$ *mm* and $L_t = 33$ *mm* respectively. Each PIFA has a shorting plate and two feeding plates. Each shorting plate dimensions are $W_s \times (h + t)$, where width of each shorting plate is $W_s = 1$ *mm*, and these are positioned at respective upper ends of the ground plane beneath the top plates of each PIFA. Feeding plates 1 and 3 being positioned beneath top plate of each PIFA at respective upper ends of ground plane, have dimensions $W_{f1} \times h$ where $W_{f1} = W_{f3} = 7$ *mm* is the width of feeding plates 1 and 3 and $h = 3.0$ *mm* is the height of each PIFA. The feeding plates 2 and 4 are positioned under top plate of each PIFA at the side of ground plane having

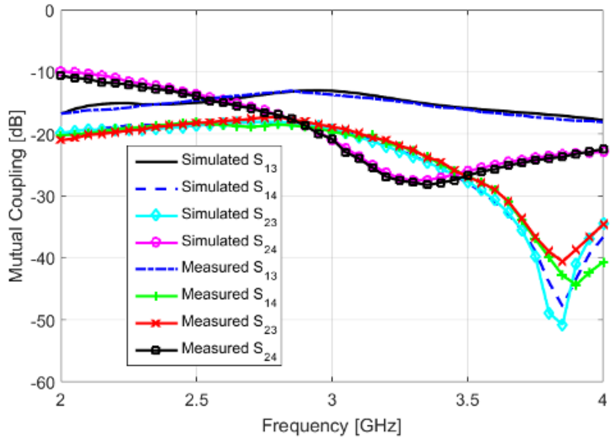

FIGURE 4. Measured and simulated mutual coupling S_{13}, S_{14}, S_{23}, and S_{24} in dB of the four-port antenna.

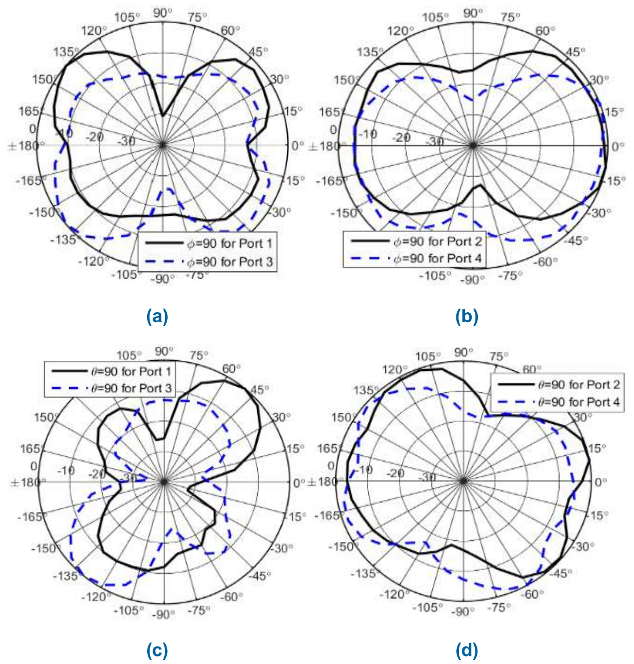

FIGURE 5. 2D rad. patterns [dB] for four-port antenna at 3.0 GHz for planes (a) YZ ($\Phi = 90°$) for ports 1 and 3, (b) YZ ($\Phi = 90°$) for ports 2 and 4, (c) XY ($\theta = 90°$) for ports 1 and 3, and (d) XY ($\theta = 90°$) for ports 2 and 4.

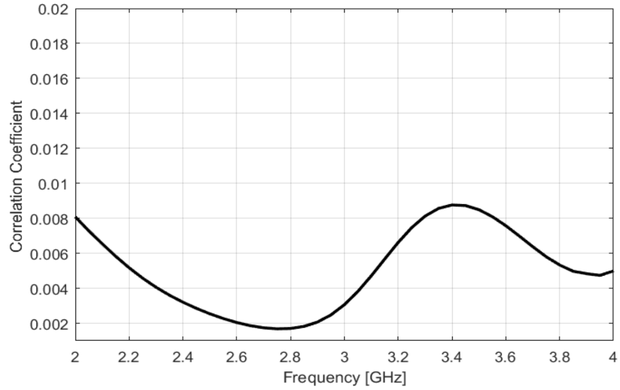

FIGURE 6. Correlation coefficient versus frequency in GHz between port 1 and port 2 of four-port antenna.

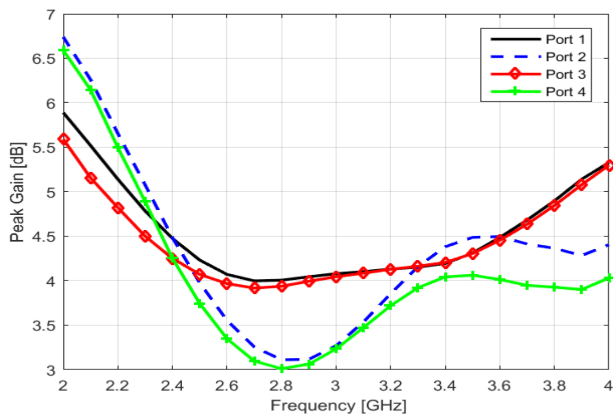

FIGURE 7. The peak gains [dB] versus frequency in GHz of the four ports of MIMO antenna.

dimensions $W_{f2} \times h$ where $W_{f2} = W_{f4} = 5\ mm$ being width of feeding plates 2 and 4. Separation between shorting and feeding plate 1 is $L_f = 1\ mm$, and separation of feeding plates 2 and 4 from their respective upper ends of ground plane is $D_f = 27\ mm$. Since the two ports under the same radiating element of each PIFA are placed very close to each other, there is a need of using an isolation technique for decreasing mutual coupling between two ports. For this purpose, a slot is cut in the ground plane beneath top-plate of each PIFA. These etched slots decrease the current flow between two feeds of the same PIFA through ground plane, which reduces the mutual coupling between them and make them work independently. Bottom side of ground plane depicted through Fig. 2, shows that two-slots are etched where the dimension of each slot is $S_x \times S_y$ $(42\ mm \times 22\ mm)$, and the separation of each slot from higher ends of ground plane is $D_y = 5\ mm$.

III. RESULTS AND DISCUSSION

Fig. 2 depicts a prototype of this four-port MIMO antenna fabricated to validate the outcomes. Simulated and measured results of reflection coefficients S_{11}, S_{22}, S_{33} and S_{44}, and the mutual coupling S_{12}, S_{13}, S_{14}, S_{23}, *and* S_{24} in dB are shown in Figs. 3 and 4. The minimum bandwidth obtained by all the four ports for $S_{11} < -10\ dB$ is approximately *900 MHz* from around *2.7 GHz* to *3.6 GHz*. It is also shown that the maximum isolation achieved between ports of two PIFAs is below -25 dB whereas the minimum isolation achieved between the ports of same PIFA element is around $-13\ dB$ in region of interest.

The measured 2D radiation patterns of four-port antenna are presented in Fig. 5, which clearly indicates that the pairs (1 & 3, 2 & 4) have complimentary radiation patterns to prove the presence of pattern diversity to obtain diversity gain.

The two conditions of obtaining the diversity gain are met by this four-port two-element antenna as the correlation coefficient remains below 0.009 as obvious from the Fig. 6, which shows a graph of correlation coefficients as a function

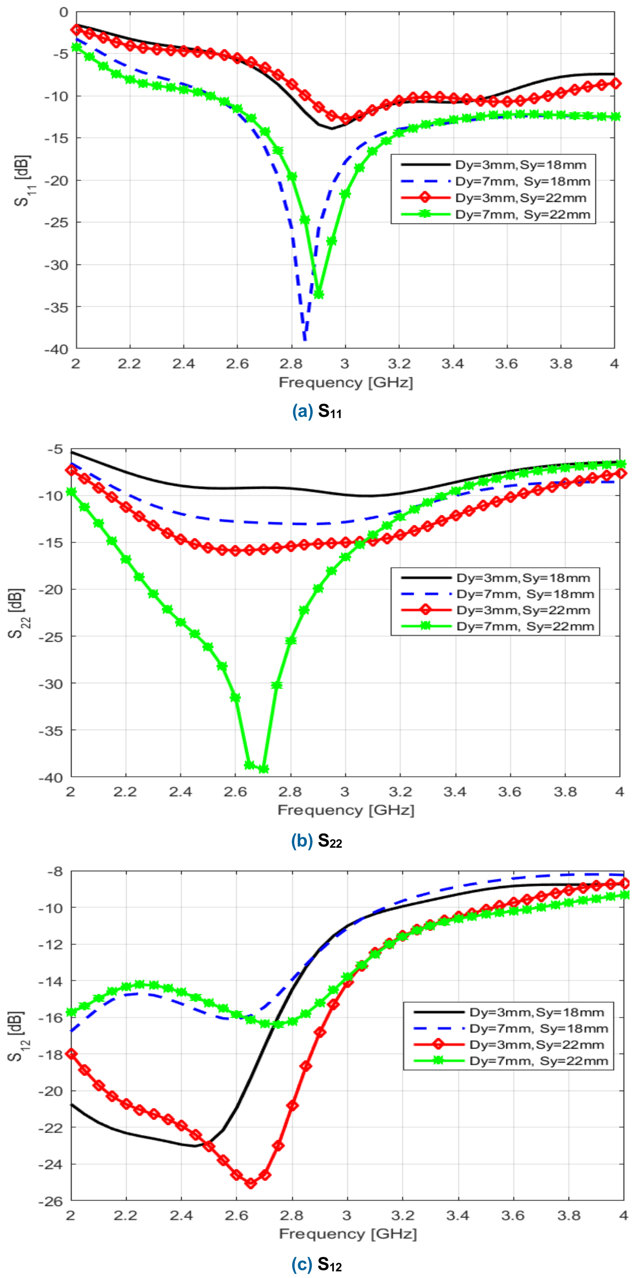

FIGURE 8. S_{11}, S_{12} and S_{22} [dB] versus frequency [GHz] for distinct values of D_y and S_y.

of frequency between ports 1 and 2 whereas mean effective gains of four ports have a ratio around 1 for frequencies from 2 GHz to 4 GHz [3], [19], [20]. Peak gains obtained by all the four ports in *2 GHz* to *4 GHz* frequency range are shown in Fig. 7, which depicts that minimum peak gain obtained between *2 GHz* and *4 GHz* is above *3 dB*. The total embedded element efficiencies of four ports vary from 80 % to 92% for the frequencies from *2.0 GHz* to *4.0 GHz*.

IV. PARAMETRIC ANALYSIS

For studying the effects of different parameter changes on antenna parameters such as resonant frequency, impedance bandwidth and mutual coupling between two ports of same

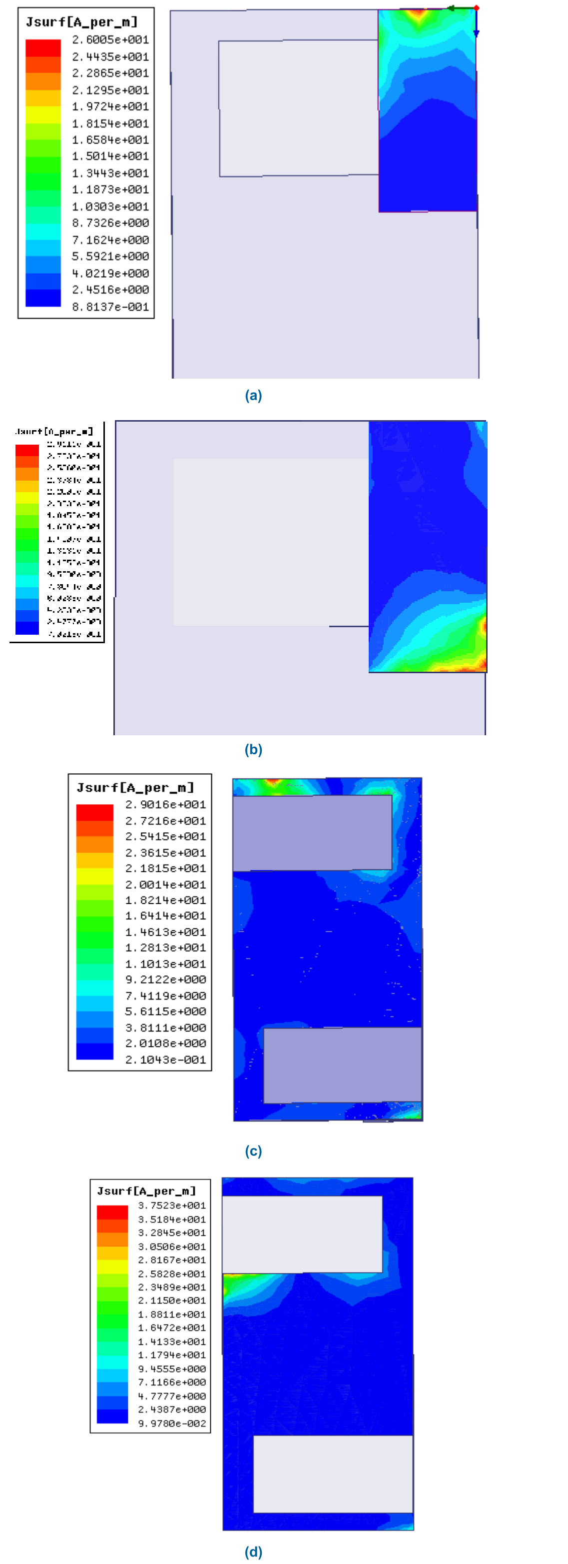

FIGURE 9. Current distributions at 3.5 GHz on (a) top-plate when port 1 is only excited, (b) top-plate when port 2 is only excited, and (c) ground plane when port 1 is only excited (b) ground plane when port 2 is only excited.

antenna element, the dimensions and position of the slots cut in the ground plane underneath top-plate of each PIFA is varied. Since both PIFA elements are identical and the dimension and position of each slot is the same from their respective ends, we only consider the slot in the ground between the Ports 1 & 2, the gap of this slot D_y from respective higher end of ground plane is varied from *3 mm* to *7 mm* and the width of slot S_y is changed from *18 mm* to *22 mm* with length of slot S_x remains constant at *42 mm.* Effects of these variations on reflection coefficient S_{11}, S_{22} and mutual coupling S_{12} are shown in Fig. 8.

It is obvious from the Fig., that the variations in the position and dimension of etched out slot not only affects mutual coupling S_{12} between ports, but also significantly affects resonant frequency and impedance bandwidth achieved by the Ports 1 & 2. Therefore, these parameters are required to be optimized for achieving the desired resonant frequency with the maximum impedance bandwidth and to obtain higher isolation between two ports.

For observing the effectiveness of the isolation techniques used, the current distributions on top-plate and the ground plane at 3.5 GHz when one of the ports 1 and 2 is excited whereas the other is terminated with 50 Ω impedance are depicted in Fig. 9. The figure shows that when Port 1 is excited only then the current does not flow to the Port 2 through either top-plate or the ground plane and similar behavior is observed when Port 2 is only excited while Port 1 being terminated with 50 Ω impedance.

V. CONCLUSION

A low-profile and compact 4-port, 2-element antenna using PIFA as antenna element for height h = 3.0 mm is presented for 5G IoT and cellular portable applications as diversity and MIMO antenna.

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HASSAN TARIQ CHATTHA (M'12–SM'17) received his B.Sc. and M.Sc. degrees in Electrical Engineering from University of Engineering & Technology, Lahore, Pakistan and completed his Ph.D. in Electrical Engineering from the University of Liverpool, UK in 2010. From 2005 to 2007, he worked as a Lab. Engineer/Lecturer in the Faisalabad Campus of the University of Engineering & Technology, Lahore, Pakistan. From 2010 to 2011, he worked as a Postdoctoral Researcher at the University of Liverpool, UK. From 2011 to 2015, he worked as an Assistant Professor in the Faisalabad Campus of the University of Engineering & Technology, Lahore, Pakistan. Currently, he is working as an Associate Professor in the Department of Electrical Engineering, Faculty of Engineering, Islamic University of Madinah, Saudi Arabia. He has published over 60 papers in the leading international ISI-indexed journals and peer-reviewed, reputed international conferences. He is the principal author of most of these papers. His research paper was shortlisted as one of the best student papers at the International Workshop on Antenna and Technology (IWAT), Lisbon, Portugal in 2010. He did the pioneering work in the design of single element multiport antennas for diversity and MIMO applications and his papers on MIMO antennas have been published as featured articles in the IET Electronics Letters and IEEE Antenna and Wireless Propagation Letters (AWPL). Dr. Chattha is an Associate Editor, IEEE Access since 2017 and has hosted different special issues on 5G as a Lead Guest Editor and Guest Editor. He is an active reviewer for many reputed IEEE and IET journals and letters. His research interests include 4G and 5G Systems, MIMO systems for portable applications, Massive MIMO systems, reconfigurable and smart cognitive systems, Internet of Thing (IoT) and smart city applications, Body Area Networks and Wearable Devices, Wireless sensor Networks, Rectenna arrays for power collection and energy harvesting, and teaching methods & assessments for engineering students.