Circular Fork Shaped MIMO Antenna for Ultra Wide Band Application

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Abstract- The objective of this paper is to present a new MIMO antenna design to be operated for "Ultra Wide Band" applications. The devised antenna has four fork shaped circular patches (micro-strip). The antenna performs very well in the UWB frequency range (3.1 to 10.6 GHz). The 4-element MIMO antenna is designed with a compact size of 60 x 60 x 1.67 mm^3 on ***Arlon CuClad 217*** substrate having relative permittivity of 2.2. When simulated in CST Studio the antenna design exhibits good MIMO performance. Results of simulation like isolation, reflection parameters, and diversity performance attributes (ECC, DG, TARC, CCL etc.) are in desirable range.

Keywords: *UWB , MIMO, TARC, ECC , CCL*

1. INTRODUCTION

"Multiple-Input Multiple-Output (MIMO) antenna systems are an effective way of improving reliability and increasing the channel capacity" [1] Multiple antennas are used at both the source (transmitter) and the destination (receiver). MIMO system is defined by spatial diversity and spatial multiplexing. MIMO networks may be structured in so many fields. It is used in antennas for the reduction of chains and costs and also in reduction of coupling effects.

1.1 ANTENNA THEORY

For any wireless systems to work, antennas are considered as the most essential component. "An antenna is defined as a means for radiating and receiving radio waves" [3]

Therefore an Antenna is designed to focus mainly on two things-

1. Impedance matching with the free space to get highest possible efficiency.

2. Achieving radiation in the omni direction in space. Given below are some of the desirable properties in a MIMO antenna.

1.2 MUTUAL COUPLING

Mutual coupling is an important parameter while designing a MIMO antenna. Basically, it is the interaction between the two antenna patches. Mutual coupling defines the energy consumed by one antenna patch when the other antenna patch is working. "Primary intend while designing a MIMO antenna is to reduce mutual coupling. Higher mutual [7]. To overcome mutual coupling problem we should increase coupling may reduce antenna efficiency and performance" the separation between the antenna elements or we can add on the decoupling networks.

1.3 ANTENNA DIRECTIVITY, GAIN AND RADIATION EFFICIENCY

"The ratio of maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic or reference antenna, radiating the same total power is called the directivity" [6]

"Antenna Efficiency is the ratio of the radiated power of the antenna to the input power accepted by the antenna" [6]

"Gain of an antenna is the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically" [6]

The higher the gain, the more directional the antenna is. The gain of an antenna in a given direction is usually referenced to an isotropic (hypothetical) antenna, which emits the radiation evenly strong in all direction.

Radiation efficiency (η) is the ratio of power delivered to the antenna relative to the power radiated from the antenna.

$$\eta = (P_{rad} / P_{input})$$

A high efficient antenna has most of the power radiated while low efficient antenna has most of the power absorbed.

1.4 UWB ANTENNA REQUIREMENTS

"UWB is short name for Ultra Wideband. While conventional wireless signals occupy bandwidth with several hundred kilohertz and tens of megahertz, UWB sends and receives data at bandwidths of over 500 MHz at very low power spectral densities and because of the low power density levels of UWB and the high frequencies they use signals can only travel up to a limited distance and do not interfere with other waves" [3]

The UWB antenna requirements are:

1. "The UWB antenna should function in a range of frequency from 3.1 GHz to 10.6 GHz.
2. The Group delay of UWB MIMO antenna must be constant.

3. UWB antenna should preferably exhibit an omni-directional radiation pattern.
4. Radiation efficiency should be as high as possible
5. The physical attributes of the antenna must be compact and planar" [1]

2. ANTENNA DESIGN

In order to design a novel UWB MIMO antenna various existing research papers were studied. After much iterations and CST simulations it was decided to go with fork shaped design.

Initial iteration was done on square shaped fork antenna patch but the results were not satisfactory as the reflection parameter value S_{11} was not below -10dB. Circular shaped patch has proven to be much effective and hence it was decided to redesign the patch also keeping the fork shape into consideration. Fig 1 shows the inspiration for antenna design.

Fig 1: Inspiration for fork shaped patch antenna

Based on the inspiration, given in figure 2 and 3 is the front view and back view of the proposed circular fork shaped MIMO antenna. The dimensions of the antenna can be referred from the table 1.

TABLE-1: DIMENSIONS OF ANTENNA

SL No	Dimensions of the MIMO Patch Antenna	
	Attribute	**Measurements in (mm)**
1	Radius of the circular patch	9
2	Length * Width * Height of the feed	12x1.2x0.035
3	Thickness of the Substrate	1.6
4	Length * Width of the Substrate	60x60
5	Length * Width of the Ground	30x8
6	Thickness of the Ground	0.035

Orthogonal 4x4 array arrangement is kept to reduce mutual coupling and induce good isolation. Arlon CuClad 217 was chosen as the substrate material with relative permeability of 2.2. Pure copper has been used for both ground as well as patch element.

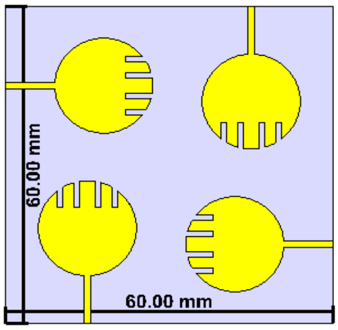

Fig 2: Front view of the proposed MIMO antenna

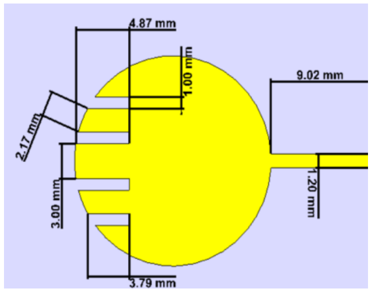

Fig 3: Dimensions of the Patch

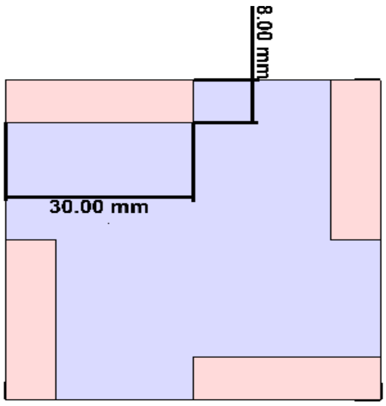

Fig 4: Back view of the proposed MIMO antenna

Ground planes have been optimised to 30mmX8mm for good scattering parameter values.

3. SIMULATION RESULTS AND DISCUSSIONS

The above antenna design was simulated using CST studio and the below results were obtained.

3.1 SCATTERING PARAMETER

For the devised antenna the scattering parameter analysis was done with the help of CST simulation and as shown in figure 4 all values are less than -10 dB.

"This indicates that the developed antenna supports about 100% of UWB Bandwidth, unlike the antenna reported" [5]

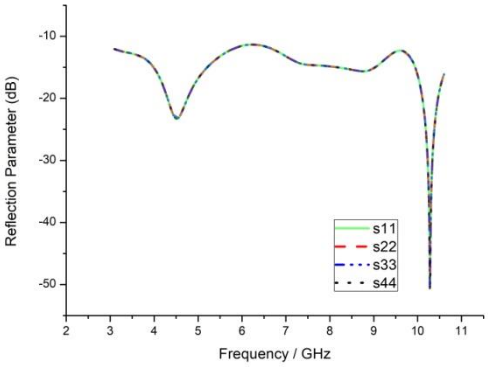

Fig 5: S- Parameters of the proposed MIMO antenna is below -10dB over UWB frequency range.

3.1 CCL (Channel Capacity Loss)

Lowest value of Channel Capacity loss is desirable for any good MIMO antenna design and for good information rate from transmitter to receiver. "The channel capacity depends on the number of antenna patches involved in the MIMO system and the quantity of correlation between antenna patches. Increasing the number of patches increases the channel capacity linearly" [5]

The value of CCL for the devised MIMO system is less than 0.016bps/Hz over the intended UWB bandwidth, which offers a very good diversity as shown in Fig 6.

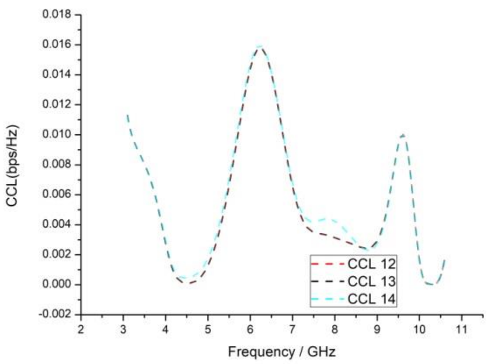

Fig 6: CCL is less than 0.016 over the UWB frequency range.

3.2 ECC (Envelope correlation coefficient)

"It measures the correlation between adjacent antenna patches. It may be calculated by using S-parameters and field based equations. Lower value of ECC indicates low correlation between the elements and lower correlation value provides lower mutual coupling"[5]. For good performance of MIMO antenna ECC value should be nearly equal to zero. Normally, tolerable value is 0.5 or less is considered for a good operating MIMO.

Envelope Correlation coefficient values are less than 0.030 in the presented antenna design.

$$ECC = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^2}{\left(1-|S_{11}|^2-|S_{21}|^2\right)\times\left(1-|S_{22}|^2-|S_{12}|^2\right)}$$

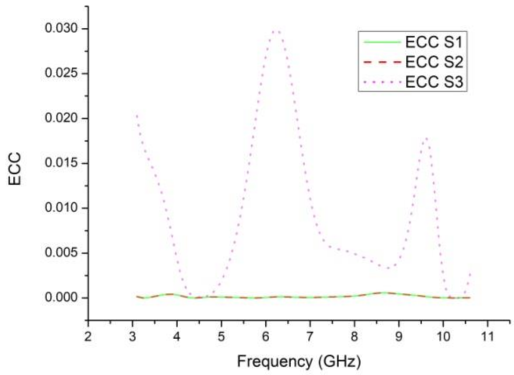

Fig 7: ECC is less than 0.030 over UWB frequency range.

3.3 TARC (Total Active Reflection Coefficient)

"It is calculated to observe the impedance bandwidth of an antenna. Different excitation phase angles are considered to check the characteristic. Normally for a good operating MIMO antenna, all the excitation phase angles follow the proper impedance bandwidth"[5].

$$TARC = \sqrt{Preflected}\Big/\sqrt{Pincident}$$

For a MIMO based antenna system the value of TARC should be a negative number or less than 0 dB. Figure 8, shows the simulated TARC of the circular fork shaped MIMO antenna and it is seen that the value of TARC is less than −30 dB in the entire Ultra wideband range which shows the desirable diversity performance of the presented antenna

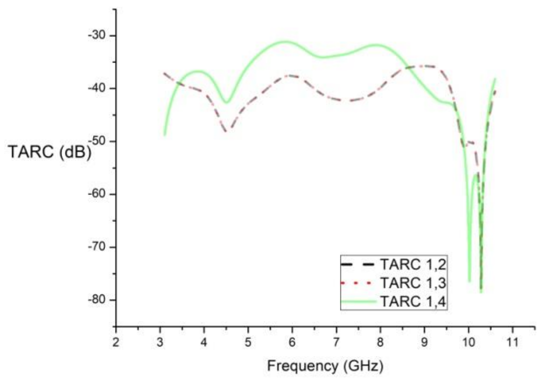

Fig 8: TARC is less than -30 dB over UWB frequency range.

3.4 Group Delay

The degree of distortion of an Ultra wideband signal is defined by group delay. The deviations in group delay cause signal distortion, therefore group delay should be nearly constant for good antenna performance. Group delay is given as

$$group\ delay = -\frac{\Delta\varphi}{\Delta\omega}$$

Where,
φ = the total phase shift in radians,
ω = $2\pi f$ = angular frequency in radians per unit time
f = frequency

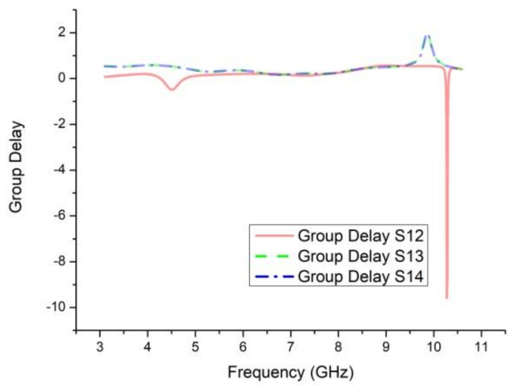

Fig 9: Observed constant group delay over UWB frequency range

3.5 FARFIELDS

Radiation Pattern – It is the 3-D plot of relative distribution of radiated power or electric field as a function of direction in space. There are essentially three type of radiation patterns.

1. Isotropic pattern- In this type of pattern, power or field is equally radiated in all direction. An isotropic pattern has the least radiation losses and is impractical in nature.
2. Omni-direction pattern- This type of antenna pattern is non-directional in a given plane and exhibits a directional pattern in any orthogonal plane.
3. Directional pattern`- Here the radiation pattern is prominent in some particular direction relative to other directions.

An omni-directional pattern is desirable for MIMO antennas deployed for UWB applications.
The proposed circular fork shaped pattern exhibits omni directional pattern as per the simulation results shown in figures 10.1, 10.2 and 10.3 at 3.1 GHz, 10.6 GHz and 6.85 GHz respectively.

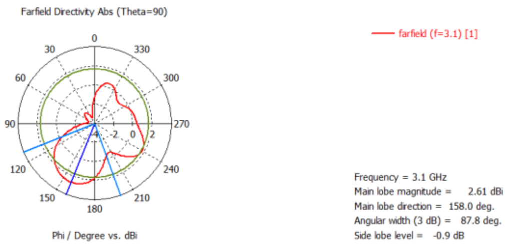

Fig 10.1: Omni Directional Pattern at 3.1 GHz

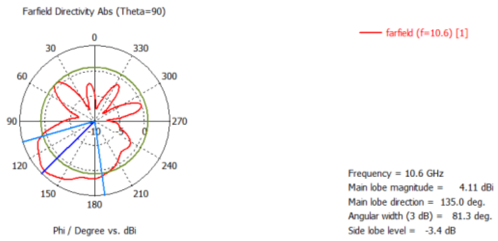

Fig 10.2: Omni Directional Pattern at 10.6 GHz.

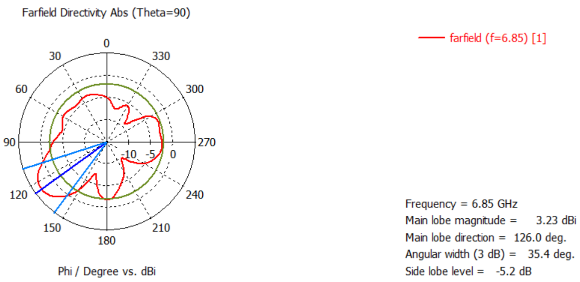

Fig 10.3: Omni Directional Pattern at 6.85 GHz.

4. CONCLUSIONS

A circular fork shaped MIMO antenna has been devised for Ultra Wideband applications. The bandwidth range at which antenna resonates is (3.1–10.6 GHz). The isolation is (≤−30 dB) which is in desirable range and the antenna also exhibits an omni-directional radiation pattern. The diversity of the antenna is also seen in terms of ECC

(≤0.030), TARC (≤−30 dB), CCL (≤0.016 bits/s/Hz).The scattering parameter is (≤ -10 dB) also shows that the antenna model is suitable for precision geolocation, obstacle avoidance, robotics , Iot , inventory tracking etc.

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