DESIGN OF HIGH ISOLATION DUAL-BAND MIMO ANTENNA USING SINGLE NEUTRAL LINE

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Abstract - A dual-band MIMO antenna with a high isolation is presented in this paper. The proposed MIMO antenna consists of two identical E-shaped micro-strip antennas which are designed on an FR4 substrate. The antenna is designed for radiating at 2.6 GHz and 5 GHz that can be used for the applications of 4G and 5G systems, respectively. Neutral line technique is used for mutual coupling reduction between the E-shaped antenna. Good isolation characteristics are obtained by using single micro-strip line connected between two elements of MIMO antenna. The antenna is fabricated and measured, and good agreement is achieved between the experimental and simulated results.

Key words - MIMO antenna; neutral line; mutual coupling; micro-strip antenna

1. Introduction

The advantage of 4G networks is that they can handle a large amount of data and are more complex than previous mobile systems. However, with the fast pace of technology development, in just a few years, 4G technology cannot meet. So wireless networks need to understand the features of each type of device and know how to respond to it. Therefore, the birth of a new generation of mobile information 5G is what will happen in the near future. The 5G information system will be a platform for innovation, which will change the industry as a whole with its powerful wireless connectivity. In addition to supporting the development of services and equipment, 5G also offers the ability to make the most of the spectrum. Previous generation information systems mainly operate in the frequency band permit less than 3GHz, but 5G is likely to increase this number significantly. 5G's ability to operate at such high frequencies poses a significant technological challenge, especially in the field of antennas [1]. Obviously, the existing antennas will not meet the high frequencies in the 5G system. Research and development of new antenna structures can be considered as an urgent need in the present time. In the world, there have been many proposed antennas for applications to next-generation mobile communications systems, namely 5G, which focus on the design of micro-strip antennas or PIFA antennas with dimensions compact, meet the good insulation and radiation at the appropriate frequency. A number of research results on antennas for typical 5G systems may be included in the studies [2-5], most of which focus on single antennas, only a few are studying about MIMO systems, further studies about MIMO antenna with most mutual reduction by methods changing the direction and the position. These methods have a big disadvantage, that is increasing the distance between the antennas to increase the size of the MIMO antenna system, which will cause the change of the antenna position and is hard to apply to designing antennas for devices in the system 5G, where almost all devices must meet the criteria of compact.

Besides, few different methods that help to reduce mutual coupling of MIMO antenna, have been proposed such as decoupling feeding network [6], parasitic element [7, 8] and defected ground structure [9, 10] and neutralization-line technique [11-13]. Regarding decoupling network, this technique can reduce the coupling coefficient efficiency using a properly lumped circuit put at between input ports of MIMO antenna. However, it is difficult to exactly calculate the parameters of decoupling circuit. Meanwhile, parasitic element is placed between the radiating elements of MIMO antenna to suppress almost the coupling near-field between elements of antenna. This technique is easier to apply for the MIMO antenna. Since these elements are inserted between antennas, it will lead to the increase in the overall size of MIMO. Defected ground structure (DGS) is also a helpful method for enhancing the port isolation of MIMO antenna. Nevertheless, the radiation characteristics of antennas can be affected by the cutting of slots in the ground plane. The complexity of these techniques will be increased since applied for the multi-band MIMO antenna.

This paper proposes a neutral line to perform the mutual reduction at both resonant frequencies with only single line. The neutral line technique allows reducing mutual but does not take up too much of the device space.

2. Elementary theory

MIMO antenna design is expected to have the ability to radiation at two frequencies, the first 2.6GHz frequency used to serve the application of 4G systems, frequency 5GHz second is provided for 5G information systems. MIMO antennas are designed to have high isolation coefficients; the interaction between the two antennas is significantly reduced by using the neutral line method.

Neutral line method provides the ability to reduce the interaction in a MIMO antenna effectively while integrating a neutral line on MIMO system is not too complicated and does not increase the size of the MIMO antenna. The proposed MIMO antenna will be designed in the following steps [14-16]:

- Step 1: Designing a rectangular micro-strip antenna that can operate at 5 GHz.

- Step 2: From the above rectangle antenna design, changing the antenna structure to create an E-band antenna capable of operating at two frequencies of 5 GHz and 2.6 GHz.

- Step 3: Implementing transplanting two micro-strip antennas that are designed at step 2 to form MIMO. Examining important parameters, which gives an assessment of the MIMO antenna performance before using neutral line.

- Step 4: Designing and integrating the neutral line into the above MIMO antenna. Adjust the parameters to achieve the desired results.

- Step 5: Fabricating and measuring S-parameters of the MIMO antennas with and without neutral line, comparing it with the simulation results to draw conclusions.

3. Antenna design

Firstly, we focus on designing and simulating single antenna that can operate at two frequencies of 2.6 GHz (applied to 4G systems) and 5 GHz (applications for 5G systems).

3.1. Design of single band rectangular antenna

This single antenna is designed on a dielectric substrate FR4-epoxy with a dielectric coefficient of 4.4 and a thickness of 1.6 mm. The antenna dimensions are calculated using the MATLAB software shown in Figure 1 and Table1.

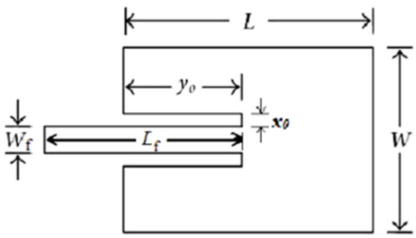


Figure 1. *Single rectangular micro-strip antenna*

Table 1. *The antenna size is calculated in MATLAB (unit: mm)*

L_g	W_g	L	W	L_f	W_f	x_0	y_0
23.3624	35	13.7	20	10	3.3895	0.2	5.0948

From the model and calculation results, the authors have used HFSS simulation software with model simulation results and S11 parameters of the rectangular single antenna as shown in Figures 2 and 3.

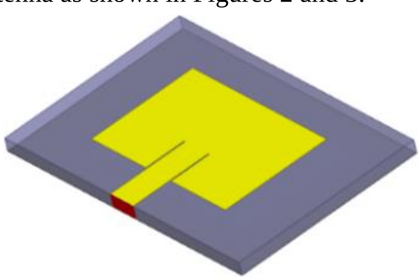


Figure 2. *Single rectangular antenna model*

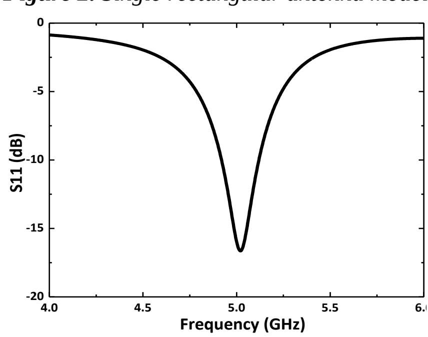


Figure 3. *Parameter S11 of the rectangular single antenna*

The rectangular single antenna is designed to radiate at frequency f_0 = 5 GHz, with a value of S11 = -16.64 dB.

3.2. Design of dual-band E-shaped antenna

3.2.1. The principle of dual-band radiation of the E-shaped antenna

Considering a conventional rectangular antenna radiation at frequencies f_0, length electrical and equivalent diagram of this antenna will be shown in Figure 4 [3].

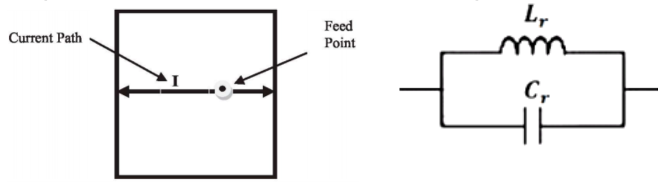


Figure 4. *Current distribution and the equivalent diagram of a rectangular antenna*

Theoretically, the current on the antenna from the point of contact will go straight to the edge of the antenna, creating a inductor component L_r; the distance between the radiated surface and the ground plane will make a capacitor component C_r which is incorporated into a radiated LC circuit at the resonant frequency f_0.

If desiring antenna radiation at the second frequency, we need to make more of a different LC circuit. The E-shaped antenna is based on this idea. Basically, the E-shaped antenna is also a rectangular antenna, but lacks two slots, resulting in an E-shaped structure.

Considering an E-shaped antenna developed from a rectangular antenna mentioned above while the electrical length of the antenna is shown in Figure 5 [3].

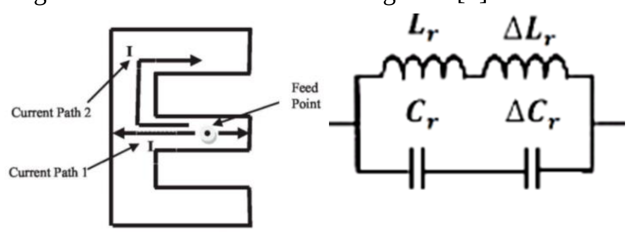


Figure 5. *Distribution current and equivalent diagram of E-shaped antenna*

Thus, the E-shaped antenna can be represented as two LC circuits. The first one is the middle strip of the antenna that will radiate at frequency f_0, and the second one is the combination of the two sides of the E that will radiate at a frequency f_0', with $f_0 < f_0'$. To design an E-shaped antenna, we need to determine the size of the defect on the radiated plane.The parameters of the missing parts in the plane radiation (L_s, W_s, P_s) shown in Figure 6 can be determined by optimized simulation in HFSS software.

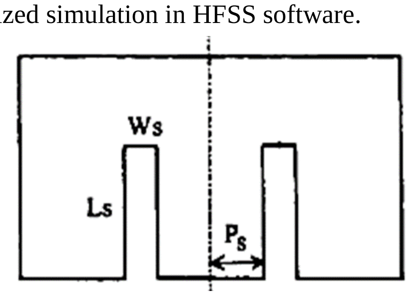


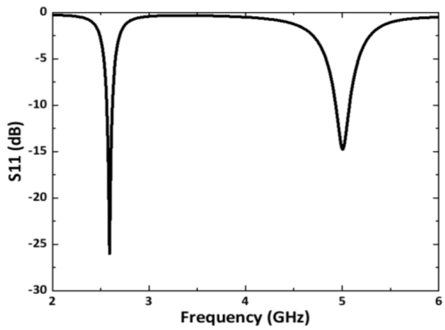
Figure 6. *The parameters of missing parts in the E-shaped antenna*

The missing parts will lead to the change of impedance on the radiation plane. Thus, we need to adjust the size of the micro-strip line to achieve the best impedance matching.

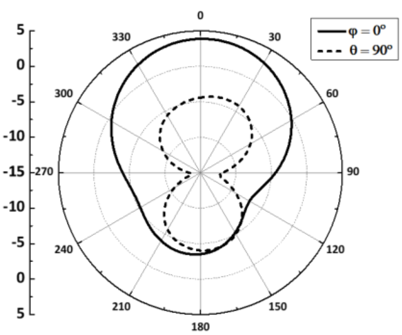
After the optimization, we get the dimensions shown in Table 2. The simulated S11 of optimized E-shaped antenna is presented in Figure 7.

Table 2. *Optimized dimensions of E-shaped antenna (unit: mm)*

W	L	W_f	L_f	y_0	W_s	L_s	P_s
20	13.7	2.6	8.1	5.85	4.4	12.4	4



(a)



(b)

Figure 7. *The simulation results of the E-shaped antenna model (a) S_{11} and (b) Radiation pattern*

The E-shaped antenna is designed to radiate at frequencies $f_0 = 5\ GHz, f_0{}' = 2.6\ GHz$, with S_{11} values of $-14.75\ dB$ and $-26\ dB$, respectively.

4. Design of 2-element MIMO antenna using the neutral line to reduce mutual for 5G communication systems

4.1. Initial MIMO antenna without neutral line

Coupling the two antennas designed in section 3 into a 2-element MIMO antenna, the two antennas will be opposite to each other and be separated by a small distance d = $\lambda_0/20$ = 3 mm, where λ_0 is the wavelength in free space at the high resonance frequency f_0 = 5 GHz. The MIMO antenna model does not use the mutual reduction method as shown in Figure 8, and the author group is simulated using the HFSS software. The simulation results are shown in Figure 9.

Although MIMO antenna radiation approximately in two frequency f_0 = 5 GHz and $f_0{}' = 2.6\ GHz$ with S_{11}, S_{22} is acceptable, the isolation is very high with S_{12} and S_{21} are -11 dB and -13 dB. To reduce the impact of mutual between two antennas, we need to apply mutual reduction methods for increasing the isolation coefficient. The neutral line technique will be used to reduce mutual in the proposed MIMO antenna.

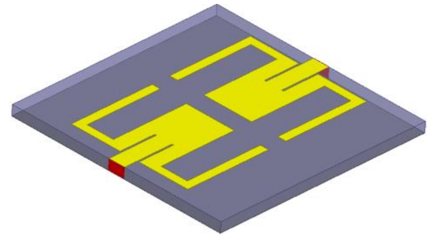


Figure 8. *MIMO antenna model without neutral line*

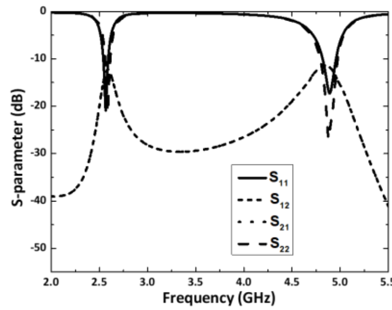
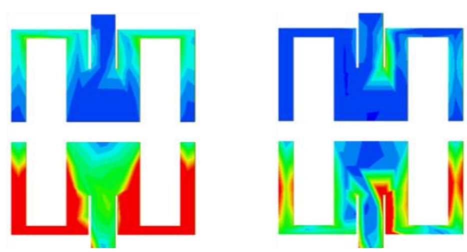


Figure 9. *S-parameter simulated of MIMO antenna*

4.2. Design of 2-element MIMO antenna using theneutral line to reduce mutual

The neutral line will be placed in the position with the lowest impedance and the highest current density. The neutral line length is chosen to be able to reverse the phase of the current flowing through. The authors will determine the relative position to set the neutral line based on the distribution of the antenna current, and then investigate the impact of the neutral line size parameters to determine the correct position. Note that the appearance of the neutral line will change a portion of the radiation structure of the antenna, which will have a small effect on the radiation frequency.



(a) *(b)*

Figure 10. *The current distribution of initial MIMO antenna at (a) 2.6 GHz and (b) 5 GHz*

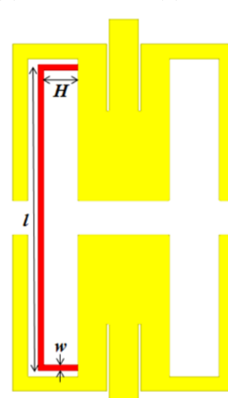


Figure 11. *The parameters of the neutral line*

Based on the current density distribution of the MIMO antenna shown in Figure 10, we can see that the position may place the neutral line that can be found in the missing part of the E. The parameters of the neutral line can be shown in Figure 11.

Placing the neutral line on the antenna's missing will reduce the antenna size, however, this will limit the value of the height *H* and the length *l* of the neutral line. Conducting the survey and calibration, the neutral line will be the size is: l = 27 mm, H = 4 mm, w = 0.5 mm. The simulation results of the two-element MIMO antenna use the neutral line method to reduce mutual as shown in Figure12.

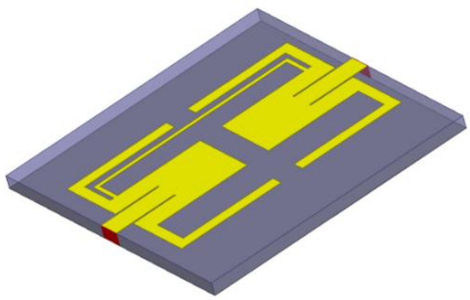


Figure 12. *Final MIMO antenna with neutral line*

MIMO antennas using neutral line are designed to achieve radiation efficiency at the desired frequency, and the mutual impact between the two antennas are significantly reduced to ensure port isolation requirements when S_{12} and S_{21} are less than -15 dB at two resonant frequencies of 2.6 GHz and 5 GHz. Figure 13 shows an improvement in the isolation coefficient of the MIMO antenna after using the neutral line. As can be seen from this figure, the transmission coefficients S_{12} and S_{21} at 2.6 and 5 GHz are -17 dB and -19 dB, respectively. Detailed S-parameters comparison between the initial and final MIMO antenna is presented in Table 3.

Table 3. *S-parameters comparison of MIMO antennas*

S-parameters	High frequency ($5\ GHz$)		Low frequency ($2.6\ GHz$)	
	Initial MIMO	Final MIMO	Initial MIMO	Final MIMO
$S_{12}\ (dB)$	-11 dB	-19 dB	-13 dB	-17 dB
$S_{21}\ (dB)$	-11 dB	-19 dB	-13 dB	-17 dB

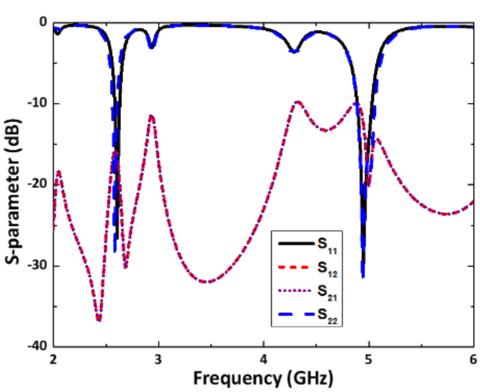


Figure 13. *S-parameters simulated of the final MIMO antenna*

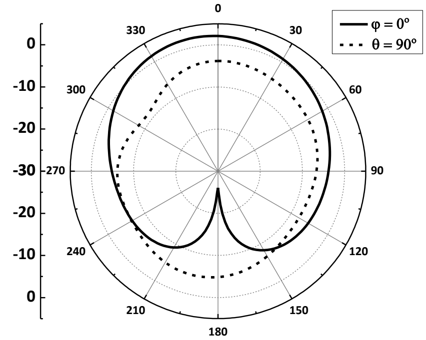


Figure 14. *Radiation patterns simulated of final MIMO antenna*

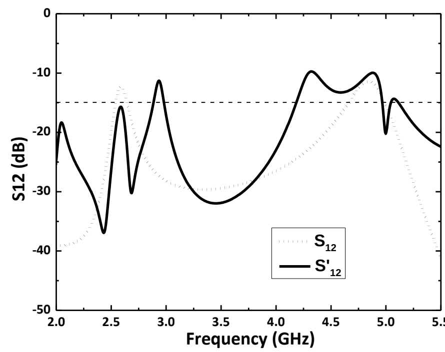


Figure 15. *Compare the S_{12} and S_{21} parameters of the MIMO antenna with and without neutral line*

4.3. The influence of the neutral line to the operation of the MIMO antennas

To see more clearly the influence of the neutral line to MIMO proposed, we will investigate the current distribution of the antenna with and without the neutral line since only the lower E-shaped antenna is excited.

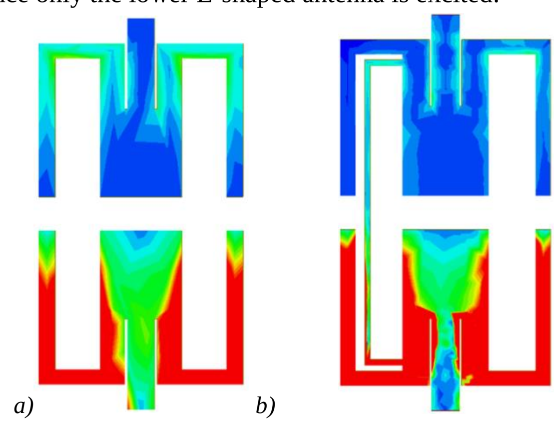
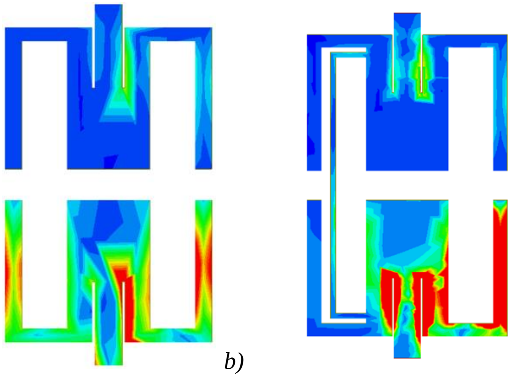


Figure 16. *Current distribution of the antenna (a) with and (b) without the neutral line at 2.6 GHz*

In Figure 16(a), at a frequency of 2.6 GHz, two branches outside of E will serve as the main radiation. When there is no neutral line, the yellow part of the upper antenna indicates the mutual of the lower antenna. The appearance of this unwanted current will negatively affect the performance of the antenna. On the other hand, in Figure 16(b), the mutual current components are almost completely eliminated in the presence of a neutral line. Current distribution in the upper antenna, in this case, is almost unaffected by any impact from the lower antenna.



a) b)

Figure 17. *Current distribution of the antenna (a) with and (b) without the neutral line at 5 GHz*

The current distribution of MIMO antennas at 5GHz is presented in Figure 17. From this figure, the center branch of the antenna will be the main components of radiation. However, it is not difficult to see that the effect of the neutral line at 5 GHz is quite similar at 2.6 GHz. With the appearance of the neutral line, the current distribution in the upper antenna will be eliminated.

In order to show the performance of the proposed neutral line with an existing one technique, the MIMO antenna with a DGS structure is investigated as shown in Figure 18. Simulated S-parameters of the proposed MIMO using dumbbell DGS structure are presented in Figure 19. It can be seen that the MIMO antenna with DGS can reduce the mutual coupling only at the lower frequency (S21 < -15 dB) while the MIMO antenna with the proposed neutral line can reduce the coupling at both frequencies with single neutral line.

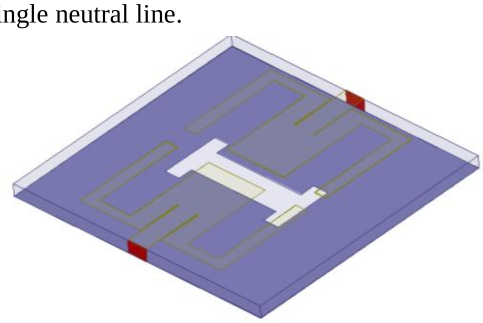


Figure 18. *MIMO antenna with dumbbell DGS cut in ground plane*

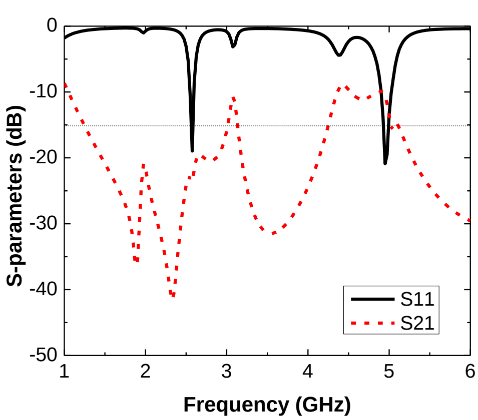
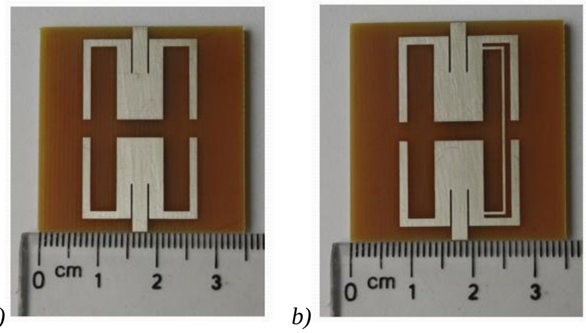


Figure 19. *Simulated S-parameters of MIMO antenna with dumbbell DGS*

4.4. Fabrication of MIMO antennas

The initial and final MIMO antenna are fabricated and measured. The prototypes of these antennas are shown Figure 18.



a) b)

Figure 18. *Prototype of MIMO antennas: (a) Initial and (b) Final antenna*

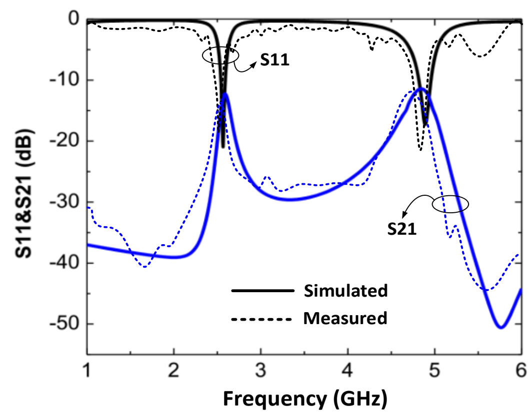


Figure 19. *Comparison of experimental with simulation results for MIMO antenna without neutral line*

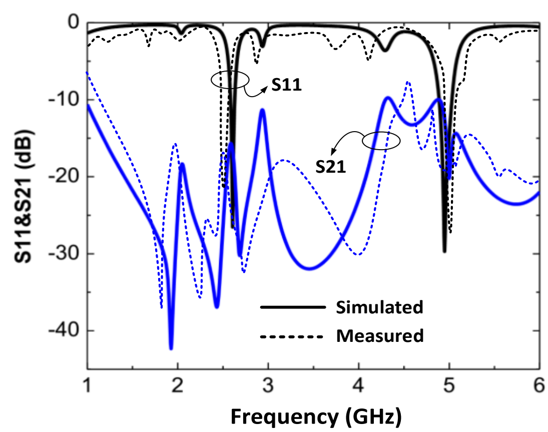


Figure 20. *Comparison of experimental with simulation results of MIMO antenna with neutral line*

Comparison of experimental results with simulation results for MIMO antennas are shown in Figure 19 and Figure 20. It can be seen that the experimental measurement results have little change compared to the simulation results, but these differences are not significant. Especially in the two operating frequencies of the MIMO antenna is 2.6 GHz and 5 GHz, the important parameters such as S11, S21 of the experimental antenna model still ensure the desired value.

5. Conclusions

This paper has successfully designed MIMO antenna radiation at two frequencies of 2.6 GHz and 5 GHz in accordance with the 5G system, achieving high isolation coefficient by using neutral lines to reduce mutual between the two antennas. At the same time, MIMO antennas have been successfully made, measuring and comparing experimental results with simulations. This proposal could be the foundation for further research in the field of antennas, especially for 5G systems.

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