Mutual Coupling Reduction Between Patch Antenna and Microstrip Transmission Line by Using Defected Isolation Wall

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Abstract **─** A mutual coupling reduction method for closely installed patch antenna (PA) and microstrip transmission line (MTL) is proposed by means of defected isolation wall structure (DIWS) which is comprised of a metal patch with periodically G-shaped structure and two dielectric substrate sheets set on both sides of the metal patch. The DIWS model, design procedure and investigation on its stop filtering characteristics are presented. Also, the dominant parameters of DIWS are discussed in order to flexibly adjust the stop band to meet the frequency band that we are interested in. Finally, the optimized DIWS is installed on the closely set PA and MTL with a distance of 2 mm to suppress the mutual coupling. The proposed structure is fabricated and measured to verify the simulation results which demonstrated that a high isolation of 27 dB and 37 dB between the antenna and MTL are achieved, respectively.

Index Terms **─** Antenna and microstrip transmission line, band stop filtering, coupling reduction, DIWS.

I. INTRODUCTION

With the proliferation of mobile electronic products and ongoing push for great functionality in a small area, miniaturization has become a key technique for many wireless communication devices. Inevitably, the density of internal elements increases, which easily cause the coupling and interference between elements. For well transmitting and receiving radio wave, antenna is almost omnipresent in most wireless communication products. Moreover, with the development of the miniaturization for wireless communication device, internal printed antenna (PA) gradually has been widely chosen instead of the external antenna [1-2]. Thus, closely spaced PA and microstrip transmission line (MTL) can be found in many microwave systems, leading to inevitable mutual coupling which probably causes performance degradation of the system.

In fact, mutual coupling problem has attached much attention in the field of signal processing [3-5], MIMO antenna arrays and electromagnetic capability [6]. In MIMO antenna array, the presence of mutual coupling will affect its radiation patterns and input characteristic, which probably degrades the performance of the antenna array [6]. In the field of electromagnetic compatibility (EMC), the undesired coupling between MTLs is one of the main issues for signal integrity. Electromagnetic coupling between tightly spaced lines will degrade the performance of the circuit or give interference to close lines, which has become an important issue that draws lots of attention in high-speed circuit design. Consequently, a large amount of coupling reduction methods have been proposed and investigated in literatures. Techniques concerning on reducing the mutual coupling between antenna array mainly based on: (i) field cancellation method which introduces an indirect coupling field to cancel out the original direct coupling field to reduce the mutual coupling, such as neutralization line [7-10], and U-shaped microstrip line in [11]. (ii) band-stop filtering method, such as electromagnetic band gap structure (EBG) [12-16], metamaterial structure [17-18], defected ground structure (DGS) [19-20], planar soft surfaces [21-22] and so on. Although these band-stop resonate structures are effective for coupling suppression, most of them have a complex structure and need a large space, which makes it difficult to implement practically. (iii) decoupling network [23-26], which is similar to field cancellation method, but its indirect coupling field is introduced by antenna feeding network rather than independent structure. For crosstalk reduction between adjacent MTLs, various methods

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have also been introduced and investigated in [27-30], such as increasing the distance between adjacent lines, reducing parallel lines, and defected microstrip structure (DMS). Some of these methods are hard to accomplish, and the complex structure will increase the overall size of the system. Moreover, unlike the existing decoupling techniques applied in antenna array and coupled MTL, decoupling technique used in adjacent antenna and microstrip transmission line is much more challenging. In order to suppress the mutual coupling, it is necessary to make a tradeoff between the antenna performance and MTL signal integrity to make the isolation better than -20 dB or more.

In this article, a simple and effective method based on band-stop filtering technique is proposed and investigated to reduce the mutual coupling between the antenna and the transmission line which might happened in the system integration like the compact terminals and the portable devices because there are antennas and the microstrip lines. The proposed defected isolation wall structure (DIWS) is comprised of a vertical metal wall with periodical G-shaped structure and thin dielectric slabs on each side. Simulation results depict that the proposed DIWS can provide a band-stop filtering characteristic with an adjustable operating frequency band, which attributes to the fact that the transmission of energy is rejected. By installing the DIWS vertically between the closely spaced PA and MTL, the mutual coupling is effectively suppressed in the operating frequency band of the antenna, and a maximum reduction of 25 dB is obtained without sacrificing the performance of the PA and MTL.

II. MODEL AND PERFORMANCE OF THE DESIGNED DIWS

The designed DIWS is presented for mutual coupling reduction between closely spaced PA and MTL. The design DIWS model and its analysis are presented in detail. The configuration of the presented G-shaped DIWS is shown in Fig. 1. The proposed DIWS comprises of a thin metal with three periodical G-shaped structure and two Polyflon NorCLAD dielectric substrates loading on both sides of the metal. The two dielectric substrates have a same thickness of 0.2 mm and permittivity of 2.55. In addition, the metal and two dielectric substrates have a same dimension of $w \times l = 18 \times 4.7$ mm^2.

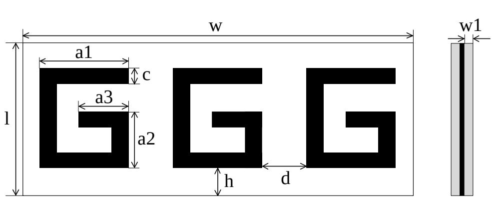


Fig. 1. The configuration of the proposed DIWS: front view and side view.

To study the electromagnetic characteristic of the proposed DIWS, a MTL printed on a FR-4 dielectric substrate is designed and modeled, where the DIWS is installed in the middle of it, and the configuration is shown in Fig. 2. The MTL is a typical 50 Ohm microstrip line printed on a FR-4 dielectric substrate whose dielectric substrate is 1.6 mm. Modeling and simulation analysis of this structure is implemented by utilizing high frequency structure simulator (HFSS). The energy is injected from port 1, and the port 2 is output. In Fig. 3, the S parameters shows a band-stop response between 4.8 GHz and 5.6 GHz. By installing the proposed DIWS in the 50 Ohm microstrip line, there is a band stop characteristic happened, which is given in Fig. 3. To understand the mechanism of decoupling intuitively, the current distribution at 5.2 GHz is given in Fig. 4. From the current distribution, we can see that the current is mainly distributed on the input port of the microstrip line.

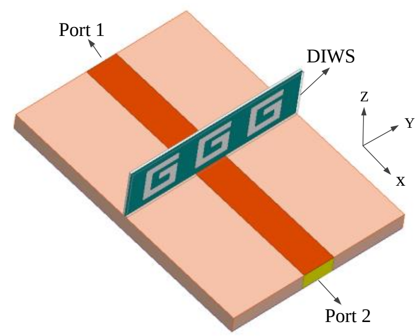


Fig. 2. The MTL loaded DIWS.

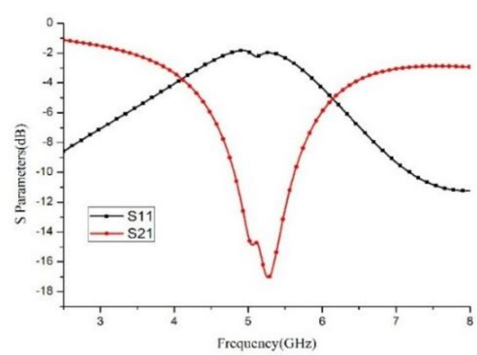


Fig. 3. S parameters of the microstrip transmission line loaded DIWS.

After the DIWS, there is almost no current because the current at the operating frequency is effectively rejected by the DIWS loaded in the middle of the transmission line. Thus, the DIWS can block the electromagnetic wave from the PA to the MTL. The band stop characteristic created by the periodical G-shaped DIWS can be used to reduce the mutual coupling between the PA and MTL. The band stop characteristic is realized by means of the DIWS, which is mainly introduced by the metal plate with G-shaped slots. Since the slots and strips act as capacitor and inductor, respectively, the current at the resonance frequency will be block by this filter, which can help to isolate the propagation between the antenna and the MTL, and the resonant frequency can be adjusted by changing the dimensions of G-shaped elements (GSEs) and distance between GSEs.

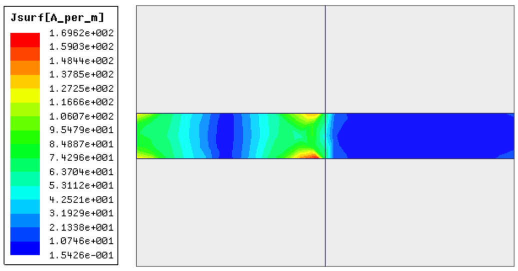
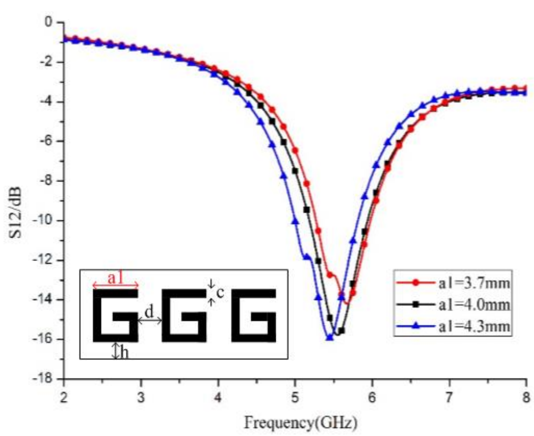
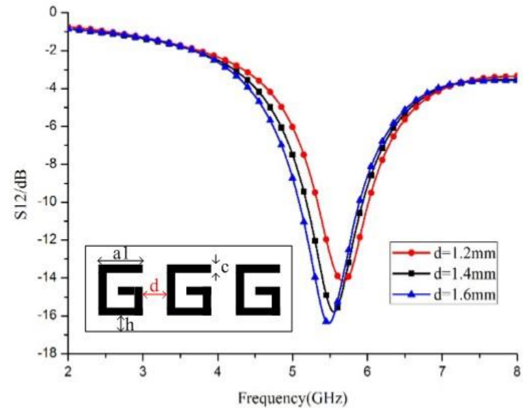


Fig. 4. Current distribution (at 5.2GHz) of the microstrip transmission line loaded with DIWS.

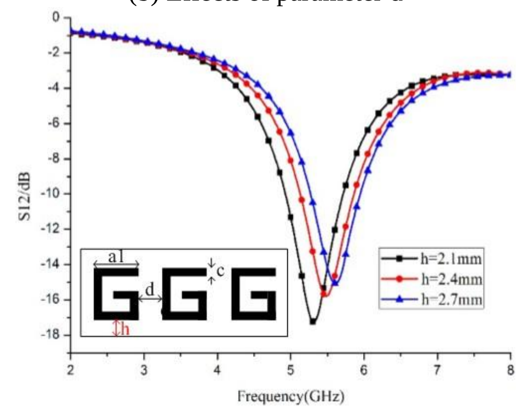
In order to flexibly adjust the stop band of DIWS to meet the frequency band we are interested in, its key design parameters are studied herein. The distance *d* between the GSEs and the distance *h* between the GSEs and the bottom edge of DIWS are selected to discuss the effects. From Fig. 5 (a), we can see that the resonance frequency decreases as the capacitance decreases, resulting in that the center frequency of the stop band moves to higher frequency as the length of GSE *a1* decreases. As shown in Fig. 5 (b), when the distance *d* between GSEs is increased, the equivalent inductance decreases, which renders that the center frequency shifts toward higher frequency. Meanwhile, the in-band attenuation decreases. Similarly, when the distance *h* is decreased given in Fig. 5 (c), the center frequency of the DIWS moves to the high frequency.



(a) Effects of parameter a1



(b) Effects of parameter d



(c) Effects of parameter h

Fig. 5. Effects on the band stop characteristic of DIWS.

From the responses and results analysis, we can draw a conclusion that the center frequency of stop band for DIWS is mainly determined by *a1*, *d* and *h*. Thus, we can adjust the resonance frequency of the proposed DIWS to meet the coupling reduce between PA and MTL.

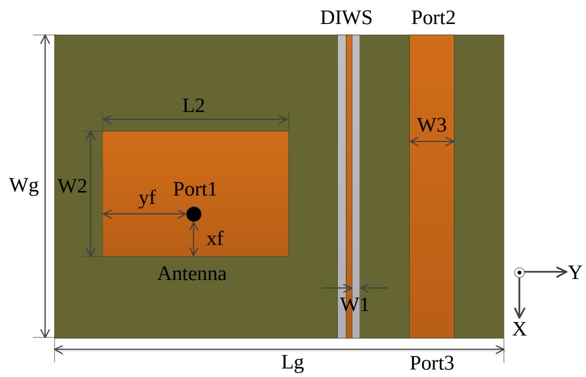
III. PERFORMANCE OF THE PROPOSED STRUCTURE

The proposed DIWS is eventually used to reduce the mutual coupling between the closely spaced PA and MTL, which is shown in Fig. 6. Herein, the PA is designed to operate in a WLAN sub-band (5.725-5.825 GHz). The original dimension of PA is given by the following equations:

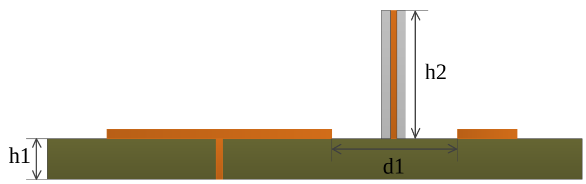
$$L2 = \frac{c}{2f_0}\frac{1}{\sqrt{\varepsilon_e}} - 2\Delta L, \quad W2 = \frac{c}{2f_0}\left(\frac{\varepsilon_r+1}{2}\right)^{-1/2}. \tag{1}$$

The feed point is also calculated based on empirical formulas. The final dimensions of the PA are 15 × 11.65 mm^2. Meanwhile, the MTL is a typical 50 Ohm microstrip line which can be regularly seen in many microwave circuits. The distance between the PA and MTL is 2 mm. Due to this small distance, the radiation from the antenna and surface current will inevitably cause strong mutual coupling to the MTL. Therefore, the proposed DIWS is considered as a coupling reduction structure to suppress the mutual coupling because it can provide a band stop characteristic that reject electromagnetic energy in a specific frequency band.

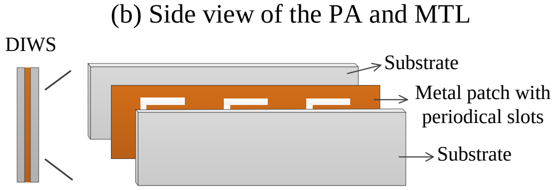
As a result, the proposed DIWS equivalently behaves to be a band stop filter which is installed on the coupling path between the PA and MTL. Since the resonance frequency of the proposed DIWS can be adjusted by properly selecting its dimensions, we adjust the dimensions of DIWS to provide a band stop characteristic at the frequency band of the PA. The optimized dimensions obtained from the sweep analysis of the HFSS are given as: w = 18 mm, l = 4.7 mm, w1 = 0.2 mm, a1 = 3.4 mm, a2 = 2.3 mm, a3 = 2 mm, h = 2.1 mm, d = 2.5 mm.



(a) Top view of the PA and MTL



(b) Side view of the PA and MTL



(c) View of the DIWS

Fig. 6. PA and MTL with the proposed DIWS.

The S-parameters with/without the proposed DIWS are given in Figs. 7 and 8. Here, mutual coupling between the PA and MTL are measured by S21 and S31, respectively. In fact, the isolations are better than -20dB, which is helpful for practical engineering applications.

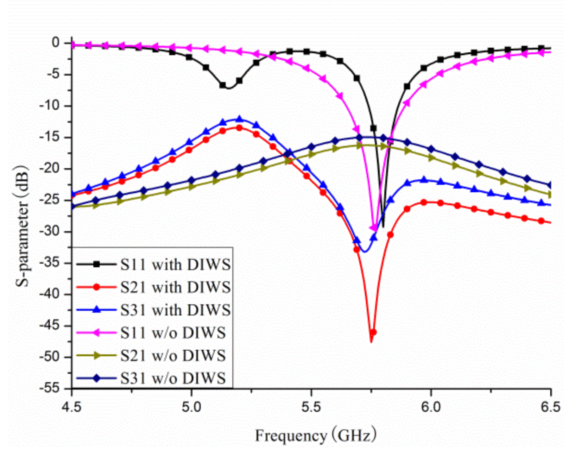


Fig. 7. S-parameter with/without DIWS.

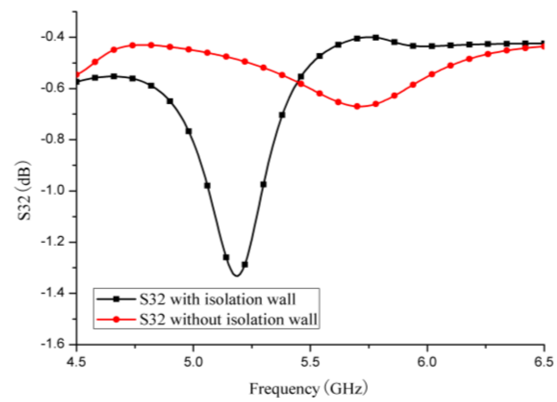
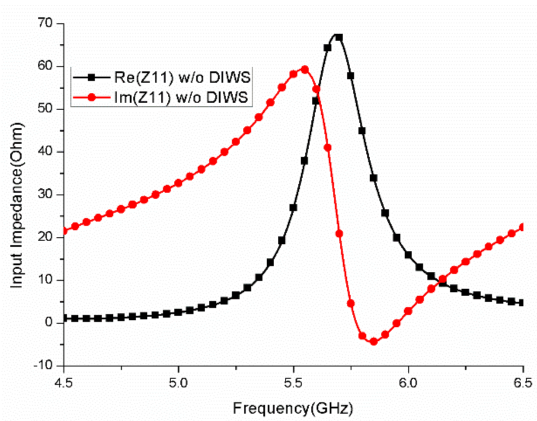
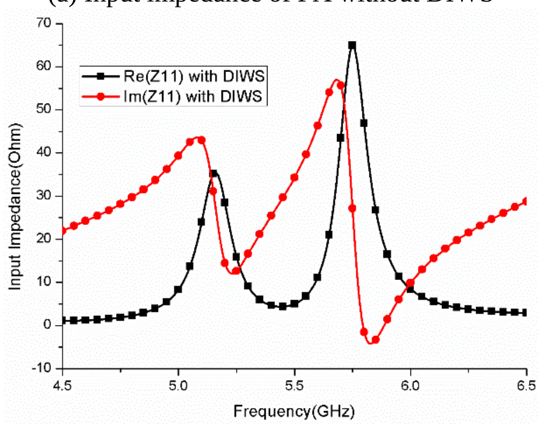


Fig. 8. S32 with/without DIWS.

It can be seen that S21 is reduced by 33dB and S31 is reduced by 18dB at operating frequency band by loading the proposed DIWS, and the center frequency of the PA is slightly shifted towards higher frequency. It is verified that the proposed DIWS can efficiently reduce the mutual coupling. Moreover, from the S32 (transmission coefficient of the MTL) shown in Fig.8, we can see that there is a decrease at low frequency band by loading the proposed DIWS. However, S32 is still less than -3 dB at the operating band, which means that almost all the energy is transmitted from the input port to the output port. It is noted that the proposed DIWS has a little effect on the transmission characteristic of the MTL. Moreover, the comparison of input impedance of PA is given in Fig.9. It is found that there is a resonance in low frequency with DIWS, which is produced by the effects of the DIWS. This is because the mutual capacitance and mutual inductance generated by the strong coupling between PA and DIWS.



(a) Input impedance of PA without DIWS



(b) Input impedance of PA with DIWS

Fig. 9. Comparison of the input impedance (Z11) of PA with/without DIWS.

IV. EXPERMENTAL RESULTS

In this section, the measurement results are presented and compared with the simulation results. Figure 10 shows the fabricated structure of proposed PA and MTL with DIWS loading. The dimension of patch antenna is 15 × 11.65 mm^2. The width of signal line (designed for 50 Ω) is $w2$ = 3.13 mm and the length is l = 18 mm. The PA and MTL are printed on a FR4 substrate with relative permittivity of 4.4 and thickness of 1.6 mm. The distance between coupled PA and MTL is $d1$ = 2 mm. In this design, the optimum dimensions of DIWS are the same as that given in section 3. The measurement results are obtained using network analyzer (Agilent N9923A).

Experimental results are given for the proposed closely coupled PA and MTL with/without DIWS from 4.5 GHz to 6.5 GHz. The measured and simulated results are compared in Fig. 11. It is found that the coupling is reduced, where the measurements agree well with the simulations. The isolation improvements between input port of PA and two ports of MTL are 27 dB and 37 dB, respectively. It is also worth noting that the measured center frequency shifts to lower frequency, which might be caused by the fabricated bias. The comparisons of radiation patterns with and without DIWS are given in Fig. 12. We can see the measured results agree well with the simulation results overall. Although there are some discrepancies, the PA still has a good direction radiating in the operating band.

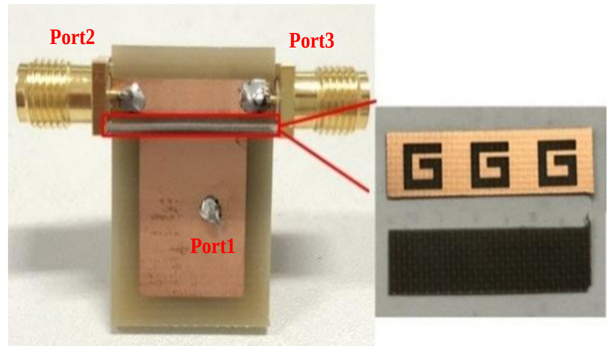


Fig. 10. Fabricated closely PA and MTL with DIWS.

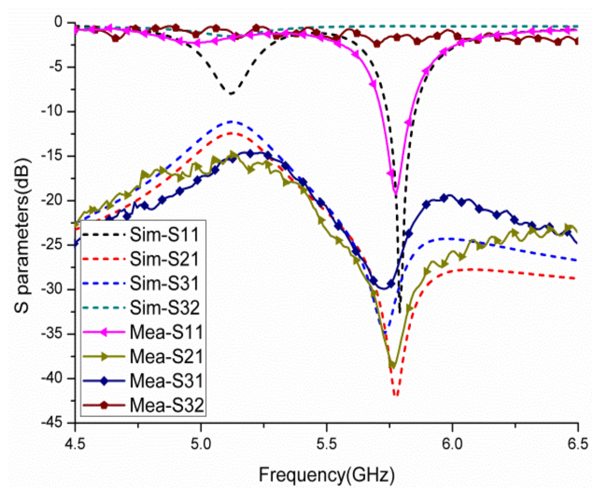
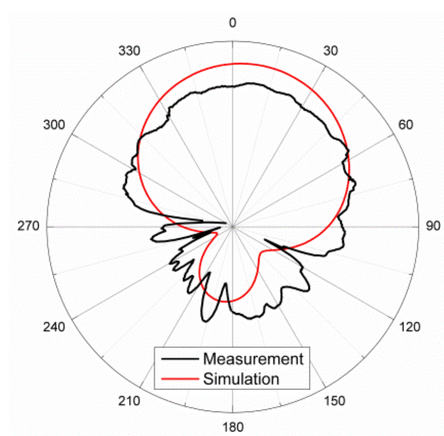
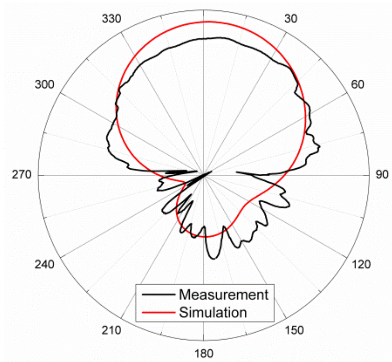


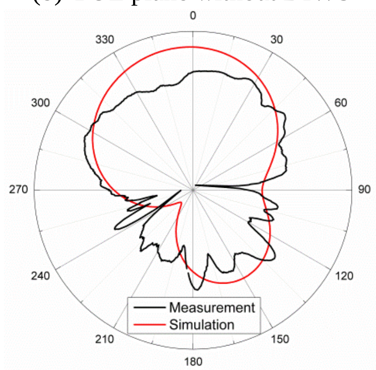
Fig. 11. Simulation and measured S parameters of closely PA and MTL with DIWS.



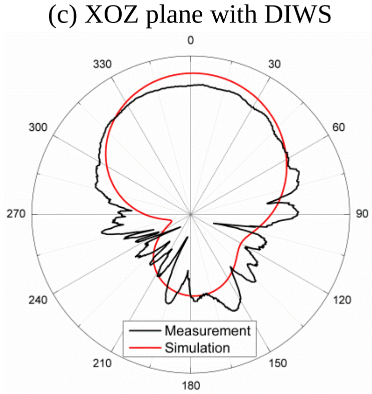
(a) XOZ plane without DIWS



(b) YOZ plane without DIWS



(c) XOZ plane with DIWS



(d) YOZ plane with DIWS

Fig. 12. Comparison between simulation results and measured results of radiation patterns of antenna with and without DIWS.

V. CONCLUSIONS

A DIWS has been devised for mutual coupling reduction between PA and MTL. The design procedure of the DIWS has been presented in detail by adjusting the key parameters. Then, the coupling reduction of the DIWS is investigated and verified when it is used in a closely set PA and MTL. The experimental results have been obtained and compared with the HFSS simulation results. The results showed that the isolations between PA and MTL are improved by 27 dB and 37 dB, respectively.

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