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Design of Penta-Band MIMO Antenna for GPS/2G/3G/4G and 5G NR Applications

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Abstract*: *In this paper a planar, MIMO antenna is proposed that can be integrated within wireless devices. The antenna is designed on FR-4 substrate with dielectric constant 4.4, thickness 1.6 mm and loss tangent 0.02. Ground plane of dimension 80 mm x 55 mm is selected for the final geometry. In order to improve the isolation between the identical antenna elements a T-shaped ground extension is designed. The proposed antenna is designed, simulated and optimized using IE3D simulation software. The five bands in which the antenna elements can resonate ranges from 700 MHz – 750 MHz, 1.47 GHz – 1.9 GHz, 2.04 GHz - 2.26 GHz, 2.7 GHz - 2.89 GHz, 3.2 GHz – 3.8 GHz and can support GPS, 2G, 3G, LTE TDD/FDD and 5G New Radio applications. Antenna characteristics regarding reflection coefficient, mutual coupling and radiation pattern in azimuth as well as elevation planes are discussed. Diversity performance is measured in terms of envelop correlation coefficient and is below 0.07 over all frequencies under consideration. The planar structure of the designed antenna provides an ease of fabrication. The ability to support multiple frequencies of different mobile communication generations makes the antenna fit to be integrated within future multi-generation compatible wireless devices.

Index Terms*: *5G New Radio, isolation improvement, MIMO antenna, Penta-band antenna.

I. INTRODUCTION

Modern wireless network is heterogeneous in nature supporting multiple standards of different generations and working on varied frequency spectrum [1]. The earlier generations of mobile communication supported only voice service, but with growth in mobile communication and introduction of new generations subscribed users were provided with voice, data and multimedia services [2]. The spectrum allocations of different generations are different. For DSC[GSM-1800], 2nd Generation mobile communication standard, spectrum between 1710.2 -1879.8 MHz is allotted; for 3rd Generation standard 'UMTS' 2.1 GHz band is allocated; for LTE standard several bands are defined within spectrum ranging from 452.5 MHz to 3.8 GHz and for early 5G roll-out frequency from 3.4 GHz to 3.8 GHz is primarily considered [3]. Designing antenna for wireless device is thus becoming increasingly complex owing to the requirement of supporting multiple frequencies and multiple standards.

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The requirement of data rate has increased considerably with introduction of every new Generation. In-order to provide higher data rate with reduced latency multiple antennas are required at transmit and receive ends [4]. Theoretically the capacity of Multiple Input Multiple Output [MIMO] antennas should enhance linearly with the increase in number of antenna elements however in practical scenario due to the close placement of identical antennas mutual coupling arises which in turn degrades the channel capacity enhancement [5-6]. Several decoupling structures have been designed to reduce the mutual coupling between closely placed identical antenna elements like introducing slots [7], introducing neutralization line [8] and introduction of protruded ground plane [9]. Several researchers have focused on developing antennas for 5G NR band after the decision was made in World Radio communication Conference to allocate 3.5GHz C-band for antenna design for 5G wireless terminals [10]. However while the concentration of most researchers has been to develop antenna system for single generation [3-4], [10-11]; some researchers have focused on including 4G and 5G frequencies [1], [12].

In this paper a novel planar two-element MIMO antenna system is presented that can be used over L1 GPS/2G/3G/4G and 5G New Radio frequencies. The antenna is printed on double copper-clad FR4 substrate. Table 1 lists the mobile communication standards and their corresponding frequencies which can be supported by the proposed antenna. In the following section steps involved in MIMO antenna design and simulated antenna characteristics like reflection coefficient, mutual coupling and radiation pattern in azimuth and elevation plane are discussed. Diversity performance of MIMO antenna system is discussed by computing ECC [envelop correlation coefficient] value for all frequencies under consideration.

II. ANTENNA DESIGN

The resonant length of planar monopole antenna can be computed using the equation,

$$L = \lambda/4 = c/4f \qquad (1)$$

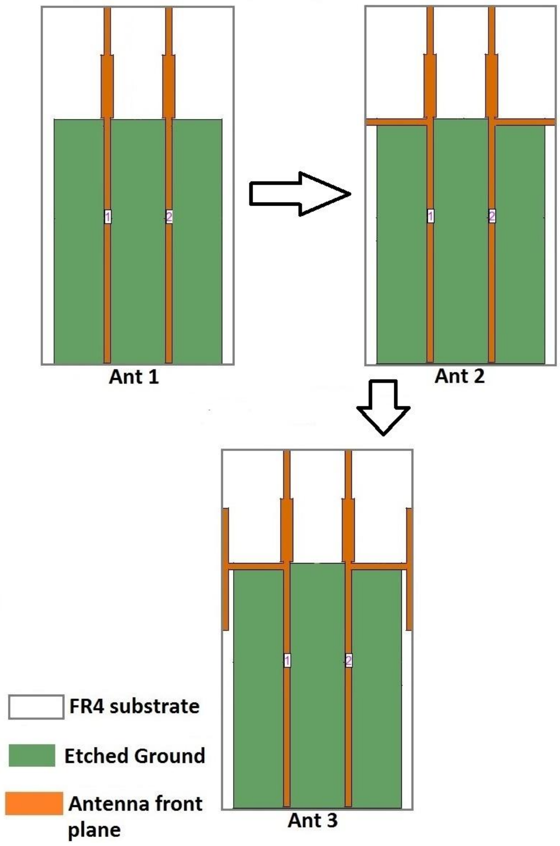
Where,

c= velocity of light= 3x 10^8 m/sec

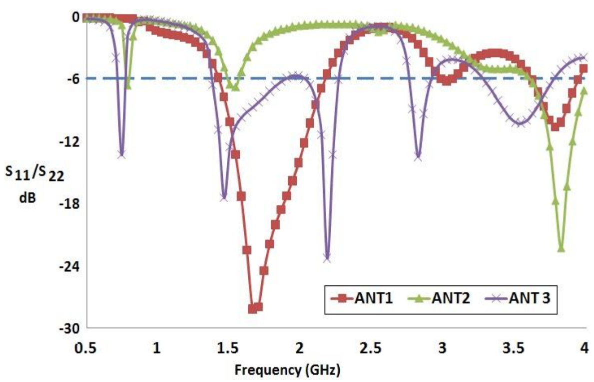
f= frequency in Hz

In order to cover multiple frequencies allotted for GPS/2G/3G/LTE FDD and TDD/5G NR application, three ranges of frequencies were considered: 700 to 800MHz with centre frequency at 750 MHz, 1.4 GHz to 2.7 GHz with centre frequency at 2.05 GHz and 3.2 GHz to 3.8 GHz with centre frequency at 3.5GHz.

The monopole antenna length for each of the centre frequency was computed using (1) and obtained as 100mm, 36.5 mm and 21.4mm respectively. However, integration of multiple monopole antennas of 100mm resonant length inside wireless device was unfeasible because it would lead the resultant device to be bulky and unusable. Hence designing of MIMO antenna was split into various stages. Fig. 1a illustrates the antenna design stages involved in obtaining the final antenna prototype. 'ANT 1' in fig.1a shows the basic MIMO antenna setup used as the first stage in design evolution path. The unit elements of the basic antenna were designed by superimposing the resonant lengths of the monopole antenna obtained for the two higher frequency ranges. These two resultant non-uniform width monopole antennas were placed at separation of 20mm.



(a)



(b)

Figure. 1. Antenna design (a) Three step evolution path, (b) Simulated S_{11}/S_{22} characteristics for each evolution phase

Table.1: Mobile Communication standard supported by proposed MIMO antenna

Generation	Supported Standards: Mobile Standard	Supported Standards: Frequency Range Covered
GPS	L1 GPS	1575 MHz
2G	GSM 1800	1710 -1785 MHz,1805 -1880 MHz
3G	UMTS	2100 MHz
4G	LTE B3	1710–1785 MHz, 1805–1880 MHz
4G	LTE B4	1710-1755MHz, 2110-2155 MHz
4G	LTE B9	1749.9–1784.9 MHz, 1844.9–1879.9 MHz
4G	LTE B10	1710-1770 MHz, 2110-2170 MHz
4G	LTE B12	698-716 MHz, 728-746 MHz
4G	LTE B17	704-716 MHz, 734-746 MHz
4G	LTE B22	3410-3500 MHZ, 3510-3600 MHz
4G	LTE B24	1626.5-1660.5 MHz, 1525-1559 MHz
4G	LTE B29	NA, 717-728 MHz
4G	LTE B32	NA, 1452-1496 MHz
4G	LTE B42	3400-3600 MHz
4G	LTE B43	3600-3800 MHz
5G	NR n78	3300 – 3800 MHz

In the second stage 'ANT 2' two horizontal extension of length 20mm were connected to each unit antenna element. In the third stage of evolution a vertical extension of 40 mm was connected to the horizontal extension of stage two resulting in a T-shape structure. IE3D simulation software was employed to obtain the S-parameter characteristics of each evolution stage. Fig. 1b illustrates the S_{11}/S_{22} characteristics obtained for each of the design stage. From the figure it can observed that in the third stage 'ANT3' the lower band could be obtained along with the higher frequency bands under consideration (taking S_{xx} less than -6 dB reference). The mutual coupling value between the identical antenna elements however was higher than threshold value of -10dB. For enhancing the isolation between the antenna elements in MIMO setup a T-shaped ground extension was designed with L_1= 33mm, W_1= 2mm, L_2=2 mm and W_2= 4mm. This ground extension helped to increase the length of surface current and hence reduce the coupling between closely placed antenna elements. Fig. 2 illustrates the comparison of mutual coupling obtained with and without the ground plane extension. It can be clearly observed that isolation improvement is obtained over the entire frequency range under consideration.

The front-plane and back-plane of the final designed two-port MIMO antenna is presented in fig.3a and fig.3b respectively. FR-4 substrate having dielectric constant of 4.4, thickness of 1.6mm and loss tangent of 0.02 was used having dimension 117 mm x 62 mm. Ground plane of dimension 80 mm x 55 mm was etched on the back plane of double-copper clad FR4 substrate. The dimensions of final prototype were: a= 16mm, b= 20.5 mm, c =20mm, d =20 mm, e =20mm, f =2 mm, g=4 mm, h =2 mm. F_1 and F_2 in the fig. 3 indicates the position of 50 ohm co-axial probe feeds.

III. RESULT AND DISCUSSION

The antenna was simulated and optimized using IE3D simulation software. Fig. 4 illustrates the S-parameter characteristics obtained for the two-port MIMO antenna system. It can be observed that by taking S_{11}/S_{22} reference as -6 dB this antenna can cover five frequency ranges: 700 MHz -750 MHz, 1.47 GHz – 1.9 GHz, 2.04 GHz - 2.26 GHz, 2.7 GHz - 2.89 GHz, 3.2 GHz – 3.8 GHz and can support GPS, 2G, 3G, LTE TDD/FDD and 5G New Radio frequencies as listed in Table 1. The simulated mutual coupling [S_{12}/S_{21}] characteristics for the antenna elements is illustrated in the same fig. 4, and it can be observed that mutual coupling lower than the threshold value of -10 dB was obtained over the entire range of frequency spectrum over which the antenna can be used. Radiation pattern for the MIMO antenna system, in both azimuth and elevation plane was recorded from the simulated output. Fig. 5 illustrates the 2D radiation pattern obtained over a few sample frequencies out of the total 16 bands of different generation supported by the designed antenna. It can be observed that for all the sample frequencies considered the antenna system radiates almost equal power in all direction in azimuth plane while in elevation plane the radiated power varies at different angle, clearly indicating Omni-directional radiation pattern which is suitable for wireless communication.

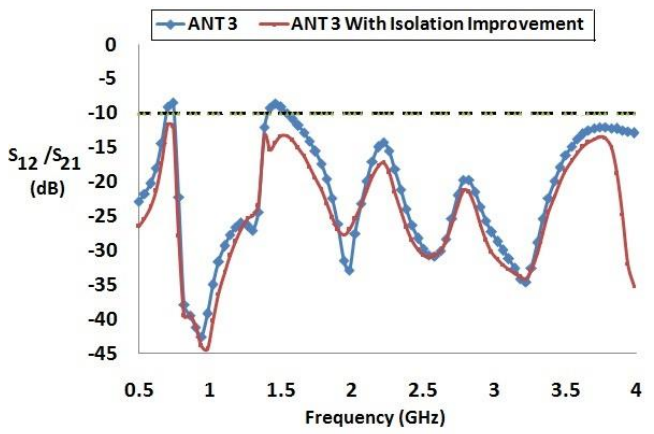
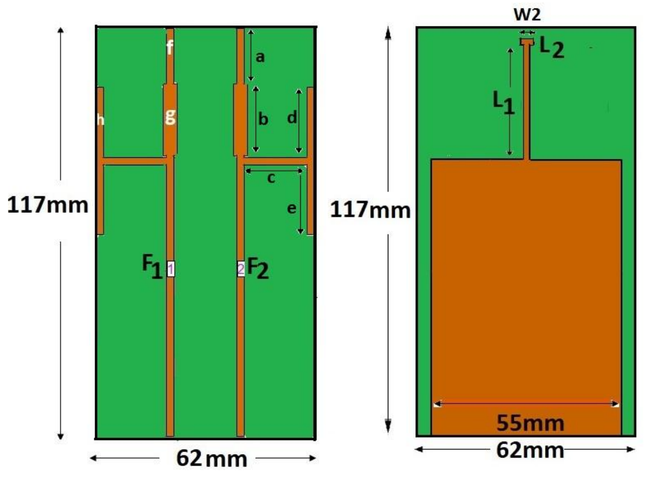


Figure. 2. Mutual coupling between antenna elements with and without isolation improvement technique



(a) (b)

Figure. 3. Final two-element MIMO antenna: (a) front plane, (b) back plane

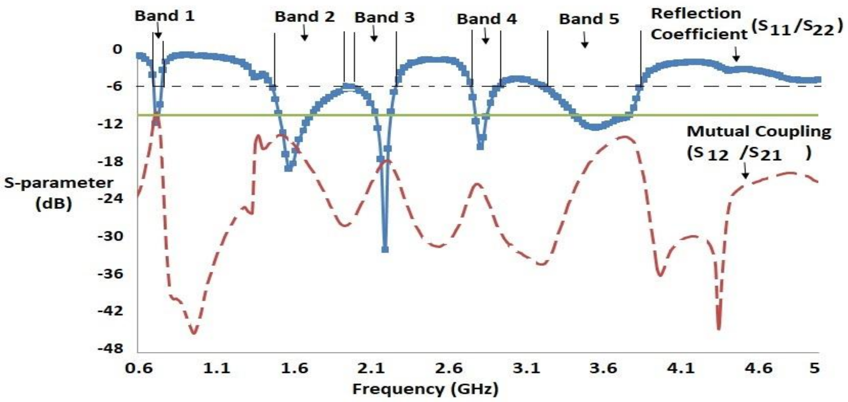


Figure. 4. Simulated S-parameter characteristics of designed antenna prototype

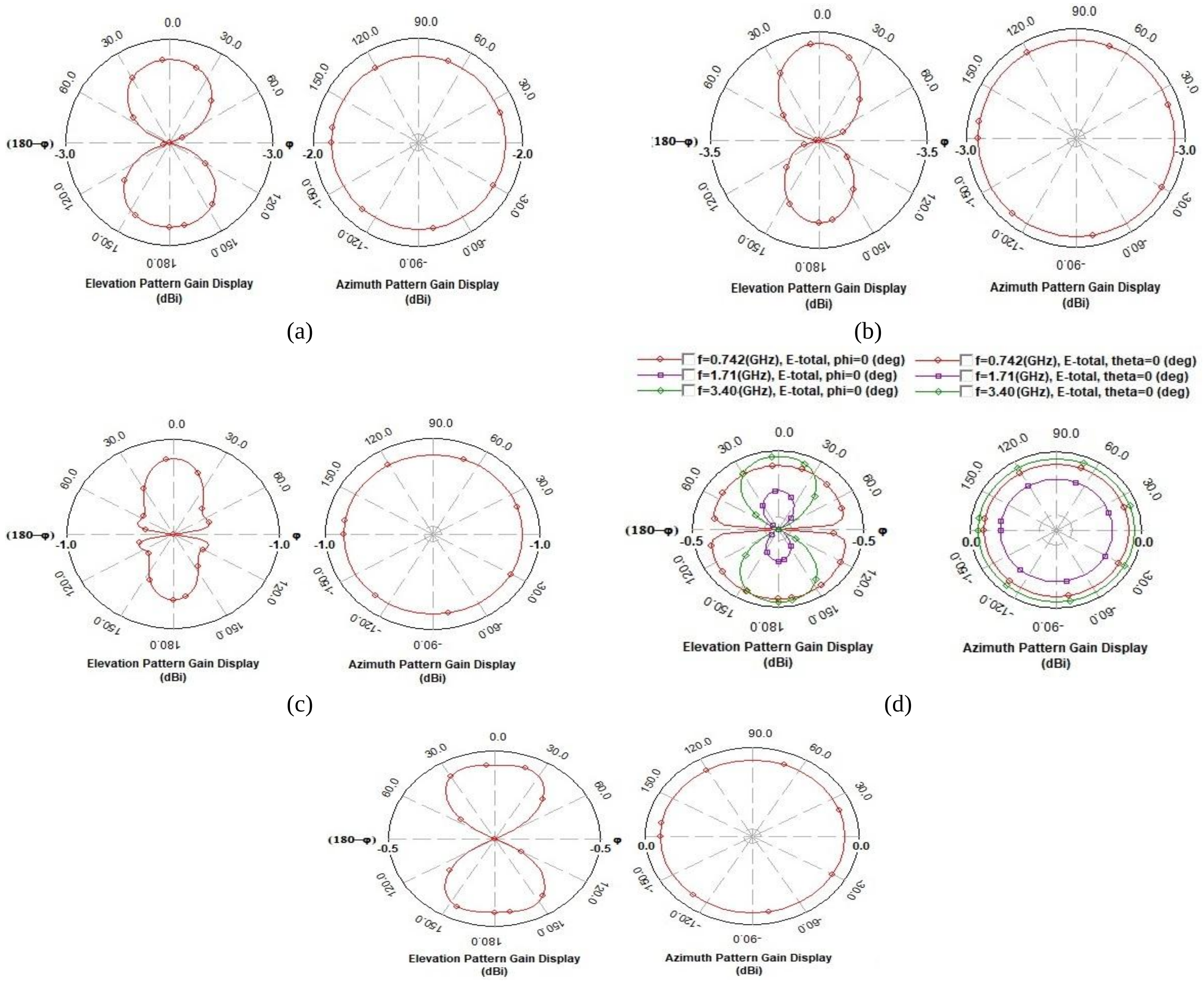


Figure. 5. Radiation pattern in azimuth and elevation plane over: (a)GPS frequency 1.575 GHz; (b) 2nd Generation GSM-1800 frequency 1800 MHz; (c) 3rd Generation UMTS frequency 2100 MHz; (d) LTE frequencies (e) 5G NR frequency at 3500 MHz

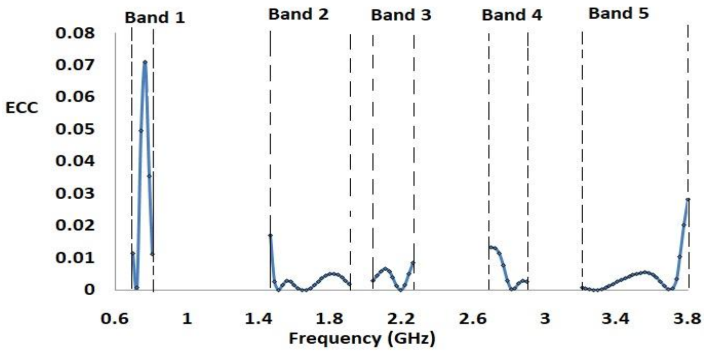


Figure. 6. ECC value obtained over five frequency bands under consideration

In MIMO antenna system study of diversity performance is of utmost importance. It can be studied by calculating the envelop correlation coefficient (ECC) 'ρ'. The ECC value of a MIMO antenna indicates how independent the radiation pattern of identical antenna elements are. It is employed as performance metric in MIMO system. The aim is to design the MIMO antenna is such a way that lesser value of ECC is obtained for the final setup [13]. In order to have an optimum performance as per industrial standard the value of ECC must be lower than 0.5 [14-15]. Fig. 6 illustrates the computed ECC over the five ranges of frequencies under consideration. It can be observed that for all bands ECC value is lower than 0.07, which is much lower than the industrial standard.

IV. CONCLUSION

A Penta-band two-port planar MIMO antenna system is proposed in this paper that can resonate over five frequency ranges: 700MHz -750MHz, 1.47GHz – 1.9GHz, 2.04GHz - 2.26 GHz, 2.7GHz - 2.89GHz and 3.2GHz – 3.8GHz. The presented antenna can be used to support GPS, 2G, 3G, 4G and future 5G NR frequencies. In order to achieve isolation above threshold value of 10dB a T-shaped ground extension is designed between the identical antenna elements. Omni-directional radiation pattern is obtained over all the bands under consideration. Envelop correlation coefficient value obtained for all frequencies are much lower than industrial standard of 0.5. The planar antenna structure and ability to support multiple frequencies of several generations makes it an ideal choice for future multi-generation compatible wireless devices.

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