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Design of Compact MIMO Antenna for 5G Mobile Terminal

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Abstract**:** ***This report gives the research work carried out for design and analysis of MIMO antenna using two identical Microstrip slot radiators having enhanced isolation. The slot radiators offer compact size in order to accommodate other electronic components for reduction of volume of the wireless communication system. The defected ground structure is formed on the ground plane in between the antenna elements and feed lines to improve the isolation between them. The substrate used for constructing the antenna is FR-4 having the measurements of 26mm x 22mm x 0.8mm and it has the relative permittivity of 4.4. The printed microfilm strip etched on the opposite side of the substratum is used to couple the signal to each antenna. The HFSS software is used in this paper for designing the antenna and for checking the performance of the antenna. The -10dB bandwidth is 1.1GHz in the frequency range of 3.1 GHZ to 4.2GHz. The maximum isolation obtained after simulation is -23.1dB at 3.13GHz. The maximum gain of 2.26dB is obtained. Simulated radiation diagram of the designed antenna indicates that it is a good radiator for 5G applications in the sub 6GHz frequency band.***

Keywords: MIMO, Microstrip Slot radiators, Reflection coefficient, Isolation, 5G

I. INTRODUCTION

There are new developments that take place in the modern radio frequency wireless field based on frequency of operation and latest invented methodologies. These include microwave frequency operation, millimeter wave frequency operation, 5G; Internet of things (IOT) etc [1]. There is an aggressive growth in speed at which data is transferred through younger generation mobile phones and newly developed portable wireless devices. There will be tens of billions of international users everywhere each employing about twenty Giga bytes of data in every month when 5G is set to turn out. It results in so many threat to new generation antenna developers [1]-[3].The fifth generation mobile technology is expected to set aside thousand times data speed while considering fourth generation mobile technology[3]. Currently, for attaining higher data speed the industry will be expected to launch a sub-6GHz, 5th Generation (5G) mobile devices whereas it is planned to use existing LTE network, and later on it will shift to millimeter wave band (28GHz to 85GHz) [4].5G will be intended to give large data handling capacity to users. By using 5G technology billions of devices can be linked together and operated concurrently [5]. In the coming years the request for excessive data speed and video on demand will be largely increased. Hence it is likely to combine with 4G and Wifi. The requirements of 5G antenna are compact size, higher data rate, better efficiency, lower cost etc[5],[6].

The frequency sources are facing a serious deficiency issue particularly under sub 6GHz band. The issue of higher link capacity is awaited to resolve definitely by many inputs many outputs (MIMO) technology [7],[8].The major merit of the MIMO system is that data holding power could be very much strengthened irrespective of the power and band width of the channel. Below sub 6GHz band, it is not possible to increase transmission bandwidth and transmitting power levels because of the limited available spectrum allocation [8], [9]. In such a situation the presence of antenna systems such as MIMO is very useful. The applications of wireless communication system are not only limited to simple audio and video communications but also for multimedia applications. In such a situation designing a miniature multiantenna having enhanced isolation which can be included inside the small mobile terminal is a sensitive issue for the antenna developers [9]. Various designs for MIMO antennas have been discussed in the literature in the recent years. The integrated 4G/5G MIMO antenna based on Microstrip slot for 4G and based on connected antenna array for 5G was proposed recently [1]. But CAA suffers from low isolation and power divider is required to excite the antenna. The two printed monopoles having orthogonal polarization formed on the opposite sides of the substrate was also proposed for ultra wide band from 2GHz to 10GHz to increase isolation [2].Here polarization diversity causes complex antenna design and the gain for the lower frequency range is only 1.8dBi.In [3] an eight element MIMO antenna operating at 3.5GHz was presented. High gain and unidirectional radiation pattern could be obtained by using antenna consisting of differentially driven radiator, annulus and copper reflector [4]. In [5] the MIMO antenna using two orthogonal rectangular patches formed on two separate substrate backed by AMC substrate was presented .The dimension of the antenna is more and not acceptable for compact handheld devices.

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The MIMO antenna discussed in [6] has the limited band width from 2.55GHzto 2.65GHz and it accommodates two antenna arrays. Some papers discussed MIMO antennas based on inverted L and printed inverted F antenna elements [7]-[9]. From the literature it is seen that there is a challenge to antenna designers for designing small size multiple antennas due to coupling of radiated power between

different antennas within MIMO antennas at a particular station[1]-[3]. Here main aspect is to design a MIMO antenna having reduced coupling of power among different antennas. The common ground plane that exists in the antenna and coupling of near-field radiation pattern are two main causes of mutual coupling [4], [5]. The mutual coupling results in reduced antenna efficiency. There are several techniques exist such as changing the orientation of the radiation pattern by cutting slot on the ground plane which resonates at a particular frequency and by employing the isolation structures among the radiating antennas to reduce the mutual coupling characteristics of the multi antenna[5]-[7]. The isolation enhancement elements used in the literature include defected ground structure, neutralization lines, and parasitic elements etc [7]-[9]. To obtain decoupling effects in the upper bands some literature discussed use of the protruded ground plane .At the specific frequency bands, ground slits disperse the surface currents [9].

The literature shows the available band for 5G mobile broad band applications is 3.1GHz- 3.8GHz .It is very essential to do the research for constructing the antenna having improved signal quality and higher transmission speed under the available limited radio frequency spectrum below Sub 6GHz[3],[4]. For hand held mobile applications it is necessary that MIMO antenna should be small, having slight weight, small profile and able to integrate easily with other components. Microstrip slot antennas are popular omnidirectional microwave antennas; they show larger bandwidth, little dispersion and little radiation loss compared to Microstrip patch antennas [6], [7]. They have the advantage of being able to produce unidirectional and bidirectional radiation patterns. The slots may have the shape of triangular, rectangular, circular etc [9]. In this discussion two element many inputs many outputs MIMO antenna based on micro strip slot radiators for 5G mobile applications is suggested. The proposed antenna has small dimension with the values of 26mmx22mmx0.8mm and covered frequency band is from 3.1GHz to 4.2GHz. The antennas include defected ground structure for decreasing the interelement coupling between radiating components. The slit in the ground can yield a direct enhancement in the port isolation and this is because of reduced current coupling through the ground plane, since it is not continuous [6], [7]. It acts as band stop filter at a particular frequency [9]. The T shaped niche etched in the ground plane suppresses current flows through the surface and decreases inter element coupling between antennas at the high frequency region. The thin line slots reduce mutual coupling at the lower frequency region. The designed MIMO antenna is good for 5G mobile hand held systems where dimension of the antenna is a main problem. The proposed antenna is designed, simulated and optimized using High Frequency Structure Simulator (HFSS).

II. DESIGN OF MIMO ANTENNA USING PLANAR SLOT RADIATORS

The slot microstrip radiators are selected for implementing MIMO antenna system because of its merits such as small profile, very easy to integrate with other components and reliable performance in closeness of metal wrappers. The size of the slot antenna specified to the guided wavelength (λg) [10], [11] is given by 2.1.

$$\lambda g = (c/f)/\sqrt{\varepsilon e} \quad (2.1)$$

Where c represents speed of light in air, f represents frequency of operation and ε_e represents effective permittivity. Frequency of a slot depends on the total dimension of the slot perimeter [6], [7]. For a practical design, the ground plane may be finite but large in size. The single layer design based on the half wave length slot ($\lambda_g/2$) is very flexible for integrating with other active components and passive components [9].The parameters affecting the performance of slot antenna include: dimension of the ground plane, conductivity and thickness of the ground plane, the size of the slot, the size and shape of the microstrip feed, taper/flare angle etc. The effective thickness (t_{eff}) of the dielectric substrate is defined in 2.2 [10], [11]

$$teff/\lambda 0 = (\sqrt{\varepsilon r} - 1)\, t/\lambda 0 \quad (2.2)$$

And $0.005\ \lambda 0 \leq teff \leq 0.03\ \lambda 0$ where $\lambda 0$ is wavelength of the signal in air at the centre frequency and εr is relative permittivity of the substrate. The dimension of the slot is given by length (Ls) = 0.4 $\lambda 0$ to 0.5 $\lambda 0$, width (W_s) =0.2 λ_s where λ_s is given by 2.3 [10], [11]

$$\lambda s = \lambda_0 \cdot \sqrt{2/(\varepsilon_r+1)} \quad (2.3)$$

One of the better rational techniques for the design of the MIMO antenna is based on the open ended slots such as rectangular slots, tapered slots etc.The maximum radiations are towards the direction of the open end of the slots[6],[7]. The bandwidth can be varied by changing shape and dimension of the antenna and also by varying thickness of the substrate used [6], [7]. The most prominent features of tapered slot antenna used in this deign are light weight, high efficiency, large frequency bandwidth, symmetrical radiation pattern etc.

In this design open circuited Microstrip feed located on the opposite side, at a right angle to it couples electromagnetic waves to the slot etched on ground plane of the substrate, and slot radiates them. The slot stretches to one quarter of a wavelength above the Microfilm strip and the Microfilm strip stretches one quarter of a wavelength above the slot. The length augmentation occurs due to fringing at the open end of the Microstrip feed, which causes the feed to seem electrically larger [6], [7]. The operating bandwidth of the designed slot antenna will be limited by the Microstrip to slot transition. Due to its low cost and compact size, FR-4(Flame retardant-4) substrate having 0.8mm thickness, permittivity 4.4 and loss tangent 0.02 is selected as substrate. The distinct stages of the modeling of the designed antenna are discussed below.

A. Stage 1: MIMO Antenna Design without isolation Enhancement

MIMO antenna design consisting of two tapered slot antennas placed back to back is shown in fig.1

Table-I: Measurements of stage 1 antenna

Length/Width	Magnitude(mm)
L1	4.4
L2	7.5
L3	4.4
L4	15
W1	1
W2	2

The main objective of selecting this shape is to reduce dimension of the antenna. The perimeter of each slot antenna is 24.8mm.Copper coating on the substrate acts as the conductive part of the antenna. Measurements of the each slot antenna and microstrip feed are given in table –I.

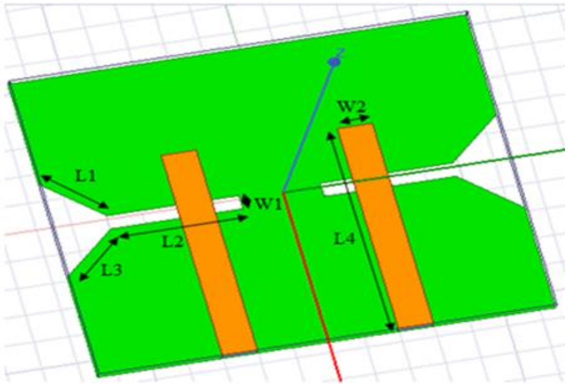
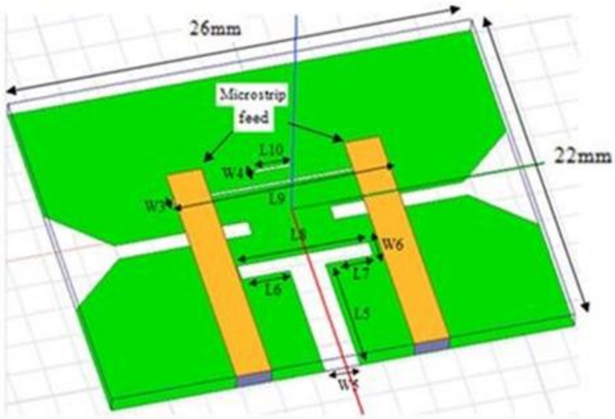
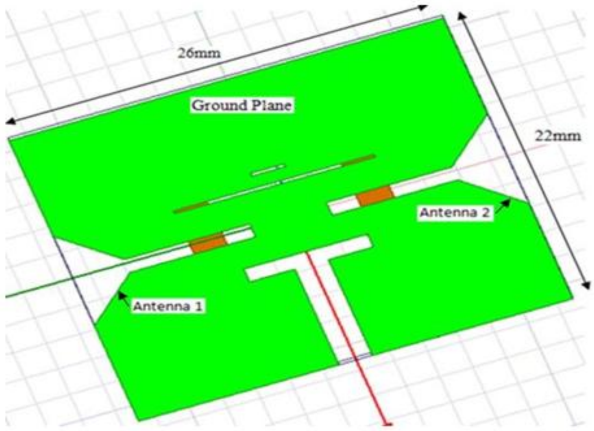


Fig. 1 MIMO antenna without Isolation enhancement

B. Stage 2: MIMO Antenna Design having isolation Enhancement



(a).Top View



(b) Bottom View

Fig. 2 MIMO antenna having isolation enhancement

For further improving the specifications and results of proposed antenna, the designed MIMO antenna is modified by including isolation enhancement slots and slits in between the antenna elements as shown in fig.2. The measurements of isolation elements such as rectangular slits and T shaped slots are given in table –II

Table-II: Measurements of isolation elements in MIMO antenna

Length/Width	Magnitude(mm)
L5	7.5
L6	2.7
L7	2.7
L8	7.4
L9	12
L10	2
W3	0.2
W4	0.2
W5	2
W6	1

III. ANTENNA DESIGN AND SIMULATION RESULTS

The antenna is designed and simulated with the help of HFSS (High frequency structure simulator) software. The designed antenna design is optimized and simulated repeatedly up to acceptable outcome achieved. The antenna design is presented with the simulation results of the antenna as follows:

- MIMO antenna without isolation enhancement
- MIMO antenna having isolation enhancement

A. Simulation Results of MIMO Antenna without Isolation enhancement

MIMO antenna consisting of two element tapered slot antenna has large interaction among antennas particularly at the designed frequency region. Moreover other performance parameters such as gain and bandwidth are not good. After observing the S-parameters, it is seen that isolation among the antennas is only low in the range of -5dB to -6 dB within the frequency region of interest. The maximum value of gain is only 1.75dB.The gains value obtained needs further improvements. The -10dB bandwidth is only 490MHz.

The isolation characteristic of the antennas in the MIMO antenna without isolation enhancement is shown (S1, 2) in fig.3.

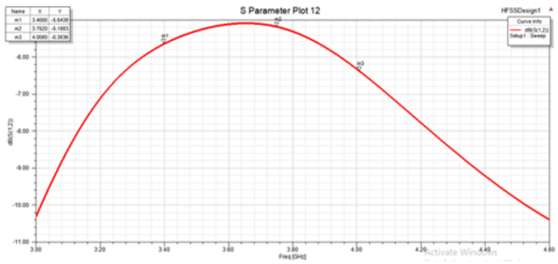


Fig.3 Isolation characteristics between antennas 1&2(S1, 2) in MIMO antenna without isolation enhancement

B. Simulation results of MIMO antenna having Isolation enhancement

This design shows enhanced isolation among the antennas, and improved gain. Also the MIMO antenna with defected ground structure shows resonance in the desired frequency band with good return loss characteristics. Moreover other performance parameters such as radiation pattern and bandwidth are improved significantly compared to the initial design.

B.1 Return loss Plot

The proportion of the signal that is reflected in to antenna1(S (1, 1) parameter) is given in fig.4 and the proportion of the signal that is reflected in to antenna2 (S (2, 2) parameter) is given in fig.5. It is the plot between return loss in dB and frequency (f) in GHz. The -10dB bandwidth is in between 3.1 to 4.2GHz, the resonant frequency is 3.26GHz and the reflection coefficient at resonant frequency is -14dB for antenna1.The -10dB bandwidth is from 3.1GHz to 4.2GHz, the resonant frequency is 3.26GHz and the reflection coefficient at resonant frequency is -16dB for Antenna 2.

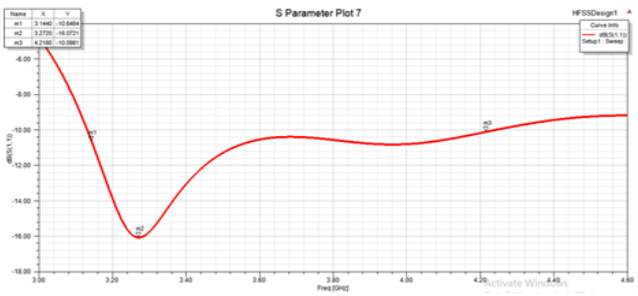


Fig.4 Simulated return loss of the antenna1 of the Proposed MIMO antenna (S1, 1)

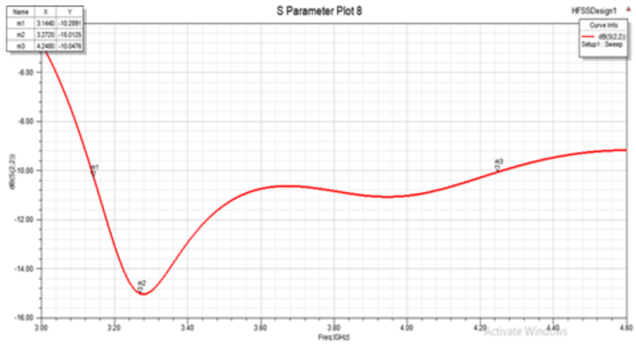


Fig.5 Simulated return loss of the antenna2 of the Proposed MIMO antenna (S2, 2)

B.2 S-Parameter Plot showing mutual coupling

During the frequency range from 3.1 to 4.2GHz isolation is equal to or more than -14.7dB.The isolation characteristics of the antennas in the designed MIMO antenna having isolation enhancement (S1,2) is given in fig.6 and (S2,1) is given in fig.7.

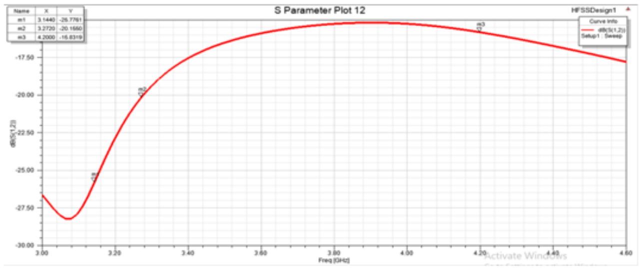


Fig.6 Isolation characteristics between antennas 1&2(S1, 2) of the designed MIMO antenna

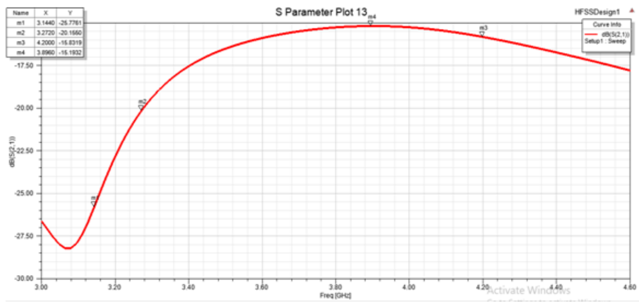


Fig.7 Isolation characteristics between antennas 2&1(S2, 1) of the designed MIMO antenna

In the suggested design the isolation among the antennas is very much enhanced. The isolation between the antennas is in the order of -14.7dB to -23.1 dB in the frequency range of interest. The plots shows that both S (1, 2) and S(2,1) are identical. It is -22.8 dB at the frequency of 3.1GHz,-23.1 dB at 3.13GHz and -15.3 dB at 4.2GHz.

B.3 VSWR Plot

Fig.8 gives the VSWR plot of the suggested antenna. It is the plot between VSWR and frequency in GHz. It is 1.9 at 3.1GHz, 1.5 at resonant frequency of 3.26GHz and 1.9 at 4.2GHz

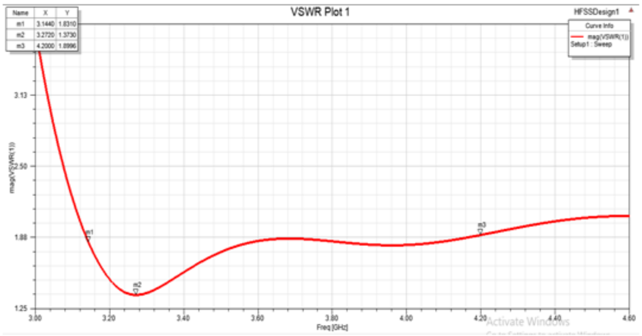


Fig.8 VSWR plot of the designed MIMO antenna

B.4 Radiation Pattern

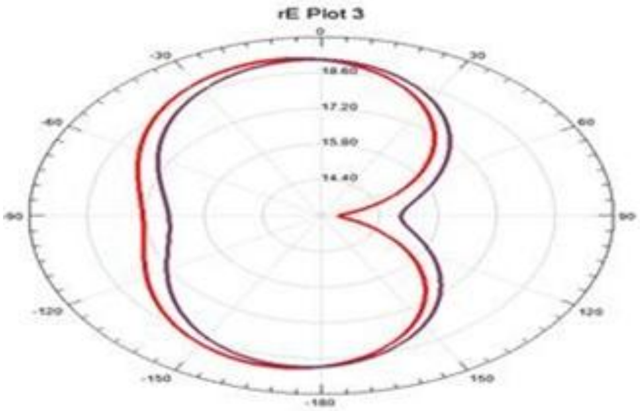


Fig.9 Simulated radiation pattern of the proposed antenna

Fig.9 gives the radiation pattern of the designed antenna after simulation. After observing the plot, it is seen that proposed antenna is an excellent radiator.

B.5 3D Gain Plot

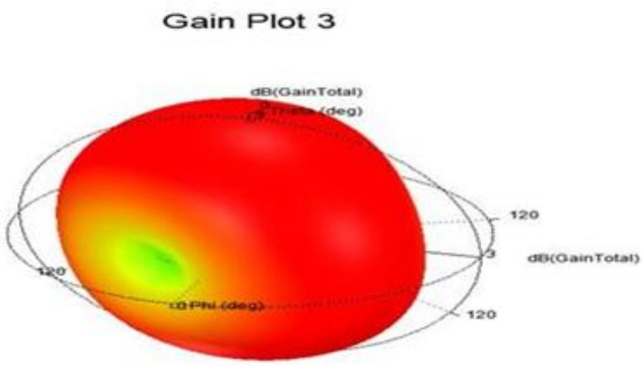


Fig.10 Simulated 3D gain plot of the proposed MIMO Antenna

Fig.10 gives 3D gain plot of the designed MIMO antenna. The maximum value of the gain of the suggested antenna is 2.26 dB. The gain value obtained is improved.

IV. RESULT VALIDATION

Table-III: Comparison between simulated results of MIMO Antenna without isolation and with isolation elements

Parameter	MIMO Antenna without isolation	MIMO Antenna with isolation elements
Isolation	Maximum value of -6.1dB	Maximum value of -23.1dB
S11 at resonant frequency	-13.44dB	-16dB
S22 at resonant frequency	-14.06dB	-15dB
VSWR	Less than 2	Less than 2
-10dB bandwidth	490MHz	1.1GHz
Maximum gain	1.75dB	2.26dB

The Comparative relation between simulated results of MIMO antenna without isolation and proposed MIMO antenna with isolation enhancement is shown in the table-III. As it can be observed from comparison given above that there is greater improvement in isolation of the antenna elements of the proposed antenna. The maximum value of isolation is improved by -17 dB within the band of interest. The -10 dB Bandwidth of 1.1GHz is obtained compared to the 490MHz bandwidth of the initial design. The reflection coefficients of both antennas S11 and S22 are also improved. The maximum gain is enhanced to 2.26dB.

V. CONCLUSION

A two element MIMO antenna based on slot radiators is presented in this paper. This antenna is having compact size of 26mm x 22mm x 0.8mm. The substrate used to design the antenna is FR-4.The design is optimized to support sub 6GHz frequency band. The tapered slot radiators are selected due to its advantages such as less cost, little weight, small profile, smooth integration with other components, wider band width etc. The perimeter of the slot radiator is 25.8mm for optimized operation. The initial design is modified by including defected ground structure to enhance the isolation. The antenna is designed and simulated by using the HFSS software. The isolation between the antenna elements is very much improved by providing isolation elements in between the antennas. The maximum isolation obtained after simulation is -23.1dB.at 3.13GHz. The -10dBbandwidth of the proposed antenna ranges from 3.1 GHZ to 4.2GHz. The 3D gain plot shows the maximum value of the gain is 2.26dB. The obtained radiation pattern of the proposed antenna indicates that it is an excellent radiator having enhanced isolation in the sub 6GHz frequency band for 5G applications.

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