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Mutual Coupling Reduction in Arrow Shaped UWB MIMO Antenna Using Defected Ground Structures

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***Abstract*— In this paper, an ultrawideband (UWB) MIMO antenna with increased isolation is discussed. The antenna designed consists of two UWB slot antennas of size 22×26 mm^2 is shown. A T-shaped slot is printed on the ground plane to improve the impedance matching characteristic in the low-frequencies and decrease the coupling for the frequencies 3-5 GHz. Neutralization line is introduced in the ground plane to cancel out the original coupling and to increase the isolation at 10–11 GHz band. The antenna has a low mutual coupling of less than -19.2 dB over the operating band from 3.1–10.6 GHz. The performance of this antenna shows that the designed antenna is a right candidate for UWB applications.**

***Index Terms*— Envelope Correlation coefficient (ECC), multiple-input-multiple-output (MIMO), Isolation, Frequency interference, small antenna, ultra-wideband (UWB)**

I. INTRODUCTION

The use of wireless systems is the latest trend in communication technology, and there is a constant demand for compactness of wireless electronic devices, as well as enhance the speed and data rate for these devices. The potential of UWB technology is huge owing to its tremendous advantages such as the capability of providing high speed data rates at small 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. Recently, academic and industrial communities become aware of the tradeoffs between antenna design and transceiver complexity [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]. Commercialization of UWB has raised over the past several years, developers of UWB systems began forcing the FCC to approve UWB for commercial use.In February 2002, the Federal Communications Commission (FCC) officially allocated an unlicensed3.1–10.6 GHz bandwidth with a very low radiated power level (less than -41dB/MHz) for commercial applications of UWB systems [3].

Some MIMO antennas for UWB applications were proposed in the past few years [4]–[8]. In order to attain the best performance of the MIMO systems, high isolation is accomplished by orthogonally feeding [4]–[6], introducing defected ground structure (DGS) to suppress surface wave [6], [7], using directional antenna elements [7], adding protruding ground stub or parasitic element as reflective component [5], [5], [8], and adopting a neutralization line to suppress the original coupling [9]. All of the decoupling methods can shorten the mutual coupling to dB or less. To integrate multiple antennas at the user terminals that is
becoming smaller and thinner each day, the design of a very compact UWB-MIMO antenna covering the entire operating frequency of UWB band is one of the most important requirements. However, decreasing the size of a MIMO antenna usually brings about reduced operating bandwidth and increase in coupling between antenna elements. Moreover, most decoupling structures occupied too large space, which are not suitable for compact MIMO antenna.

In this letter, a very compact MIMO antenna with high isolation is designed for UWB systems. The antenna measures only 22×26 mm2. In order to increase isolation of such a compact MIMO antenna, two defected ground structures are introduced. The T-shaped slot printed on the ground has two functions, extending the current path, enhance the impedance matching characteristic in the low-frequencies and decrease the mutual coupling for the frequencies 3-5 GHz. Neutralization line introduced in the ground plane to nullify the original coupling, and to increase the isolation at 10–11 GHz band and has a very small occupied space. Compared to the traditional neutralization line technology, which is connected at radiation patch or feeding line to produce an additional current path between two antenna elements, the DGS has less effect on original antenna impedance because the additional current path is realized by introducing coupling slot on the ground [10].

II.ANTENNA CONFIGURATION

Fig. 1 shows the geometry of the proposed UWB-MIMO antenna. It is printed on the FR4 substrate with compact size 22×26mm^2, thickness of 0.8 mm, and relative dielectric constant of 4.4.The top layer consists of two arrow shaped monopole antenna and the bottom layer is a metal ground with a T-shaped slot, a line slot and two stepped slots. An arrow shaped monopole antenna and a stepped slot compose a UWB antenna element and the two antenna elements are symmetrically arrayed. To improve the impedance matching characteristic and reduce the mutual coupling, a T-shaped slot and a line slot are used on the ground.

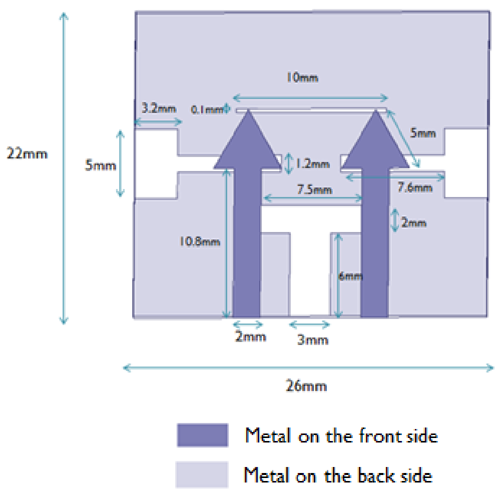

Fig.1.Structure of the proposed arrow shaped UWB-MIMO antenna

III. ANTENNA DESIGN

The proposed antenna was designed step by step. Two configurations of single UWB antenna element and four different arrow shaped UWB MIMO antennas will be investigated in this section.

The width of the microstrip lines (Wm) for 50Ω characteristic impedance can calculated using the following equations,

$$\frac{W_m}{h} = \begin{cases} \frac{8e^A}{e^{2A}-2} ; \text{when } z_0 \gg 44-2\varepsilon_r \\ \frac{2}{\pi}\left[B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(2B-1)+0.36-\frac{0.61}{\varepsilon_r}\right\}\right] \end{cases}$$

When $z_0 \ll 44-2\varepsilon_r$ (1)

Where $A = \frac{z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right)$ and

$$B = \frac{377\pi}{2z_0\sqrt{\varepsilon_r}} \quad (2)$$

The length of the microstrip lines (*L*) can be calculated using the following equations,

$$\text{Length, } L = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \quad (3)$$

Where $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+12(h/w)}}$ and

$$\lambda_0 = \frac{c}{f} \quad (4)$$

A. UWB Antenna Element

The stepped slot antenna which is similar to that in [10] is adopted as an element of the proposed MIMO antenna. In this antenna 50 Ω microstripline used as antenna element as implemented in [11]. But here instead of microstripline arrow shaped monopole antenna is used in order to achieve high isolation.

The antenna shown in Fig.2(a), the -10dB impedance bandwidth is only from 3.6 to 11.45 GHz, which does not cover the entire UWB band (3.1 to 10.6 GHz). In order to enhance the impedance matching characteristic in the low frequency, an open-ended slot is established on the back of the feed as shown in Fig. 2(b).

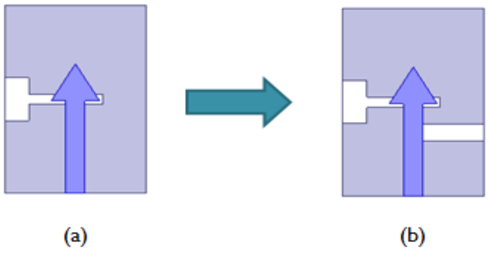

Fig.2. (a) Geometry of arrow shaped UWB antenna without open ended slot
(b) Geometry of arrow shaped UWB antenna with open ended

The simulated S11 of the stepped slot antenna with and without the open-ended slot is illustrated in Fig. 3. As observed, the open ended slot makes the first resonant frequency of the antenna becomes lower. Moreover, the simulated for different the length of the open-ended slot indicates the mainly affects the lowest operating frequency.

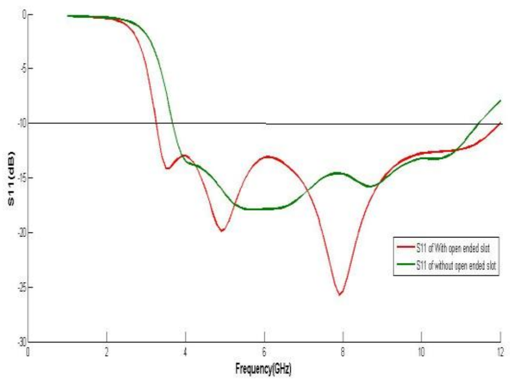

Fig.3. S_{11} of with and without open ended slot of UWB antenna.

If the length of the open-ended slot was extended further, the lower the first resonant frequency could be obtained. But it will reduce the isolation of the antenna.

B. T shaped slot

Fig. 4(a) shows the MIMO antenna A, which is implemented by adding two UWB antennas symmetrically. The two antenna elements are using a common ground plane with compact size of 22×26 mm^2. For such a small antenna, the ground plane a part of the antenna radiator. Its size has a relationship with the impedance matching and radiation of the antenna. The ground surface currents and near-field lead to a strong mutual coupling between two elements.

To reach better isolation, a rectangular slot cut from the ground plane is adopted in MIMO antenna B as show in Fig. 4(b). The simulated results of two antennas are shown in Fig. 5. Compared to antenna A, which has less reflection coefficient and isolation, s_{12} of antenna B in the frequency bands of 5 to 8 GHz has a significant reduction, representing an isolation increased. Besides, the impedance matching characteristic in the corresponding frequency bands is improved. That is because the cutting can change the distribution of ground surface currents and increase the distance between the two feed ports.

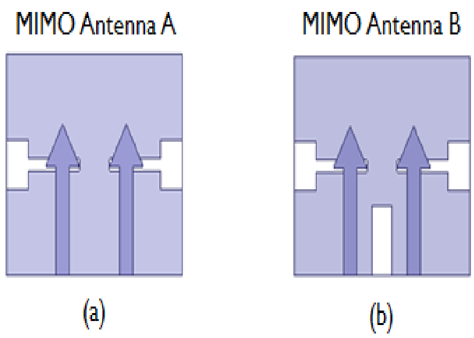

Fig.4. (a) Geometry of antenna A (b) Geometry of antenna B

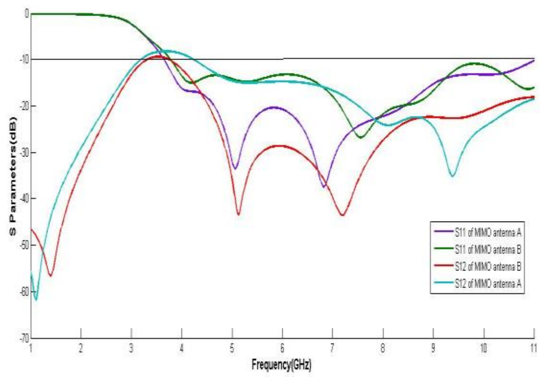

Fig.5. S parameters of antenna A and antenna B

As mentioned earlier, the first resonant frequency of the antenna can be reduced by introducing an open-ended slot in the ground plane of the antenna, and the mutual coupling can be weakened by cutting a rectangular slot between two antenna elements. Thus, adding the two structures, a T-shaped slot is adopted in MIMO antenna C as show in Fig. 6. The S-parameters for antenna A (with only ground plane) and antenna C (with T-shaped slot) are given in Fig. 7. It can be observed that the antenna C has wider operating frequency band and higher isolation. The first resonant frequency was reduced by the top part of the T-shaped slot, and high isolation at middle frequency band was achieved by the bottom part. As a result, both impedance matching characteristic and isolation between the two ports are enhanced.

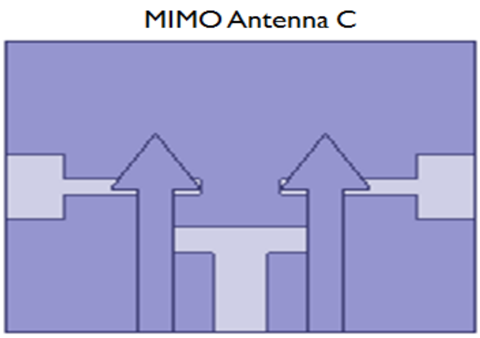

Fig.6. Geometry of antenna C

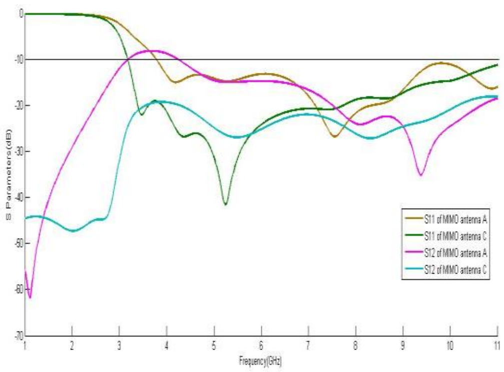

Fig.7. S parameters of antenna A and antenna C

Observing Fig. 7, we can find that the isolation is larger than 20 dB for the frequencies 3-10 GHz, and that is because the T-shaped slot increased the distance between the two feed ports.

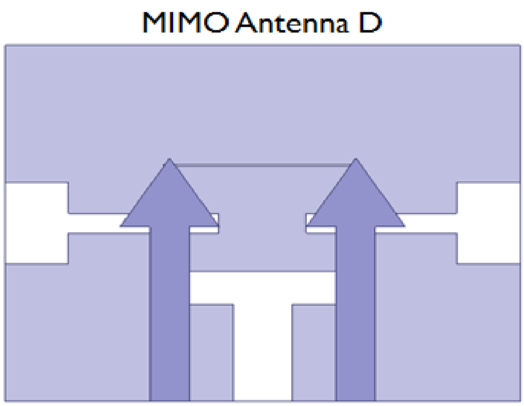

Fig.8. Geometry of antenna D

C. Line slot

To reduce the mutual coupling for the band of 10–11 GHz, a line slot printed on the ground plane with width 0.1 mm is applied in the antenna D as shown in Fig. 8. Antenna D is the proposed compact arrow UWB-MIMO antenna with high isolation. The line slot improves the isolation at the band of 10–11 GHz and has little effect to the return loss. It can be proved by the comparison of results shown in Fig.9.

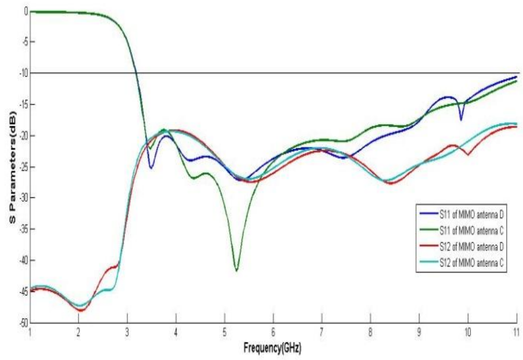

Fig.9. S parameters of antenna C and antenna D

For antenna D, the coupled currents distributing on the non-excited antenna element is smaller comparing to antenna C. That is because the line slot produces an additional coupling current path for the coupling currents, and the current path can cancel out a part of original coupling currents from the excited port to the non-excited port.

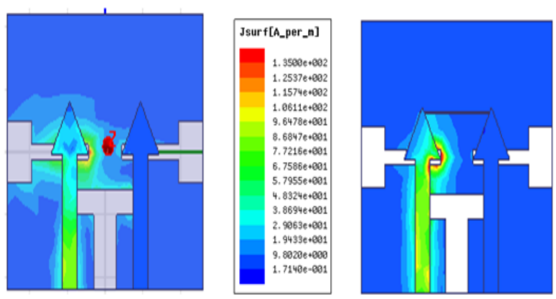

Fig.10.Current distributions on MIMO antennas C and D at 3GHz.

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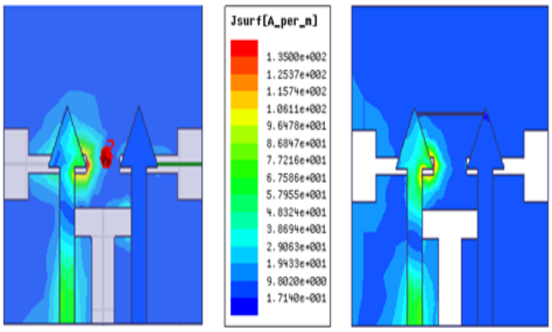

Fig.11.Current distributions on MIMO antennas C and D at 5 GHz.

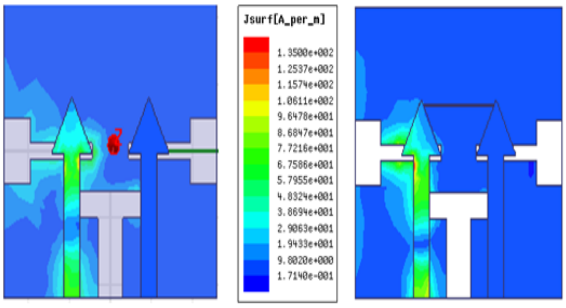

Fig.12.Current distributions on MIMO antennas C and D at 7 GHz.

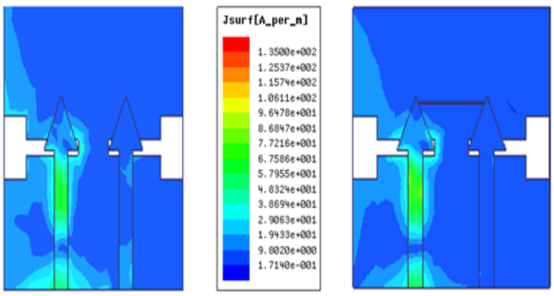

Fig.13.Current distributions on MIMO antennas with and without neutralization line at 10 GHz.

When one of the two adjacent MIMO antennas radiates (or gets excited), it induces some currents on its neighbour, which increases their mutual coupling and correlation values. In this design port 1 is excited, while the port 2 is terminated with a 50- load. For antenna with neutralization line, the coupled currents distribution on non-excited antenna element is smaller comparing to antenna without neutralization line.

IV. RESULTS AND DISCUSSIONS

The proposed antenna with the ground plane structures is simulated using the commercial software HFSS, which is commercial electromagnetic structures solver that uses finite element method.

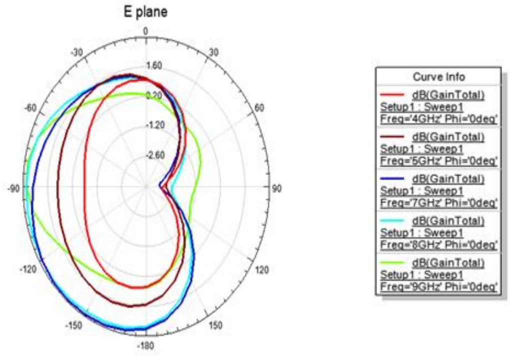

Fig.14. E plane radiation pattern of arrow shaped UWB MIMO antenna at various frequencies

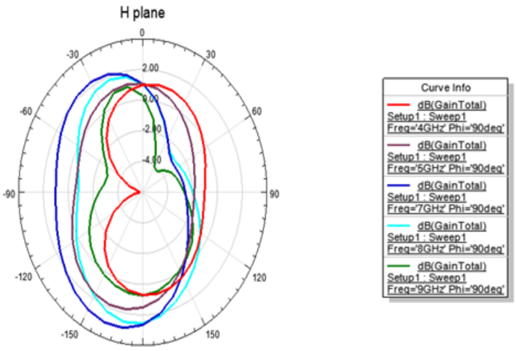

Fig.15. H plane radiation pattern of arrow shaped UWB MIMO antenna at various frequencies.

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. When the return loss was measured, port 1 is excited, while the port 2 is terminated with a 50- load. According to the simulated results, S 11 (Return loss) is found to be less than -10 dB from 3.18GHz - 11GHz. And isolation of less than -19.2 dB achieved entire band which better than the isolation of antenna proposed with compact size.

Simulated E plane and H plane radiation patterns are shown in Fig. 14 and Fig. 15 at frequencies of 4,5,7,8 and 9 GHz which are nearly Omni directional pattern. And 3D radiation patterns of the antenna shown in Fig. 16.

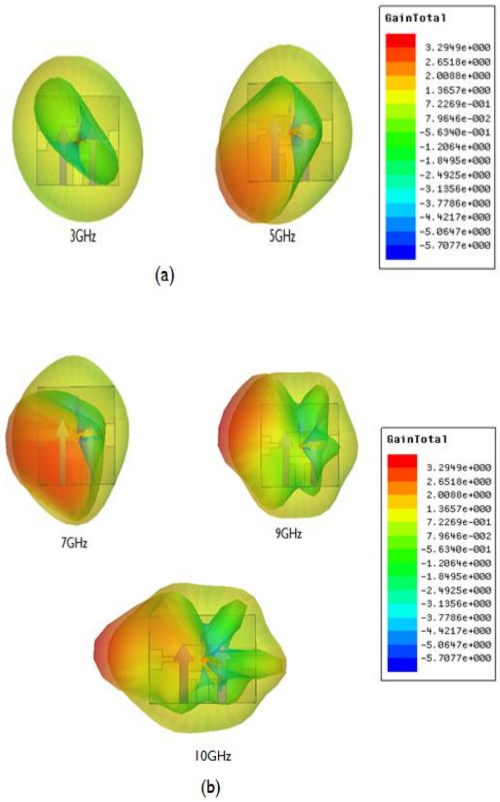

Fig. 16 (a) (b) 3D radiation pattern of arrow shaped UWB MIMO antenna at different frequencies

The antenna gain has been simulated and plotted in Fig 17. It can be seen that the simulated peak gains range from 1dB to 4.3 dB entire frequency band from 3.18GHz to 10.6 GHz in the UWB. In this antenna, the maximum gain is 4.5dB. We can clearly see from the Fig.17 that the gain of an antenna keeps on increasing with respect to the increasing values of the frequency.

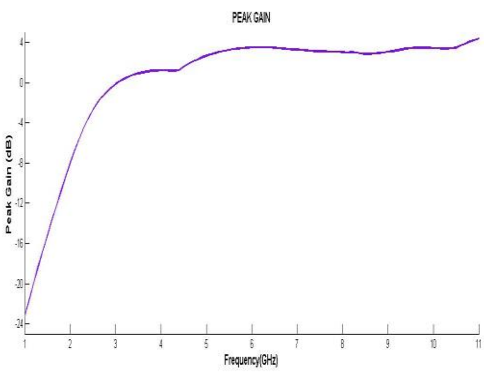

Fig.17. Simulated Gain of Arrow shaped MIMO antenna.

As we can clearly see from the Fig.18, the antenna has more than 89% of radiation efficiency entire UWB. That means 89%of power present at the antenna's input radiated away. Remaining 11% of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch.

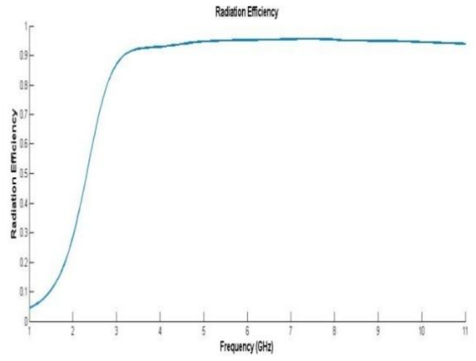

Fig.18. Simulated Gain of Arrow shaped MIMO antenna.

In order to verify the performance of proposed antenna for MIMO application, it is necessary to achieve a low envelope correlation coefficient (ECC). An envelope correlation coefficient value of 0.5 has been set as an acceptable value for diversity conditions [12].

ECC can be calculated using the following equation,

$$ECC = \rho_e = \frac{|S_{11}^{*}S_{12}+S_{21}^{*}S_{22}|^2}{(1-(|S_{11}|^2+|S_{21}|^2))(1-(|S_{22}|^2+|S_{12}|^2))} \quad (5)$$

The proposed arrow shaped UWB-MIMO gives the envelope correlation coefficient below 0.0023 over the complete UWB frequency band shown in Fig.19.

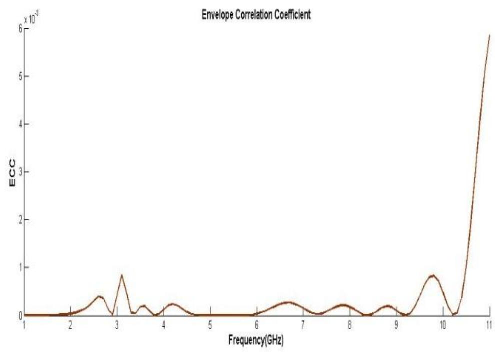

Fig.19. Simulated ECC of Arrow shaped MIMO antenna.

TARC is defined as the ratio of the square root of the total reflected power divided by the square root of the total incident power in a multiport antenna system.

TARC can be calculated using S parameters by following equation,

$$TARC = \frac{\sqrt{((|S_{11}+S_{12}e^{j\theta}|^2)+(|S_{21}+S_{22}e^{j\theta}|^2))}}{\sqrt{2}} \quad (6)$$

TARC has a value between 0 and1, where a 0 means all power was radiated, whereas a 1 means all incident power was reflected and nothing was radiated. TARC of the antenna is shown in Fig.20 which is below 0.36 over the entire UWB.

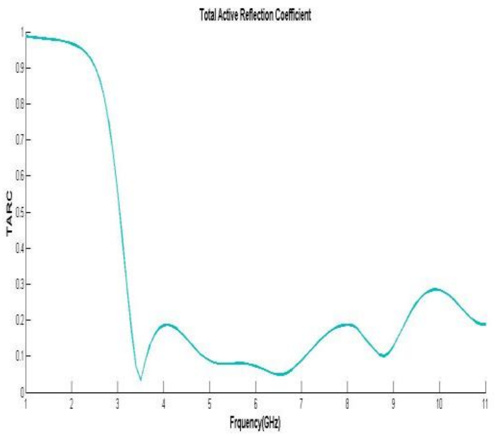

Fig.20. Simulated TARC of Arrow shaped MIMO antenna.

IV.CONCLUSION

In this letter, an arrow shaped UWB-MIMO antenna has been proposed. By implementing the proposed T shaped slot and a line slot in the ground plane of the antenna, the performances in terms of impedance bandwidth and isolation can be increased significantly. Analysis results show that the designed MIMO antenna provides high isolation and keeps omnidirectional radiation performance an entire UWB bandwidth successfully. The performance of the proposed compact antenna system with DGS is analyzed and it is found suitable for portable MIMO applications.

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