A Transparent UWB Antenna with a 5 to 6 GHz Band Notch Using Two Split Ring Resonators

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Abstract **─** A miniaturized thin film transparent ultra-wideband (UWB) antenna design with a band notch is presented. A pair of split-ring resonators (SRRs) is placed besides the radiating element to realize the band notch centered at 5.5 GHz. The proposed transparent antenna covers the whole 3.1 to 10.6 GHz UWB frequency band with a notch from 5 to 6 GHz to isolate interferences from wireless local area network (WLAN) and dedicated short-range communication (DSRC) applications. The transparency of this antenna of up to 80% is enabled by the fabrication on a conductive silver coated thin film (AgHT-8). Hence, the proposed transparent antenna is a suitable for UWB home entertainment network (IEEE 1394 over UWB network) for green building applications, where high data rates are required for multimedia transfer. Implementation of the proposed transparent antenna will reduce the space consumption due to its very low thickness and low profile, while at the same time increasing the aesthetic values of the installed wireless system due to its high transparency.

Index Terms **─** AgHT-8, band notch, split ring resonator, transparent antenna, UWB.

I. INTRODUCTION

Ultra wideband (UWB) antenna covers the 3.1 to 10.6 GHz frequency range, as approved by the Federal Communication Commission (FCC) for unlicensed radio frequency applications. A frequency notch is needed to eliminate the possibilities of interferences between this application and other wireless services. Narrow bands wireless services such as IEEE 802.a (5.15 GHz - 5.825 GHz) for WLAN and IEEE 802.11p (5.50 GHz - 5.925 GHz) for dedicated short-range communication (DSRC) frequency band are included within the UWB frequencies [1]. Hence, it is highly desirable that the frequency bands for these applications be segregated from the UWB receiver.

Several techniques have been reported recently for realizing band notches in UWB antennas [2-4], which mainly comprises of various slot configurations. The implementation of split ring resonators (SRR) to introduce an antenna band notch is one of the best techniques for realizing band notches as it does not consume a large area in the antenna topology [5]. SRRs are commonly placed in the radiating element, near the transmission line to maximize the coupling effect, as in [6-8]. However, slot placement on these locations results in gain degradation due to the partial removal of the radiating element. Several other SRR positioning techniques have been reported in previous works [9-12] to address this issue, where the SRRs are placed outside the radiating element but in close vicinity of the transmission line. Most of these topologies are implemented on non-transparent substrates such as Rogers, Taconic, and Fire Retardant-4 (FR-4).

Due to the use of conventional, non-transparent materials, the antenna loses its aesthetic values and this becomes apparent to the users when they are installed in public areas. Several previous investigations on transparent antenna have also been performed to overcome this issue. An example is the optically transparent UWB antenna [13] using conductive silver coated thin film (AgHT-4/8), with Perspex substrate. Another transparent UWB antenna with tunable notch reported in [14], consists of a simple rectangular radiating element with vertical slots for band notching. However, the resulting resonant frequency is dependent on the length of the vertical slots. This complicates its implementation at the lower frequency, as long slots are needed, thus requiring a larger radiator footprint. Several disadvantages of the transparent materials have been reported in [15-16], where it is highlighted that the high material losses and consequently, feeding line losses has limited the usage

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of such materials. Table 1 summarizes a comparison of the proposed band notch transparent antenna against other recent transparent UWB antennas in term of.

Despite these investigations, the implementation of SRRs on a transparent antenna patch has yet to be reported. In this paper, a transparent UWB antenna with SRRs outside the radiating element [10] using conductive silver coated thin film (AgHT-8) is proposed. The design concept and the resulting performance of the transparent antenna are analyzed and thoroughly discussed. Its structure is potentially suitable for UWB home entertainment network (IEEE 1394 over UWB network) [17].

Table 1: Transparent UWB antennas comparison

Ref.	Description*			
	Notch Freq. (GHz)	Min RL at Notch (dB)	Max Gain (dBi) @ Freq. (GHz)	Gain at Notch (dBi)
[13]	*Transparent antenna using Perspex			
	-	-	-5 @ 6	-
[14]	*Tunable transparent UWB antenna with vertical slot			
	5	-10	-2 @ 15	-7
This design	*Notched transparent UWB antenna using SRR			
	5.8	-10	-5 @ 9.5	-9.5

II. MATERIALS AND ANTENNA DESIGN

A. Split ring resonator and UWB antenna

The proposed antenna is implemented on a conductive silver coated thin film (AgHT-8) as the conductor. Its estimated conductivity, σ is 1.25 x 105 S/m. A thin polyethylene terephthalate polymer with permittivity of $\varepsilon_r = 3.228$ is used as the substrate. Both materials are optically transparent with a total thickness, h, of, 0.175 mm.

SRR consist of a pair of concentric metallic rings, etched on a dielectric substrate. The SRR structure is introduced onto the antenna topology to create a band notch. Split ring resonators are formed using two concentric metallic rings with a split on opposite sides, see Fig. 3. This structure behaves similarly to an LC resonant circuit driven by an external electromotive force. The resonant frequency of the of the SRR can be expressed as [11-12]:

$$\omega_0 = \sqrt{\frac{2}{\pi r_0 LC}}, \qquad (1)$$

where L is the total inductance of the circular SRR, C is the capacitance per unit length between the rings and r_0 is the average radius of the rings. Therefore, the SRR resonant frequency can be easily tuned by optimizing its parameters shown in Fig. 1.

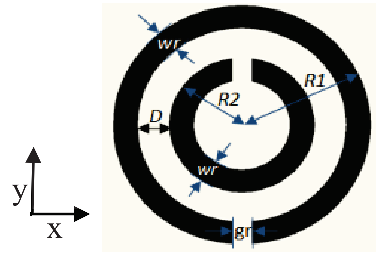


Fig. 1. Geometry of the split ring resonator.

A two port network for the thin film transmission line was constructed to analyze the insertion loss. Figure 2 shows a high insertion loss is evident in this transmission line caused by the high AgHT-8 losses. Moreover, the insertion loss increases as the frequency increases. The implementation of the SRR inside the transmission line interrupts the current flowing on the transmission line causing further insertion losses. This indicates that a good band notch with high insertion losses can be potentially created using an optimized SRR.

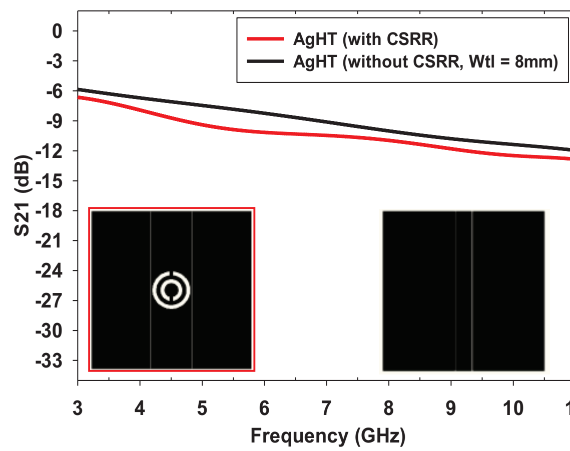


Fig. 2. Simulated insertion loss for two port network using AgHT (with and without SRR).

The transparent UWB antenna consists of a co-planar waveguide (CPW) feed attached to a circular radiating element, as shown in Fig. 3. The optimized parameters of the proposed UWB antenna and SRR are listed in Table 2.

The gap between the ground and the transmission line, g, is optimized to g = 0.15 mm to achieve the 50-Ω impedance matching. Simulations and optimizations were performed using Computer Simulation Technology (CST) Microwave Studio. Figure 4 shows the effect of the size variation of the circular radiating element on the antenna reflection coefficient. The minimum radius for the circular radiating element to exhibit UWB characteristics is at least 8 mm.

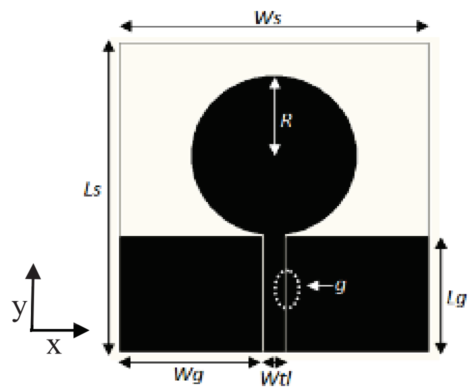


Fig. 3. Geometry of the proposed transparent UWB antenna.

Table 2: Optimized geometries of the proposed UWB antenna with SRRs

Symbols	Parameter	Dimensions (mm)
Ws	Substrate width	30.0
Ls	Substrate length	30.0
Wg	Ground width	13.85
Lg	Ground length	11.5
R	Patch radius	8.0
g	CPW gap	0.15
Wtl	Transmission line width	2.0
R_1	Outer SRR radius	3.2
R_2	Inner SRR radius	1.8
wr	Width of resonators	0.6
D	Separation of SRR	0.8
gr	Gap of resonators	0.5

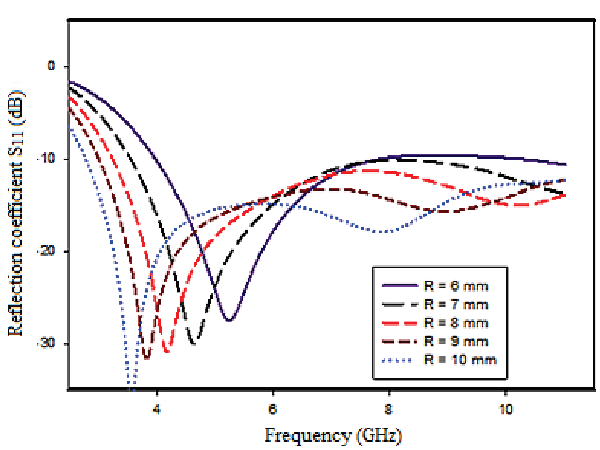


Fig. 4. Antenna reflection coefficient due to different radiating element radius "R".

B. Integration of the SRR into UWB antenna

It is important to determine the optimum SRR location for maximum coupling between the SRR and the antenna to properly enable the desired band notch characteristics. Two SRRs are used to increase the notch bandwidth and ensure a symmetrical radiation pattern. Figure 5 shows the proposed SRRs locations; they are placed on each side of the radiating element.

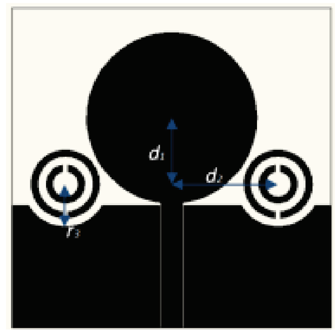
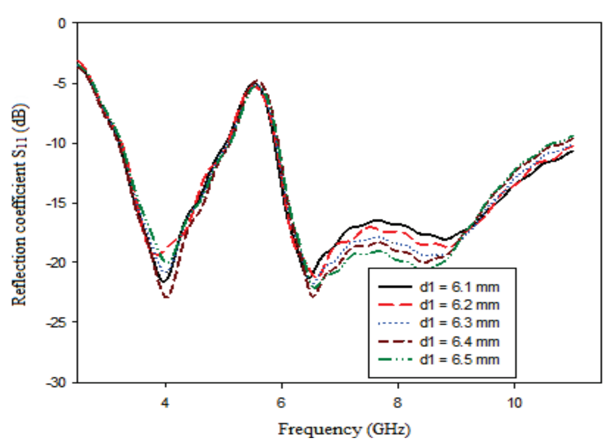
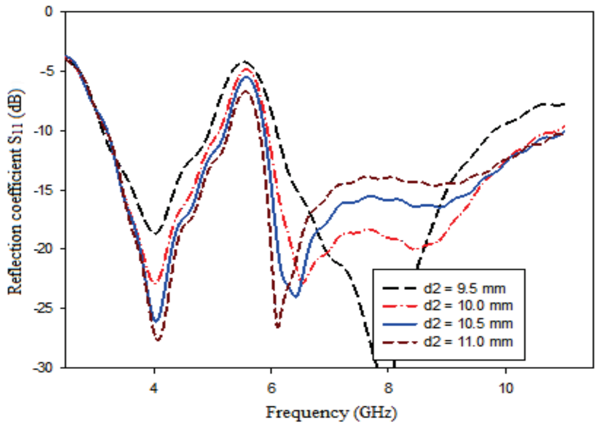


Fig. 5. Proposed SRRs location.

The optimal SRR locations are determined via a series of parametric studies. The first study concerns the location of the SRRs. Figure 6 (a) shows the reflection coefficient (S_{11}) of the proposed antenna when the distance between the SRRs and the center of the radiating element along the transmission line (y-axis), d1, is increased. It can be observed that this change has a minimal effect on the S_{11}. On the contrary, increasing the distance between the SRRs and the radiating element in x-axis, d2, shows a significant S_{11} degradation, see Fig. 6 (b). The optimum distance for the *d1* and *d2* are 6.2 mm and 10 mm, respectively. Areas where the SRR structures are overlapping with the antenna ground are removed using a semi-circular slot with a radius of *r3* = 3.7 mm from the center of SRRs. This ensures that the SRRs are not grounded.



(a)



(b)

Fig. 6. Reflection coefficients: (a) due to the different distances of SRR in the y-axis "*d1*", and (b) due to different distance of SRR in the x-axis "*d2*".

The final antenna is then fabricated using a transparent conductive silver coated thin film (AgHT-8), as shown in Fig. 7 (a). Figure 7 (b) depicts the oxidation effect when the antenna is exposed to a high humid environment, which can be avoided by an additional tint film on top of the conductive layer.

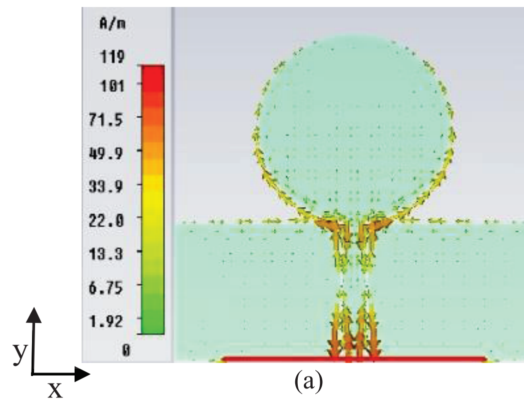
(a) (b)

Fig. 7. Transparent UWB antenna with SRRs: (a) fabrication with low humidity environment exposure, and (b) after exposure to high humidity environment.

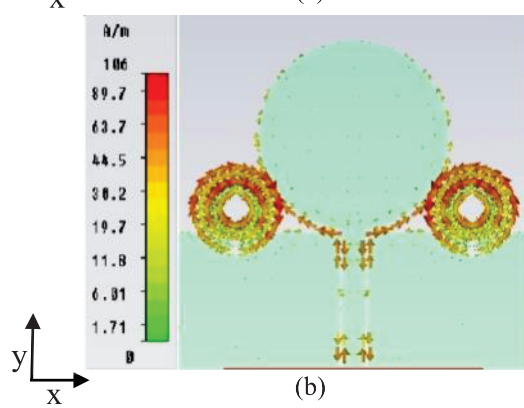
III. RESULTS AND DISCUSSION

Figure 8 shows the surface current distribution of the proposed antenna at 5.5 GHz. An evenly distributed surface current is observed at the circular edges of the radiating element when the SRRs are yet to be introduced (Fig. 8 (a)). The addition of the SRRs resulted in the high surface current concentration on the structures at 5.5 GHz, thus creating the reject band centered at this frequency.

Figure 9 shows the comparison between simulated and measured S_{11} for the antenna with and without the SRRs. The simulations indicated an operating frequency between 3.1 to 10.6 GHz, whereas the measurements are slightly shifted upwards, starting from 3.7 to more than 10.6 GHz. Simulations show that the antenna with SRRs generated a notch band centered at 5.5 GHz with S_{11}=-4.5 dB, which attenuated signal reception/transmission by nearly 60%. Meanwhile, measurements performed on the same structure resulted in a band notch S_{11} of only -9 dB. These discrepancies may be caused by the high sheet resistance of the material, which restricted the current from properly exciting the SRRs, coherent with the report in [15-16]. Moreover, the narrow dimensions of the slots and rings may have also caused fabrication discrepancies [14].



(a)



(b)

Fig. 8. Simulated surface currents at 5.5 GHz for the: (a) UWB antenna, and (b) UWB antenna with SRRs.

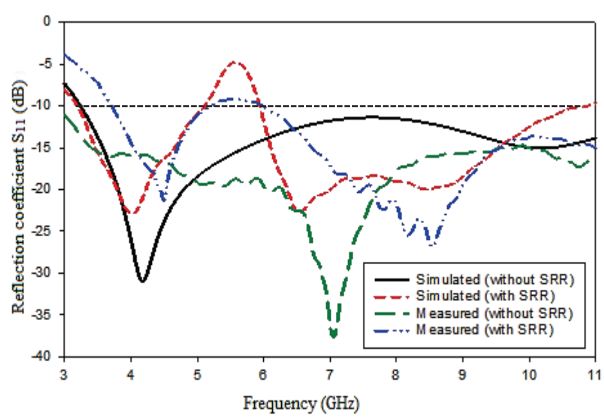
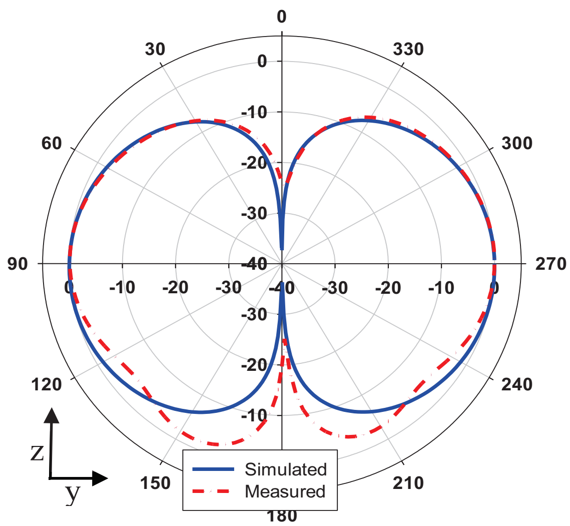
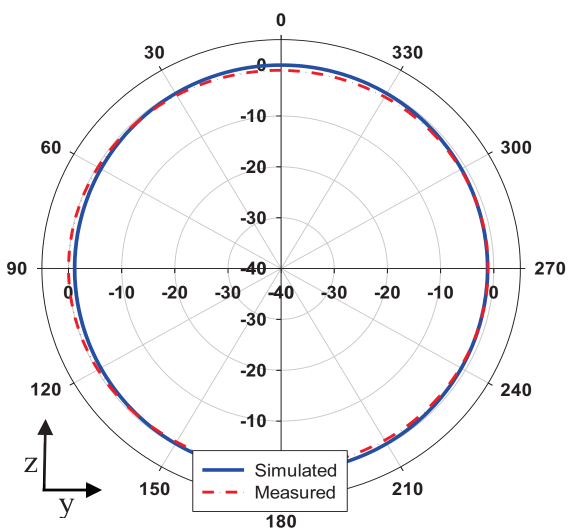


Fig. 9. Simulated and measured reflection coefficients.

Figure 10 illustrates the simulated and measured radiation patterns of the proposed antenna at 4, 7 and 10 GHz. The proposed antenna has a bi-directional radiation pattern at 4 GHz in the E-plane, and an omnidirectional pattern in the H-plane, see Figs. 10 (a) and 10 (b). The symmetrical radiation pattern is produced due to the implementation of two SRRs instead of a single SRR in comparison to [10]. At higher frequencies, the antenna produced slightly unsymmetrical and more directive radiation patterns, see Figs. 10 (c), 10 (d), 10 (e) and 10 (f). For instance, the antenna is pointing towards θ = 330° in the y-z plane at 10 GHz, resulting in a gain increase towards this direction. Due the high conductor losses at higher frequencies [14], a maximum gain of -5.0 dBi is obtained at 9.5 GHz.



(a)



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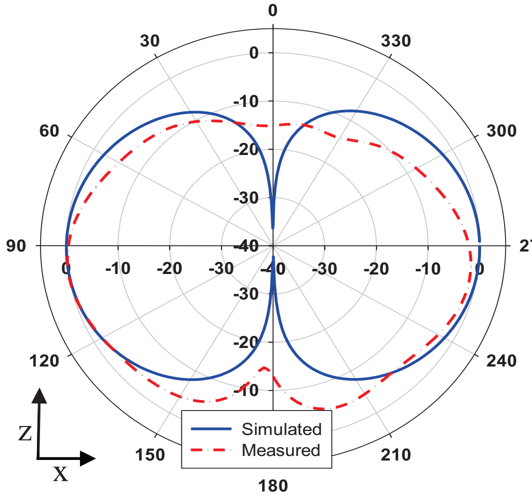
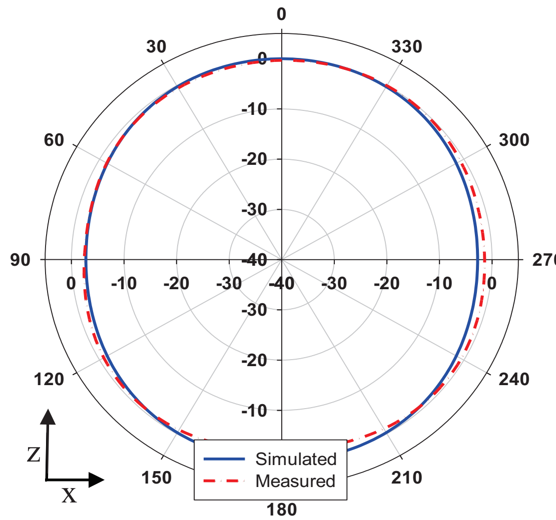
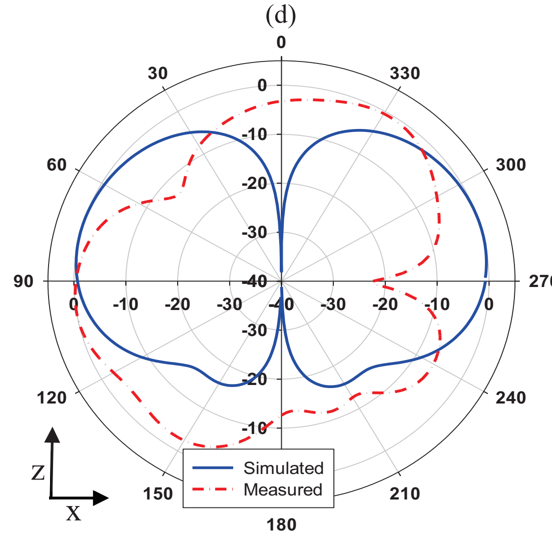


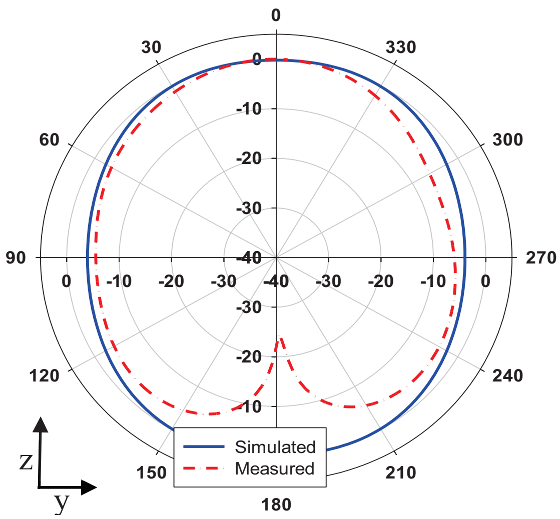
(c)



(d)



(e)



(f)

Fig. 10. Simulated and measured radiation patterns at: (a) 4 GHz (E-plane), (b) 4 GHz (H-plane), (c) 7 GHz (E-plane), (d) 7 GHz (H-plane), (e) 10 GHz (E-plane), and (f) 10 GHz (H-plane).

Figure 11 shows the measured gain of each antenna, where it can be seen that the highest gain achieved is only -5 dBi, which is comparable to [14]. There are 1.6 dB gain drops at 5.8 due to the implementation of the SRRs. This gain values are expected when using the thin film material because of its low conductivity, low electrical properties and the high losses of the conductive surface. The thin transmission line that has been used in this proposed design has the tendency to have higher losses according to [15]-[16]. However, this antenna is designed for UWB applications which only support short distance and high data rate transmission/reception such as near field communication; the gain of this antenna is still acceptable for practical implementation. The maximum efficiency of this antenna is 18%, which is comparable to the same notched transparent antenna designed in [14].

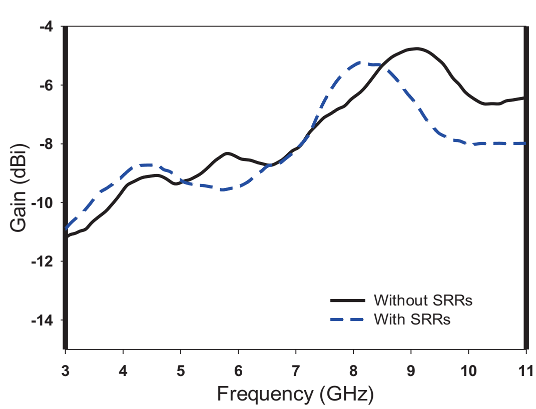


Fig. 11. Measured gain of proposed antenna with and without SRRs.

IV. CONCLUSION

A new optically transparent UWB antenna with band notch at 5.5 GHz is presented in this paper. Optical transparency is achieved by using conductive silver coated thin film (AgHT-8) and a polyethylene terephthalate (PET) substrate. The proposed antenna exhibits a band notch at 5.5 GHz by introducing a pair of SRR at both the sides of the radiating element. The proposed antenna operates with S_{11} better than -10 dB impedance bandwidth and bi-directional radiation pattern throughout the whole UWB band, except in the 5 to 6 GHz notch band. The antenna shows satisfactory agreement between simulated and measured results. The proposed transparent antenna is applicable for UWB home network (IEEE 1394) for green building applications. It enables high data rate multimedia transfer and simultaneously reduces space consumption due to its low profile and size. Moreover, due to its transparent property, it can also be deployed without compromising aesthetic values or users' noticing, especially for covert operations. Since this is a pulsed system, the lower gains in a limited higher frequency band will not severely affect its overall performance in real applications.

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REFERENCES

[1] R. Azim and M. T. Islam, "Compact planar UWB antenna with band notch characteristics for WLAN and DSRC," *Progress In Electromagnetics Research*, vol. 133, pp. 391-406, Nov. 2013.

[2] F. D. Dahalan, S. K. B. A. Rahim, M. R. Hamid, M. Z. B. M. Nor, M. S. B. A. Rani, and P. S. Hall, "Archimedean spiral antenna with band-notched characteristics," *Progress In Electromagnetics Research C*, vol. 37, pp. 83-94, Jan. 2013.

[3] S. R. Emadian, C. Ghobadi, and J. Nourinia, "A novel compact dual band-notched slot antenna for ultrawideband applications," *Microwave and Optical Technology Letter*, vol. 54, no. 6, pp. 1365-1368, June 2012.

[4] M. Naser-Moghadasi, L. Asadpor, and B. S. Virdee, "Compact ultra-wideband slot antenna with band-notch property," *Microwave and Optical Technology Letter*, vol. 54, no. 8, pp. 1829-1832, Aug. 2012.

[5] M. C. Tang, S. Xiao, T. Deng, D. Wang, J. Guan, B. Wang, and G. D. Ge, "Compact UWB antenna with multiple band-notches for WiMAX and WLAN," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 4, pp. 1372-1376, Apr. 2001.

[6] X-J. Liao, H-C. Yang, N. Han, and Y. Li, "A semi-

circle-shaped aperture UWB antenna with triple band-notched character," *Journal of Electromagnetic Waves and Applications*, vol. 25, no. 2-3, pp. 257-266, 2011.

[7] T-N. Chang and M-C. Wu, "Band-notched design for UWB antennas," *IEEE Antennas Wireless Propagation Letters*, vol. 7, pp. 636-640, 2008.

[8] J. Y. Deng, Y. Z. Yin, X. S. Ren, and Q. Z. Liu, "Study on a dual-band notched aperture UWB antenna using resonant strip and CSRR," *Journal of Electromagnetic Waves and Applications*, vol. 23, no. 5-6, pp. 627-634, 2009.

[9] J. Montero-de-Paz, E. Ugarte-Muñoz, F. J. Herraiz-Martínez, V. González-Posadas, L. E. García-Muñoz, and D. Segovia-Vargas, "Multifrequency self-diplexed single patch antennas loaded with split-ring-resonators," *Progress in Electromagnetics Research*, vol. 113, pp. 47-66, 2011.

[10] M. S. A. Rani, S. K. A. Rahim, H. Rezaie, F. D. Dahalan, M. I. Sabran, M. Z. M. Nor, and A. Zainal, "Directional UWB antenna with a parabolic ground structure and split ring resonator for a 5.8 GHz band notch," *Journal of Electromagnetic Waves and Applications*, vol. 27, no. 1, Jan. 2013.

[11] D-O. Kim, N-I. Jo, D-M. Choi, and C-Y. Kim, "Design of the ultra-wideband antenna with 5.2 GHz/5.8 GHz band rejection using rectangular split-ring resonators (SRRS) loading," *Journal of Electromagnetic Waves and Applications*, vol. 23, no. 17-18, pp. 2503-2512, Apr. 2009.

[12] R. Marques, F. Mesa, J. Martel, and F. Medina, "Comparative analysis of edge- and broadside-coupled split ring resonators for metamaterial design-theory and experiments," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 10, pp. 2572-2581, Oct. 2003.

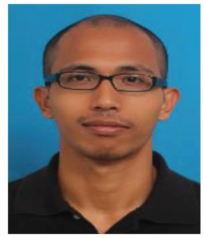
[13] A. Katsounaros, Y. Hao, N. Collings, and W. A. Crossland, "Optically transparent antenna for ultra wide-band applications," *3rd European Conference on Antennas and Propagation*, Berlin, Germany, pp. 1918-1921, 2009.

[14] T. Peter, Y. Y. Sun, T. I. Yuk, H. F. AbuTarboush, R. Nilavalan, and S. W. Cheung, "Miniature transparent UWB antenna with tunable notch for green wireless applications," *2011 International Workshop on Antenna Technology (iWAT)*, pp. 259-262, Mar. 7-9, 2011.

[15] B. M. Levin, "Transparent antennas," *2011 XVth International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED)*, pp. 101-104, Sep. 26-29, 2011.

[16] B. Levin and M. Haridim, "Conical feed transparent antenna," *2012 IEEE 27th Convention of Electrical & Electronics Engineers*, pp. 1-5, Nov. 14-17, 2012.

[17] S. Ullah, M. Ali, M. A. Hussain, and K. S. Kwak, "Applications of UWB Technology," *The 5th Annual International New Exploratory Technologies Conference 2008 (NEXT 2008)*, Turki, pp. 225-232, Aug. 2008.



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