PROPOSAL AND DEVELOPMENT OF TWO DIRECTIONAL UWB MONOPOLE ANTENNAS

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Abstract—Two directional UWB monopole antennas are proposed. It is shown that a design methodology for omnidirectional UWB rectangular planar monopole antennas can be applied for directional ones. The directional features are taken by introducing a slanting angle between the radiator and the ground plane. The slanting angle also plays a role in the low cutoff frequency, and it is considered in a proposed equation to determine that frequency. For the two UWB antennas the radiators have a rectangular shape, and the bandwidth is extended by choosing beveling angle and an appropriate height-width ratio. The developed antennas have a bandwidth wider than 10 GHz for a reflection coefficient lower than −10 dB. The directional radiation pattern has an average gain of 5 dB.

1. INTRODUCTION

Since 2002, the UWB antenna research is focused on satisfying the requirements settled by the FCC for UWB Communication Systems. The omnidirectional radiation pattern characteristic in UWB antennas is required because efforts have been carried out to improve mobile and portable wireless communication systems. This peculiarity has reduced the interest in directional UWB planar antennas.

Some modern electronic devices such as fixed high data wireless local systems, ground penetration radars, localization systems and

microwave radio-systems for cancer detection require directional antennas with a wide impedance bandwidth. Beside planar and planarized UWB dipoles and monopoles with omnidirectional radiation pattern [1–22], there are also published volumetric, planar and planarized UWB monopoles with a directional radiation pattern [23–33]. Among them, the most popular planarized UWB directional antenna is the Vivaldi one [31, 32].

The developments of a high-performance UWB antenna face significant challenges due to the critical tradeoff between bandwidth, gain, size, phase linearity and radiation pattern stability. For example, the Vivaldi antenna has high phase linearity, but its size is increased at low frequencies for a high directive radiation pattern [31]. Meanwhile, ridged horn antennas compared with the Vivaldi ones also have several disadvantages: Hard to be fabricated, high cost and relatively big size [32].

The main goal of this paper is to offer a design methodology for directional UWB monopoles, in order to provide a required versatility to develop these antennas for a needed lower cutoff frequency. The paper is organized as follows: Section 2 presents the design of the radiator; the development of directional UWB monopoles is described in Section 3; Section 4 details the obtained results for the bandwidth and the radiation pattern of the prototypes, and in Section 5 the conclusions are formulated.

2. RECTANGULAR RADIATOR DESIGN

The radiator's design methodology uses five parameters to be tuned: bevel angle, ψ, height/width ratio, l/W, feeding point width, a, feeding point height, h, and slanting angle, β between the radiator and the ground plane. Figure 1 shows the parameters and areas (A1, A2 and A3) of the radiator.

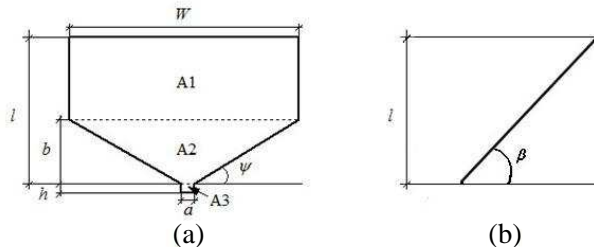The methodology for the radiator design is represented by the flow

Figure 1. Design parameters of the rectangular radiator.

diagram shown in Figure 2 [34]. There, the first tune process uses a set of different bevel angles, ψ, for a square planar monopole (in this case, for example, for $f_L = 6.5$ GHz, $l = W = 19$ mm). The selected bevel angle, ψ_μ, is the one that provides the best UWB reflection coefficient.
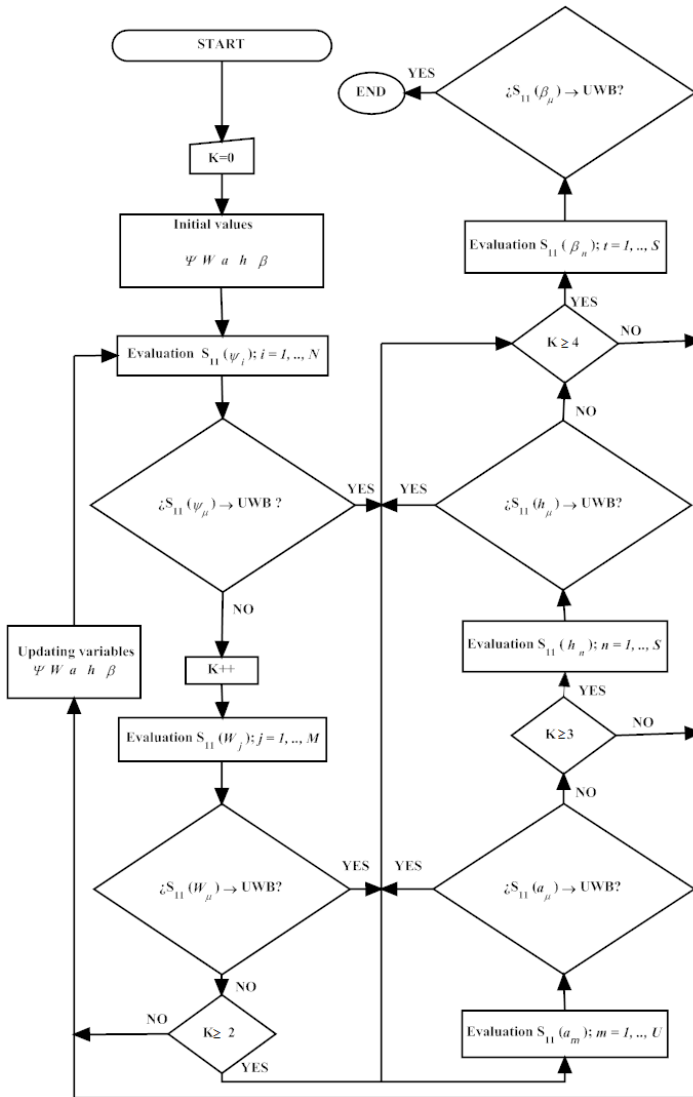

Figure 2. Schematic diagram of the design methodology of a directional UWB monopole antenna.

The second tune process uses different radiator widths, W, for ψ_μ obtained from the first tune process. Now, before determine the lower cutoff frequency, it is important to make some comments related to the parameter W.

A square planar monopole could be seen as a planar cylindrical monopole with a wide effective radius, and as well known due to the direct relationship between the radius of a cylindrical monopole and its bandwidth [35], the greater the radius is, the wider the bandwidth is. Therefore, a rectangular planar monopole ($W > l$) provides a wider bandwidth when $W = l$, and it is the reason that the design methodology always requires the height/width ratio less than one.

Once the above is stated and continuing with the design methodology, the selected value of W is now W_μ and corresponds to the value that provides wider bandwidth in this second tune step. It is important to point out that the variation of W implies a different radiator area, which requires a new tune process to get the impedance matching. Therefore, as can be seen in Figure 2, the design methodology provides the possibility of verifying both in a new set of bevel angles (where now ψ_μ has been updated to the new dimension W_μ). Note that this re-tune process is carried out depending on the value of a counter, K.

After the bevel angle with the best UWB reflection coefficient has been attained, the third tunes process start, which uses the feed width, a, as a parameter to obtain the widest bandwidth. Following the same procedure used in the other tune process, the feed width is selected, in this case, a_μ, which provides the best UWB reflection coefficient in the process. At this point, the designer could repeat the first tune process in order to try to improve the bandwidth matching through the bevel angle; otherwise, the methodology can continue to the fourth tune process, which uses the feed height, h, as a parameter to enhance the UWB impedance matching. Then the feed height h_μ is selected, which provides (until now) the best UWB reflection coefficient. As before, the designer could repeat all the tune processes to try to improve the impedance matching. If not, the designer proceeds to the fifth and final tune task, which uses the slant angle, β, as the last parameter to yield the directional radiation pattern maintaining the best UWB impedance matching.

From the description of the methodology given above, it can be observed that the selection of the best UWB reflection coefficient is considered inside of each tune process. In Figure 3, the schematic diagram of the evaluation process can be discerned. There, the term parameter is used for any of the tune variables ψ, W, a, h or β. It is important to remark that the best value requires that two conditions
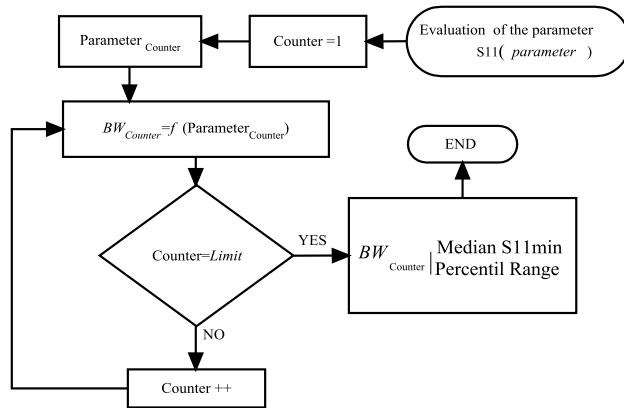
Figure 3. Schematic diagram of the evaluation process for each parameter design.

are achieved; on one hand, it must provide the reflection coefficient with the lowest median, and, on the other hand, the highest percentile range for a threshold $S_{11} \leq -10\,$dB. However, these statistical values are only guides to help the designer's choice.

The lower cutoff frequency of the directional UWB monopole antenna can be found by [36]:

$$l = 0.24\lambda F \tag{1}$$

where l is the length of a cylindrical monopole and of a planar radiator. λ is the wavelength, both in mm. The length-radius equivalent term, F, is used to find an equivalent area between a cylindrical monopole and a planar monopole radiator [37], and it is determined by all design parameters. This dimensionless term F is given by:

$$F = \frac{l}{r_d + l} \tag{2}$$

where r_d is the radius of a cylindrical monopole given in mm.

Now, making the cylindrical area equal to the rectangular planar monopole area shown in Figure 1 (formed by the sum of areas A1, A2 and A3):

$$2\pi r_d l = (l - b)\,W + \left(\frac{W + a}{2}\right) b + ah \tag{3}$$

Making some algebraic manipulations, an equivalent expression for the cylindrical radius r_d is obtained:

$$r_d = \frac{W\,(2l - b) + a(b + 2h)}{4\pi l} \tag{4}$$

Therefore, the proposed equation that includes the five design variables to determine the theoretical lower cutoff frequency of a directional UWB monopole antenna is attained by substituting Equations (2), (3) and (4) in (1), where it is got:

$$f_{L_{teo}}\,(\text{GHz}) = \frac{288\pi l}{[W\,(2l-b) + a\,(b+2h) + 4\pi l^2]\sin\beta} \tag{5}$$

In Equation (5), β is introduced to consider the virtual electrical length of the radiator, which is formed through its projection over a perpendicular plane to the ground plane. Thus, once the design methodology has been finished, the radiator's dimensions for a specific operational band requirement are achieved.

3. DIRECTIONAL UWB MONOPOLE DESIGN

3.1. Prototype I

In this subsection, the development of a directional UWB monopole using the proposed design methodology for a lower cutoff frequency of 6.5 GHz is detailed. The parameter values of a rectangular planar radiator by considering $f_L = 6.5$ GHz and after the tune tasks for all the parameters are: $l = 19$ mm, $b = 8$ mm, $W = 26$ mm, $a = 3$ mm, $h = 0.9$ mm, and $\beta = 30°$. Figure 4 shows all the dimensions of the directional UWB monopole model using the CST [38], where a planar

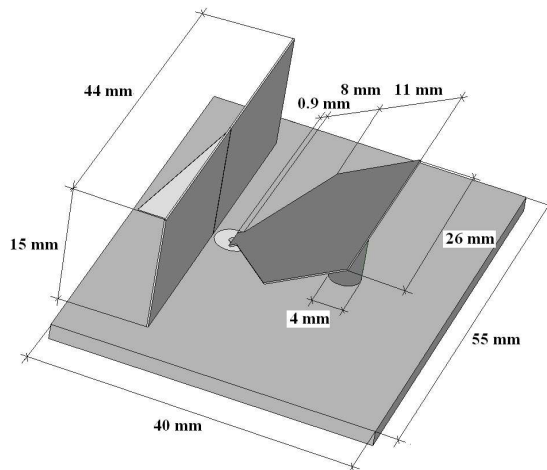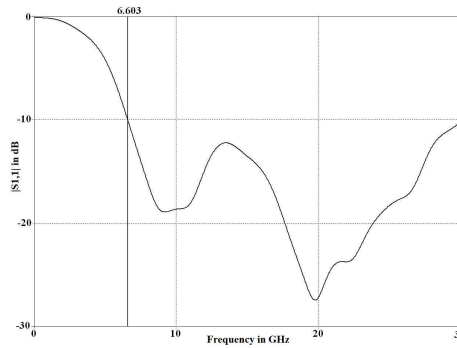**Figure 4.** Geometry and dimensions of the directional UWB monopole.

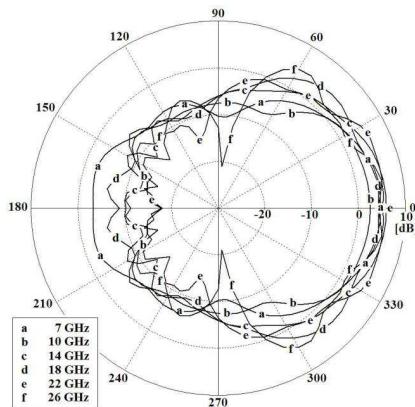**Figure 5.** Simulated reflection coefficient magnitude of the directional UWB monopole.

Figure 6. Simulated radiation patterns at 7, 10, 14, 18, 22 and 26 GHz of the directional UWB monopole.
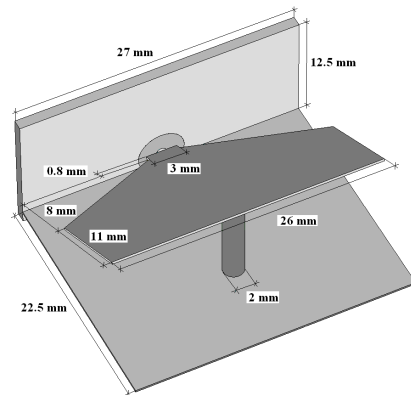

Figure 7. Geometry and dimensions of the modified directional UWB monopole.

reflector is collocated to improve the directional radiation pattern. The error between the f_L obtained by using Equation (5) and the one obtained by simulations is about 0.6% (see Figure 5).

The radiation pattern for 7, 10, 14, 18, 22 and 26 GHz obtained by simulations is depicted in Figure 6, where it can be seen that its gain goes from 3 to 5 dB; meanwhile, the ratio main to back lobe goes from 5 to 20 dB. The angular width (3 dB) of the main lobe is about 75°.
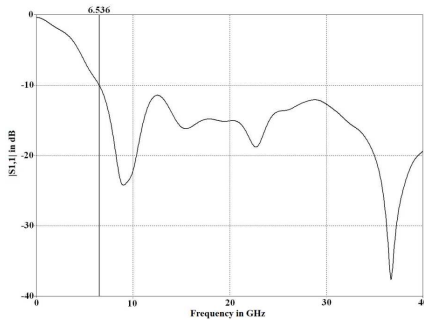
Figure 8. Simulated reflection coefficient magnitude of the modified directional UWB monopole.
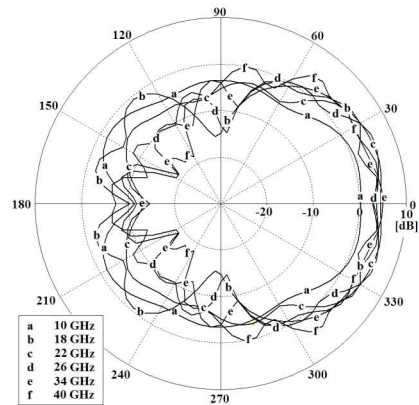
Figure 9. Simulated radiation patterns at 10, 18, 22, 26, 34 and 40 GHz of the modified directional UWB monopole.

3.2. Prototype II

The directional UWB monopole described above now is modified with the main goal of extending the bandwidth and decreasing the ground plane size, without significant penalty in gain, size of the back lobe and directivity. In this case, the antenna input is placed near the vortex formed by the ground and reflector planes as shown in Figure 7, and its design is supported by the design methodology above described. Here, the design of the antenna maintains the same lower cutoff frequency. Therefore, after the tune process the radiator dimensions: $l = 19$ mm, $b = 8$ mm, $W = 26$ mm, $a = 3$ mm, $h = 0.8$ mm and $\beta = 30°$. To avoid significant changes of the radiation pattern, it was experimentally determined that the length of the ground plane must be at least 3 mm bigger than $l\sin\beta$; meanwhile the height of the plane reflector must be at least 6 mm bigger than $l\cos\beta$. Figure 7 shows the dimensions of the modified directional UWB monopole. Equation (5) is still applicable to estimate the lower cutoff frequency, which in this case is: 6.43 GHz. As can be seen, the error between the lower cutoff frequencies predicted by Equation 5 and the one obtained by simulation is disregarded (see Figure 8).

The simulated radiation pattern for several frequencies is given in Figure 9. From this figure it can be deduced that this antenna keeps its feature of directivity, where the back lobe goes from -2 dB to -12 dB. Finally, the main lobe angular width has an average of $70°$.

4. MEASURED RESULTS

Both of the directional UWB monopoles were constructed using a brass sheet of 0.2 mm thickness for the radiator and a brass sheet of 1.3 mm thickness for the reflector and ground plane. Figure 10 shows the photograph of both prototypes.
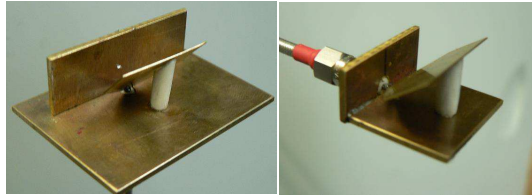

Figure 10. Prototypes of the directional UWB monopole and the modified one.

Figure 11 shows the measured reflection coefficient magnitude. The measures were obtained through an Agilent NPA Series Network Analyzer E8362B. The lower and upper cutoff frequencies for the directional UWB monopole antenna are 6.32 GHz and 18.06 GHz respectively. Meanwhile, the lower and upper cutoff frequencies for the modified one with the same radiator's size are 6.62 GHz and > 20 GHz, respectively.
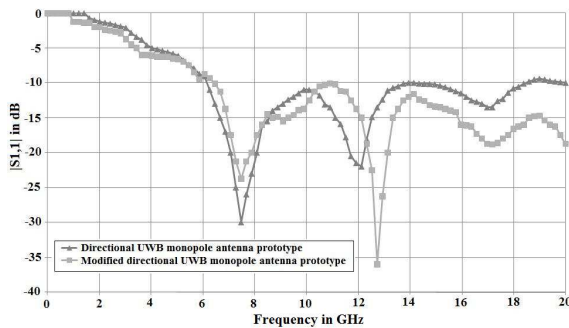

Figure 11. Measured reflection coefficient magnitudes of the prototypes.

Figure 12 shows the measured radiation pattern at 7, 10 and 14 GHz for both prototypes: (a) Directional UWB monopole and (b) Modified one. The average gain for both antennas in the operational band is 5 dB. The radiation pattern of the modified directional UWB
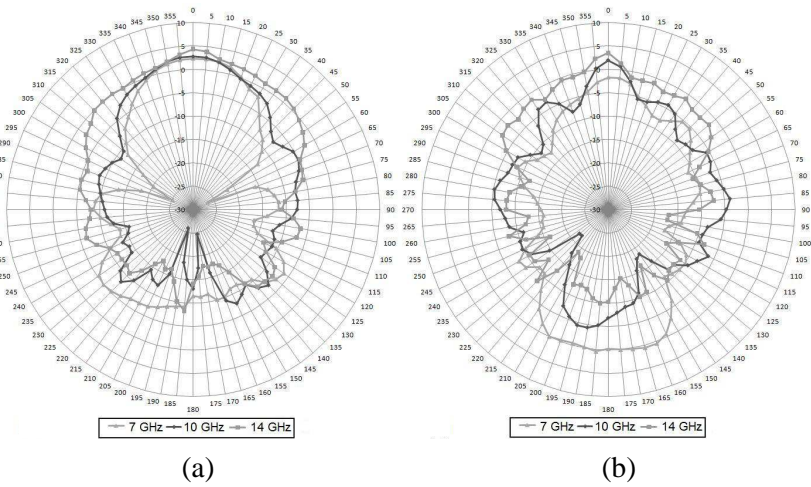
(a)   (b)

Figure 12. Measured radiation pattern at 7, 10 and 14 GHz (a) Directional UWB monopole. (b) Modified directional UWB monopole.

monopole undergoes changes due to the ground plane size reduction. The main/back lobe ratio for the Directional UWB monopole antenna is at least of 10 dB, whereas for the Modified is lower than 10 dB.

5. CONCLUSION

Two directional UWB antennas were developed. It was shown that directional UWB monopoles can be developed from omnidirectional ones if a slanting angle between the radiator and the ground plane is introduced. The lower cutoff frequency using proposed equation is very close to the one obtained by simulations.

The antenna features in both cases are based on selecting through a design methodology five parameters (bevel angle, height/width ratio, width and height of the feeding point and the slanting angle) to get UWB impedance matching and directivity. The prototypes have a measured frequency band of at least 11 GHz with a $S_{11} \leq 10$ dB and an average gain of 5 dB. These directional UWB antennas can be useful in applications where a simple and small directional antenna is needed.

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REFERENCES

1. Choi, S. H., J. K. Park, S. K. Kim, and J. Y. Park, "A new ultra-wideband antenna for UWB applications," *Microwave and Optical Technology Letters*, Vol. 40. No. 5, 399–401, Mar. 5, 2004.

2. Yi, D., G.-M. Wang, and Z.-W. Yu, "Compact UWB printed monopole antenna," *IEEE 2007 International Symposium on Microwave Antenna, Propagation and EMC Technologies for Wireless Communications*, 612–614, 2007.

3. Zhao, A. and J. Rahola, "Compact printed and bent-patch monopole ultra-wideband (UWB) antennas for mobile terminals," *2007 IEEE International Symposium on Antennas and Propagation Society*, 5135–5138, 2007.

4. Deng, H.-W., J. Jiao, X. He, and Y.-J. Zhao, "A novel UWB planar antenna," *8th International Symposium on Antennas, Propagation and EM Theory*, 133–136, 2008.

5. Deng, H.-W., J. Jiao, X. He, B. Yao, and Y. Zhou, "A compact square-ring printed monopole ultra wideband antenna," *International Conference on Microwave and Millimeter Wave Technology 2008*, Vol. 4. 1644–1646, 2008.

6. Wu, Q., R. Jin, J. Geng, and M. Ding, "Printed omni-directional UWB monopole antenna with very compact size," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 3, 896–899, Mar. 2008.

7. Yeo, J., Y. Lee, and R. Mittra, "Wideband slot antennas for wireless communications," *IEE Proceedings Microwave and Antennas Propagation*, Vol. 151, No. 4, 351–355, Aug. 2004.

8. Lee, J. N., J. H. Yoo, J. H. Kim, J. K. Park, and J. S. Kim, "A novel UWB antenna using PI-shaped matching stub for UWB applications," *Proceedings of the 2008 IEEE International Conference on Ultra-wideband*, Vol. 1, 109–112, 2008.

9. Bialkowski, M. E. and A. M. Abbosh, "Design of UWB planar antenna with improved cut-off at the out-of-band frequencies," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 408–410, 2008.

10. Fortino, N., J.-Y. Dauvignac, G. Kossiavas, and R. Staraj, "Design optimization of UWB printed antenna for omnidirectional pulse radiation," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 7, 1875–1881, Jul. 2008.

11. Abbosh, A. M. and M. E. Bialkowski, "Design of UWB planar band-notched antenna using parasitic elements," *IEEE Transactions on Antennas and Propagation*, Vol. 57, No. 3, 796–

799, Mar. 2009.

12. Terence, S., P. See, and Z. N. Chen, "A small UWB antenna for wireless USB," *IEEE International Conference on Ultra-wideband*, 198–203, 2007.

13. Liang, J., C. C. Chiau, X. Chen, and C. G. Parini, "Printed circular disc monopole antenna for ultra-wideband applications," *Electronics Letters*, Vol. 40, No. 20, 1246–1247, Sep. 30, 2004.

14. Viani, F., L. Lizzi, R. Azaro, and A. Massa, "A miniaturized UWB antenna for wireless dongle device," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 714–717, 2008.

15. Guo, L., S. Wang, Y. Gao, X. Chen, and C. Parini, "Miniaturization of printed disc UWB monopoples," *Proceedings of iWAT 2008*, 95–98, Chiba, Japan, 2008.

16. Zhang, H., H. Xin, and R. W. Ziolkowski, "Design of novel printed elliptical monopole antenna for UWB applications," *International Symposium on Antennas and Propagation Society*, 1–4, 2008.

17. Suh, S.-Y., W. L. Stutzman, and W. A. Davis, "A new ultrawideband printed monopole antenna: The planar inverted cone antenna (PICA)," *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 5, 1361–1365, May 2004.

18. Chang, D.-C., J.-C. Liu, and M.-Y. Liu, "A novel tulip-shaped monopole antenna for UWB applications," *Microwave and Optical Technology Letters*, Vol. 48, No. 2, 307–312, Feb. 2006.

19. Wu, X. H. and A. A. Kishk, "An ultra-wide band omnidirectional monopole antenna," *International Workshop on Small and Smart Antennas Metamaterials and Applications*, 345–347, 2007.

20. Su, S.-W., K.-L. Wong, and C.-L. Tang, "Ultra-wideband square planar monopole antenna for IEEE 802.16a operation in the 2–11 GHz band," *Microwave and Optical Technology Letters*, Vol. 42, No. 6, 463–465, Sep. 20, 2004.

21. Alipour, A. and H. R. Hassani, "A novel omni-directional UWB monopole antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 12, 3854–3857, Dec. 2008.

22. Peyrot-Solis, M. A., G. M. Galvan-Tejada, and H. Jardon-Aguilar, "A novel planar UWB monopole antenna formed on a printed circuit board," *Microwave and Optical Technology Letters*, Vol. 48, No. 5, 933–935, May 2006.

23. Kan, H. K., A. M. Abbosh, R. B. Waterhouse, and M. E. Bialkowski, "Compact broadband coplanar waveguide-fed curved quasi-Yagi antenna," *Microwaves, Antennas & Propagation, IET*, Vol. 1, No. 3, 572–574, Jun. 2007.

24. Yao, F.-W., S.-S. Zhong, and X.-L. Liang, "Experimental study of ultra-broadband patch antenna using a wedge-shaped air substrate," *Microwave and Optical Technology Letters*, Vol. 48, No. 2, 218–220, Feb. 2006.

25. Lee, R. T. and G. S. Smith, "A design study for the basic TEM horn antenna," *IEEE Antennas and Propagation Magazine*, Vol. 46, No. 1, 86–92, Feb. 2004.

26. Armbrecht, G., E. Denicke, N. Pohl, T. Musch, and I. Rolfes, "Compact directional UWB antenna with dielectric insert for radar distance measurements," *Proc. of the 2008 International Conference on Ultra-wideband*, Vol. 1, 229–232, 2008.

27. Elsherbini, A. and K. Sarabandi, "A compact directional coupled slot antenna for ultra-wideband applications," *Antennas and Propagation Society International Symposium*, 1–4, 2008.

28. Ericsson, R., "WP 2.3-1 wideband antenna radiators-TEM horn," Swedish Defense Research Agency, 2004.

29. Chung, K.-H., S.-H. Pyun, S.-Y. Chung, and J.-H. Choi, "Design of a wideband TEM horn antenna," *2003 IEEE International Symposium and Meeting on Antennas and Propagation and USNC/URSI National Radio Science*, 229–232, 2003.

30. Khalaj Amineh, R., A. Trehan, and N. K. Nikolova, "TEM horn antenna for ultra-wideband microwave breast imaging," *Progress In Electromagnetics Research B*, Vol. 13, 59–74, 2009.

31. Gazit, E., "Improved design of the Vivaldi antenna," *IEE Proceedings*, Vol. 135, No. 2, Part H, 89–92, Apr. 1988.

32. Wang, Z. and H. Zhang, "Improvements in a high gain UWB antenna with corrugated edges," *Progress In Electromagnetics Research C*, Vol. 6, 159–166, 2009.

33. Cheng, D., "Compact ultra wideband microstrip resonating antenna," US Patent 7872606 B1, Jan. 18, 2011.

34. Peyrot-Solis, M. A., "Research and development of UWB antennas," Ph.D. Thesis, 248, Aug. 2009.

35. Schantz, H., *The Art and Science of Ultrawideband Antennas*, Artech House, 2005.

36. Balanis, C. A., *Antenna Theory: Analysis and Design*, John Wiley & Sons, New York, 1982.

37. Amman, M. J., "Square planar monopole antenna," *IEE National Conference on Antennas and Propagation*, 37–38, Mar. 30–Apr. 1, 1999.

38. CST Microwave Studio Electromagnetic Field Simulation Software, Computer Simulation Technology, Darmstadt, Germany.