REDUCING MUTUAL COUPLING FOR A SQUARE UWB MIMO ANTENNA USING VARIOUS PARASITIC STRUCTURES

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Abstract

In this study, a compact ultra-wideband (UWB) multiple input multiple output (MIMO) antenna system is designed for mobile terminals. The antenna system consists of two symmetrical 8x8 mm^2 square antenna elements fed by a 50 Ohm microstrip transmission line (MTL). The UWB MIMO antenna operates at large frequency range of 2.5–13.3 GHz with an isolation level of about 9 dB less than 5 GHz and 15 dB greater than 5 GHz in average. In fact, the isolation level is almost sufficient for MIMO operation especially for high frequency. Nevertheless, various techniques are then investigated, and additional parasitic structures (PSs) such as monopole, V-shaped, plus-shaped, T-shaped PSs and neutralization line are thus designed on the square UWB MIMO for further reducing the mutual coupling. Among the PSs, T-shaped PS shows better return loss and isolation performance. Moreover, the proposed UWB MIMO antenna with T-shaped structure is investigated in terms of resonant bandwidth, radiation pattern, peak gain and envelope correlation coefficient (ECC). According to the results, the compact MIMO antenna has nearly omnidirectional patterns, stable gain and better diversity performance.

Keywords: Antennas, printed antennas, MIMO antennas, UWB antennas, mutual coupling, mobile terminals.

1. Introduction

Ultra-wideband (UWB) systems have been received a growing interests due to the successful applications of high throughput, multimedia streaming, radar and biomedical imaging [1]. Federal Communications Commission (FCC) has approved the use of the frequency range of 3.1–10.6 GHz without license for low power emitting systems [2]. The UWB systems operate over a wide bandwidth with low spectral power level. The signal to noise ratio (SNR) is hence too low at the receiver. The throughputs of the systems have been also extremely increased thanks to the recent developed data coding techniques. However it has been almost restricted, since the emitted signals are inherently subjected to interference and multipath fading in propagating environments [3]. The transfer rate can be excessively increased and the fading effects can be reduced by utilizing multiple input multiple output (MIMO) concept because of introducing spatially multiplexing and diversity [4].

Designing MIMO systems with multiple antenna elements for mobile terminals has been more difficult since the mobile terminals have been towards to be smaller, and thus MIMO antenna elements must be accommodated in these constricted terminals with the other electronic components. At the same time, the elements are inevitably exposed to high mutual coupling among them, because of operating closely each other. Mutual coupling must be minimized to isolate the channels electrically to provide an efficient MIMO system. In order to avoid the mutual coupling, a distance of λ/2 should be leaved between the elements or additional geometric modification such as orthogonally positioning the elements [5], designing parasitic structure (PS) [6], inserting neutralization-line (NL) [7], shorting pin [8] and loading slots [9] should be performed on the antenna geometry. Note that designing these additional geometries together with MIMO elements needs extra considerable efforts. Antenna designers should design additional structures to reduce the mutual coupling between antenna elements. Therefore, investigating and comparing PS or NL with different shapes are important researches and will help the antenna design.

In this study, a low-profile dual-port square UWB MIMO antenna systems for mobile terminals is designed, and then PSs are investigated for this system to reduce the mutual coupling between the antenna elements. The MIMO antenna each of which element is 8x8 mm^2 operates over a large frequency range of 2.5–13.3 GHz for UWB applications. Each element is fed through a 50 Ohm microstrip transmission line (MTL) with a strip line to provide impedance matching. In fact, the isolation level between the two elements is almost sufficient for MIMO operation, PSs with various shapes are formed to further decouple the antenna elements especially for low frequency. The antenna systems are designed and modelled by using a computer-based software HyperLynx® 3D EM simulator incorporated with computational electromagnetic (CEM) [10] of method of moment (MoM) [11]. It is a powerful and effective CEM tool for patch antenna giving very close results to measurement [12]. The antenna’s characteristics such as S-parameters, radiation pattern, peak gain and envelope correlation coefficient (ECC) [13] are investigated by the simulations.

2. Square UWB MIMO Antenna Structure

The three dimensional (3D) structure of UWB MIMO antenna system with square elements is illustrated in Figure 1. The antenna system consists of two symmetrical square elements each of which is 8x8 mm^2 for the UWB applications. Each element is fed via a 50 Ohm MTL with 29.5 mm length, and a 1 mm width strip line with 6.5 mm length is inserted between the square element and MTL for impedance matching. The system is modelled on 50x42 mm^2 FR4 mobile PCB of which dielectric permittivity, tangent loss and thickness are 4.4, 0.02 and 1.6 mm, respectively. The antenna geometry is fine-tuned by genetic algorithm (GA) [14] in optimization module integrated with HyperLynx® 3D EM. The simulated S-parameters are plotted in Figure 2. The antenna operates over the frequency range of 2.5–13.3 GHz at the level of about15 dB return loss. The isolation is also about 9 dB up to 5 GHz and approximately15 dB after 5 GHz. Although it is almost sufficient for UWB over the whole band. However, it should be reduced at low frequency for efficient MIMO operation.

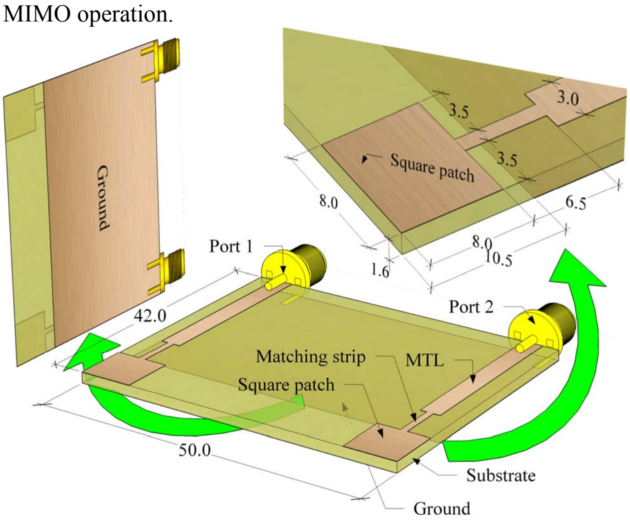


Fig. 1. 3D structure of the square MIMO antenna systems (unit: mm)

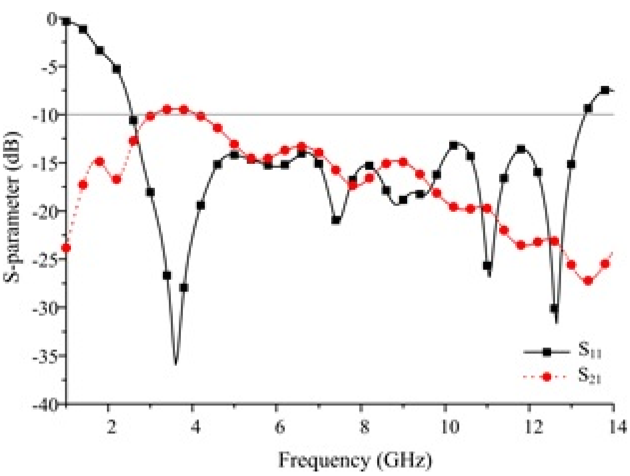


Fig. 2. S-parameters of the square UWB MIMO antenna

3. Design of PSs for Mutual Coupling Reduction

The isolation level of MIMO antenna without any additional structure is almost adequate specifically for high frequency. It does not need at higher frequency because of short wavelength at that frequency. Aforementioned isolation techniques such as designing PS, inserting NL, shorting pin and loading slots are essayed to further enhance the isolation. It is seen that PSs on the ground give more successful results. Hence various potential additional structures such as monopole, V-shaped, plus-shaped [15], T-shaped [16] PSs and NL [7] have been modelled on the square UWB MIMO design illustrated in Figure 3. These are the most employed and potent PSs for reducing the mutual coupling. They are designed and optimized through HyperLynx® 3D EM with GA. The structures with dimensions are placed in the middle of the antenna elements for achieving the same channels. It should be noted that the PSs decouple the antenna elements by creating an alternative path on the ground to reduce the mutual current. On the other hand, the NL inverts the phase of the current when the current pass through the NL from one element to the other. In this wise, some mutual coupling current can be neutralized on it. At this time, selection of the location of the NL becomes importance. In our NL implementation, its location is optimized to achieve the best performance.

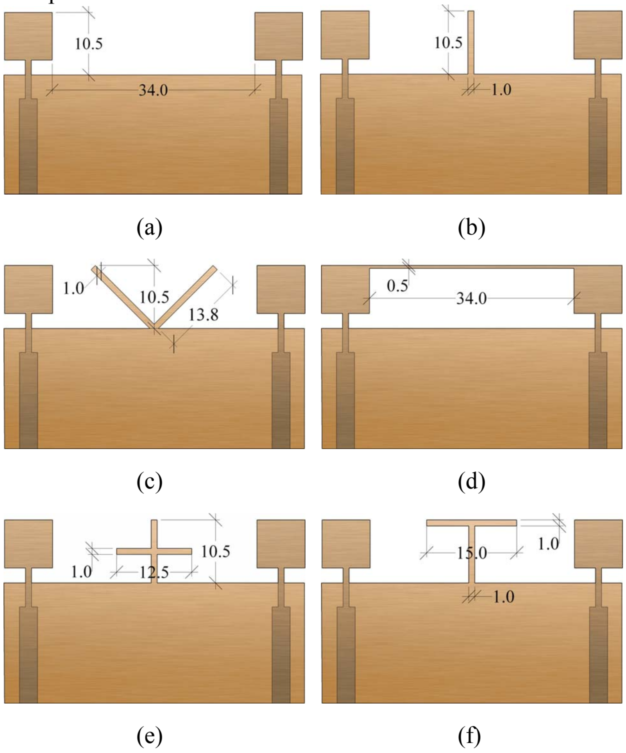


Fig. 3. Geometries of the additional structures on the square MIMO antenna system: a) without any structure; with b) monopole, c) V-shaped, d) NL, e) plus-shaped, f) T-shaped structures (unit: mm)

4. Comparison of the PSs

The impacts of the additional structures on the scattering parameters are investigated in Figure 4. S_{11} and S_{21} parameters are only considered because of symmetricity. Positive S_{11} represents return loss while positive S_{21} stands for isolation level. For efficient MIMO operation, they should higher than at least 10 dB. They are compared with the UWB MIMO antenna without any structure. To appreciate the impact of the additional structure in comparison, not only isolation level but also return loss should be taken into consideration. The performance of the additional structure in terms of bandwidth, return loss and isolation levels is studied and the results are tabulated in Table 1.

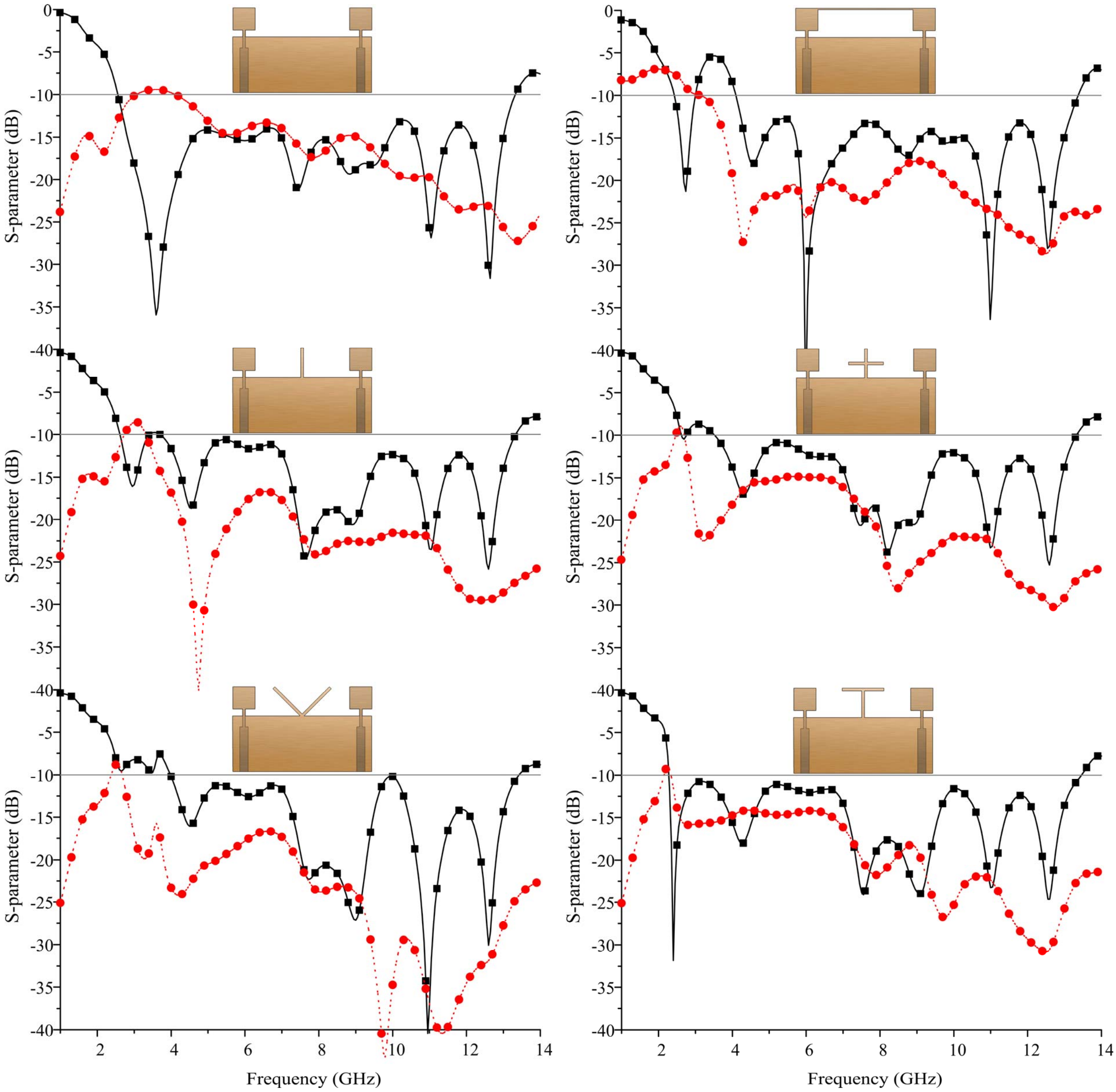


Fig. 4. S-parameters of the UWB MIMO antenna with various additional structure (black solid line for S_{11}, red dot line for S_{21})

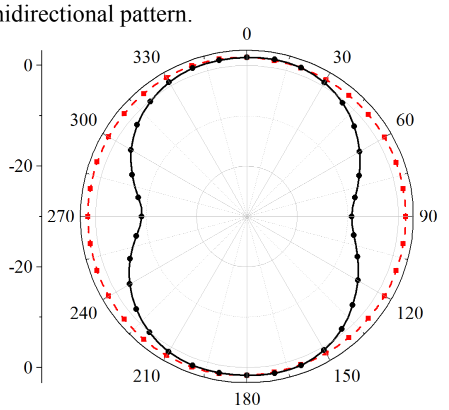
Table 1. Bandwidth, return loss and isolation results of the UWB MIMO antenna with and without additional structure.

Geometry of PS	Bandwidth (GHz)	Return loss				Isolation			
		Frequency range less than 10 dB (GHz)	Min. level (dB)	Max. Level (dB)	Avg. (dB)	Frequency range less than 10 dB (GHz)	Min. level (dB)	Max. Level (dB)	Avg. (dB)
–	2.5-13.3	–	13	35	15	3.0-4.2	9.4	23	17
Monopole	2.6-13.3	3.4-3.7	9.7	25	12	2.7-3.3	8.5	35	20
V	4.0-13.3	–	10	35	13	–	16	35	21
NL	2.4-13.3	3.0-4.1	5.3	35	15	2.4-3.2	7.5	28	20
Plus	2.6-13.3	2.7-3.5	8.5	25	13	–	15	30	20
T	2.3-13.3	–	11	32	14	–	14	30	20

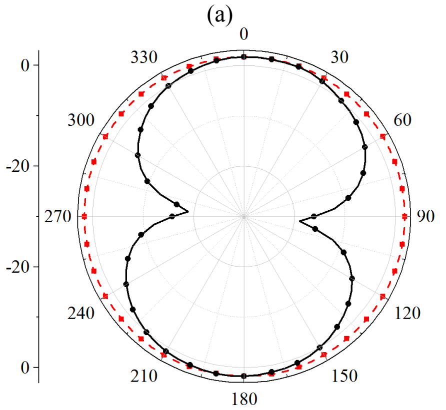
All structures keep the overall bandwidth about 2.5-13.3 GHz, except V-shaped structure partly derogates the bandwidth. As the monopole slightly improves the isolation level, it reduces the return loss about 3 dB. V-shaped structure successfully enhances the isolation at satisfactory result, unfortunately it deteriorates the return loss and thus reduces the bandwidth. NL also increases the overall isolation level, however it decreases the bandwidth as V-shaped structure. Plus-shaped structure increase the isolation to a satisfactory level. On the other hand, it has negative effects on the return loss performance and it is decreased about 2 dB as well as it exceeds the 10 dB at 2.7-3.5 GHz. As a results, T-shaped structure is successful for both return loss and isolation at the full band of the antenna. Nevertheless, monopole, V-shaped, NL and plus-shaped structures are can be used for mutual coupling respectively at greater than 3.7 GHz, 4 GHz, 4.1 GHz and 3.5 GHz.

5. Performance Study of the UWB MIMO Antenna with T-Shaped Structure

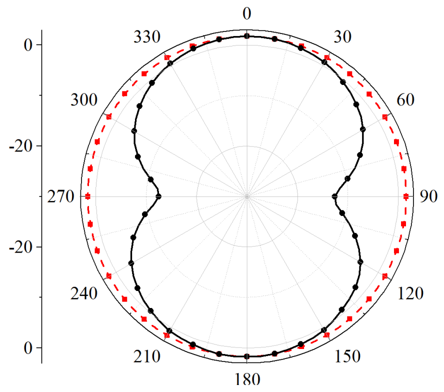
Performance analysis of the UWB antenna with T-shaped structure such as radiation, peak gain, ECC is presented in this section. Two dimensional (2D) radiation absolute gain patterns on x–z and y–z planes at the frequency points of 3.5, 7.0 and 10.5 GHz are displayed in Figure 5. Since the two elements show similar patterns, the result of Element 1 is merely considered for the sake of simplicity. From the figure, maximum gains are 1.87 dB (in direction of 330° at 3.5 GHz), 1.8 dB (in direction of 165° at 7.0 GHz) and 1.75 dB (in direction of 210° at 10.5 GHz) on x–z plane. Likewise, they are 1.62 dB (in direction of 10° at 3.5 GHz), 1.74 dB (in direction of 185° at 7.0 GHz) and 1.72 dB (in direction of 175° at 10.5 GHz) on y–z plane. The radiation shows nearly omnidirectional pattern.



(a)



(b)



(c)

Fig. 5. Simulated patterns of the square MIMO antenna with T-shaped structure: a) 3.5 GHz, a) 7.0 GHz, c) 10.5 GHz (red dash line is on x-z plane, black solid line is on y-z plane)

Figure 6 indicates the peak gain accompanying the ECC of the MIMO antenna. The peak gain varies between -0.1 dBi and 5.9 dBi levels across the interested frequency bands of 2.5–13.3 GHz ; whereas maximum and minimum gain occur 5.9 dBi and -0.1 dBi at 4.25 GHz and 13.0 GHz, respectively. The ECC is kept less than 0.2 which is much lower than the isolated channels criteria of 0.5 [17] over the operating band.

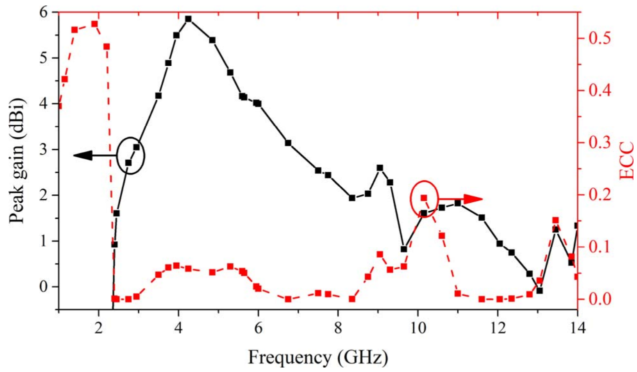


Fig. 6. The simulated peak gain and ECC variations

6. Conclusions

A low profile UWB MIMO antenna system operating between 2.5 GHz and 13.3 GHz for mobile terminals is formed in this study. The antenna design is composed of two symmetrical 8x8 mm^2 square antenna elements fed with 50 Ohm MTL. The proposed antenna is printed on 42x50 mm^2 double layer copper 1.6 mm FR4 material. The antenna’s isolation level is about 9 dB up to 5 GHz and 15 dB beyond 5 GHz. The isolation level is indeed almost enough for MIMO operation especially for high frequency. To further reduce the mutual coupling, several modification techniques are then tested and it is seen that additional PSs are more successful in reducing mutual coupling. Then various PSs like monopole, V-shaped, plus-shaped, T-shaped PSs and NL are constructed on the square UWB MIMO. T-shaped additional structure successfully improves not only return loss but also isolation level. Note that these results are valid for the proposed UWB MIMO design, different results can be obtained for another MIMO structures. The UWB MIMO antenna with T-shaped structure are investigated in terms of important antenna parameters of resonant bandwidth, radiation pattern, peak gain and envelope correlation coefficient (ECC). From the result, the MIMO antenna with T-shaped structure has nearly omnidirectional patterns, stable gain between -0.1 dB and 5.9 dB and better ECC performance less than 0.2.

7. Acknowledgment

This study is supported by the Scientific Research Fund Department of Karamanoglu Mehmetbey University under grant no: 01-M-17.

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