International Journal of Natural and Engineering Sciences 8 (2): 42-46, 2014
ISSN: 1307-1149, E-ISSN: 2146-0086, www.nobel.gen.tr

Compact Super Wide Band Printed Monopole Antenna with a Band Notched Function

Parisa MAHMOUDZADEH[1] Changiz GHOBADI[1*]
[1]Departemant of Electrical Engineering, Urmia Branch, Islamic Azad University, Urmia, Iran

*Corresponding author:
Email: ch.ghobadi@urmia.ac.ir

Received: July 05, 2014
Accepted: August 23, 2014

Abstract

A 25×25mm^2 implementation of a microstrip-fed printed monopole antenna for the future super wideband (SWB) wireless systems application is presented. It has features of possesses band notched function (from 4.88 to 6.07GHz), extremely wide impedance bandwidth (from 2.58 to 40GHz) and its compact size. By using a smooth tapering between the semi fractal-shaped patch and the half ellipse-shaped defected ground plane, the super wide impedance bandwidth is achieved with ratio bandwidth larger than 15.5:1. Furthermore by carving an open-loop rectangular-shaped slot (OLRS) on the patch, a band notched characteristic is obtained. Numerical and experimental results are in good agreement and they indicate that the proposed antenna has a measured 2:1 VSWR bandwidth of 175.76%, except the rejected WLAN band.

Keyword: SWB antenna, microstrip-fed, band notched.

INTRODUCTION

High data rate wireless communications technology is developing rapidly since the release of the ultra-wideband (UWB) frequency range by the Federal Communications Commission (FCC) [1]. As in the case of conventional narrowband wireless systems, antennas play a crucial role in UWB systems. However, the design of antennas for UWB systems is more challenging as they need to operate over a bandwidth of 7.5 GHz from 3.1GHz to 10.6GHz, and at the same time satisfactorily radiating energy over the entire UWB frequency range [2]. For this application printed monopole antennas are attractive as they provide the following features: (i) large impedance bandwidth, (ii) ease of fabrication, and (iii) possessing acceptable radiation characteristics. Within the UWB spectrum coexists other narrowband systems including WLAN (5.15-5.35 GHz and 5.725-5.825 GHz). As these systems operate using a significantly stronger power density than UWB systems they are therefore likely to fatally interference with the operation of UWB systems. This necessitates an additional function from UWB systems to suppress such interfering signals. The conventional solution to eliminated or suppressed the interfering signal is by using a band reject filter in the UWB system. However, since the filter is wavelength dependent it will result in an increase of the physical size of the UWB system. To overcome this issue, UWB antenna with a band rejected function is required.

UWB antennas with notch bands have been proposed using various techniques, some of which include: applying resonant structure and inverted U-shaped parasitic element [3], vertical coupling strip [4], using slots [5] - [6] and a pair of T-shaped strips [7]. On the other hand, demand for the systems that can operate over a wide frequency range to provide the requirements of many future wireless applications is increased; consequently, a single SWB antenna covering both short- and long-range transmitting services is favorite choice. It is well-known that some antennas provide a ratio bandwidth larger than 10:1 impedance bandwidth, called super wideband [8]-[14]. Several antennas with different techniques for SWB applications have been reported in literature [8]-[14]. some of these techniques are: introducing an asymmetric dual-branch feed with an L-shaped feed branch [8], applying a semi elliptical fractal-complementary slot [9], using a tapered microstrip impedance transformer and implementing a semi-ring feed interface to the radiation patch [10], designing based on the planar inverted cone antenna (PICA) [11] and embedding an M-shaped notch at the patch bottom, a tapered coplanar waveguide (CPW) ground out of the notch, and a T-shaped CPW ground in the notch [12] . These techniques are very suitable for use in SWB applications, but aforementioned antennas are incapable to avoid interference with other wireless narrowband standards such as WLAN bands; hence, the SWB antenna designers are eager to propose super wide band antennas that can solve the interference problem. Use of slot on the patch to realize the band-notched in the SWB antennas has been presented in [13] and [14].

In this letter, a new SWB antenna with a compact size is presented. This design that not only demonstrate a very large impedance bandwidth of 175.76%, but also exhibits a band notched characteristic that is vital to eradicate interference from WLAN systems. The evolution of the proposed SWB antenna design, its simulated and measured results and comparison with other similar works are presented and discussed in the next sections.

Antenna Structure

Fig.1 displays the geometry of the proposed SWB antenna structure. It is printed on a FR4 substrate with relative permittivity 4.4, loss tangent 0.02 and thickness of 1.6mm. The total dimension of this compact structure is approximately $25(0.206\lambda_o) \times 25(0.206\lambda_o)$ mm2, where the λ_o is the lower-end frequency of the band wavelength that with comparison to the recent SWB antenna structures is admirable.

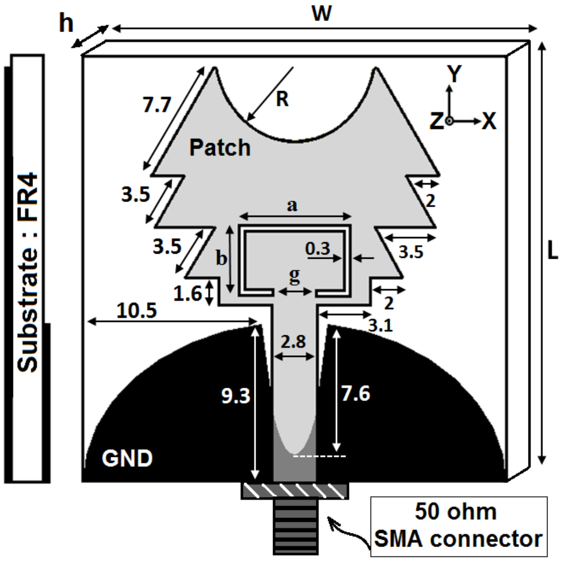

Figure 1. Geometry of the proposed antenna with L=25, W=25, h=1.6, a=6.5, b=4, g=2.5 and R=4.6 (optimized dimensions in mm).

As illustrated in the figure, the antenna consists of a semi fractal-shaped patch that includes a rectangular stub loaded sequentially three unequal trapezoidal metal elements to the top side of the stub in three steps and a semi-elliptical shaped ground plane with a semi-elliptical notch on the vicinity of the patch. For achieving 50Ω impedance matching, the SWB antenna is fed by a microstrip line with width and length of 2.8mm and 10.4mm respectively, that soldered to an SMA connector serves as antenna port. Two goals are considered for proposed antenna in this design. First, widening the bandwidth to satisfy the SWB antennas requirements and second achieving a band-notched function in WLAN band. Fig.2 shows the six steps employed to attain these two goals. It is seen that by increasing the size of the radiation element by addition of the three unequal trapezoidal metal elements to the stub and providing a smooth tapering between the semi fractal-shaped patch and the half ellipse-shaped defected ground plane, the super wide IBW can be achieved. In the four steps (i.e., step 1, 2, 3 and 4) the SWB antenna is realized and in the step-5 by carving an OLRS on the patch, a band notched characteristic is obtained. In step-6 a semi-circle notch etched on the top-end of the patch for improving the antenna performance. The reflection-coefficient curves of the above mentioned steps are plotted in the fig.3 and fig.4. It is clearly demonstrated in the fig.3 that by addition of the trapezoid-shaped metal elements to the rectangular stub at each step, the IBW increases till in step-4, it becomes 2.22GHz- 40GHz. In step-5 by applying an OLRS on the patch, a band-notched from 4.98GHz to 6.45GHz is obtained and the lower-end frequency of the band fixed in 2.97GHz.

Consequently in the step-6 by etching a semi-circle notch on the top-end of the patch, the band-notched is located in 4.91GHz-6.05GHz band that absolutely covering the WLAN (5GHz-6GHz) band with very low band losses in comparison to step-5, and the beginning frequency of the band is 2.30GHz that shows a band width increasing in lower frequencies.

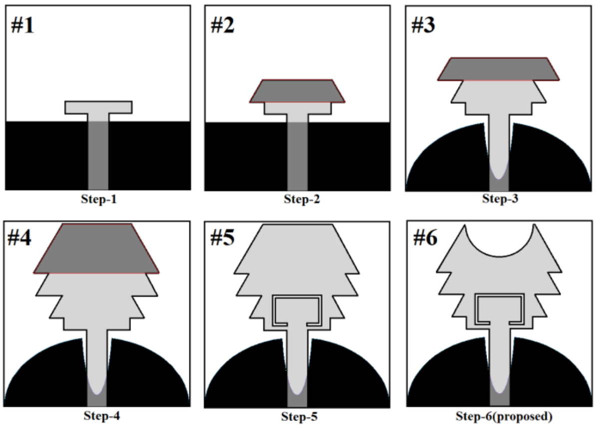

Figure 2. Six supplementary antenna designing steps

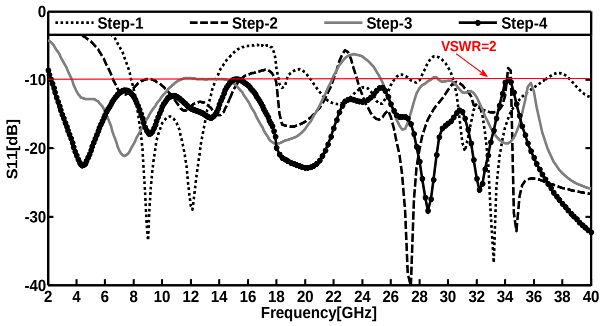

Figure 3. Simulated return losses of the four designing steps of the antenna

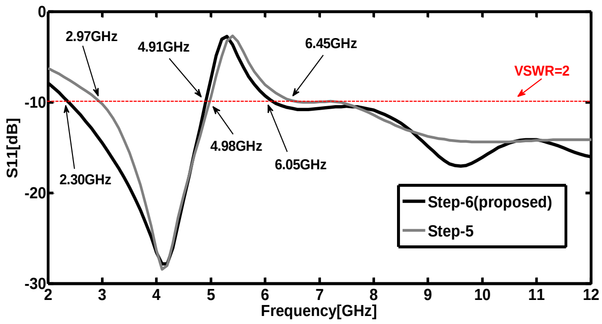

Figure 4. Simulated return losses of the step -5 and -6 of the antenna

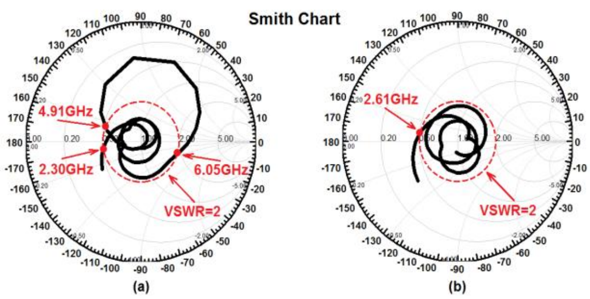

Figure 5. Smith chart for the (a) proposed antenna and (b) antenna without OLRS

Simulation Results And Measurements

The smith chart of the antenna performance with/without OLRS is plotted in fig.5, to understand the band filtering phenomenon of the antenna. As depicted in fig.5, by loading the OLRS on the patch, an inductance enhancement is provided that prevents radiation over particular narrow band. For more explanation about aforementioned antenna performance the fig.6 is plotted. It shows the current density distribution and electric fields over the patch at the notch frequency (5.3GHz). In this frequency the electric fields are more dominant around OLRS. The current vectors around the slot are in opposite directions resulting in cancellation of signals predominately at or very close to a specific frequency determined by slot length.

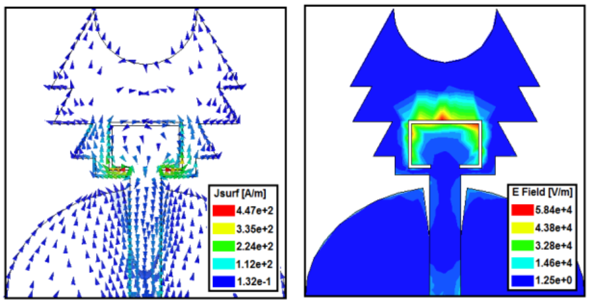

Figure 6. Current density distribution and electric field over the patch at the notch frequency (5.3 GHz)

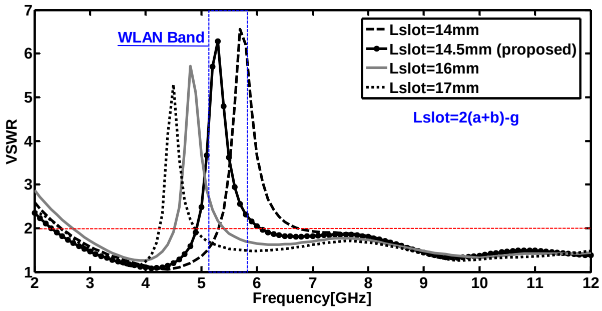

Figure 7. Simulated VSWR characteristics of the proposed SWB antenna for various L_{slot} lengths

The length of slot is nearly equal to quarter wavelength at the center frequency of the notched band. The guided wavelength is given by [15]:

$$L_{slot} = \frac{\lambda_g}{4} = \frac{c}{4f\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$\varepsilon_{eff} = \frac{1+\varepsilon_r}{2\varepsilon_r} \tag{2}$$

Where c is the speed of light in vacuum, f (notch center frequency) =5.3GHz, εeff (effective dielectric constant) = 0.61, and εr (relative permittivity) = 4.4. The length of the slot (L_{slot}) in this study is 18.5mm.

As shown in Fig. 7, the L_{slot} plays an important role in the position of the notch center frequency. When L_{slot} is increased from 18mm to 21.5mm the position of notch frequency is reversely changed, approximately from 5.6GHz to 4.4GHz. The optimal dimension of the slot length is L_{slot}=18.5mm, whereas it is nearly, equal to the quarter wavelength at center frequency of the notch band (i.e., 5.3GHz).

Bandwidth Dimension Ratio

In the recent years a new useful index term in contemporary articles is introduced to compare between two or more SWB antennas [8], this index term named the bandwidth dimension ratio (BDR). Indeed in the SWB antennas, the fundamental tradeoff between compactness and wideband characteristics of a planar antenna, will allow antenna designers to recognize if their SWB antenna design is compact in size while wide in bandwidth. This index term will indicate how much operating bandwidth (in percentage) can be provided per electrical area unit. The equation is written as follows [8]:

$$BDR = \frac{BW\%}{\lambda_{length} \times \lambda_{width}} \tag{3}$$

Table 1. Comparison of the proposed antenna with some references

Reference	*IBW (GHz)*	*Ratio BW*	*10-db BW (%)*	*Electrical dimension*	*BDR*	*Notched band*
[8]	8.35	15:1	175.06	0.28λ×0.21λ	2952	WLAN
[9]	17.36	13.06:1	172	0.17λ×0.37λ	2735	×
[10]	26.32	25:1	184.83	0.45λ×0.43λ	955	×
[11]	27.8	13.63:1	172	0.44λ×0.44λ	886	×
[12]	20.48	10.31:1	164	0.23λ×0.32λ	2224	×
[13]	31.65	31:1	187.5	0.26λ×0.28λ	2586	×
[14]	27.9	14.29:1	173.83	0.20λ×0.22λ	3950	WLAN
Proposed	*37.42*	15.5:1	175.76	0.21λ×0.21λ	*3985*	WLAN

Where, λ is the wavelength of the lower-end operating frequency of the band. Here, a larger BDR will show that the design antenna is smaller in dimension and wider in bandwidth. In the Table 1, some characteristics of the SWB antenna such as IBW, ratio BW, 10-dB BW, electrical dimension, BDR and notched band are presented for a fair comparison between the proposed antenna and references [8]-[14]. The ratio bandwidth of the proposed antenna is one of the best in the Table 1, while the BDR and IBW with 3985 and 37.42GHz amounts respectively are the most outstanding ones and so admirable.

EXPERIMENTS and RESULTS

Radiation patterns of the SWB antenna with the co- and cross-polarizations in the H-plane (x–z plane) and E-plane (y–z plane), at low frequencies (i.e. 4.2, 7.5 and 10.5GHz) and at high frequencies (i.e.12, 25 and 40GHz), are plotted in fig. 8 and fig.9 respectively. In fig.8, it is observed that the radiation patterns in H-plane and E-plane are approximately omnidirectional and monopole-like, respectively in low frequencies but in fig.9 it can be seen that at higher frequencies the cross-polarization level rises due to the increasing orthogonal surface currents. Also, a few nulls are observed at higher frequencies. The simulated and measured gain of the proposed antenna is plotted in fig. 10. As shown in this figure the measured gain abruptly drops to -6 dB in the vicinity of the notch bands, and it is around 2-4 dB till 32GHz while gain decreases after 32GHz. Fig.11 shows the measured and simulated VSWR characteristics of the proposed SWB antenna. The fabricated antenna has a frequency band from 2.58GHz to 40GHz with a rejection band around 4.88GHz - 6.07GHz. Any discrepancy is attributed to fabrication tolerance and the effect of the SMA port of the prototype. The antenna was analyzed and optimized using a commercial electromagnetic (EM) simulation tool (HFSS 11) and the final optimized SWB structure has been fabricated. The fabricated antenna is also shown in fig. 12. The measured results of the proposed SWB antenna are attained using the Agilent E8363CPNA network analyzer.

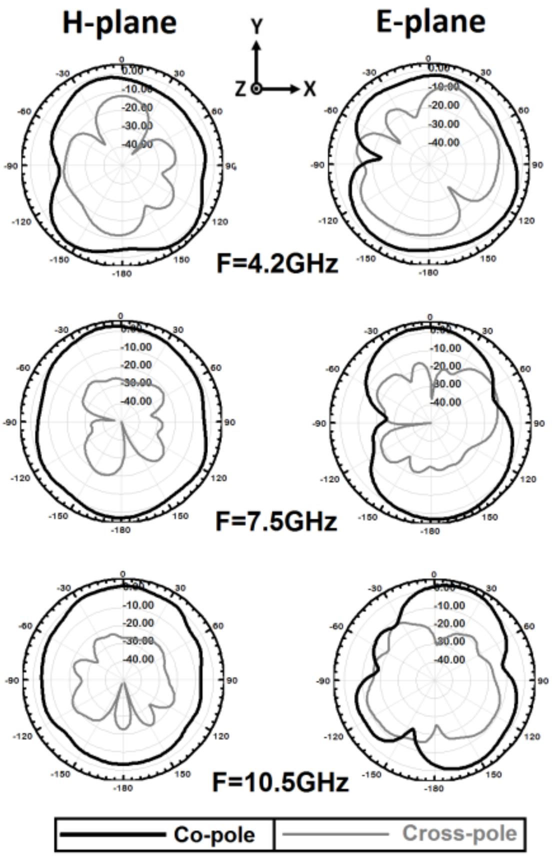

Figure 8. Measured antenna radiation patterns at 4.2GHz, 7.5GHz and 10.5GHz

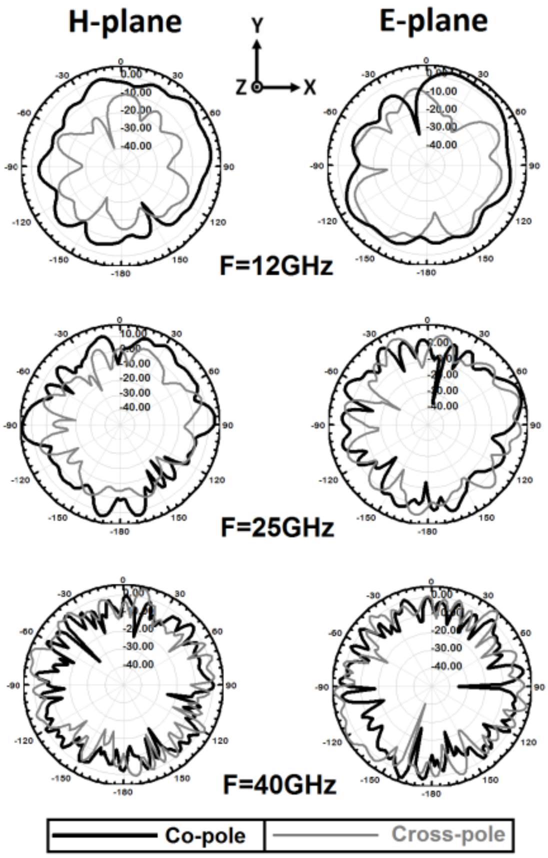

Figure 9. Measured antenna radiation patterns at 12GHz, 25GHz and 40GHz

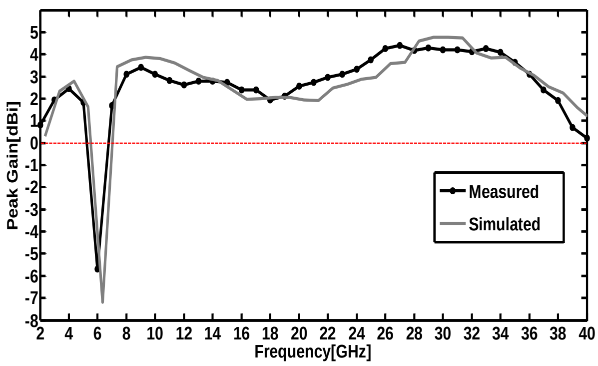

Figure 10. Measured and simulated gain of the proposed antenna

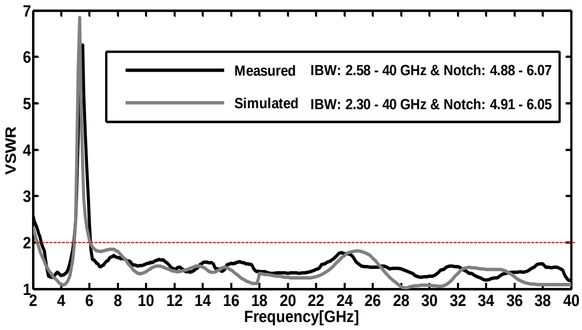

Figure 11. Measured and simulated VSWR of the proposed SWB antenna

Figure 12. Photograph of the fabricated prototype, SWB antenna

CONCLUSION

In this paper a compact SWB antenna with a band notched function has been designed and tested. By generating a semi fractal-shaped patch by addition of the unequal trapezoidal metal elements to the stub and increasing the size of the patch leads to a smooth tapering between the patch and the ground plane, the super wide IBW can be achieved. With a measured 2:1 VSWR bandwidth of 175.76% with 15.5:1 ratio bandwidth (from 2.58 to 40GHz), except the rejected WLAN band, this antenna can operate over a large frequency range to support multiple wireless communication services. In comparison between other recent designs, the proposed antenna has very good performances especially in BDR index term.

REFERENCES

[1] Federal Communications Commission: First report and order, revision of part 15 of the Communication's rules regarding ultra-wideband transmission system, 2002.

[2] J. Pourahmadazar, C. Ghobadi, J. Nourinia, and H. Shirzad, "Multiband ring fractal monopole antenna for mobile devices," IEEE Antennas Wireless Propag. Lett, vol. 9, pp. 863–866, 2010.

[3] Majid Shokri, Hamed Shirzad, Sima Movagharnia, Bal Virdee, Zhale Amiri, and Somayeh Asiaban, "Planar Monopole Antenna With Dual Interference Suppression Functionality," IEEE Ant. Wireless. Propage. Lett. vol.12, 2013. pp. 1554–1557.

[4] Hsien-Wen Liu, Chia-Hao Ku, Te-Shun Wang and Chang-Fa Yang, "Compact Monopole Antenna with Band-Notched Characteristic for UWB Applications," IEEE Ant. Wireless. Propage. Lett. vol.9, 2010. pp. 397–400.

[5] Ke Zhang, Yuanxin Li, and Yunliang Long, "Band-Notched UWB Printed Monopole Antenna with a Novel Segmented Circular Patch," IEEE Ant. Wireless. Propage. Lett. vol.9, 2010. pp. 1209–1212.

[6] Y. L. Zhao, Y. C. Jiao, G. Zhao, L. Zhang, Y. Song, and Z. B. Wong, "Compact planar monopole UWB antenna with band-notched characteristic," Microw. Opt. Technol. Lett., vol. 50, 2008, pp. 2656–2658.

[7] M. Ojaroudi, Sh. Yazdanifard, N. Ojaroudi, and R. A. Sadeghzadeh," Band-Notched Small Square-Ring Antenna With a Pair of T-Shaped Strip Protruded Inside the Square Ring for UWB Applications," IEEE Ant. Wireless. Propage. Lett. vol.10, 2011. pp. 227–230.

[8] J. Liu, K.P. Esselle, S.G. Hay and S.S. Zhong, "Compact super-wideband asymmetric monopole antenna with dual-branch feed for bandwidth enhancement," Electronics Letter. Vol. 49, No. 8, April 2013. pp. 515–516.

[9] Ke Ren Chen, Chow Yen Desmond Sim, and Jeen Sheen Row," A Compact Monopole Antenna for Super Wideband Applications," IEEE Antennas Wireless Propag. Lett. VOL. 10, 2011. pp. 488–491.

[10] Jianjun Liu, Karu P. Esselle, Stuart G. Hay, and Shunshi Zhong, "Achieving Ratio Bandwidth of 25:1 From a Printed Antenna Using a Tapered Semi-Ring Feed," IEEE Antennas Wireless Propag. Lett. vol.10, 2011. pp. 1333–1336.

[11] Shi Cheng, Paul Hallbjörner, and Anders Rydberg, "Printed Slot Planar Inverted Cone Antenna for Ultrawideband Applications," IEEE Antennas Wireless Propag. Lett. VOL. 7, 2008. pp. 18–21.

[12] Chao Deng, Yong-jun Xie, and Ping Li, "CPW-Fed Planar Printed Monopole Antenna with Impedance Bandwidth Enhanced," IEEE Antennas Wireless Propag. Lett. VOL. 8, 2009, pp. 1394–1397.

[13] Xiao Rong Yan, Shun Shi Zhong, and Guo Yu Wang, "The band-notch function for a compact coplanar waveguide-fed super-wideband printed monopole," Microw. Opt. Technol. Lett., Vol. 49, No. 11, November 2007, pp. 2769–2771.

[14] A. C. Shagar and R. S. D. Wahidabanu, "Compact Slot Antenna with Band-Notch Characterization for Multifunctional Communication Systems," Microw. Opt. Technol. Lett., Vol. 55, No. 1, January 2013, pp. 218–223.

[15] You-Zhi Cai, Hong-Chun Yang, and Ling-Yun Cai, "Wideband Monopole Antenna With Three Band-Notched Characteristics," IEEE Antennas Wireless Propag. Lett. VOL. 13, 2014, pp. 607–610.