MIMO Antenna System with High Isolation for Smart Phone Applications

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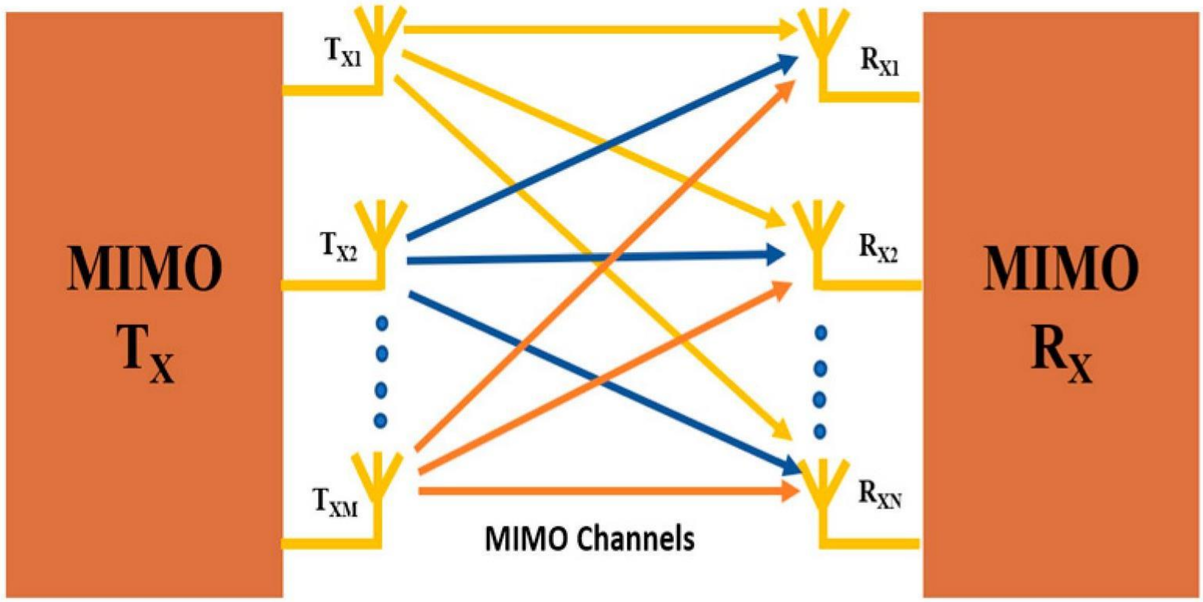


Introduction

MIMO (Multiple Input Multiple Output) antennas are a key technology used in modern wireless communication systems. They help increase the speed, capacity, and reliability of networks like Wi-Fi and mobile communication systems (4G and 5G). MIMO technology uses multiple antennas at both the transmitter and receiver to send and receive multiple signals simultaneously, improving the performance of the communication system.

Working Principle of MIMO Antennas

The core idea behind MIMO (Multiple Input Multiple Output) is to use multiple antennas at both the transmitter and receiver to send and receive data simultaneously. This approach takes
advantage of a phenomenon called spatial diversity or multiplexing, allowing the system to transmit multiple data streams over the same frequency channel.

Explanation of how MIMO antennas work:

1.Signal Transmission

At the transmitter, MIMO antennas divide the data into multiple streams and send them through different antennas. These data streams travel through the same frequency channel but take different paths to reach the receiver. Each path may have a unique set of characteristics, such as signal strength and interference.

2. Signal Propagation

When the signals are transmitted, they travel through different paths in the environment, known as multipath propagation. Obstacles like buildings, walls, and trees cause signals to reflect, refract, or scatter, creating multiple versions of the same signal that arrive at the receiver at slightly different times.

Multipath, which is often a challenge in traditional systems, is an advantage in MIMO. Each
version of the signal carries unique information, which can be combined to improve performance.

3. Signal Reception

At the receiver, multiple antennas collect these transmitted signals. Since each antenna captures signals that traveled through different paths, the receiver has access to multiple versions of the same data, improving the chances of recovering the original information.

The receiver uses advanced signal processing algorithms to:

- Separate the signals from different antennas.
- Correct any interference or overlapping of data.
- Combine the streams to reconstruct the original message.

4. Key Techniques in MIMO

MIMO works through the following techniques:

- Spatial Diversity: In this mode, the system uses the multiple antennas to send the same data redundantly. This improves the reliability of communication, as at least one signal is likely to reach the receiver without significant distortion.
- Spatial Multiplexing: Here, different antennas send different parts of the data. This increases the system's data rate, as multiple streams are transmitted simultaneously.

- Beamforming: Beamforming adjusts the phase and amplitude of the signals sent from the antennas to focus energy toward a specific receiver. This improves signal strength and reduces interference.

MIMO Diversity Parameters

The MIMO diversity parameters, including the envelope correlation coefficient (ECC), total active reflection coefficient (TARC), channel capacity, mean effective gain (MEG), and spectral efficiency play crucial roles in the performance and effectiveness of MIMO antennas.
These parameters collectively contribute to the performance, reliability, and efficiency of MIMO antennas. By optimizing these parameters, MIMO systems can achieve higher data rates,
improved signal quality, enhanced system capacity, and better utilization of available wireless resources, ultimately enabling advanced wireless communication applications.

1. Envelope Correlation Coefficient (ECC):

In MIMO systems, evaluating the coupling between radiating elements is crucial, and ECC
serves as a vital parameter for this purpose. Unlike isolation parameters, ECC considers return- loss of all ports and isolation among different ports to characterize complete antenna mutual
coupling. The recommended value of ECC by the ITU should be less than or equal to 0.5 for mobile communication systems. Better performance in MIMO systems is indicated by a low ECC value, which signifies reduced coupling between radiating elements. Conversely, a higher
ECC value can have an adverse effect. ECC for higher radiation efficiency greater than 90% can be obtained directly from the s-parameter.

2. **<u>Total Active Reflection Coefficient (TARC):</u>**

TARC is a parameter of the MIMO antenna to validate the scattering parameters (s-parameters) for diversity performance. TARC employs both random signals and phase angles for diagonal and adjacent antenna ports to determine the behavior of s-parameters such as s11, s12, and s13 for phase combinations between the ports. TARC is calculated using the incident vector ai and reflected vector bi, which is independent and identically distributed Gaussian random variables.

<u>Types of MIMO Systems</u>

1. SISO (Single Input Single Output): One antenna at both the transmitter and receiver. This is the simplest form but has lower performance.
2. SIMO (Single Input Multiple Output): One transmitting antenna and multiple receiving antennas for better reception.
3. MISO (Multiple Input Single Output): Multiple transmitting antennas and one receiving antenna to improve signal reliability.
4. MIMO (Multiple Input Multiple Output): Multiple antennas at both ends, allowing simultaneous transmission of multiple data streams.

<u>Applications of MIMO Antennas</u>

1. Wi-Fi Routers: MIMO technology is used in modern Wi-Fi routers to improve speed and coverage.
2. Mobile Networks (4G and 5G): MIMO is essential for increasing the capacity and speed of mobile communication networks.
3. Satellite Communication: MIMO improves signal quality in satellite systems.
4. IoT Devices: Internet of Things (IoT) devices use MIMO to handle large numbers of connections.

Advantages of MIMO Antennas

The growing range of mobile applications has led to a demand for Gigabit data rates to cater to users with different mobility levels, including both low and high-mobility scenarios. To address this requirement, traditional single antennas in mobile devices are being replaced with MIMO antennas. By implementing MIMO technology, mobile devices can deliver enhanced quality of service, offering uninterrupted signaling, high data rates, increased capacity, and improved spectral efficiency. Some of the advantages are listed below

1. **Increased Data Rates:**
   MIMO technology allows for higher data rates compared to traditional single-input single-output systems, as multiple data streams can be transmitted simultaneously over the same frequency band. As the number of MIMO layers increases, the overall throughput of the system also increases.

2. **Improved Signal Quality:**

   MIMO technology helps to improve signal quality by reducing the effects of fading, interference, and noise. As conventional SISO (single input single output), a single stream of data will be transmitted between transmitter and receiver which results in more interference and fading effects at the coverage boundary due to the large beamwidth of base station antennas shown in figure 1, whereas MIMO or massive MIMO at gNodeB (base station antenna in 5G) generates a more directional beam, which improves the coverage and reduces the effects of interference at the coverage boundary as shown in figure 2.

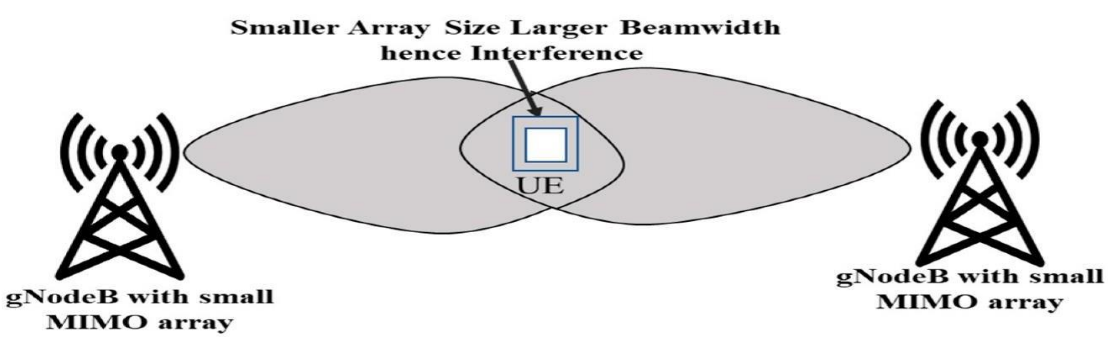


Figure 1: The smaller the array size and large beamwidth, the more interference at the coverage boundary.

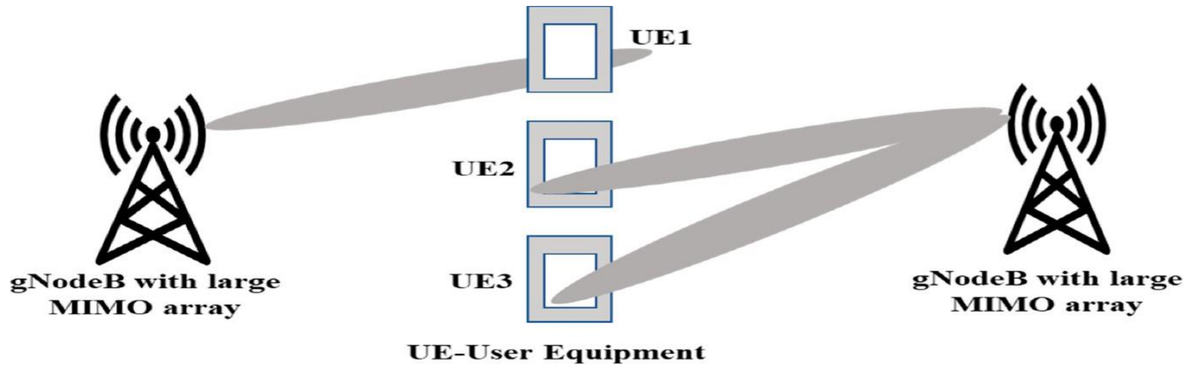


Figure 2: Larger array size sharper beam low interference.

3. **<u>Increased Range and Coverage:</u>**

MIMO technology can extend the range and coverage of wireless networks by improving link quality and reducing the likelihood of signal dropouts. Figure 3 shows that a larger MIMO array or massive MIMO
generates a more directional beam which can improve the coverage area as compared to a conventional SISO system.

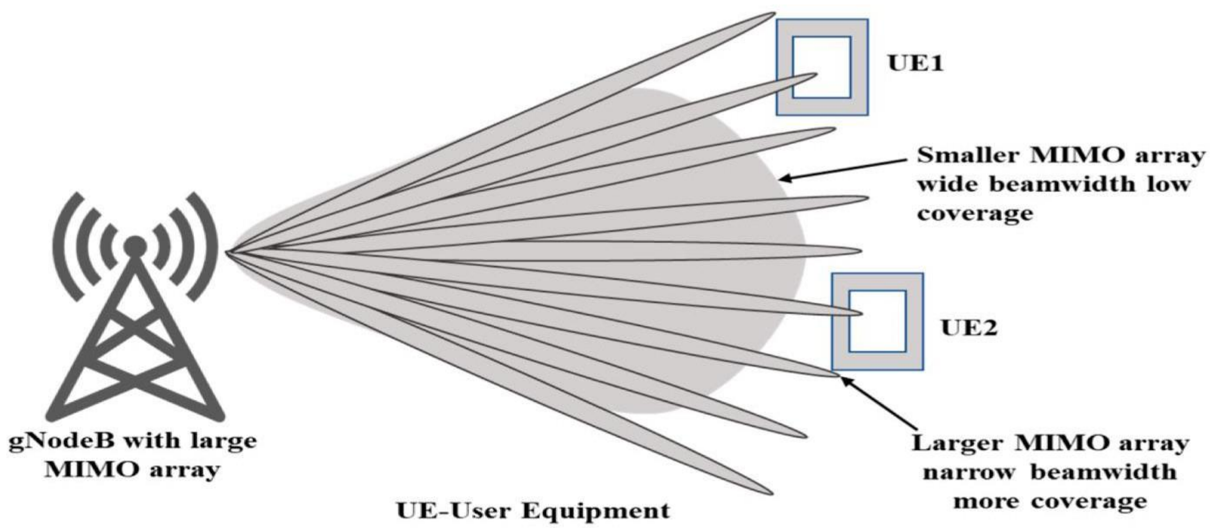


Figure 3: Directional beams have a stronger coverage area and improved signal-to-noise ratio.

4. **<u>Better Spectral Efficiency:</u>**

MIMO technology enables better spectral efficiency which allows more effective use of the available radio spectrum. This is achieved by transmitting or receiving multiple data streams simultaneously.

5. **Compatibility with Existing Standards:**

   MIMO technology is retrograde compatible with existing wireless standards, which means that it can be easily integrated into existing wireless networks without any major changes in the infrastructure.

Challenges of MIMO Antennas

1. Complex Design: Using multiple antennas requires sophisticated design and signal processing.
2. Cost: MIMO systems are more expensive than simpler systems due to their complexity.
3. Power Consumption: Devices with MIMO antennas may use more power, which can be an issue for battery-powered devices.

A MIMO Antenna System with High Isolation for Smart Phone Applications

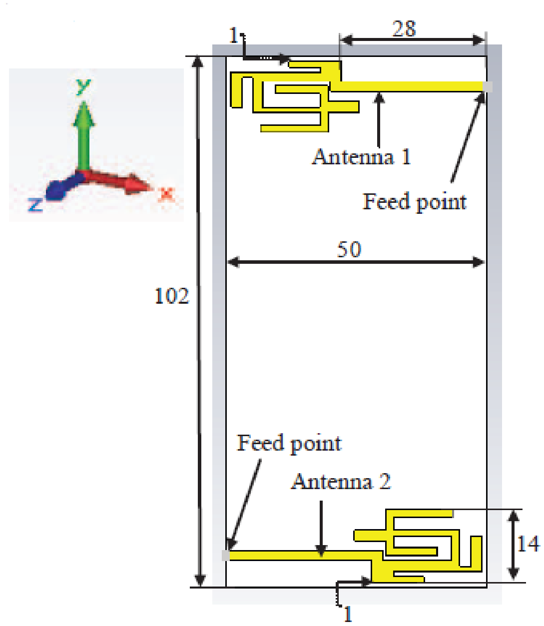
Modern smartphones require multiple antennas to support high-speed data and reliable connectivity. However, the proximity of antennas often leads to signal interference, reducing performance, The challenge is to design a compact antenna system with minimal mutual coupling (interference) and high isolation, especially for small smartphones.

Proposed Solution

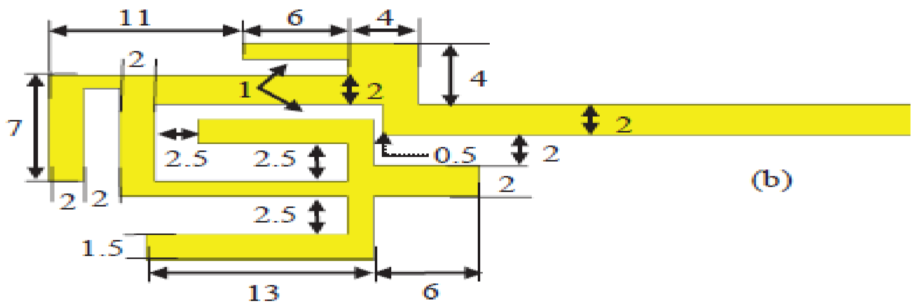
- We come up with a new MIMO antenna design with two identical antennas placed on opposite ends of a smartphone's circuit board.

- A "defected ground structure" (DGS) is introduced to reduce mutual coupling and achieve high isolation between antennas.

Antenna Design

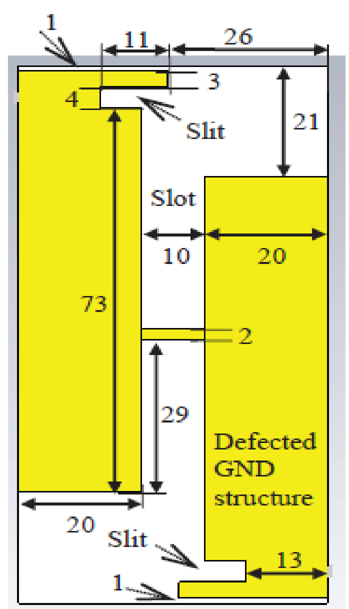


- The antennas are compact and fit within a smartphone-sized circuit board measuring 50 ×102 mm².

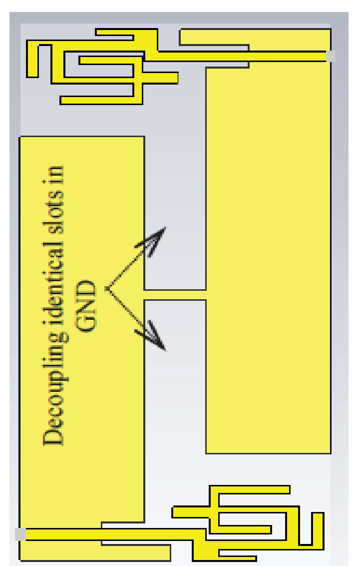


(b)

- Each antenna uses specific structures (meandered monopoles and branch strips) to achieve triple-band resonance.



(c)



(d)

- The ground plane of the board includes slots and slits (DGS) to minimize the interaction between antennas and improve isolation.

RESULTS, ANALYSIS AND DISCUSSION

Fig 2 shows the reflection coefficient of Antenna 1 alone without Antenna 2. The antenna shows three resonant modes excited at 2.05, 3.7 and 6.3 GHz. Fig. 3 shows the simulated S-parameters for the proposed MIMO antenna system (Antenna 1 accompanied with Antenna 2) before introducing the defected GND structure. The S11 shows that the impedance bandwidth of the proposed MIMO system without any slots offers (at return loss better than 6 dB) a lower band at resonant frequency 2.15 GHz which requires tuning and widening to cover LTE2300 (2305-2400 MHz) and WLAN2400 (2400-2484 MHz). The second frequency band resonates at 3.6 GHz to cover WiMAX3500 (3300-3700MHz). The third band resonates at 5.56 GHz to cover WLAN, WiMAX, and HIPERLAN 5200/5800. The simulated S21 of the system without decoupling slots show isolation better than 18 dB over the entire frequency range of interest except for the lower band where it reaches 9 dB as shown in Fig. 3. The simulated S-parameter results obtained by inserting the decoupling slots in the ground plane are shown in Fig. 4. It can be seen from the S11 that the lower band has been improved significantly to 2.13–2.64 GHz to cover the LTE2300 band. The slots in the ground plane have not degraded performance in the LTE, WiMAX, WLAN, and HIPERLAN bands.

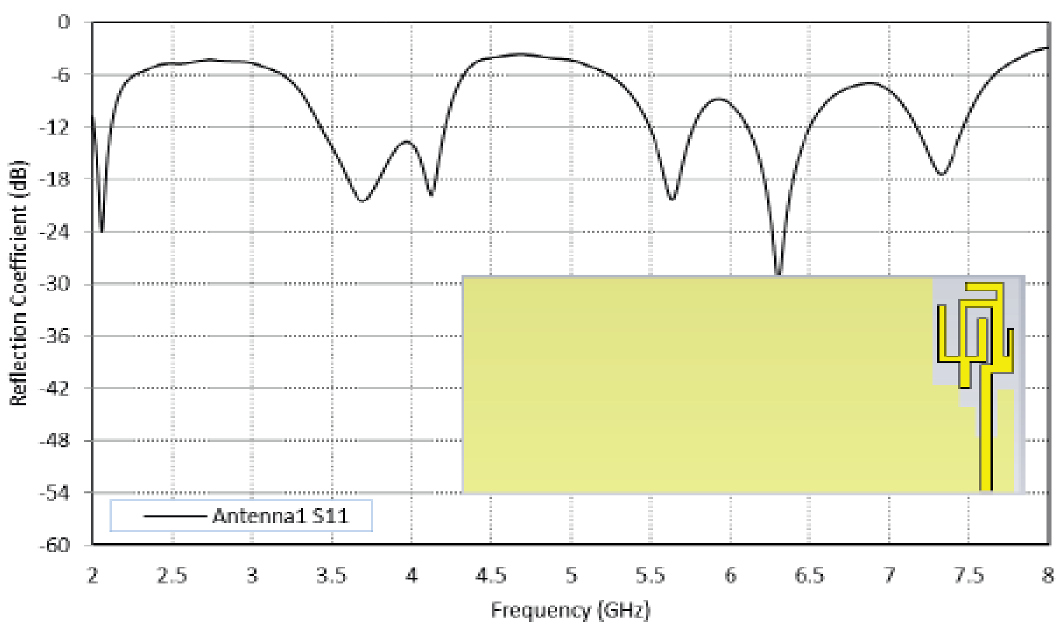


Fig. 2. Simulted reflection coeffiecient of Antenna1 alone (unaccompanied with Antenna 2).

One of the common methods assessing the performance of multiple port devices is calculating the envelope correlation coefficient (ECC) in terms of S-parameters using the following equation

$$\rho_e(i,j,N) = \frac{\left|\sum_{n=1}^{N} S_{i,n}^{*} S_{j,n}\right|^2}{\prod_{k=i,j}\left[1-\sum_{n=1}^{N}\left|S_{k,n}\right|^2\right]}$$

where N is the number of antennas in the system. This simple equation does not give precise information about the coupling between the antennas since it does not include either scattering parameters or the intrinsic power losses in the radiating structures simultaneously [6].

It is a useful parameter to consider in MIMO designs. It should be highlighted here that the decoupling slots resonate and play an important role in covering the lower bands because the entire structure resonates even before adding Antenna 2. The calculated ECC to measure the diversity gain of the proposed MIMO antenna system is plotted in Fig. 5.

Parametric studies have led to optimized dimensions and positions for the slots resulting in high isolation and good S-parameter performance, especially in the lower band. 4 in the lower band. It is noticeable from Fig. 5 how introducing the decoupling slots into the GND reduces significantly the ECC from 0.038 to less than 0.006 for all the frequency bands, implying good diversity gain.

The introduced decoupling slots block and suppress the current flowing from the excited Feed Point 1 to the coupled excited Feed Point 2 and vice versa. Another vital part introduced into the GND is the two identical rectangular slits with the optimized dimensions shown in Fig. 1 (c).
These slits vary the input impedance characteristics of the proposed triple-band MIMO antenna system. Fig. 6 shows the reflection coefficient of proposed MIMO with and without rectangular slits in the ground. There is a significant difference in the antenna performance (reflection coefficient) in bands of interest when there are no slits in the ground.

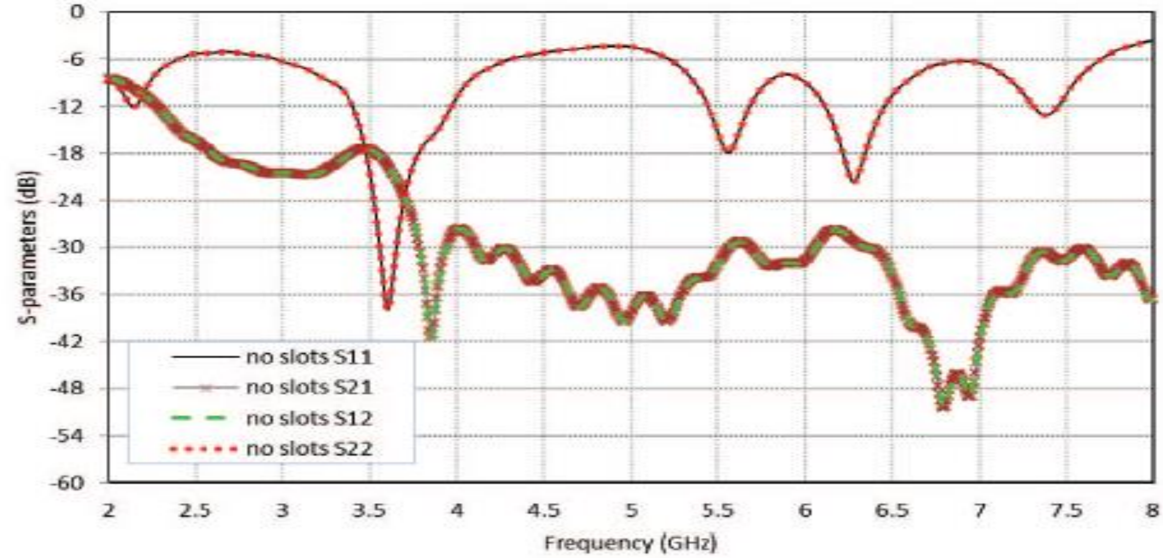


Fig. 3. Simulted S-parameters of of proposed MIMO antennas without decoupling slots.

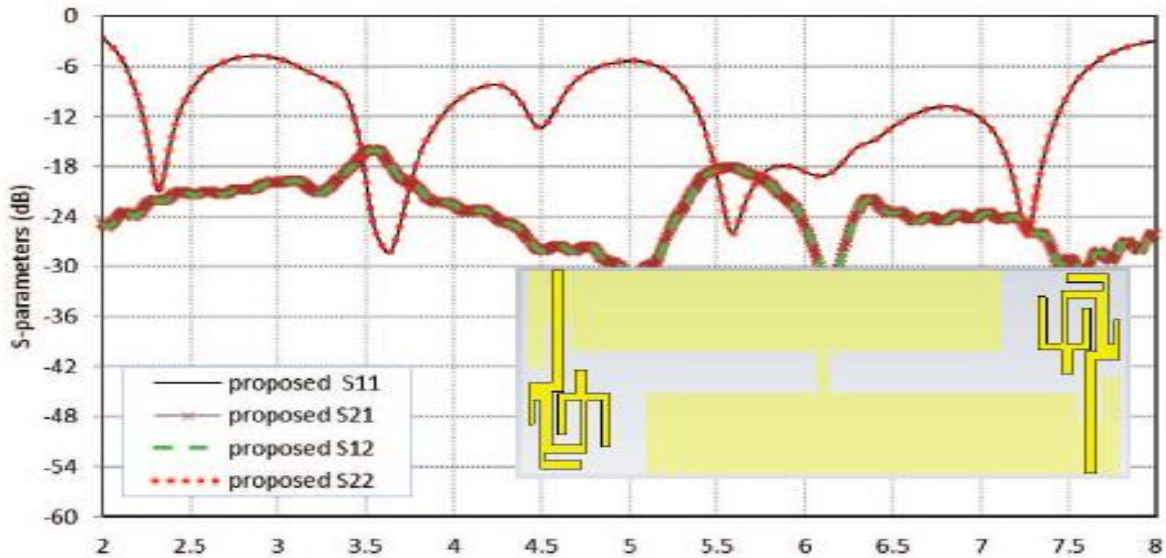


Fig. 4. Simulated S-parameters of the proposed MIMO antenna system with decoupling slots.

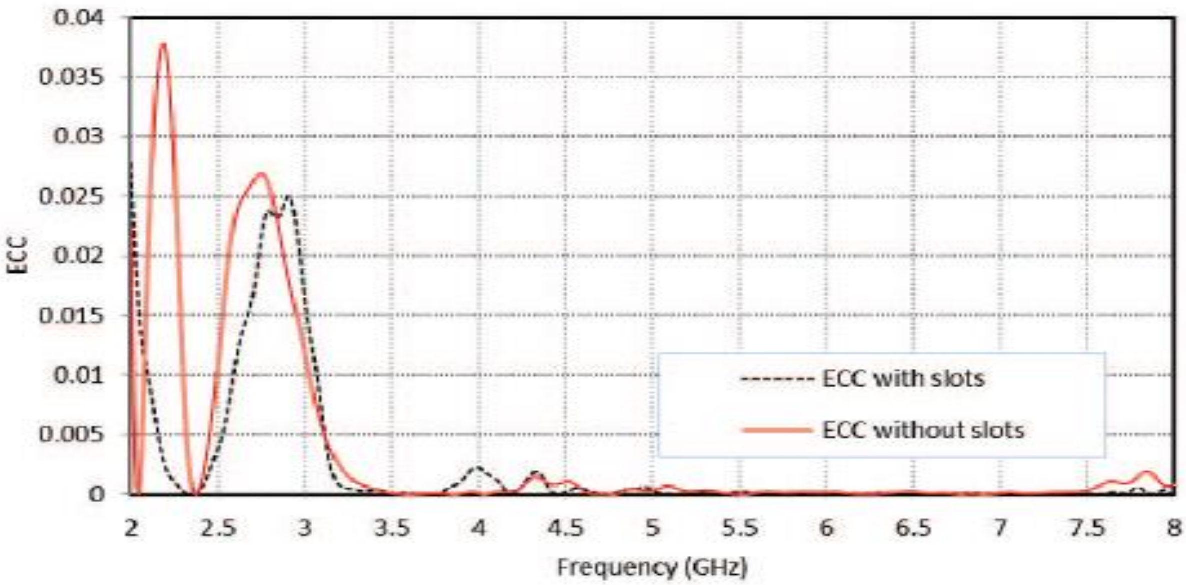


Fig. 5. Calculated results of enevelope correlation coeffiecient with and without proposed decoupling slots over frequency range (2-8 GHz).

Operating Frequency Bands

The system operates efficiently across multiple frequency bands:

- 2.3 GHz Band (LTE2300 and WLAN2400)
- 3.6 GHz Band (WiMAX3500)
- 5.6 GHz Band (WLAN, HIPERLAN)

Key Features of the Design

- High Isolation: Achieved through the defected ground structure, with an isolation level of over 18 dB.
- Low Envelope Correlation Coefficient (ECC): ECC is kept below 0.006, indicating excellent diversity and minimal interference between antennas.
- Compact Size: Each antenna element occupies an area of only 24.5 × 14 mm², suitable for smartphone integration.

Performance Evaluation

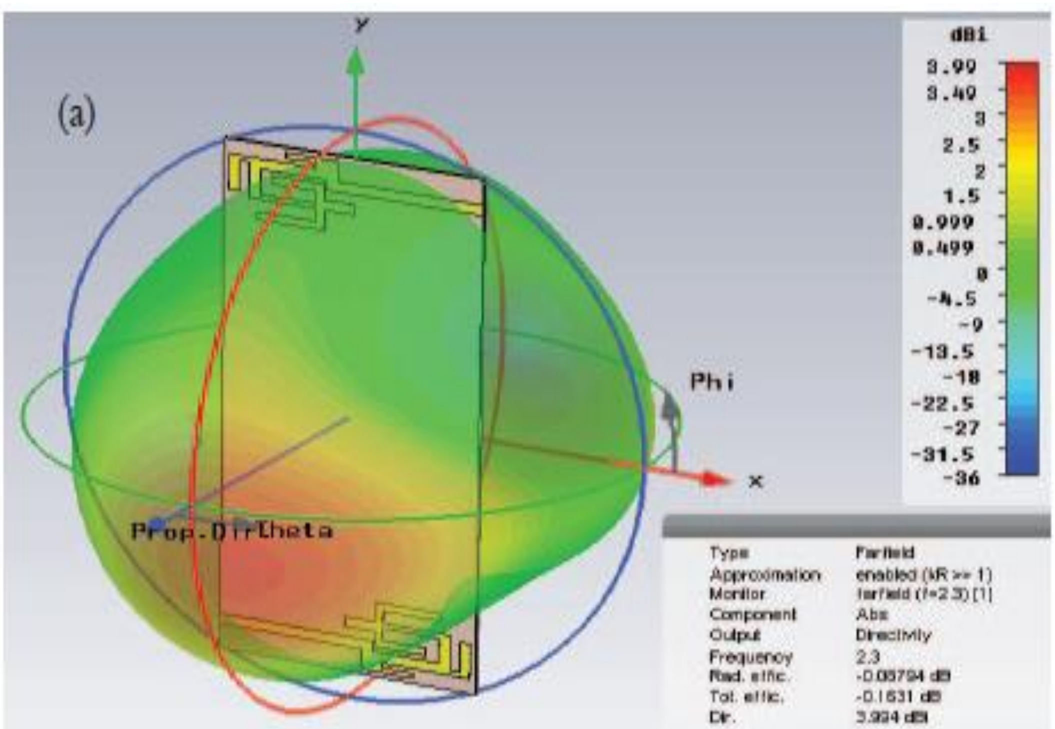
The proposed design was evaluated using simulation and experimental measurements:

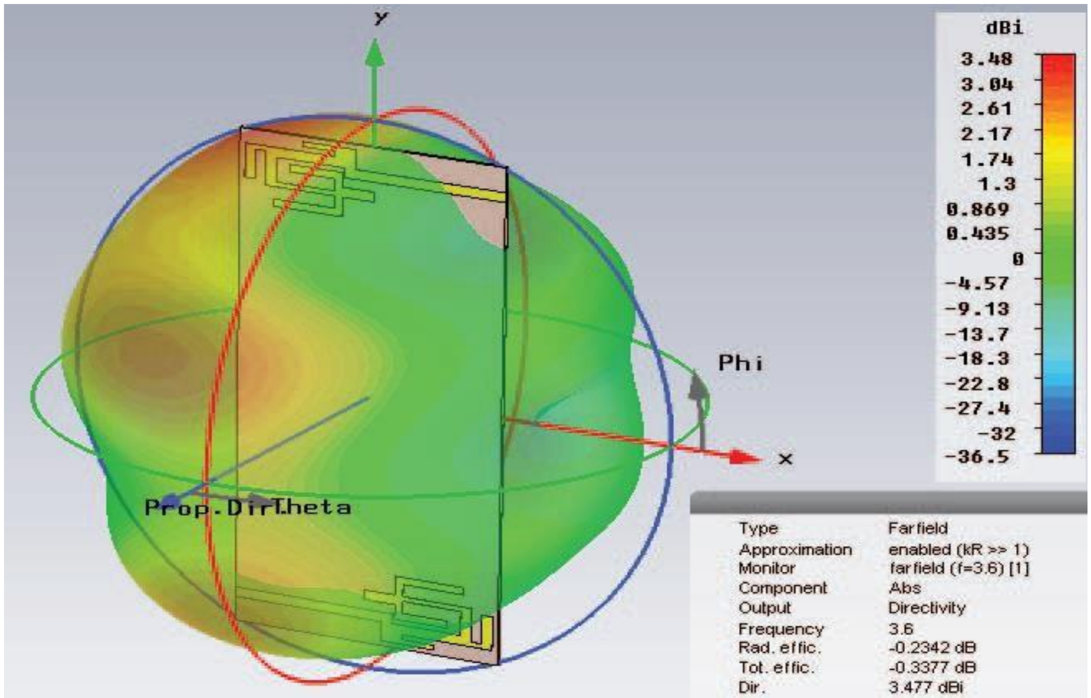
- S-parameters: Showed excellent impedance matching and consistent isolation across frequency bands.
- Radiation Efficiency: The antennas achieved efficiency above 85% across all operating bands.
- Radiation Patterns: Provided near-omnidirectional coverage at lower frequencies and consistent patterns at higher frequencies.

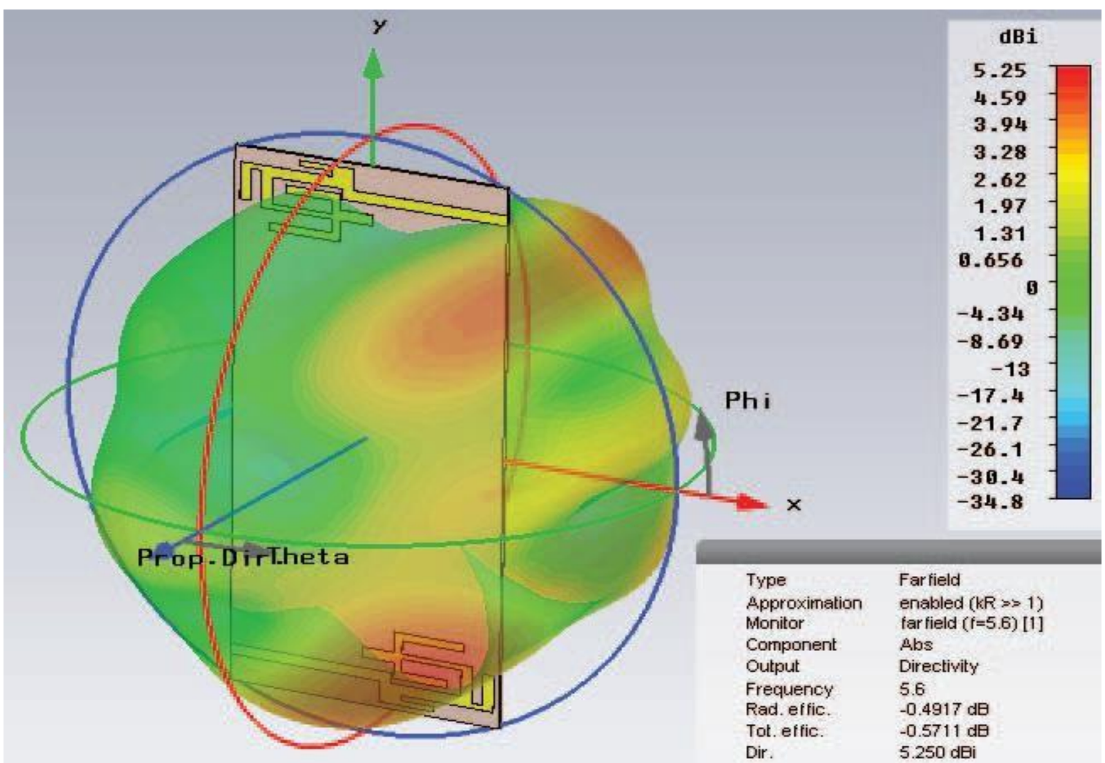
Comparison with Existing Designs

- The design compared its results with other MIMO antenna designs. The proposed design achieves:
  - Better ECC values (<0.006 compared to 0.03–0.54 in other designs).
  - Wider frequency band coverage with simpler decoupling structures.

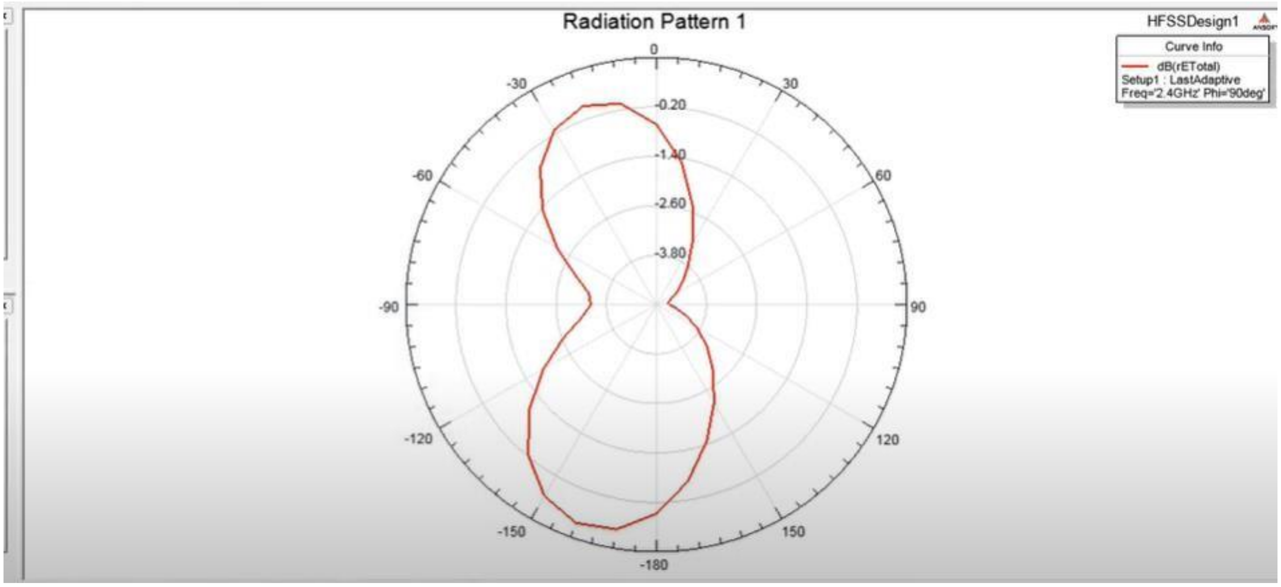
Radiated characteristics of the proposed MIMO antenna system



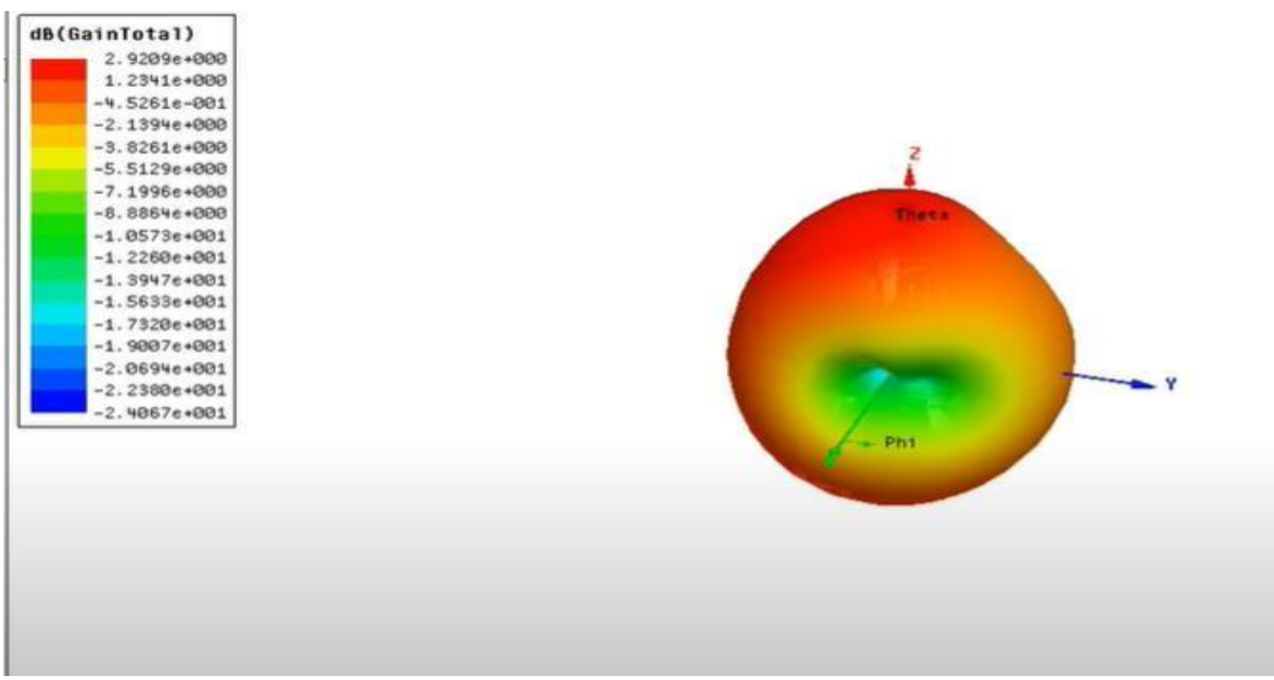

y
dBi
3.48
3.04
2.61
2.17
1.74
1.3
0.869
0.435
0
-4.57
-9.13
-13.7
-18.3
-22.8
-27.4
-32
-36.5
Phi
x
Prop.Dir
Theta
Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=3.6) [1]
Component Abs
Output Directivity
Frequency 3.6
Rad. effic. -0.2342 dB
Tot. effic. -0.3377 dB
Dir. 3.477 dBi


y
dBi
5.25
4.59
3.94
3.28
2.62
1.97
1.31
0.656
0
-4.34
-8.69
-13
-17.4
-21.7
-26.1
-30.4
-34.8
Phi
x
Prop.Dir
Theta
Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=5.6) [1]
Component Abs
Output Directivity
Frequency 5.6
Rad. effic. -0.4917 dB
Tot. effic. -0.5711 dB
Dir. 5.250 dBi

Radiation Pattern from Ansoft HFSS simulation



2DPattern



3D Pattern

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