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Study of Wide-Slot Antenna Using Microstrip feed line with Slot-Ring Resonator (SRR) for Super Ultra-Wideband Communication Systems

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Abstract
In this paper presents characteristics of the wide-slot antenna for super UWB communication systems. The proposed antenna consists of a wide-rectangular slot on the ground plane fed by microstrip line with slot-ring resonator (SRR) in rectangular tuning stub on the other side. The simulated results of characteristics slot antenna can achieve widen the bandwidth of 118 % coverage the frequency band from 2.95 GHz to 11.40 GHz (8.45 GHz) coverage UWB operations. Moreover, a technique of asymmetrical SRR in rectangular tuning stub shifted left/right can enhanced the impedance bandwidth more than 7.5 GHz for super UWB communication. The simulated result of the slot antenna can achieved the impedance bandwidth of 164% coverage the frequency band from 2.90 GHz to 29.36 GHz (26.46 GHz) for super UWB communication. The average gain of the proposed antenna is 5dBi, and the far-field radiation pattern in xz-plane and yz-plane of frequencies are bi-directional.

Keywords: Slot antenna, Bandwidth enhancement, Slot-ring resonator (SRR)

INTRODUCTION

The Federal Communications Commission (FCC) gave formal approval for the unlicensed use of ultra-wideband (UWB) technology between 3.1 GHz to 10.6 GHz [1] for UWB communication systems. The UWB technology is the most important for wireless communication systems. Because, the advantages of UWB technology are good noise immunity, signals can penetrate variety of materials easily, high immunity to multi path fading, potentially very high data rates and low power, respectively. For this reason, challenges of antenna design to increase more impedance bandwidth the UWB and super UWB (more than 7.5 GHz) communication systems.

The microstrip slot antenna is a device which can be used for transmitting and receiving of the signals for wireless communication systems. The advantages of this antenna are light weight, low profile, low cost and small size. Therefore, the many researchers are interested in developing this antenna support for wireless communication. For example, design of the antenna for a single frequency band [2-3], dual frequency [4-6] and multi frequency [7-9]. These researches are designed for specifically frequency band only for WLAN operations. Moreover, the researchers are designed wideband slot antenna for WLAN applications by using for enhanced bandwidth [10-14]. The impedance bandwidths of the antennas are 30% to 90%, support wideband communications and the bandwidth not cover the UWB communications. The antennas with the multitudinous tuning stub for enhanced more bandwidth [15-19] and the results can achieved the impedance bandwidths of 110 %, support wideband communications (WLAN, WiMAX) but the impedance bandwidths cannot coverage UWB communications. Moreover, the researcher is designed of the UWB antenna for UWB systems [20-24]. These antennas can be achieved the impedance bandwidth for UWB systems. In the future, wireless communication is defined the frequency band more than 7.5 GHz. Thus, it should design the slot antenna for enhance super wide-bandwidth by using various tuning stub and a techniques shifted tuning stub to left and right for increase bandwidth for super UWB communication and other wireless communications.

This paper presents characteristics of slot antenna to increase bandwidth for super UWB communication systems. The structure of the proposed antenna consists of a wide-rectangular slot on the ground plane, and fed by microstrip line with slot-ring resonator (SRR) in rectangular tuning stub on the other side. The slot antenna is analyzed for return loss (S_{11}), VSWR, input impedance (Z_{in}), current distributions, gain and far-field radiation patterns by using the IE3D software. Moreover, a technique of asymmetrical SRR in rectangular tuning stub shifted left/right can enhanced the impedance bandwidth more than 7.5 GHz for super UWB communication. From the simulated results of the proposed slot antenna can achieve the impedance bandwidths support the UWB and super UWB communication.

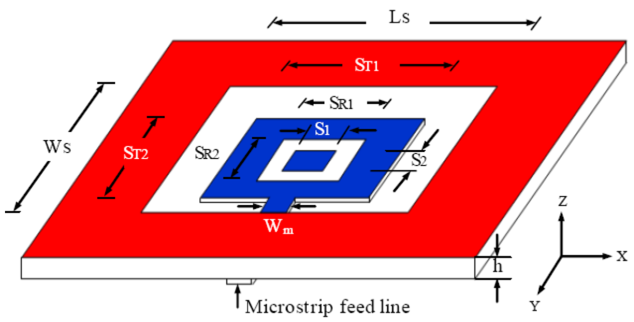
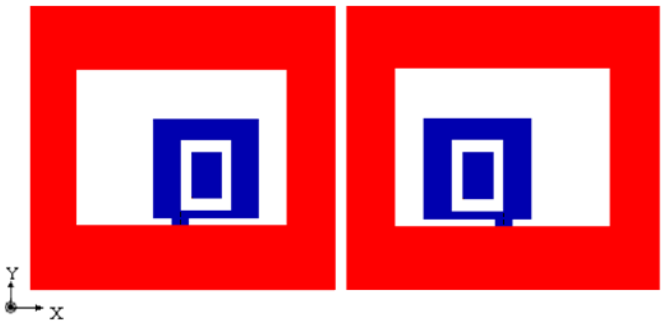


Figure 1: Structure of slot antenna using microstrip feed line with slot-ring resonator in rectangular tuning stub

ANTENNA STRUCTURE AND DESIGN

The geometry and configuration of the wide-slot antenna fed by microstrip line with slot-ring resonator (SRR) in rectangular tuning stub are shown figure 1. The proposed antenna consists of a wide-rectangular slot on the ground plane for used as a radiator, and fed by microstrip line with slot-ring resonator (SRR) in rectangular tuning stub in another side for excitation. The objective of the proposed slot antenna is designed for super UWB communication. The proposed slot antennas are fabricated on RO4000 substrate with thickness (h) of 0.80 mm, relatively permittivity (ε_r) of 3.5 and loss tangent of 0.02, respectively. The configuration of the slot antenna fed by microstrip line with slot-ring resonator (SRR) in rectangular tuning stub are: length of the slot (Ls), width of the slot (Ws), length of the tuning stub (ST1), width of the tuning stub (ST2), length of SRR (RS1), outer width of SRR (RS2), inner length of slot-ring in tuning stub (S1), inner width of slot-ring in tuning stub (S2), as shown in figure 1. In addition, a technique of asymmetrical SRR in rectangular tuning stub shifted left/right for increase bandwidth more than 7.5 GHz for supper UWB communication, as shown in figure 2.



(a) SRR Shifted left (b) SRR shifted right

Figure 2: slot antenna using microstrip feed line with slot-ring resonator with tuning stub in case shift left and right of tuning stub

The guide wavelength (λ_g) [25] at 3.0 GHz is given by

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_{eff}}} \quad (1)$$

where

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_m}\right]^{-1/2} \quad (2)$$

where c is the light velocity = 2.998 × 10^8 m/s, f is the design frequency, ε_{eff} is an effective dielectric constant of the substrate, ε_r is relative permittivity, h is the thickness of the antenna and W_m is the width of the microstrip feed line.
Percent bandwidth of the antennas [25], is defined as following

$$BW(\%) = \frac{f_u - f_l}{f_0} \times 100 \quad (3)$$

where BW is the bandwidth of the antenna
f_u is the edge of the high frequency
f_l is the edge of the low frequency
f_0 is the center frequency

THE SIMULATION RESULTS AND DISCUSSION

The microstrip feed line is designed with the conductor strip line (W_m) of 1.5 mm corresponding to the characteristic impedance of 50 ohms transmission line. The proposed antennas are analyzed by using IE3D [26] software. The proposed antenna design step by step as follows:

First, design of slot antenna fed by microstrip feed line is designed for the resonance frequency at 3 GHz. Second, modify the first slot antenna by added slot-ring resonator in rectangular tuning stub at the edge of microstrip feed line for increase bandwidth for UWB communication. Moreover, the proposed design can be further enhanced by adjusting of SSR tuning stub ST1, ST2, RS, RS12, and thickness (h) of 0.80 mm, relatively permittivity (ε_r), respectively. The characteristics studies of proposed antenna are shown step by step as follow in next sections.

A. Effect of Adjusting Length of the Tuning Stub (ST1)

First, show an effect from adjusting the length of the tuning stub (ST1). By adjusted ST1 to 10 mm, 12 mm and 14 mm by fixed Ls = 24 mm, Ws =14mm, ST2= 7.5 mm, RS1 = 8 mm, RS2 = 5.5 mm, S1= 3 mm, and S2 = 2 mm, respectively. The simulated result of return loss (S_{11}) in adjusting ST1 is shown in Figure 3.

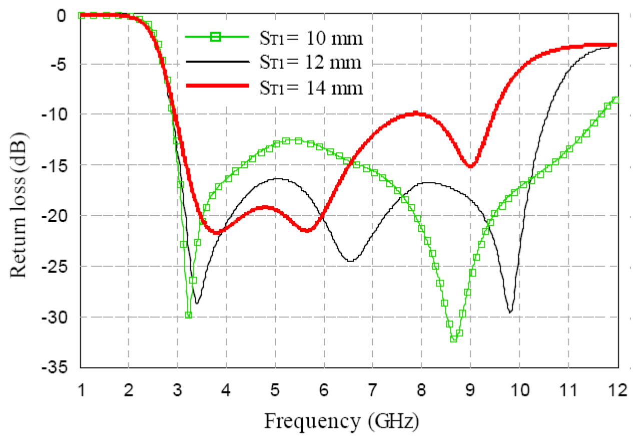


Figure 3: The return loss (S_{11}) of the slot antenna in the case adjusting ST1.

Figure 3 shown simulated results of the return loss (S_{11}) in three cases by adjusting the length of the rectangular tuning stub (ST1), mainly influences the impedance matching at frequencies to range from 3 GHz to 11 GHz and can increased bandwidth at the high frequency band. The optimal dimension of the tuning stub (ST1) is 12 mm and uses this value to study other parameters of the tuning stub.

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B. Effect of Adjusting width of the Tuning Stub (ST2)

Second, study the effect of the tuning stub by adjusting the width of the tuning stub (ST2). The parameter of ST2 is adjusted to 6.5 mm, 7.5 mm and 8.5 mm by fixed ST1= 12 mm. The simulation results of return loss (S_{11}) in adjusting ST2, is shown in Figure 4.

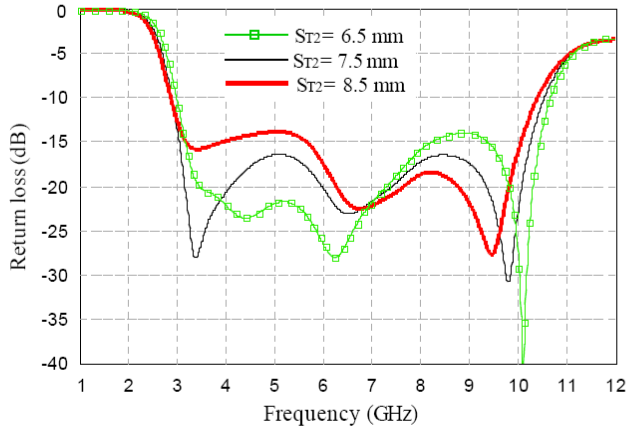


Figure 4: The return loss (S_{11}) of the slot antenna in the case adjusting ST2.

The simulated return loss (S11) in three adjusting ST2 are shown in figure 4. It is shown that the width of the tuning stub (ST2), mostly affect on impedance matching all frequencies range from 3 GHz to 11 GHz. The optimized value of ST2 is 7.5 mm and use this value to study other parameters.

C. Effect of Adjusting Length of Slot-ring Resonators (SR1)

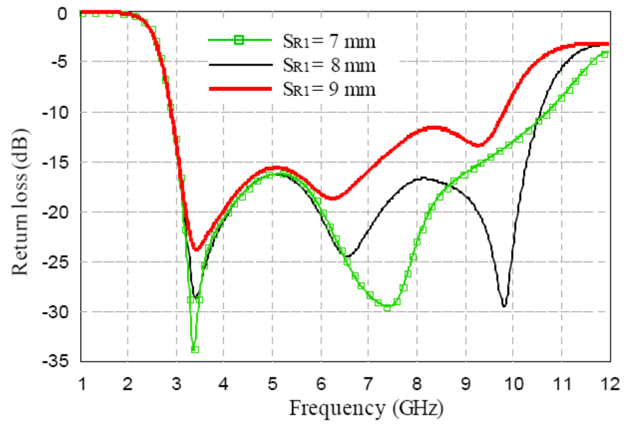


Figure 5: The return loss (S_{11}) of the slot antenna in the case adjusting SR1.

Third, a study characteristic of return loss by adjusts the length of slot-ring resonators (SR1). The parameters of SR1 is adjusted to 7 mm, 8 mm and 9 mm by fixed ST1 = 12 mm and ST2 = 7.5 mm. The simulation results of return loss (S_{11}) by adjusting SR1, is shown in figure 5.

Figure 5 shows the simulation return loss (S_{11}) of the slot antenna in case adjusting three values of the slot-ring resonators (SR1). Its effect mainly influences the impedance matching at high frequencies band from 6.5 GHz to 11 GHz and the optimal dimension of SR1 is 8 mm.

D. Effect of Adjusting width of Slot-ring Resonators (SR2)

Fourth, adjust the inner width of slot-ring resonators (SR2) is 4.5 mm, 5.5 mm and 6.5 mm by fixed ST1 = 12 mm and ST2 = 7.5 mm and SR1 = 8 mm. The simulation results of return loss by adjusting SR2 are shown in figure 6.

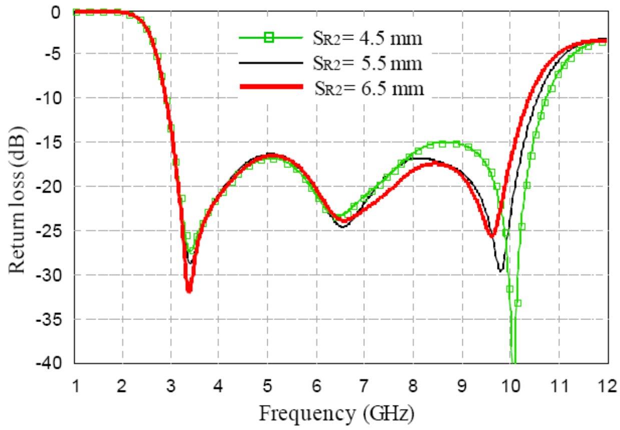


Figure 6: The return loss (S_{11}) of the slot antenna in the case adjusting SR2.

The simulated return loss (S_{11}) of the slot antenna in case adjusting SR2 is shown in Figure 6. It will affect the return loss, mainly affect on enhance bandwidth at high frequency bands. The optimal of SR2 is 5.5 mm.

E. Characteristics Dielectric Constant of Slot Antenna

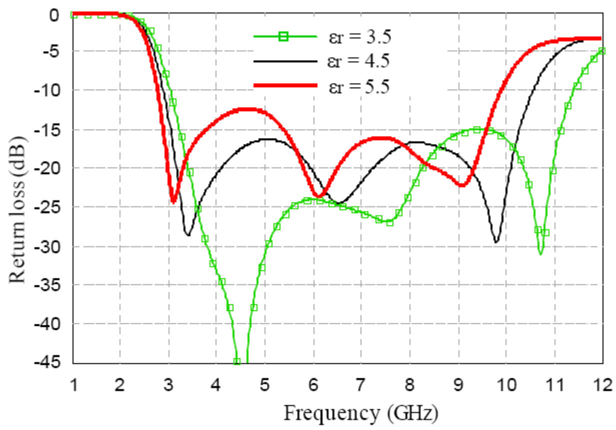


Figure 7: The return loss (S_{11}) of the slot antenna in the case adjusting dielectric constant (ε_r)

In this case, study characteristics of the relatively permittivity or dielectric constant (ε_r) of the slot antenna by change three constant are 3.5, 4.5, and 5.5 and the simulation results are shown in figure 7.

Figure 7 shows simulated dielectric constant of the slot antenna. It can be seen that the effect mainly influences the impedance matching all the frequency range from 3 GHz to 11 GHz and enhance bandwidth at high frequency bands. Therefore, selection of dielectric constant is affected to increase bandwidth and a good impedance matching of the slot antenna.

F. Characteristics Thickness of Slot Antenna

In this case, study characteristics of the thickness of the slot antenna by change three thicknesses are 0.4, 0.8, and 1.6 mm. The simulation results of return loss (S_{11}) in case change thickness are shown in figure 8.

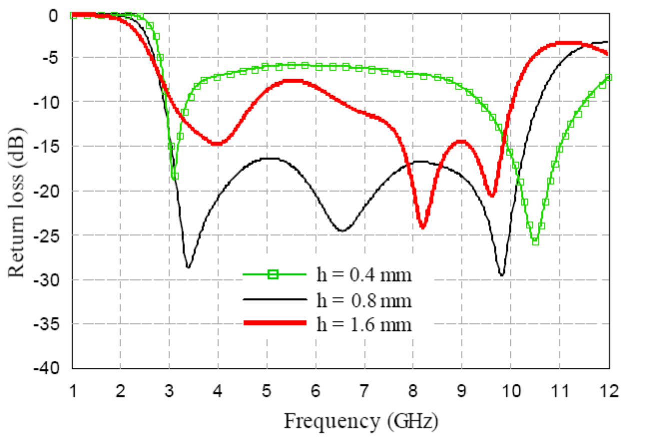


Figure 8: The return loss (S_{11}) of the slot antenna in the case adjusting h

Figure 8 shows simulated in case change thicknesses of slot antenna, mainly affect influences the impedance matching at frequencies range from 3 GHz to 11 GHz.

G. The Wide-Slot Antenna with Slot-Ring Resonator in Tuning Stub for UWB Applications

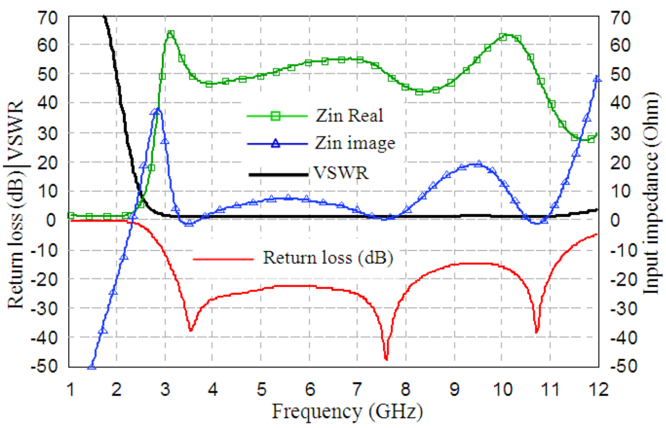


Figure 9: The return loss (S_{11}) of slot antenna with SRR tuning stub

From the Characteristics of the slot antenna by adjusting six parameters (ST1, ST2, SR1, SR1, ε_r and h) which will effect on matching impedance over the entire frequency band and increase wide bandwidth for UWB operations. Finally, the optimal value of tuning stub are ST1 = 12 mm and ST2 = 7.5 mm, and SR1 = 8 mm, SR2 = 5.5 mm, ε_r = 3.5 mm, and h=0.8 mm, respectively. The simulation result of the proposed slot antenna is shown in figure 9.

Figure 9 shows the simulated results of the return loss can achieve widen the bandwidth of 118 % coverage the frequency band from 2.95 GHz to 11.40 GHz (8.45 GHz) for UWB operations. The simulated results of VSWR of this antenna may be considered as VSWR $\leq$ 2, coverage the frequency band from 2.95 GHz to 11.40 GHz. The input impedance at the frequency range from 2.95 GHz to 11.40 GHz is nearly 50 ohms of the transmission line.

H. Bandwidth Enhancement Techniques of Slot Antenna with SRR in Tuning stub

In addition, extended the slot antenna with SRR in tuning stub is presented in Figure 1. By using a technique shifted SRR in tuning stub to left/right for enhancing bandwidth, are shown in figure 2(a) and 2(b). In this study two cases: SRR stub shifted left and SRR stub shifted right. The optimal value of tuning stub are ST1 = 9.5 mm and ST2 = 8.6 mm, and SR1 = 5 mm, SR2 = 3.5 mm, S1= 1.5 mm, and S2 = 2 mm, ε_r = 3.5 mm, and h = 0.8 mm, respectively. The simulated result of the slot antenna is shown in Figure 10.

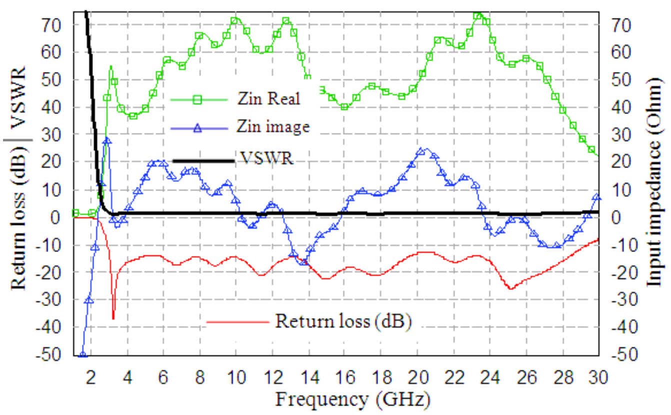
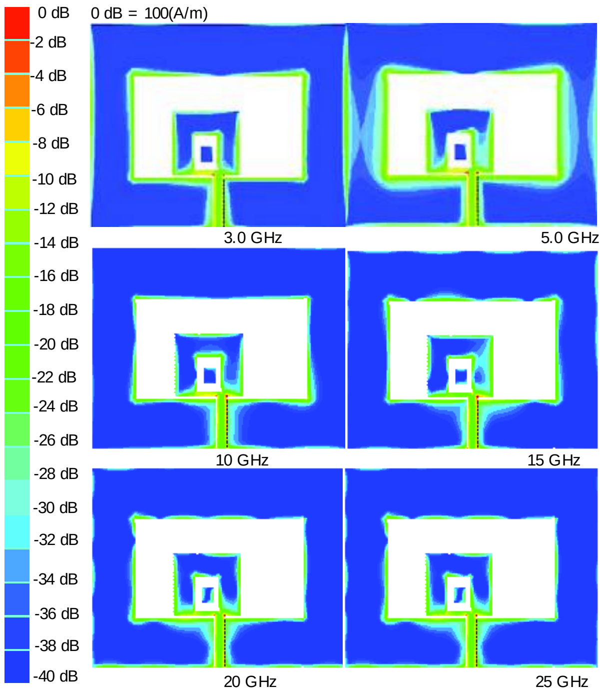


Figure 10: The return loss (S_{11}) of the slot antenna in the case shifted left/right of SRR in tuning stub

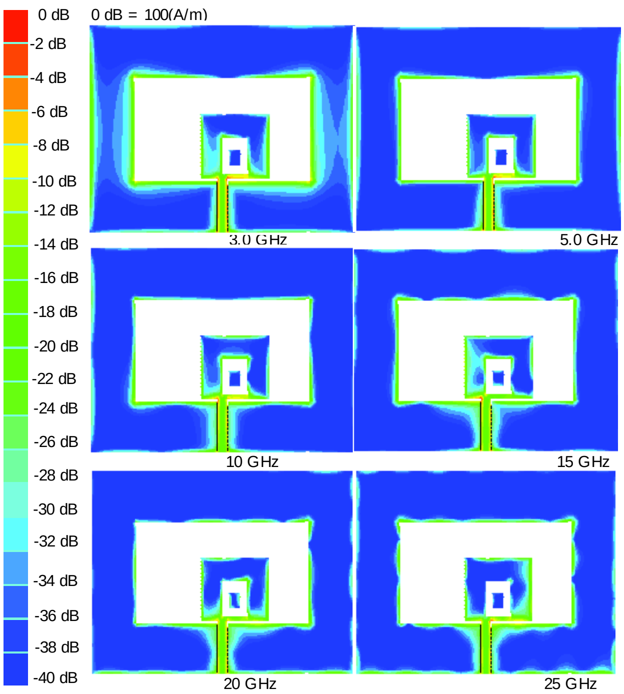
Figure 10 shows the simulated return loss of the slot antenna with ring-shaped tuning stub in case shift left/right of tuning stub. The impedance bandwidth of the proposed antenna is well matched as the 10-dB return loss, and the impedance bandwidth of 164% coverage the frequency band from 2.90 GHz to 29.36 GHz (26.46 GHz) has been achieved.

The simulated result of VSWR of the slot antenna is considered at VSWR $\leq$ 2, coverage the frequency band from 2.90 GHz to 29.36 GHz. The input impedance of the frequency band from 2.90 GHz to 29.36 GHz is nearly 50 ohms of the transmission line, as shown in figure 10.

The simulated average current distributions of slot antenna in case shifted left/right SRR tuning stub is shows in figure 11.



(a) SRR shifted left

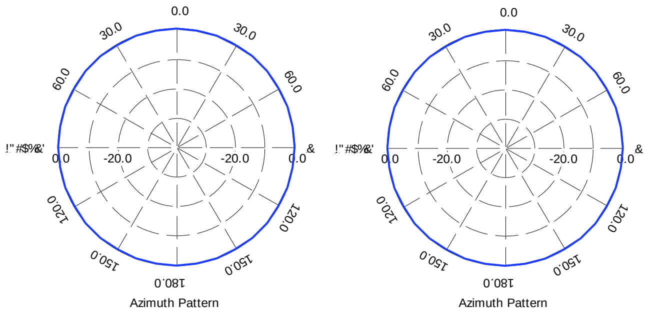


(b) SRR shifted right

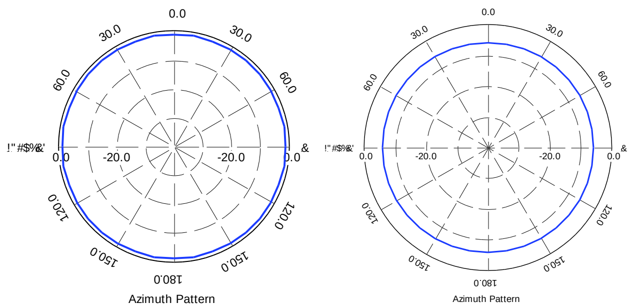
Figure 11: Current distributions of the slot antenna in case shifted left/right SRR tuning stub

Figure 11 shows the simulated surface current distribution of the slot antenna with shift left/right tuning stub at 3 GHz, 5 GHz, 10 GHz, 15 GHz, 20 GHz, and 25 GHz, respectively. The average current distributions of slot antenna in case shifted left SRR tuning stub increase on microstrip feed line and below SRR tuning stub, as shown in Figure 11(a). The average current distributions of slot antenna in case shifted right SRR tuning stub increase on microstrip feed line and below SRR tuning stub, as shown in Figure 11(b). All the areas are farthest average current distribution of the slot antenna will affect to increase wideband. Therefore, it can increase wideband by varying the length and width and shifted left/right SRR tuning stub.

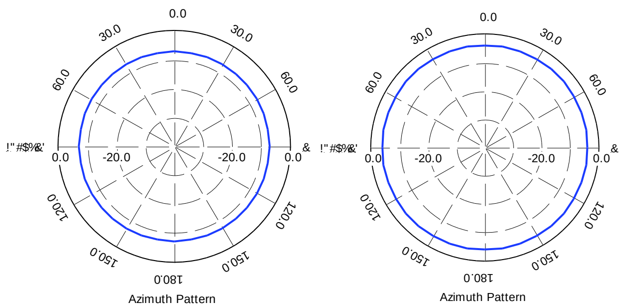
The simulated radiation patterns of the proposed slot antenna at 3 GHz, 5 GHz, 10 GHz, 15 GHz, 20 GHz, and 25 GHz, are shown in Figure 12. The simulated results of the gains of the proposed antenna, is shown in Figure 13.



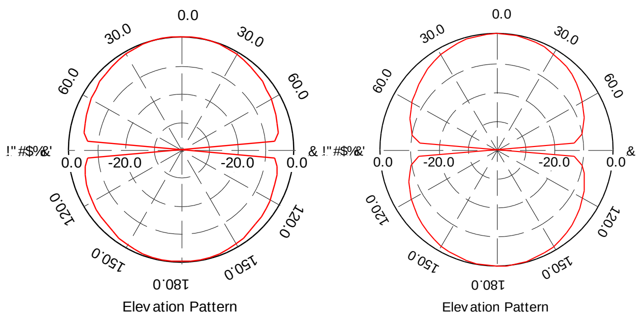
(a) xy plane at 3.0 GHz (b) xy plane at 5.0 GHz



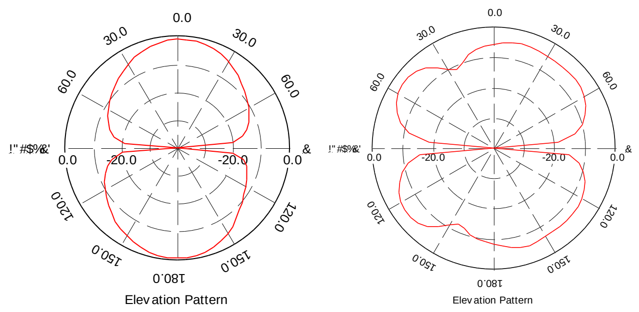
(c) xy plane at 10 GHz (d) xy plane at 15 GHz



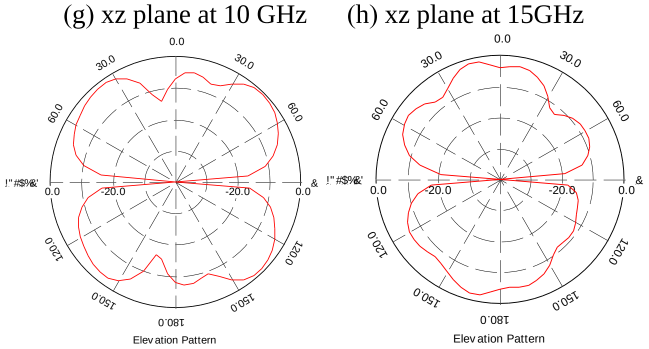
(c) xy plane at 20 GHz (d) xy plane at 25 GHz



(e) xz plane at 3.0 GHz (f) xz plane at 5.0 GHz



(g) xz plane at 10 GHz (h) xz plane at 15GHz



(i) xz plane at 20 GHz (j) xz plane at 25 GHz

Figure 12. Radiation pattern of proposed slot antenna

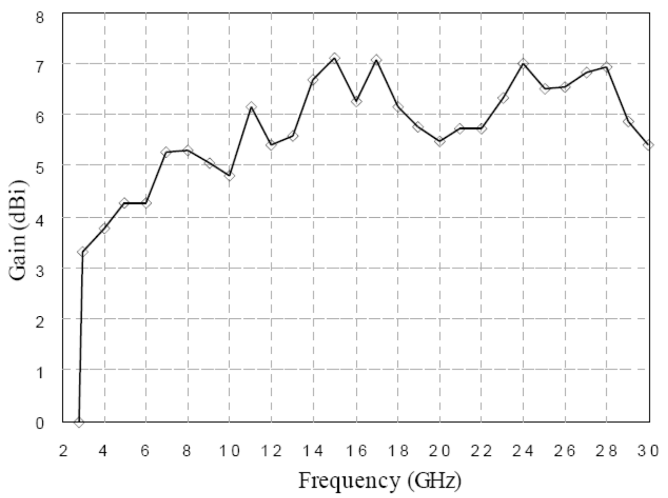


Figure 13: Gain of proposed slot antenna

The simulated radiation pattern of the slot antenna of the x-y plane (Azimuth pattern) is Omni- directional and the x-z plane (Elevation pattern) is bi-directional. The maximum direction of the azimuth pattern is consistently around direction, which is normal in the slot plane, as shown in Figure 17(a)-(d). Moreover, the radiation pattern of the slot antenna is the maximum direction on elevation pattern with the ± z direction, as shown in Figure 17(e)-17(j).

Figure 13 shows simulated gains of the proposed antenna at 3-30 GHz, it can see that the maximum gain of 7 dBi at 14.5 GHz and the average gain of the proposed antenna is 5.5 dBi.

CONCLUSION

In this paper presents characteristic of the slot antenna with SRR tuning stub for super UWB communications systems. The proposed antenna consists of a wide-rectangular slot on the ground plane and the microstrip feed line with SRR tuning stub on the other side. The simulated results can achieved widen the bandwidth of 118 % coverage the frequency band from 2.95 GHz to 11.40 GHz (8.45 GHz) coverage UWB operations. Moreover, a technique of asymmetrical SRR tuning stub shifted left/right for enhanced bandwidth more than 7.5 GHz. This antenna designed can achieved the impedance bandwidth of 164% coverage the frequency band from 2.90 GHz to 29.36 GHz (26.46 GHz) for super UWB communication. The average gain of the proposed antenna is 5.5 dBi, and the far-field radiation pattern in xz-plane and xy-plane are bi-directional.

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REFERENCES

[1] Federal Communications Commission. First report and order, revision of Part 15 of Commission's rule regarding ultra-wideband transmission system FCC, April 2002, pages 2-48

[2] Osama W. Ata, "Comparative Analysis of Various Feeding Structures for a Rectangular Microstrip Patch Antenna with FR4 Epoxy Substrate", International Journal of Applied Engineering Research, Vol. 11, No. 23, 2016, pp. 11461-11470.

[3] W. Kueathaweekun, N. Anantrasirichai, J. Nakasuwan, and T. Wakabayashi, "Broadband Slot Antenna Fed by Microstrip Line". The International Conference on Engineering, Applied Sciences, and Technology (ICEAST 2007), 21-23 November 2007.

[4] T. Kueathaweekun. "Design of Dual Frequency Slot Antenna using FDTD Method for WLAN Applications", SDU Research Journal Sciences and Technology. Vol. 8, No. 1, 2015, pp. 1-16.

[5] D. Prabhakar, P. M. Rao, M. Satyanarayana "Characteristics of Patch Antenna with Notch gap Variations for Wi-Fi Applications" International Journal of Applied Engineering Research, Vol. 11, No. 8, 2016, pp. 5741-5746.

[6] U. Deepak, T. K. Roshna, C. M. Nijas, K. Vasudevan, "A dual band SIR coupled dipole antenna for 2.4/5.2/5.8 GHz applications", IEEE Trans. Antennas Propag., Vol. 63, No. 4, April 2015, pp.1514–1520.

[7] R.-Z. Wu, P. Wang, Q. Zheng, R.-P. Li, "Compact CPW-fed triple-band antenna for diversity applications", Electron. Lett., Vol. 51, No. 10, 14 May 2015, pp. 735-736.

[8] S.-W. Chen, D-Y Wang, W-H Tu, "Dual-band/tri-band/broadband CPW-fed stepped-impedance slot dipole antennas", IEEE Trans. Antennas Propag., Vol. 62, No. 1, January 2014, pp. 485–490.

[9] Thep Kueathaweekun. "A Study of Dual/Triple-Band Microstrip-Fed Slot Antenna Design for WLAN/ WiMAX Communication Systems", International Journal on Communications Antenna and Propagation, Vol.**7**, No. 2, 2017, pp. 95-103.

[10] J. Liu, S. Zhong, and K. P. Esselle, "A Printed Elliptical Monopole Antenna With Modified Feeding Structure for Bandwidth Enhancement", IEEE Trans. Antennas Propag., Vol. 59, No.2, Feb. 2011, pp. 667–670.

[11] J. Y. Sze and K. L. Wong, "Bandwidth Enhancement of a Microstrip line-fed Printed Wide-slot Antenna", IEEE Trans. Antennas Propag., Vol. 49, No. 7, Jul. 2001, pp. 1020–1024.

[12] Y. J. Sung, "Bandwidth Enhancement of a Wide Slot Using Fractal-Shaped Sierpinski", IEEE Trans. Antennas Propag., Vol. 59, No.8, Aug. 2011, pp. 3076–3079.

[13] Y. Sung, "Bandwidth Enhancement of a Microstrip Line-Fed Printed Wide-Slot Antenna With a Parasitic Center Patch", IEEE Trans. Antennas Propag., Vol. 60, No. 4, Apr. 2012, pp. 1712–1716.

[14] Thep Kueathaweekun, "Simulation of Rectangular Slot-Ring Antenna Fed by Microstrip Line with Tuning Stub for WLAN/WIMAX Communication Applications", International Journal of Applied Engineering Research ISSN 0973-4562 Vol. 12, No. 22, 2017, pp. 12997-13004.

[15] Hossein Eskandari, Mohammad Naghi Azarmanesh, "Bandwidth enhancement of a printed wide-slot antenna with small slots", Int. J. Electron. Commun. (AEU), Vol. 63, 2009, pp. 896–900.

[16] W.-L. Chen, G.-M. Wang, and C. X. Zhang, "Bandwidth Enhancement of a Microstrip-line-fed Printed Wide Slot Antenna with a Fractal-shaped Slot", IEEE Trans. Antennas Propag., Vol. 57, No. 7, Jul. 2009, pp. 2176–2179.

[17] P. Jearapraditkul, W. Kueathaweekun, N. Anantrasirichai, O. Sangaroon and T. Wakabayashi, "Bandwidth Enhancement of CPW–Fed Slot Antenna with Inset Tuning Stub", *ISCIT*, 21-23 October, Vientiane, Lao. 2008.

[18] W. Kueathaweekun, P. Jearapraditkul, N. Anantrasirichai, O. Sangaroon, and T. Wakabayashi, "Wide-band CPW-fed Slot Antenna with Tuning Stub and π-Strip for WLAN/WiMAX Application", ISPACS, 8-11 December, Bangkok, Thailand, 2008.

[19] G. Pan, Y. Li, Z. Zhang, and Z. Feng, "A Compact Wideband Slot-Loop Hybrid Antenna with a Monopole Feed", IEEE Trans. Antennas Propag., Vol. 62, No. 7, Jul. 2014, pp. 3864–3868.

[20] Dastranj, A., Imani, A. and M. Naser-Moghaddasi, "Printed Wide-Slot Antenna for Wideband Applications", IEEE Trans. Antennas Propag., Vol. 56, 2008, pp. 3097-3102.

[21] Dastranj, A. and Imani, A., "Bandwidth Enhancement of Printed E-Shaped Slot Antenna Fed by CPW and Microstrip Line", IEEE Trans. Antennas Propag., vol. 58, 2010, pp.1402-1407.

[22] S. Bekturganova, A. H. Shah and V. Thangasamy, "Design and Analysis of An Enhanced Microstrip Patch Antenna For Ultrawideband (Uwb) Applications", Vol. 9, No. 10, 2015, pp.23899-23907.

[23] S. Bandi, A. Sudhakar, K. P. Raju, "A Tri Shaped Printed Patch Antenna For UWB Applications", Vol. 9, No. 10, 2015, pp. 20429-20439.

[24] Rajan Mishra, Vijay Shanker Tripathi, "A Compact Circular Disc Shaped Monopole Antenna for UWB Applications", International Journal of Applied Engineering Research, Vol. 12, No. 12, 2017, pp. 3049-3053.

[25] C. A. Balanis, "Antenna Theory Analysis and Design", John Wiley & Sons, Inc, 2005.

[26] Zeland Software, Inc. IE3D. New York, 2010.