Synthesis and Simulation for MIMO Antennas with Two Port for Wide Band Isolation

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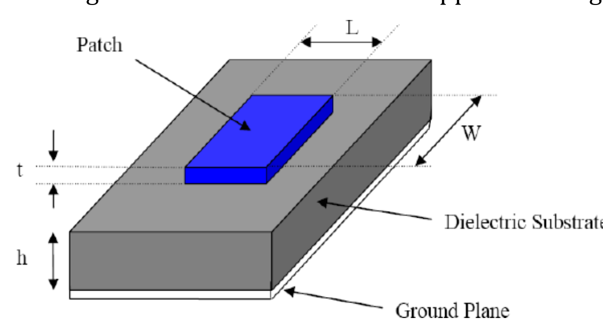
ABSTRACT: Ultra wide band (UWB) technology has rapidly gained popularity and demand for recent wireless communication systems after the allocation of 3.1- 10.6 GHz by the Federal Communications Commission (FCC) for UWB applications. Since then, a myriad of research opportunities and challenges exist for the design of UWB antenna systems for application in high speed wireless devices. Multiple-Input-Multiple-Output (MIMO) systems provide a significant increase in channel capacity without the need of additional bandwidth or transmit power by deploying multiple antennas for transmission to achieve an array. Gain and diversity gain, thereby improving the spectral efficiency and reliability. Since MIMO systems employ multiple antennas, they require high decoupling between antenna elements. Overall UWB MIMO systems require a high isolation of less than -16 dB and also a compact size for compatibility with integrated circuits. This work focuses on the analysis and design of MIMO antennas with a compact planar profile that have an operating range in the entire UWB (3.1- 10.6 GHz) and desired antenna performance characteristics. The design of two- element MIMO antennas and various isolation structures and mechanisms to reduce the mutual coupling between the two elements, out of which two major antenna designs are proposed and analyzed separately for their isolation, bandwidth and radiation characteristics. First, a printed ultra wideband (UWB) MIMO antenna system is proposed for portable UWB applications. The MIMO antenna system consists of two semicircular radiating elements on a single low-cost FR4 substrate of a compact size of 35 mm × 40 mm and is fed by a 50-Ω micro strip line

Introduction: The potential of UWB technology is enormous owing to its tremendous advantages such as the capability of providing high speed data rates at short transmission distances with low power dissipation. The rapid growth in wireless communication systems has made UWB an outstanding technology to replace the conventional wireless technologies in today's use like Bluetooth and wireless LANs, etc. A lot of research has been done to develop UWB LNAs, mixers and entire front-ends but not that much to develop UWB antennas. Recently, academic and industrial communities have realized the tradeoffs between antenna design and transceiver complexity. In general, the transceiver complexity has been increased, with the introduction of advanced wireless transmission techniques. In order to enhance the performance of transceiver without sacrificing its costly architecture, advanced antenna design should be used as the antenna is an integral part of the transceiver. Also ,the complexity of the overall transceiver is reduced [1].To implement UWB technology, there are many challenges to overcome. UWB has a significant effect on antenna design. It has attracted a surge of interest in antenna design by providing new challenges and opportunities for antenna designers as UWB systems require an antenna with an operating bandwidth covering the entire UWB (3.1- 10.6 GHz) and capable of receiving on associated frequencies at the same time [2]. Consequently, the antenna behaviour and performance have to be consistent and predictable across the UWB. Moreover, UWB is a technology that modulates impulse based waveforms rather than continuous carrier waves. Hence, the design of UWB antennas requires different considerations from those used in designing narrowband antennas. The hardest challenge in designing a UWB antenna is to attain wide impedance bandwidth with high radiation efficiency. UWB antennas achieve a bandwidth, greater than 100% of the center frequency to ensure sufficient impedance so that only less than 10 % of incident signal is lost due to reflections at the antenna's input terminal [2]. A return loss of greater than 10 dB is necessary in order to obtain high radiation efficiency. It is required as UWB transmission is of very low power (below the noise floor level) and with high sensitivity [1].The concurrent surge of wireless devices, with high level of miniaturization and high frequency of operation, has enhanced the interest in designing high performance antenna types. Therefore, there is a growing demand for small and low cost UWB antennas that are able to provide satisfactory performance in both time and frequency domains. The trend in recent wireless systems, including UWB based systems, are to build small, low-profile integrated circuits so as to be compatible with portable wireless devices. Also, the size affects the gain and bandwidth. Therefore, the size of the antenna is considered as one of the critical issues in UWB system design. The use of a planar design can minimize the volume of the UWB antennas by replacing three-dimensional radiators with their planar versions. Also, the two-dimensional (2D) geometry makes the fabrication easier. As a result, the planar antenna can be printed on a PCB and thus can be easily integrated into RF circuits [3].Recently; there is a demand to increase the data rate of existing wireless communication systems. The application of diversity techniques, most commonly assuming two antennas in a mobile terminal, can enhance the data rate and reliability without sacrificing additional spectrum or transmitted power in rich scattering environments.

2. MIMO Systems: The historical background and advancements in the present wireless communication systems, which use the MIMO technology, emphasizing mainly on the development of MIMO antennas and their related issues. It also discusses the trends in present advanced wireless communication systems operating at larger data rates and the role of MIMO systems in achieving the improved channel capacities and spectral efficiencies. The literature available on different types of antennas like Micro strip antennas and Dielectric Resonator Antennas (DRAs) used for the MIMO systems and various studies made in improving the impedance bandwidth and isolation of these antennas, when employed in MIMO systems are presented. Usually a single antenna is used at both the transmitter side and receiver side. This system, also known as Single Input Single Output (SISO) system suffers from bottleneck in terms of the channel capacity as explained by Shannon capacity limit. However, the present advanced wireless communications require the systems with higher channel capacities and 14 improved spectral efficiencies to handle the larger data rates. This problem was solved, when the pioneer Foschini first proposed the concept of employing multiple antennas at the transmitter and receiver in a wireless communication system for improving the channel capacity, leading to another revolution in the field of wireless communications known as Multiple Input Multiple Output (MIMO) technology in 1998. These systems operate by utilizing the spatial properties of multipath channel, a new dimension that can give an improved system performance in terms of channel capacity. Usually, multipath propagation is a pitfall in any communication system, However it turns out as an advantage in the MIMO systems. The traditional smart antenna system also uses multiple antennas at the transmitter or receiver or at both sides for .under multipath fading conditions. Using the MIMO systems, the channel capacity can be improved in addition to achieving the above two benefits.

3.Micro strip patch Antennas: The Micro strip patch antenna has a dielectric substrate with a radiating patch and the feed lines are etched on one side and a ground plane on the other side as shown in Fig.3.1. The shape of the patch is not constrained (could be square, rectangular, circular, triangular or elliptical) and it is generally made of conducting material such as copper or gold.



The fringing fields between the patch edge and the ground plane cause the micro strip patch antennas to radiate. A better performance in the antenna calls for a thick dielectric substrate having low dielectric constant which provides better efficiency, larger bandwidth and better radiation. However, such a configuration results in large size of antenna.

4.Model Analysis of Microstrip Antennas:

The most widely used microstrip patch configuration is the rectangular patch. Analysis of this patch is easy using transmission-line and cavity models. The transmission-line model is the easiest of all and yields accurate results.This model represents the microstrip antenna by two slots separated by a transmission line of length *L.* Fringing effects occur at the edges of the patch and is a function of *L,* width *W* of the patch and height *h* of the substrate.Due to fringing effects, the length of the patch is extended on the ends by a distance *ΔL,* which is a function of the effective dielectric constant ϵ_{reff} and width-to-height ratio. The approximate relation for extended length is given by:

$$\frac{\Delta_L}{f} = 0.412\frac{(\hat{I}_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\hat{I}_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \qquad (3\text{-}10)$$

Where

$$\hat{I}_{reff} = \frac{\hat{I}_r+1}{2}+\frac{\hat{I}_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2} \qquad (3\text{-}11)$$

Hence, the effective length of the patch is

$$L_{eff} = L + 2\Delta L \qquad (3\text{-}12)$$

The resonant frequency of the microstrip antenna is related to its length as:

$$(f_r)_{010} = \frac{1}{2L\sqrt{\epsilon_0}\sqrt{\mu_0\epsilon_0}} = \frac{\vartheta_0}{2L\sqrt{\epsilon_0}} \qquad (3\text{-}13)$$

Now, the xtended length *ΔL* can be calculated using equation (3-10).

Practical Design Procedure:

For a specified dielectric constant of the substrate ϵ_r, resonant frequency f_r and height of the substrate *h*, the following design equations are used to calculate the length and width of the patch:

$$W = \frac{1}{2f_r\sqrt{\mu_0\hat{I}_0}}\sqrt{\frac{2}{\hat{I}_{r+1}}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\hat{I}_r+1}} \qquad (3\text{-}14)$$

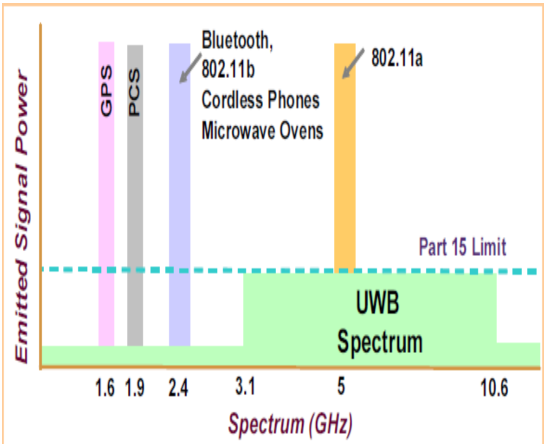
where v_0 is the free-space velocity of light.

4. UWB Systems :

Ultra-wideband (UWB) formerly known as '*pulse radio*' is a modern technology for transmitting information over a large bandwidth (> 500 MHz), promising high data rates with low power consumption. The unlicensed use of 3.1 -10.6 GHz has been authorized by the Federal Communications Commission for short distance high data rate indoor applications like PAN wireless connectivity. Recently, International Telecommunication Union Radio communication Sector (ITU-R) defined UWB as the transmission in which the bandwidth of the emitted signal exceeds the minimum of either 500 MHz or 20% of the center frequency, i.e. fractional bandwidth should be larger than 20% throughout the transmission. Fractional Bandwidth B_f is defined as the ratio of bandwidth at return loss (<-10 dB) to its center frequency.

$$B_f = \frac{BW}{f_c}\times 100\% = 2\frac{(f_h-fl)}{(f_h+f_l)}\times 100\% \qquad (4\text{-}1)$$

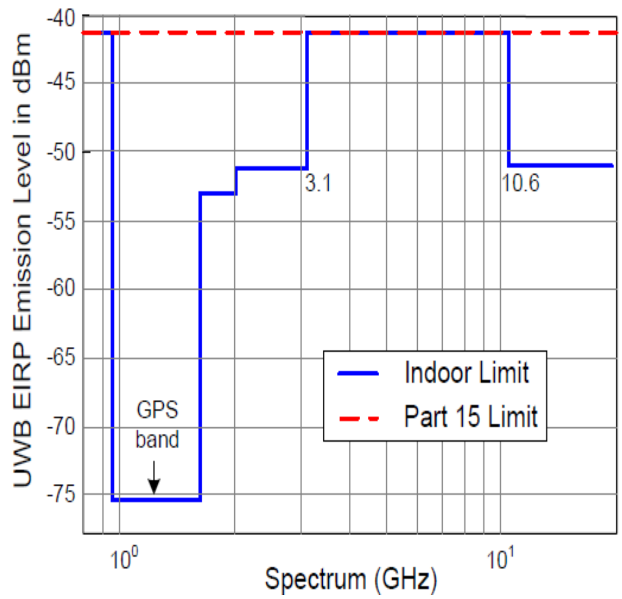
Table 4-1 Classification of signals based on fractional bandwidth



Based on [18], UWB systems with center frequency above 2.5 GHz are required to have a -10 dB bandwidth of at least 500 MHz, whereas UWB systems with center frequency below 2.5 GHz should have a minimum fractional bandwidth of 0.2. The FCC has authorized that UWB transmission can operate in the range from 3.1 GHz to 10.6 GHz, with the power spectral density PSD) satisfying a specific spectral mask assigned by the FCC.

Fig.4.1.UWB sspectral mask for indoor communication systems.

The above figure 4.1 illustrates the spectral mask for indoor UWB systems. According to the spectral mask, the PSD of UWB signal measured in 1 MHz bandwidth must not exceed -41.3 dBm, which complies with the Part 15 general emission limits to successfully control radio interference. For particularly sensitive bands, such as the global positioning system (GPS) band (0.96 - 1.61 GHz), the PSD limit is much lower. As depicted in Fig.3.1, such ruling allows the UWB devices



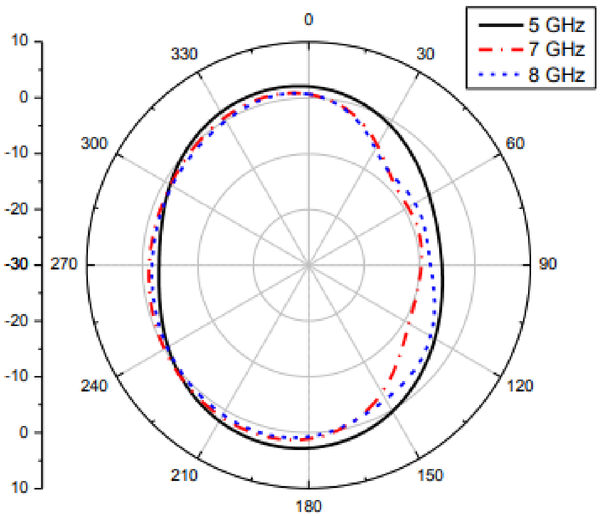
To overlay existing narrowband systems, while ensuring sufficient attenuation to limit adjacent channel interference.

Currently, regulatory efforts are under way in many countries, especially in Europe and Japan Market drivers for UWB technology are many even at this early stage, and are expected to include new applications in the next few years.

5.1 Simulation Results & Antenna Performance Characteristics:

The proposed antenna with the various ground plane structures is simulated using the commercial software CST MICROWAVE STUDIO. The simulated results of S- parameters and radiation pattern are obtained in the frequency range of 3-11 GHz and analyzed for isolation and bandwidth performance characteristics.

5.1.1 Radiation Performance:



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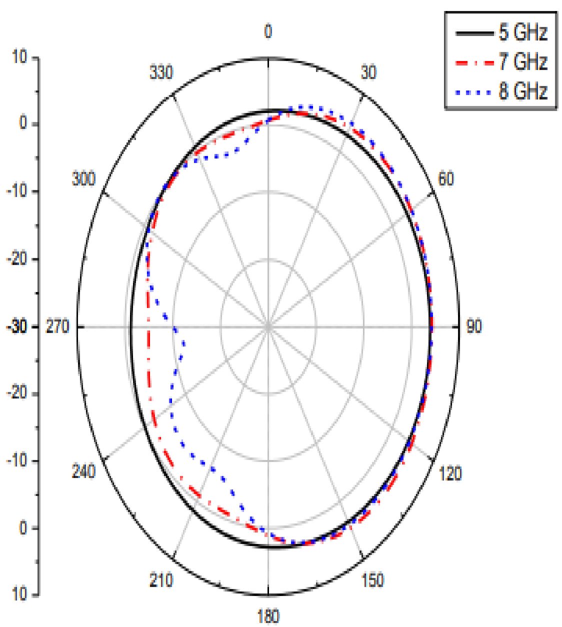

Fig.5.8. Simulated radiation patterns of the proposed antenna system: (a) x-y plane, (b) x-z plane,

The radiation characteristics of the proposed antenna system are investigated in the operating frequency range of 4.4-10.7 GHz. Simulated radiation patterns for one port are shown in Fig.5.8 at frequencies of 5,7 and 8 GHz, in the three principal planes at $\theta = 90^0$,$\phi = 0^0$ and $\phi = 90^0$, corresponding to the x-y, x-z and y-z planes respectively. The radiation pattern is found to be nearly omni-directional at 5 GHz and more directional at 7 GHz. The radiation patterns are stable across the UWB. The radiation patterns are obtained at one port, while terminating the other port at 50 Ω load.

5.1.2 Antenna Gain

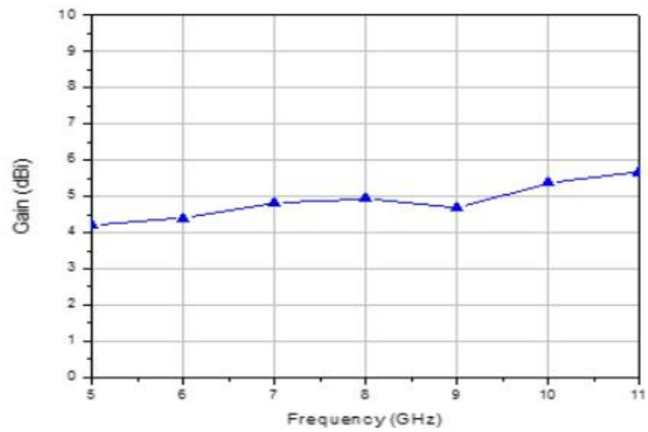

Fig. 5.9 Simulated Antenna Gain.

The antenna gain has been simulated and plotted in Figure 5.9 in the UWB from 5 to 11 GHz. Due to symmetry of structure, the gains of two radiators are same. Hence the gain for one port is presented. The variation of antenna gain across the UWB is within 2 dBi.

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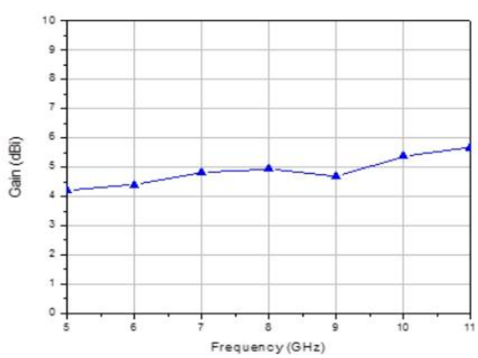

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6.DGS System :Defected Ground Structure or DGS is one of the new concepts applied to distributed microwave circuits, where the ground plane of a micro strip circuit or antenna is modified in order to enhance the performance of the antenna. The basic element of a DGS is a resonant slot or gap in the ground plane aligned with the transmission line in order to provide efficient coupling to the line. Recently, Defected Ground Structures (DGS) are introduced to improve antenna performance characteristics like size reduction, gain and bandwidth enhancement, and it is also used in reduction of mutual coupling between antenna elements. The cross- polarized radiation of a micro strip antenna was reduced by 8 dB by introducing a circular DGS . A double U- shaped DGS was proposed to broaden impedance bandwidth of a monopole antenna by 112%. Enhanced isolation of more than 40 dB is achieved by a dumbbell like DGS [7], but with very low impedance bandwidth. In the proposed antenna design presented in this chapter, a single hexagonal-shaped DGS is introduced in the ground plane of a two- element compact MIMO antenna system. Different from the traditional DGS, the hexagonal shaped DGS enhances isolation and at the same time broadens the impedance bandwidth of the proposed antenna system.

6.2. Antenna Design:

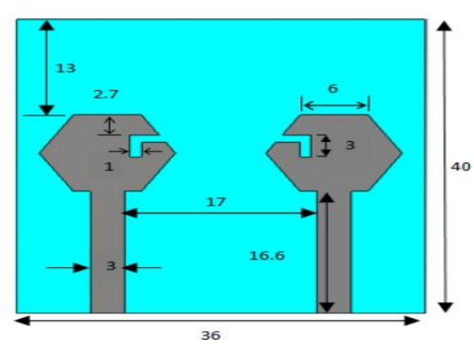

Fig. 6.1 Geometry of the proposed MIMO antenna system-Front view

The two- element MIMO antenna system of a compact size of 36 mm × 40 mm with the proposed DGS is shown in Fig.6.1. The antenna system is printed on a FR4 substrate with a dielectric constant of 4.4 and

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thickness of 1.6 mm. Each radiator is fed through a 50-Ω micro strip line. The length and width of the micro strip line is 16.6 mm and 3 mm respectively. The distance between the two feed lines is optimized at 17 mm so as to minimize the surface current flowing to the other port, thereby reducing the coupling between the elements. The radiators have a similar, regular hexagonal geometry of side 6 mm, offering more impedance bandwidth than the antennas with rectangular, square or triangular geometries. A slot of 1 mm width is etched on each of the hexagonal antenna elements to adjust the bandwidth, which is determined by the length of the slot.

6.1 Proposed DGS:

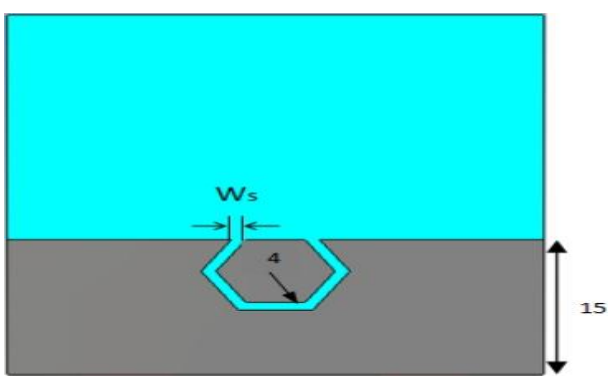

Fig. 6.2 Geometry of the proposed DGS

A defected ground structure (DGS) is introduced as shown in Fig. 6.2, to enhance the bandwidth and to reduce the coupling between the antennas. A hexagonal slot of uniform width W_s = 1 mm is etched on the ground plane. The distance between hexagonal radiator and the hexagonal DGS is optimized at 1.6 mm. varying this gap, adjusts the impedance bandwidth of the antenna system. The proposed hexagonal – shaped DGS offers a high order matching network for enhancing the bandwidth and at the same time acts as an isolation structure by suppressing the ground current flowing between the two ports, thereby enhancing isolation between the antenna elements.

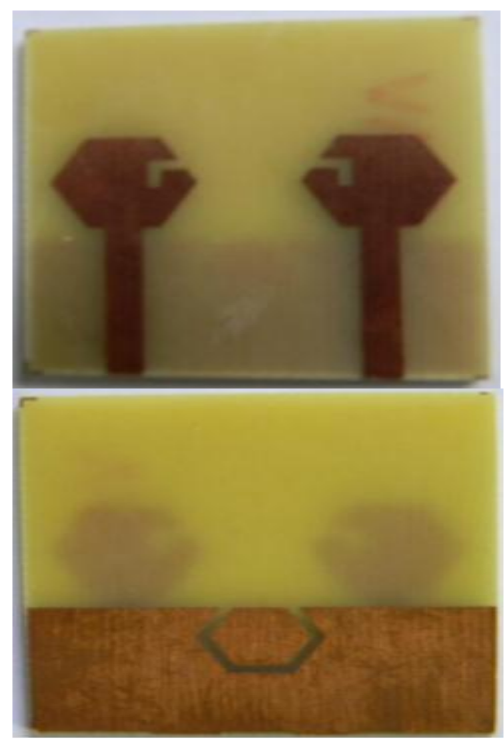

Fig.6.3 Prototype of the MIMO antenna system with DGS

7.Simulation Results and Discussions:

Isolation and return loss characteristics of the MIMO antenna system with and without DGS are analyzed to find out the

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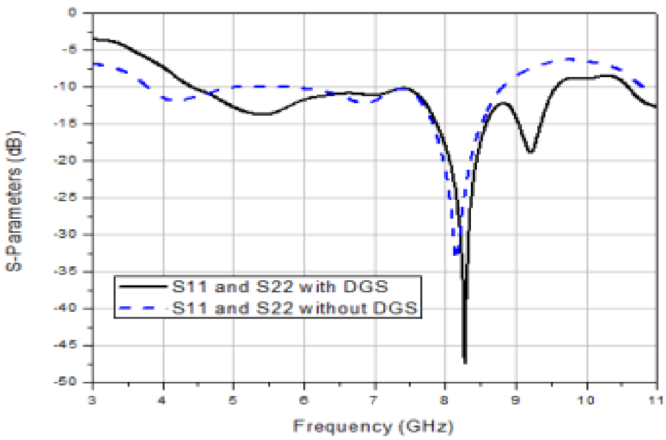
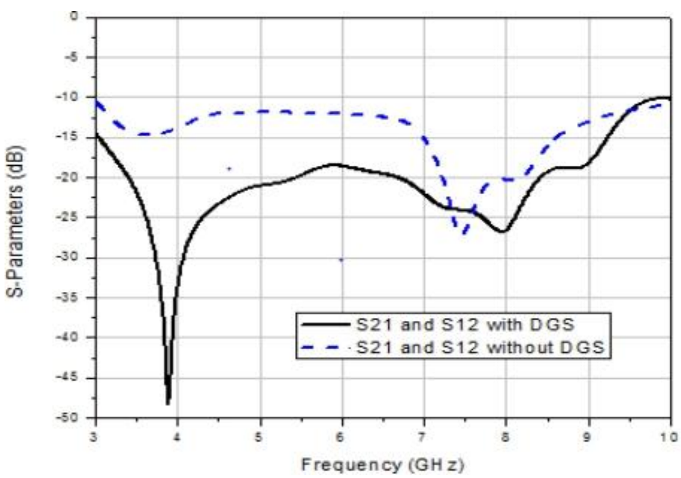
effectiveness of the proposed DGS.



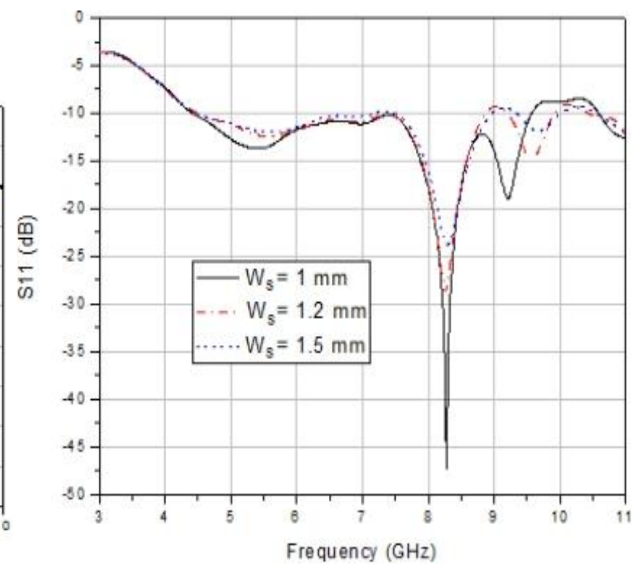


(a)

is observed that isolation has increased after incorporating the hexagonal DGS. S_{21} is less than -15 dB throughout the operating band of the antenna system and also a maximum isolation of more than 25 dB is achieved.

Parametric Study:

The isolation and bandwidth behaviour of the MIMO antenna with DGS is studied by varying one of the design parameters.



Conclusion: This presented the work on the analysis a 6.
design of two-element UWB MIMO antennas taking ir
consideration of two major performance characteristics, v
isolation and bandwidth. Two antenna designs were propos
and discussed which satisfy the required isolation a
bandwidth requirements.. Good isolation performance w 7.
achieved through the proposed fork-shaped structu
Isolation was found to be better than -17 dB throughout t
UWB. The bandwidth of the proposed antenna covers almo
the entire UWB from 4.4 to 10.7 GHz. The obtained results
isolation and bandwidth characteristics show that t 1.
proposed MIMO antenna system can work well in extreme
wideband range and it is found suitable for application in UV
portable devices.The proposed antenna system present
shows good MIMO/ diversity performance by achievi
isolation of – 20 dB, facilitated through a hexagonal shap
DGS. Bandwidth also is enhanced by the DGS so as to have 2.
operating frequency range from 4.4 GHz to 9.57 GHz, whi
covers almost the entire UWB (3.1 – 10.6 GHz band). Hen
wideband isolation is achieved in the proposed compa
antenna system with DGS and it is found suitable for portal
MIMO applications.The performed simulation results a 8.
investigations proved sufficient port-to-port isolation in t
UWB and the designed antenna systems can be used, whe
high data rate and support for MIMO transmission is require

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