A Switchable UWB Slot Antenna using SIS-HSIR and SIS-SIR for Multi-Mode Wireless Communications Applications

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Abstract **─** A coplanar waveguide (CPW) fed ultra wideband (UWB) antenna with switchable functions and notched band characteristics for multi-mode wireless communication applications is proposed in this paper. The proposed UWB antenna has two stop bands which are achieved by using stepped impedance stub (SIS) loaded stepped impedance resonators (SIR) and SIS loaded hexagon stepped impedance resonators (HSIR). The switchable characteristics are obtained by employing two ideal switches on SIS-HSIR and SIS-SIR. By controlling the two switches ON and OFF, the proposed UWB antenna can work in multiple modes. The proposed switchable UWB antennas have been designed, analyzed, fabricated and measured. Simulated and experimental results show that the proposed antenna has switchable characteristics, tunable notch band functions and good radiation patterns. The proposed switchable UWB slot antenna can be used as a multi-mode antenna for multiple protocol communications.

Index Terms **─** UWB antenna; notch band characteristics; switchable antenna; resonator filters; reconfigurable antenna

I. INTRODUCTION

With the development of wireless communication, high speed data and high efficiency communications have been studied widely in recent years. Especially, in February 2002 the Federal Communications Commission (FCC) in United States conditionally released unlicensed operation of the personal UWB products ranging from 3.1GHz to 10.6GHz [1]. Ultra-wideband (UWB) technology has attracted much attention for use in communication and sensing applications in the commercial domain. Ultra wideband (UWB) is a well-known high speed data ratio, low power and high resistance to interference in wireless communication [1]. For these reasons, UWB communication has been a good topic in academic and industrial field. UWB antenna is an important part in UWB wireless communication applications. Therefore, designing a good antenna can not only reduce the potential interference between UWB systems and narrow band systems but also meet multiple protocol communication requirements. A lot of UWB antennas have been proposed for UWB applications and notch band UWB applications [2-24]. However, most of the previous UWB antennas have large size and complex structures. A number of previous antennas cannot work as a UWB antenna and a notch band UWB antenna, simultaneously. To reduce the size of the antennas, printed wide slot antennas are developed for UWB applications such as rectangular wide slot [7], polygon wide slot [8], circular wide slot [9,23]. Plenty of effective technologies are proposed to reduce the potential interference between UWB systems and narrow band systems. Most of proposed notch band UWB antennas are designed by etching various slots on radiation patch or ground plane

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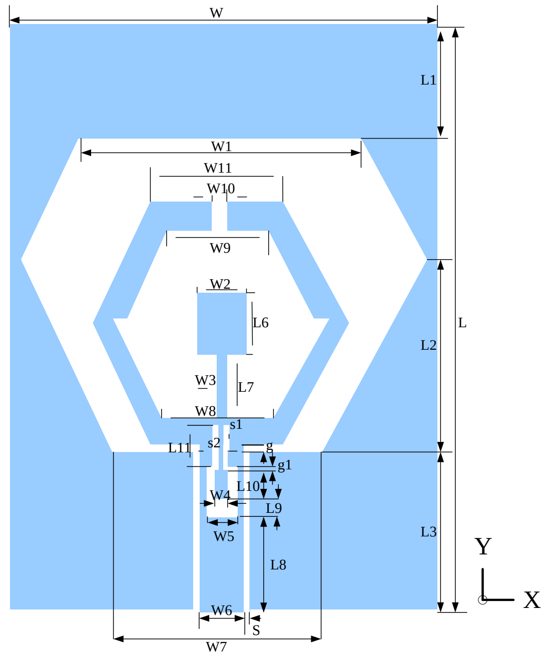
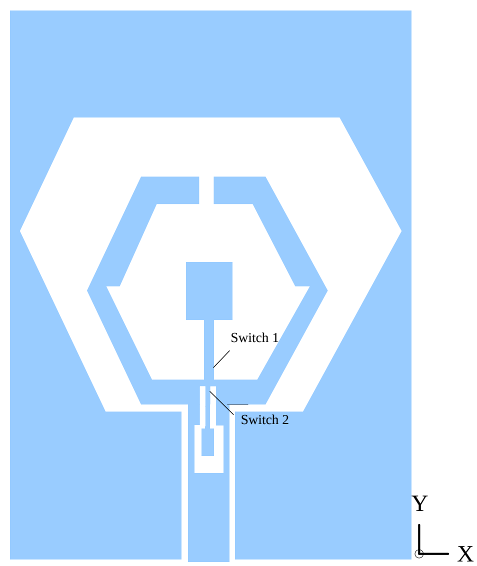
[7-14]. The notch band UWB antennas using stubs [15-18], parasitic strip [19], SRRs [20-23] and integrating with filters in active area [25] are also investigated. However, the notch band characteristic is not good enough to filter the out band signal. The etched slots on radiation patch and ground plane will leak electromagnetic wave. And most of the notched band structures are complex and difficult to design. In addition, the notch depth is poor. The proposed UWB antennas just work in UWB states or notch band UWB states. To let antenna work in multi-mode communications, switch technologies and reconfigurable methods are proposed to meet those requirements [26-30]. SIS and SIRs has good resonator characteristics in designing filters. Recently, SIS is used to design couplers and shown in [31] and SIR and HSIR are employed to design filters [32-34]. These proposed structures have good coupling characteristics and out band suppression functions. In this article, a polygon wide slot antenna for reconfigurable UWB communication applications is presented numerically and experimentally. The proposed antenna can be used as a multi-mode antenna, such as a UWB antenna, a dual notch band UWB antenna or a dual band antenna. The dual notch band functions are obtained by integrating a SIS-HSIR in hexagon radiation patch and a SIS-SIR in CPW transmission signal strip line. By adjusting the dimensions of SIS-HSIR and SIS-SIR, the center frequency and bandwidth of the two notch bands can be tuned to meet practical requirement. The reconfigurable characteristic is achieved by using two ideal switches on SIS-HSIR and SIS-SIR. By controlling the two switches ON and OFF, the proposed antenna can work as a UWB antenna, a dual notch band antenna/tri-band antenna, a notch band UWB antenna or a dual band UWB antenna. Details of the antenna design and both numerical and experimental results are presented and discussed. Good agreement between measured and simulated results demonstrates that the designed antenna is suitable for UWB communications, multi-band communications and notch band UWB communication applications.

II. ANTENNA DESIGN

The geometries of the proposed antennas are shown in Fig. 1. Figure 1 (a) illustrates the geometry of the proposed dual notch band UWB antenna (antenna 1). Antenna 1 consists of a polygon wide



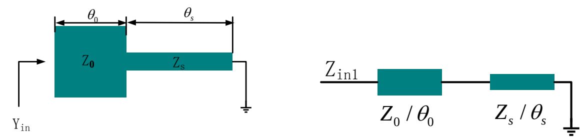
(a) Proposed dual notch band UWB antenna.



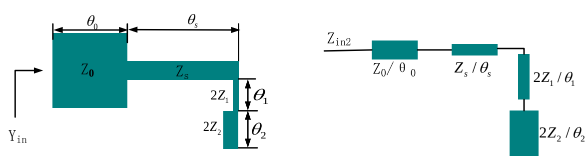
(b) Proposed switchable UWB antenna.

Fig. 1. Geometry of proposed antennas.

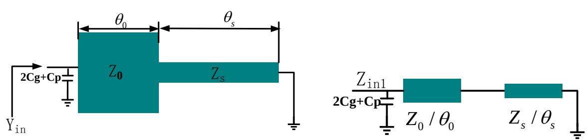
slot, a hexagon radiation patch, a SIS-HSIR etched in hexagon radiation patch, a SIS-SIR embedded in CPW fed signal strip line and a 50 Ω CPW fed structure. Figure 1 (b) is the proposed switchable UWB antenna based on the proposed dual notch band UWB antenna 1. In this paper, the proposed switchable antenna is denoted as antenna 2. To obtain reconfigurable function, two switches are set on SIS-HSIR and SIS-SIR, respectively. In this design, the two switches are ideal and the presence of a metal bridge represents ON state and the absence of a metal bridge represents OFF state [29]. In this paper, a substrate with relative permittivity of 2.65, a loss tangent of 0.002 and a thickness of h=1.6mm is used in antenna designs. The SIS-HSIR produces the notch band near 5.5GHz (lower notch band) and the SIS-SIR generates the notch band near 8.5GHz (higher notch band). The two switches control the mode of the proposed reconfigurable UWB antenna. The 50 Ω CPW fed structure consists of the CPW transmission signal strip line with a signal strip width W6=3.6mm, and gap between the CPW ground plane and transmission signal strip with width S=0.2mm. The 50Ω CPW structure of the proposed UWB antenna is designed by using the standard equations [35-36]. The designed antenna has a compact size which is 32mm×24mm (L×



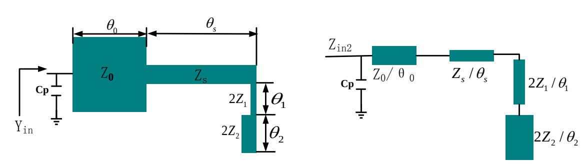
(a) Odd resonance model of SIS-SIR.



(b) Even resonance model of SIS-SIR.



(c) Odd resonance model of SIS-HSIR.



(d) Even resonance model of SIS-HSIR.

Fig. 2. Transmission line model of symmetrical SIS-SIR and SIS-HSIR.

W). In this paper, the proposed antenna is investigated by means of HFSS which is based on finite element method (FEM).

Transmission line model of the symmetrical SIS-SIR and SIS-HSIR are shown in Figs. 2 (a-d). Figs. 2 (a) and (b) are the transmission line models of SIS-SIR. Figs.2 (c) and (d) are the transmission line model of SIS-HSIR. From Fig. 1, the SIS-HSIR and SIS-SIR with quasi-lumped SIS connected to the central position of the high impedance line are employed to generate the two notch bands. As illustrated in Fig. 2, Z_0 and θ_0 denote the characteristic impedance and electrical length of the low impedance coupled lines, respectively. The high impedance line has the characteristic impedance and electrical length Z_s and θ_s. The Z_i and θ_i $(i=1,2)$ show the characteristic impedance and electrical length of the sections of the inner SIS of SIS-HSIR which is etched on the hexagon radiation patch and SIS-SIR which is embedded on the CPW transmission signal strip line. Moreover, gap W10 of the proposed SIS-HSIR is equivalent to capacitances C_p and $C_g/2+C_p$ for odd mode and even mode, respectively [33]. The proposed dual notch band UWB antenna integrated with SIS-HSIR and SIS-SIR configurations can be analyzed in terms of odd and even excitations. The following resonance frequencies of SIS-HSIR and SIS-SIR for the odd and even excitations can be separately extracted from condition $Y_{in}=0$ ($Z_{in}=\infty$) [32-34].

(a) Odd mode resonance condition

$$\tan\theta_0 \tan\theta_s = R, \tag{1}$$

(b) Even mode resonance condition

$$\frac{1}{2R_1}\left[1+\frac{\tan\theta_0\tan\theta_1}{R}\right]\left[\frac{\tan\theta_1}{R_1}+\frac{\tan\theta_2}{R_2}\right] + \left[\tan\theta_s+\frac{\tan\theta_0}{R}\right]\left[\frac{1}{R_1}+\frac{\tan\theta_1\tan\theta_2}{R_2}\right]=0, \tag{2}$$

where the parameters are described as: $R=Z_0/Z_s$, $R_1=Z_1/Z_s$, $R_2=Z_2/Z_s$.

As expected from Fig. 2 and the equations (1) and (2), the resonance frequencies for odd mode and even mode can be postulated by using the equations (3) to (6) [32-34].

$$f_r(\tan\theta_0+\frac{\tan\theta_s}{R})-\frac{1}{\pi Z_s R}+\frac{\tan\theta_0\tan\theta_s}{\pi Z_s R^2}=0, \quad (3)$$

$$f_r\begin{bmatrix} 2R_1(\frac{\tan\theta_1\tan\theta_2}{R_2}-\frac{1}{R_1})(1-R\tan\theta_s\tan\theta_1) \\ +(\frac{\tan\theta_1}{R_1}+\frac{\tan\theta_2}{R_2})(\tan\theta_s+R\tan\theta_0) \end{bmatrix}$$
$$+\frac{1}{2\pi Z_s}(\frac{\tan\theta_1}{R_1}+\frac{\tan\theta_2}{R_2})(\frac{\tan\theta_0\tan\theta_s}{R}-1) \quad (4)$$
$$+\frac{R_1}{\pi Z_s}(\frac{\tan\theta_1\tan\theta_2}{R_2}-\frac{1}{R_1})(\tan\theta_s+\frac{\tan\theta_0}{R})=0,$$

$$f_r(2C_g+C_p)(\tan\theta_0+\frac{\tan\theta_s}{R})-\frac{1}{\pi Z_s R}+\frac{\tan\theta_0\tan\theta_s}{\pi Z_s R^2}=0, \quad (5)$$

$$f_r C_p\begin{bmatrix} 2R_1(\frac{\tan\theta_1\tan\theta_2}{R_2}-\frac{1}{R_1})(1-R\tan\theta_s\tan\theta_1) \\ +(\frac{\tan\theta_1}{R_1}+\frac{\tan\theta_2}{R_2})(\tan\theta_s+R\tan\theta_0) \end{bmatrix} \quad (6)$$
$$+\frac{1}{2\pi Z_s}(\frac{\tan\theta_1}{R_1}+\frac{\tan\theta_2}{R_2})(\frac{\tan\theta_0\tan\theta_s}{R}-1)$$
$$+\frac{R_1}{\pi Z_s}(\frac{\tan\theta_1\tan\theta_2}{R_2}-\frac{1}{R_1})(\tan\theta_s+\frac{\tan\theta_0}{R})=0.$$

In this paper, equations (3) and (4) are used to calculate the resonance frequency of SIS-SIR. Equations (5) and (6) are employed to calculate the center resonance frequency of SIS-HSIR. Gap W10 is a capacity which can adjust the center frequency of the proposed lower notch band. The proposed reconfigurable characteristic is obtained by using two ideal switches on SIS-SIR and SIS-HSIR. By controlling the switches ON and OFF, the designed antenna can be used as UWB antenna, a dual notch band UWB antenna/ tri-band antenna, a notch band UWB antenna/dual-band antenna. In this paper, the presence of a metal bridge represents ON states and the absence of a metal bridge represents OFF states. During parametric study, two ideal switches are replaced by using a microstrip line with width equal to 1.2mm for SIS-HSIR and 0.6mm for SIS-SIR.

III. PARAMETRIC STUDY

Every geometrical parameter has different effects on the performance of the proposed switchable UWB antenna. In this design, SIS-HSIR and SIS-SIR have public high impedance line between two ideal switches. So, the parameters of SIS-HSIR and SIS-SIR play an important effect on impedance bandwidth and notch characteristics. In this section, the parameters of SIS-HSIR, SIS-SIR, gap W10 of SIS-HSIR, notch band characteristics and switchable function are investigated and discussed using HFSS. The proposed switchable antenna is optimized and the details parameters are listed as follows: L=32, W=25, L1=5.7, L2=10.3, L3=9, L6=4, L7=2, L8=5, L9=0.3, L10=2, L11=3, W1=15.8, W2=5, W3=1.2, W4=1.4, W5=2.2, W6=3.6, W7=12, W8=6.4, W9 =5.6, W10=0.6, W11=8.4, s1=0.5, s2=0.4, S=0.2, g=0.5, g1=0.7. (all in mm). During the investigation, one parameter is changed and the other parameters are fixed.

A. Effects of length L6 of SIS-HSIR

Figure 3 gives the simulated return losses of proposed antenna 1 with varying L6. It can be seen from Fig. 3 that the center frequency of the lower notch band moves to low frequency with higher notch band changeless. L6 alters the characteristic impedance Z_i(i=1,2) and electrical length θ_i(i=1,2) of SIS-HSIR. This can be calculated using equations (1), (2), (5) and (6). In this design, SIS-HSIR works in even mode. Therefore, the equations (2) and (6) are chosen to calculate the center frequency of the lower notch band at the beginning of this design.

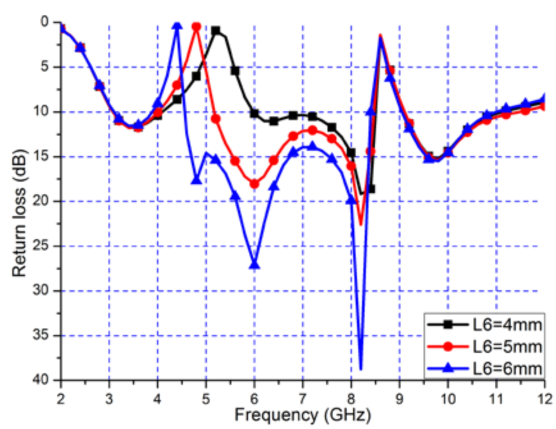


Fig. 3. Effects on return losses of L6.

B. Effects of length W2 of SIS-HSIR

Figure 4 shows the simulated return losses of antenna 1 as a function of frequency for different values of W2. It is found that the center frequency also moves to low frequency with the increase of width W2 of SIS-HSIR. The center frequency of higher notch band keeps constant. This is due to W2 which changes the characteristic impedance Z_i(i=1,2) and electrical length θ_i(i=1,2) of SIS-HSIR. So, the center frequency has been changed. This can be verified by the equations (2) and (6).

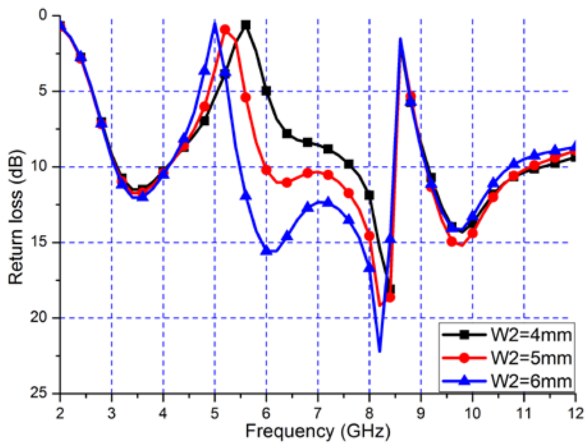


Fig. 4. Effects on return losses of W2.

C. Effects of length L7 of SIS-HSIR

Figure 5 demonstrates the simulated return losses of the proposed dual notched band antenna 1 in terms of L7. With varying L7 from 1.5mm to 2.5mm, the center frequency of lower notch band also moves to low frequency. Furthermore, the impedance bandwidth between 5.4GHz and 8.5GHz is improved. However, the notch depth of the higher notch band deteriorated more or less. This is caused by changed L7 which has effects on the characteristic impedance and electrical length of public high impedance line of SIS-HSIR and SIS-SIR between two ideal switches of antenna 2.

D. Effects of gap W10 of SIS-HSIR

Figure 6 illustrates the simulated return losses of antenna 1 with respect to gap W10 of SIS-HSIR. With the increasing of W10, the center frequency of lower notch band is adjusted. The gap W10 of the proposed SIS-HSIR is equivalent to capacitances C_p and $C_g/2+C_p$ for odd mode and even mode, respectively. The changed gap alters the capacity of SIS-HSIR. So, the resonance frequency of SIS-HSIR will be adjusted and can be calculated using formula (5) and (6).

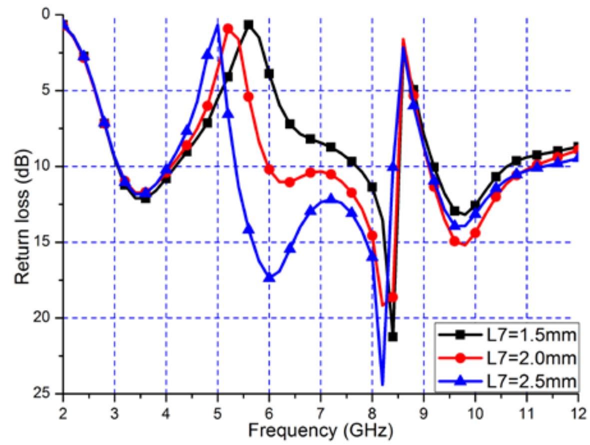


Fig. 5. Effects on return losses of L7.

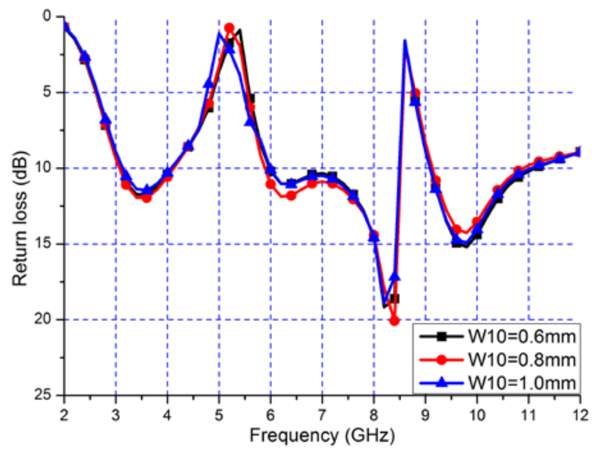


Fig. 6. Effects on return losses of W10.

E. Effects of the length L10 of SIS-SIR

Figure 7 shows the simulated return losses of SIS-SIR with varying L10. In terms of L10 ranging from 1.0mm to 2.0mm, the higher notch band moves to low frequency. The impedance bandwidth between the two notch bands deteriorated more or less, and then the impedance bandwidth is getting better. In addition, the notch depth of higher notch band is also improved. This is due to that the length L10 changes the coupling between SIS and SIR. The changed parameters of SIS-SIR alter the resonance frequency of SIS-SIR.

F. Effects of width W4 of SIS-SIR

The simulated return losses of antenna 1 with various W4 are shown in Fig. 8. It can be seen from Fig. 8 that the higher notch band moves to low frequency with the increasing of W4. The impedance bandwidth and notch depth are also improved. However, the lower notch band keeps constant. This is caused by the changed SIS which not only alters the distribution inductance but also changes the characteristic impedance Z_i(i=1,2) and electrical length θ_i(i=1,2) of SIS-SIR. This can be postulated using (1)-(4). In this paper, the SIS-SIR works in its even mode. So, the resonance frequency can be calculated using equations (2) and (4).

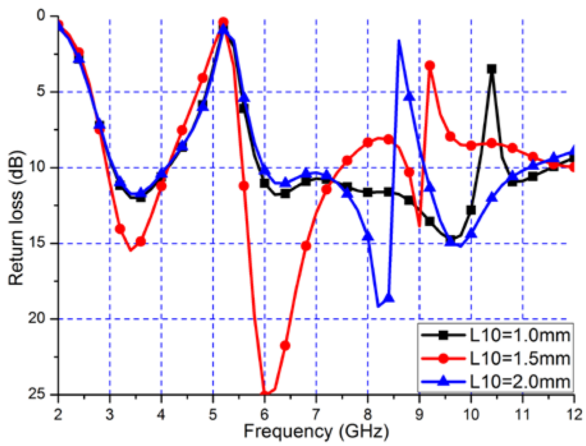


Fig. 7. Effects on return losses of L10.

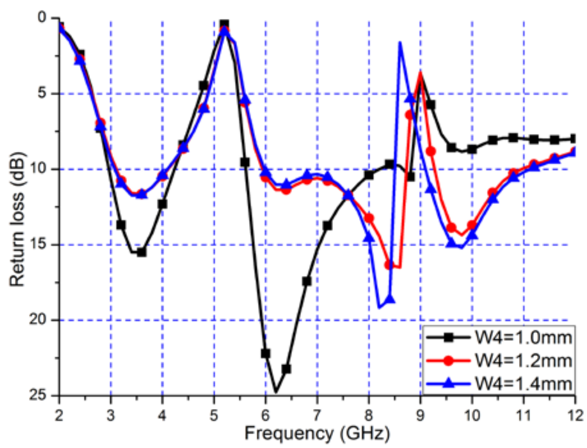


Fig. 8. Effects on return losses of W4.

G. Effects of gap g1 of SIS-SIR

Figure 9 illustrates the simulated return losses in terms of gap g1. From Fig. 9, the notch depth of higher notch band is improved and then the notch depth is deteriorated. The higher notch band also moves to the low frequency by increasing g1 from 0.5mm to 0.9mm. The length of SIS is changed by various g1 which changes the coupling capacity of gap g1. The coupling between SIS and SIR is also changed. In this paper, the adjustment of SIS-SIR is limited by the width of the CPW transmission signal line W6. Therefore, by choosing proper coupling gap g1, a proper higher notch band can be adjusted to meet the requirement of our project.

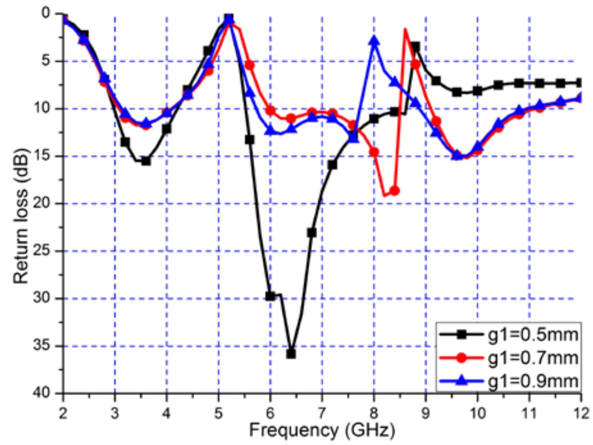


Fig. 9. Effects on return losses of g1.

H. Notch band characteristics

Figure 10 demonstrates the proposed notch band characteristic of antenna 1. It can be seen from Fig. 10 that antenna 1 with SIS-HSIR and SIS-SIR has two notch bands near 5.5GHz and 8.7GHz, respectively. Antenna 1 with only SIS-HSIR only has a lower notch band and antenna 1 with only SIS-SIR has a higher notch band. So, the lower notch band near 5.5GHz is produced by SIS-HSIR and the higher notch band is generated by SIS-SIR. The two notch band can be adjusted independently according to the investigation and discussions aforementioned. Antenna 1 without SIS-HSIR and SIS-SIR is a UWB antenna covering the whole band ranging from 3.1GHz to 10.6GHz. In addition, antenna 1 with only SIS-SIR has a resonance frequency near 11GHz. This is caused by SIS-SIR embedded in CPW transmission line which changes the current flowing along CPW excitation line.

I. Switchable characteristics

Figure 11 expounds the simulated switch characteristic of proposed switchable antenna 2. In this simulation, two ideal switches are used to simulate the switchable functions. Two ideal switches are replaced by using a microstrip line with width equal to 1.2mm for SIS-HSIR and

0.6mm for SIS-SIR. The presence of a metal bridge represents ON states and the absence of a metal bridge represents OFF states. The switchable antenna 2 has the same dimension as antenna 1. It can be seen from Fig.11 that antenna 2 is dual notch band UWB antenna with both switches ON. Antenna 2 can be used as a dual notch band UWB antenna or a tri-band antenna. Antenna 2 is a notch band UWB antenna with one switch ON and the other switch OFF. When switch 1 (SW1) is ON and switch 2 (SW2) is OFF, antenna 2 has a notch band near 5.5GHz. The notch band is produced by SIS-HSIR. When switch 1 (SW1) is OFF and switch 2 (SW2) is ON, antenna 2 has a notch band near 8.5GHz. The notch band is produced by SIS-SIR. So, the lower notch band is switched using SW1 and the higher notch band can be switched by controlling SW2. Antenna 2 is a UWB antenna with two switches OFF. The UWB antenna covers the whole UWB band. Antenna 2 has an impedance bandwidth of 8GHz. In a word, antenna 2 can be used as a notch band UWB antenna/ dual band antenna, a dual band antenna/ tri-band antenna or a UWB antenna by controlling proposed switches ON and OFF.

IV. RESULTS AND DISCUSSIONS

Based on the studies and discussions of the parameters of proposed antenna 1, the notch characteristic and switchable functions of antenna 2, antenna 2 has been optimized utilizing HFSS. According to our project, the proposed two notches are located at 5-6GHz for HiperLAN/2 (5.15-5.35GHz and 5.47-5.725GHz in Europe) and IEEE 802.11a bands (5.15-5.35GHz and 5.725-5.825GHz in US) which is used for wireless local area network (WLAN) communications and 4.4GHz-5.0GHz and 8.5GHz-9.0GHz for satellite communication and military communication applications. In this paper, the two notch bands are designed for reducing potential interference between UWB and narrow bands systems. During the optimizing process, the parameters are adjusted according to the results of the parameters study and the optimized results given in section 3.

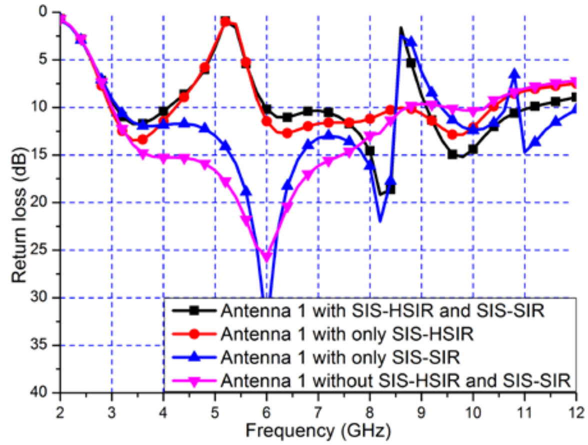


Fig. 10. Effects of SIS-HSIR and SIS-SIR.

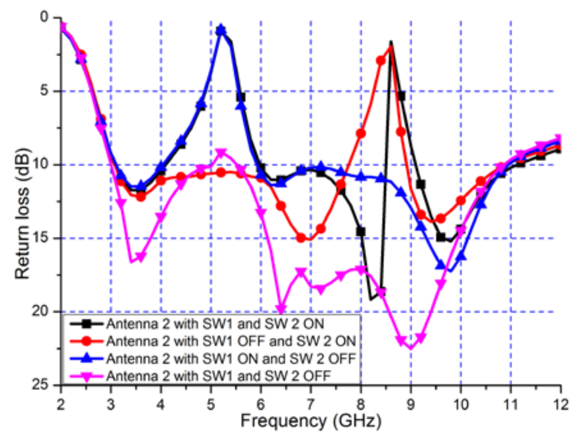
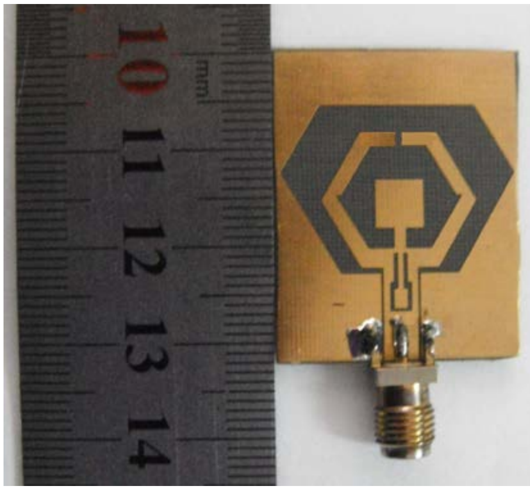


Fig. 11. Effects of the two switches.

To evaluate the performance of optimized UWB antenna 2, the proposed antenna 2 with two switches ON and OFF are fabricated and tested. In this paper, the proposed switchable antennas are manufactured using ideal switches. The presence of a metal bridge represents ON states and the absence of a metal bridge represents OFF states. This is the same as the simulation. The measured return losses of the antennas are obtained by using Anritsu 37347D vector network analyzer. The photographs of the proposed antenna 2 with two switches ON and OFF are shown in Fig.12. Fig.12 (a) is antenna 2 with two switches ON and Fig.12 (b) is antenna 2 with two switches OFF. The return losses of the fabricated switchable antennas are shown in Fig.13.



(a) Antenna 2 with two switches ON.

(b) Antenna 2 with two switches OFF.

Fig. 12. photographs of switchable antennas.

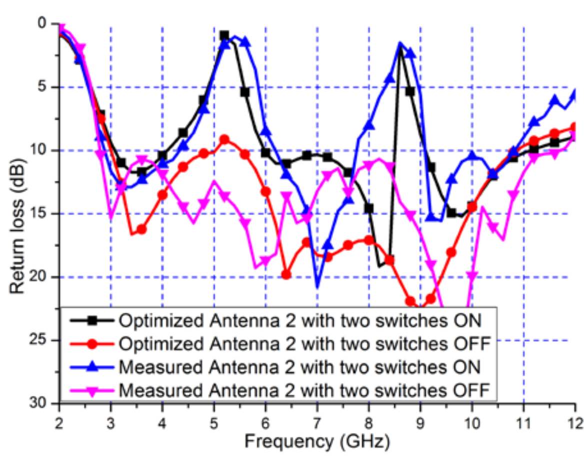
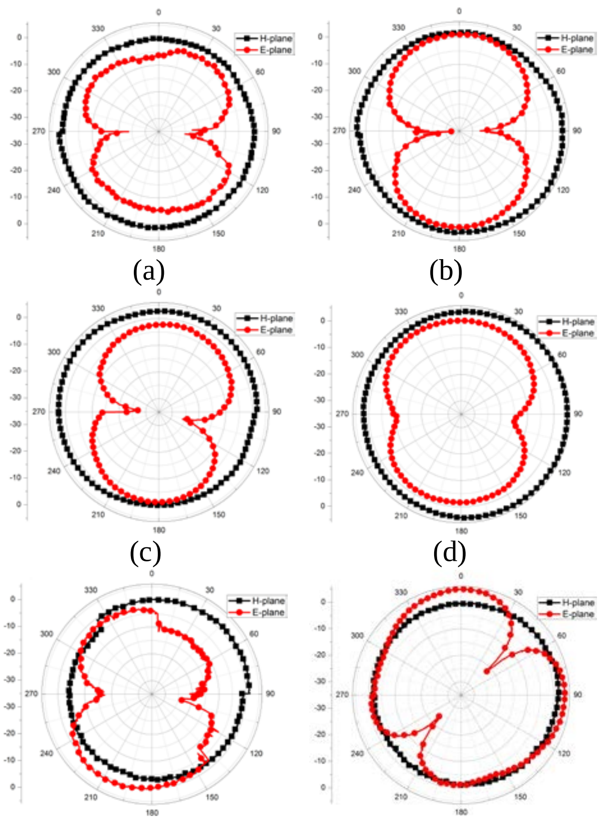


Fig. 13. Return losses of switchable antennas.

From Fig. 13, the measured results agree well with the simulated results which help to verify the accuracy of the simulation. The differences between the simulated and measured values may be due to the errors of the manufactured antenna and the SMA connector to CPW-fed transition, which is included in the measurements but not taken into account in the calculated results. Antenna 2 with two switches ON is a dual notch band UWB antenna. The two notch bands covers C-band (4.4GHz-5GHz), WLAN (5.1GHz-5.9GHz) band and X-band (8.5GHz-9GHz). The two notches can reduce or avoid the potential electromagnetic interference (EMI) between UWB system and narrow band systems, such as WLAN and X-band. Antenna 2 with two switches OFF is a UWB antenna with an impedance bandwidth of 114% according to the center frequency of the proposed UWB antenna. In this paper, antenna 2 is a multi-mode antenna which can be regarded as a UWB antenna, a dual notch UWB antenna/tri-band antenna, a notch band UWB antenna/dual band antenna. It can be seen from Fig.13 that the proposed dual notch bands have better quality factor (notch depth) than most of the previous proposed notch band UWB antennas.

The measured radiation patterns at 4.0GHz, 7.0GHz, 10.0GHz are shown in Fig. 14. The three frequencies are chosen form the frequency under lower notch band, the frequency between lower notch band and higher notch band, and the frequency beyond the higher notch band. In this design, xz plane is H-plane (φ=0º) and yz-palne is E-plane (φ=90º) for the proposed switchable antenna. From Fig. 14, we can see that antenna 2with two switches ON and OFF can give a nearly omni-directional characteristic in H-plane and monopole-like radiation characteristics in E-plane. It was found that the radiation patterns in E-plane deteriorate more or less with the increasing frequency. However, the radiation characteristics are still monopole-like radiation patterns. The radiation patterns of antenna 2 with the two switches ON has a little distorted at upper band. This is caused by the two resonators which leak electromagnetic wave. The leaked electromagnetic wave has some effect on the radiation patterns.



(a) (b) (c) (d) (e) (f)

Fig.14. Radiation patterns of proposed switchable antennas (a) 4.0GHz of antenna 2 with two switches ON; (b) 4.0GHz of antenna 2 with two switches OFF; (c) 7.0GHz of antenna 2 with two switches ON; (d) 7.0GHz of antenna 2 with two switches OFF; (e) 10.0GHz of antenna 2 with two switches ON; (f) 10.0GHz of antenna 2 with two switches OFF.

The peak gains of the proposed switchable antennas at these frequencies are achieved by comparing to a double ridged horn antenna. A stable gain can be obtained throughout the operation band except the two notched frequencies. It can be seen from Fig. 15 that the switchable antenna 2 with two switches ON has two notch bands which can reduce the EMI from C-band, WLAN and X-band. The notch band can be adjusted by changing the dimensions of SIS-HSIR and SIS-SIR. The measured gain of the switchable with two switches OFF is increased from 1.7dBi to nearly 5.3dBi which is caused by the deteriorated radiation patterns of the proposed antenna at the high band. In the operation band, the switchable antenna 2 with two switches OFF has stable gains with fluctuation less than 3.6dBi. But the gain of the switchable antenna with two switches ON dropped quickly from 4.0GHz to 6.0GHz and from 8GHz to 9GHz. As desired, two sharp gains decreased in the vicinity of 5.5GHz and 8.7GHz. The gains drop deeply to -5.2dBi at the lower notch band and -3.6dBi at the higher notch band.

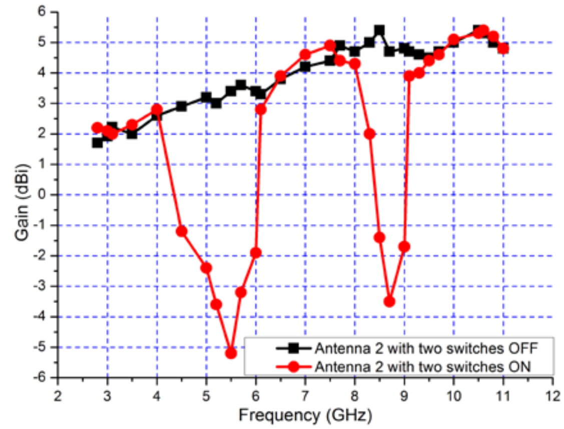


Fig. 15. Gains of antenna 2 with two switches ON and OFF.

V. CONCLUSION

A switchable UWB antenna is presented in this paper numerically and experimentally. The switchable functions are obtained by using two switches on SIS-HSIR and SIS-SIR. By controlling the two switches ON and OFF, the proposed antenna can be used as a UWB antenna, a dual-notch UWB antenna/ tri-band antenna, a notch band antenna/ dual-band antenna. The two notch band characteristics are achieved by using SIS-HSIR and SIS-SIR. The lower notch band is produced by SIS-HSIR and the higher notch band is generated by SIS-SIR. The proposed switchable antenna with two switches ON is a dual notch band antenna which can reduce potential EMI between UWB systems and narrow band systems. While the switchable antenna with one switch ON and the other switch OFF is a notch band UWB antenna or a dual band antenna. The switchable antenna with two switches OFF is a UWB antenna which covers the whole UWB band. The proposed switchable antenna has a small size $32\times24mm^2$. The ideal switches are used in the simulation and the measurement. The results show that the proposed switchable antenna has a good switchable function, reconfigurable multi-mode characteristic and omni-directional radiation patterns.

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