

FINITE GROUND CPW-FED UWB ANTENNA OVER THE METALLIC CYLINDRICAL SURFACES

Rafal Lech^{*}, Wojciech Marynowski, and Adam Kusiek

Gdansk University of Technology, 11/12 Narutowicza Str., Gdansk 80-233, Poland

Abstract—The investigation of finite ground coplanar fed ultra-wideband (UWB) antenna and the influence of its curvature and the proximity of circular metallic screen on the reflection coefficients and radiation characteristics is presented. The antenna is composed of two circular coplanar strips which enclose slot aperture of similar shape and is designed on a thin and flexible substrate which allows its bending. The antenna configuration has been modeled and experimentally tested, showing good performance in 2–15 GHz frequency with return losses less than -10 dB. It is shown that the bending of antenna does not significantly affect its performance. The existence of metallic screen deteriorates its radiation pattern and reflection coefficient, however with the correct choice of the distance between screen and antenna the required level of return losses can be provided.

1. INTRODUCTION

The ultra-wideband (UWB) systems have become very attractive for their many advantages and drawn interests of researchers and industry for over a decade now since the Federal Communications Commission (FCC) released the unlicensed frequency band of 3.1–10.6 GHz for commercial UWB applications [1]. UWB systems are characterized by low operating power level, low complexity, high data rates and great capacity. They find application not only in wireless communication but are also used in see-through-wall radar-imaging [2, 3] and ultra-wideband microwave imaging for the detection and localization of breast cancer [4–8]. One of the most essential parts of the UWB systems are antennas. They are required to operate in a wide

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* Corresponding author: Rafal Lech (rafal.lech@eti.pg.gda.pl).

frequency band, be compact and simple with small dimensions and light weight [9–24].

When the antenna is designed on thin and flexible dielectric substrate it can be bent and placed on curved surfaces. As authors have recently shown [25] that the bending of coplanar fed UWB antennas does not significantly affect their performance. Therefore, this type of antenna is suitable for use in flexible electronic systems [26, 27]. Conformal antennas are becoming popular due to their many advantages and possibilities of applications they offer [28–30]. The advantages of using antennas with a curved surface arise not only from the possibility of integrating them with the object on which they are mounted on but also from the increase, relatively to planar antennas, of their visible angular range. The circular antenna arrays, or arrays of radiators located on the surface of a cylinder may be the examples of such antennas that provide omni-directional radiation patterns in azimuth plane or provide, in this plane, the possibility of beam control. Such antennas can be used, e.g., in base stations for mobile communications systems. The conformal antenna arrays find their applications in a variety of fields such as airborne, space-borne, ship-borne, missile-borne radar, space vehicles, wireless communication and sonar.

The analysis of finite ground coplanar fed UWB antennas mounted on a circular metallic cylinders is being conducted in this paper. The influence of curvature of the antennas as well as the proximity of metallic surface on their reflection coefficients and radiation patterns is investigated and the comparison between planar and conformal radiators is made. A commercial software is used to design the UWB radiators and investigate the influence of the curvature. The obtained results are verified by own measurements of manufactured antenna prototypes.

2. UWB ANTENNA STRUCTURE

The investigated UWB antenna structure consists of circular radiator enclosed by a ground plane realized in planar technology. The basic configuration of the investigated antenna was the coplanar structure, proposed for the first time in [31]. The structure was composed of the circular patch enclosed by the circular slot etched in the infinite ground plane and fed directly from the coplanar line. The modification of this antenna was presented in [18], where the infinite ground plane was reduced to the strip. The authors have found that the effect of external edge of the ground strip ring is relatively small and can be neglected. However, the detailed investigation of the width of ground

plane strip presented in [19] have shown its significant influence on the cutoff capability at low frequencies of the antenna operation band. The UWB antenna which is under investigation here is the modified version of the antenna proposed in [19], with thinner, more flexible dielectric layer and redesigned feeding line. The schematic configuration of the antenna with its dimensions is presented in Figure 1.

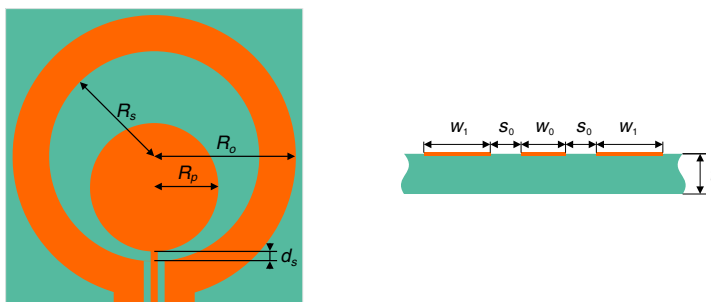


Figure 1. Schematic configuration of the investigated antenna and the cross-section of feeding line: antenna dimensions: $R_o = 32.4$ mm, $R_s = 23$ mm, $R_p = 13.5$ mm, $d_s = 0.3$ mm; feeding line dimensions: $w_0 = 3.5$ mm, $w_1 = 9$ mm, $s = 0.15$ mm; substrate parameters: $t = 0.254$ mm, $\epsilon_r = 3.44$.

The overall dimensions of the antenna including a dielectric border from the substrate are about 7×7 cm and it is designed to operate in the frequency range from 1.9–13 GHz with reflection coefficient -13 dB. The antenna can be additionally redesigned to operate more precisely in the UWB band (3.1–10.6 GHz) which allows to obtain smaller dimensions. Similar antennas with smaller dimensions have already been presented in literature [9, 10], but their reflection coefficients were up to -10 dB. Although, the -10 dB value of reflection coefficient is acceptable in UWB antennas, taking into consideration the aim of the investigation conducted in this study, which involve testing the influence of metallic screen proximity and curvature of the antenna without introducing additional adjustments, the choice of the bigger and better matched antenna was more appropriate in this case. This is due to the possibility of deterioration of the antenna performance caused by its bending and the presence of the metallic screen.

The investigated configurations of the antenna are schematically depicted in Figure 2. The curvature of the antenna with radius r around both orthogonal axes is investigated and the existence of metallic cylinder of radius r_g is assumed (the distance between cylinder and antenna is $d = r - r_g$).

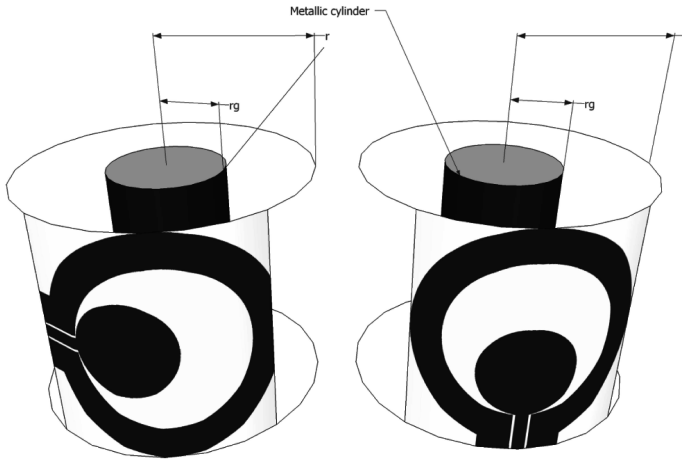


Figure 2. Configurations of the analyzed antenna.

3. SIMULATION RESULTS

In this section the results of antenna simulation are presented. First the influence of antenna curvature and the existence of metallic screen on the antenna reflection parameters are considered. Next the radiation patterns of chosen antenna configuration are calculated and presented. The simulations were performed with the use of commercial electromagnetic software.

3.1. Reflection Parameters

The orientation of the analyzed antenna configurations is depicted in Figure 3.

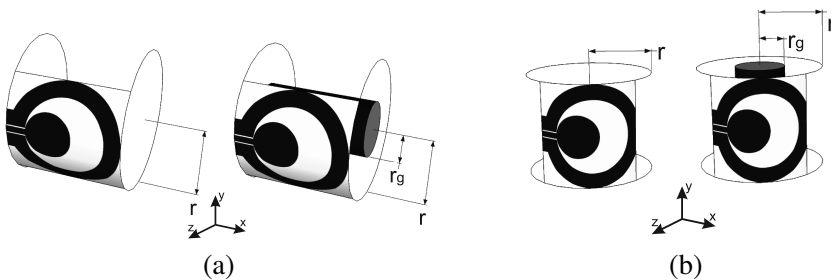


Figure 3. Orientation of the analyzed antenna configurations: (a) curved antenna around x axis, (b) curved antenna around y axis.

For the designed antenna in its planar version the reflection coefficient obtained from the simulation is better than -13 dB in the frequency range from 1.9 GHz to 12 GHz. The influence of the curvature of the antenna on its reflection coefficient is analyzed. Figure 4 presents the characteristics of reflection coefficients for the antenna curved around x and y axes (see Figure 3) without metallic cylinder, whereas, Figure 5 illustrates the reflection characteristics for the curved antenna with the metallic cylinder. As can be observed from the obtained results, the curvature of the antenna, especially around the x axis, only slightly affects its performance. The existence of metallic cylinder deteriorates the reflection characteristics; however,

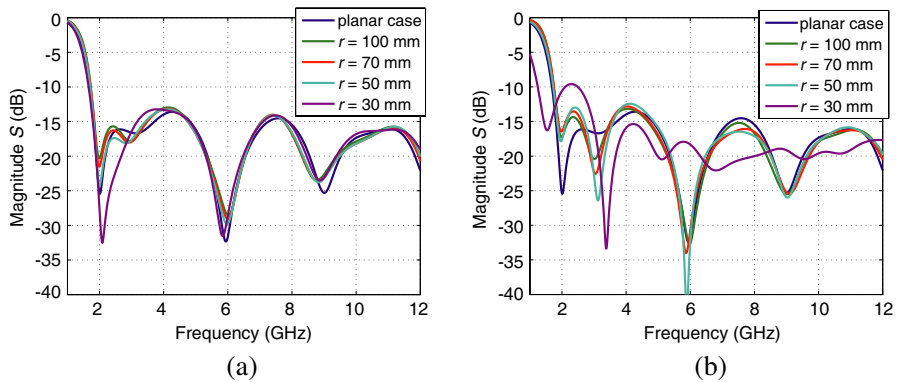


Figure 4. Magnitude of reflection coefficient for UWB antenna without metallic cylinder curved around (a) x axis and (b) y axis.

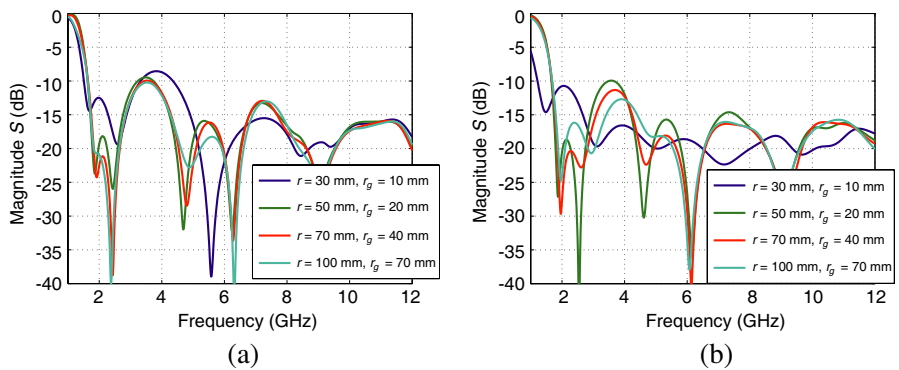


Figure 5. Magnitude of reflection coefficient for UWB antenna with metallic cylinder curved around (a) x axis and (b) y axis.

it is possible to select a proper distance between the antenna and the metallic screen to keep the reflection coefficient value below -10 dB in the desired frequency range. The investigations show that this distance should not be smaller than 20 mm.

3.2. Radiation Patterns

For the investigated antenna the radiation patterns at three frequencies ($f = 3, 5$ and 10 GHz) were calculated to illustrate the influence of antenna curvature and the existence of metallic screen. First the planar antenna is analyzed and the obtained results are presented in Figure 6.

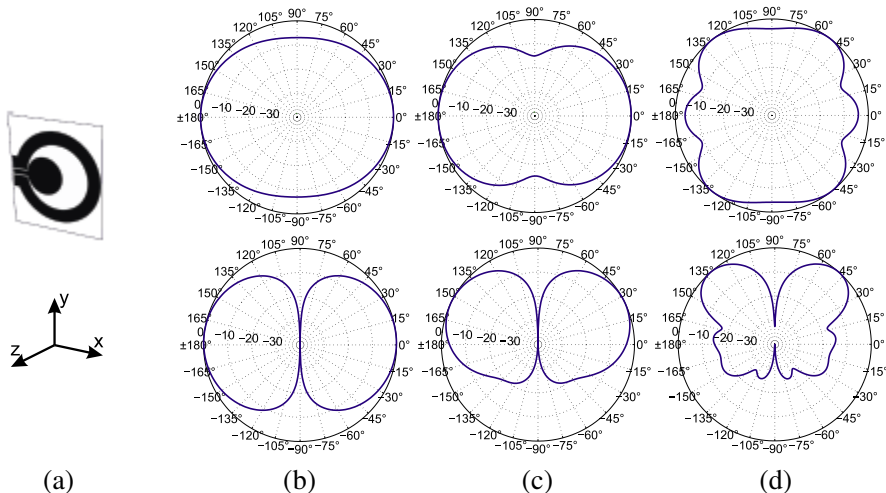


Figure 6. Planar antenna: (a) orientation of antennas, and radiation patterns at frequencies (b) 3 GHz, (c) 5 GHz and (d) 10 GHz. First row — yz plane for $x = 0$, second row — xz plane for $y = 0$.

As can be seen, the radiation patterns in yz plane are symmetric which is a consequence of the structure symmetry. The antenna radiates in every direction, however the existence of thin dielectric layer of the substrate results in the increase of radiation level in $+z$ direction. When the substrate is thicker the differences in radiation level in $+z$ and $-z$ direction are more visible [19]. From the radiation patterns in xz plane we can observe that the direction of maximum radiation depends on the operation frequency. For lower frequencies the direction of maximum radiation level is normal to the antenna surface ($+z$ and $-z$), while for higher frequencies it tilts toward x axis.

Next, the investigation of curved antenna with and without the existence of metallic cylinder is conducted. Figures 7 and 8 present the calculated radiation patterns for the antennas curved around x

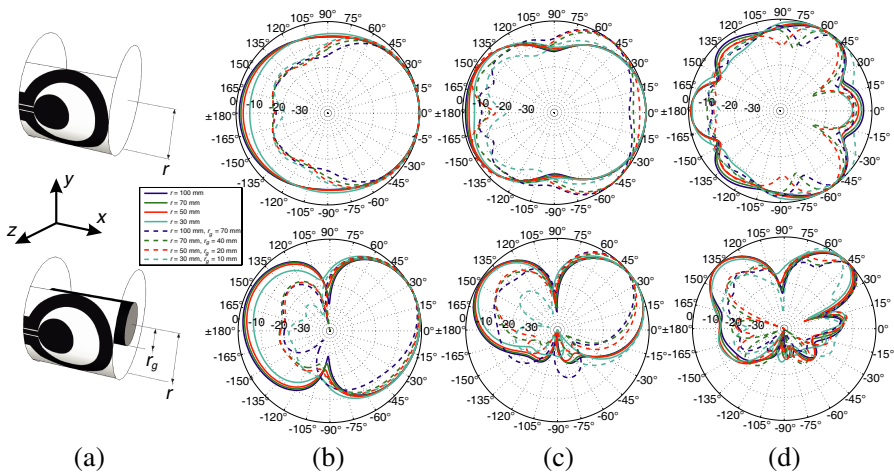


Figure 7. Curved antenna: (a) orientation of antennas, and radiation patterns at frequencies (b) 3 GHz, (c) 5 GHz and (d) 10 GHz. First row — yz plane for $x = 0$, second row — xz plane for $y = 0$.

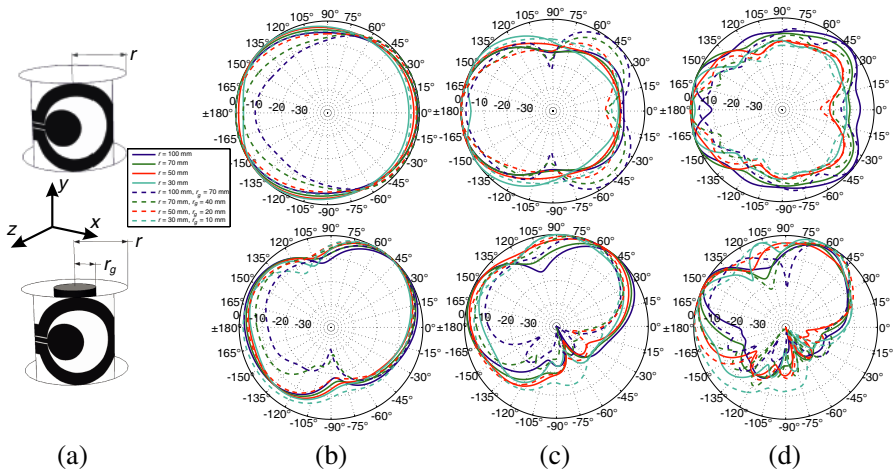


Figure 8. Curved antenna: (a) orientation of antennas, and radiation patterns at frequencies (b) 3 GHz, (c) 5 GHz and (d) 10 GHz. First row — yz plane for $x = 0$, second row — xz plane for $y = 0$.

axis and y axis, respectively. The curvature radii for the analyzed antenna are from $r = 100$ mm to $r = 30$ mm. When the antenna is placed on the metallic cylinder the assumed distances are $d = 30$ mm or $d = 20$ mm.

As can be observed in the case of antenna without metallic cylinder the curvature of the antenna around x axis only slightly affects the radiation pattern. In the case of antenna curved around y axis the influence is more visible. The 3D radiation characteristics for the considered cases are illustrated in the Appendix.

The existence of metallic cylinder deteriorates the antenna patterns. At a fixed value of distance between the screen and antenna the distance in terms of wavelength varies in the antenna wide frequency operation range. Therefore, the antenna pattern deterioration are more visible at higher frequencies. Because the metallic cylinder does not cover entire space behind the antenna, as it would be in the case of planar antenna placed in front of planar metallic screen, the radiation in $-z$ direction occurs in this case. The selection of the distance value allows to shape the antenna pattern. Therefore, the correct choice of the distance value should be made depending on the application and the required shape of radiation characteristic.

4. EXPERIMENTAL RESULTS

The prototype of the investigated antenna was manufactured and measured to verify the results obtained from simulations. The reflection parameters were measured using Agilent PNA-X N5242A VNA Network Analyzer, and the radiation patterns were measured in anechoic chamber using Agilent E5071C ENA Network Analyzer with GeoZondas UWB AU-3.1G10.6G-1 antenna for measurements at 3 GHz and 5 GHz, and waveguide horn antenna EMCO model No. 3160-07 for measurements at 10 GHz. Figure 9 presents the photos of manufactured antenna, the antenna placed on the tower in anechoic



Figure 9. Photographs of the fabricated antenna and antenna placed on a tower in anechoic chamber.

chamber during measurements and the antenna placed on metallic cylinder. The correct distance between the antenna and metallic cylinder was assured by a holder made form Rohacell material (which permittivity is close to 1) which was cut with the use of circuit board plotter.

4.1. Reflection Parameters

The measurement results, compared with the simulations, of the planar antenna configuration are presented in Figure 10.

The reflection coefficient of the manufactured antenna is lower

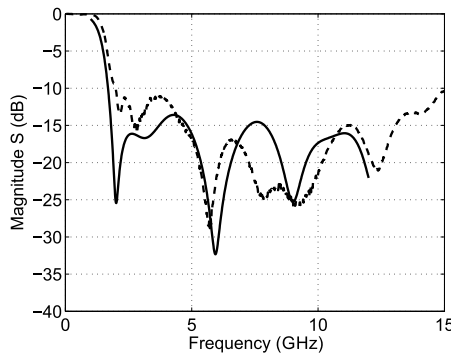


Figure 10. Magnitude of reflection coefficient for planar UWB antenna. Solid line — simulations, dashed line — measurements.

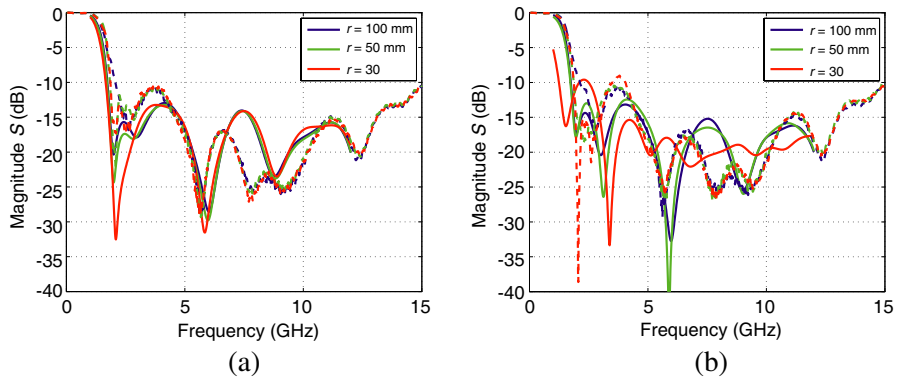


Figure 11. Magnitude of reflection coefficient for curved UWB antenna: (a) antenna curvature around x axis, (b) antenna curvature around y axis. Solid line — simulations, dashed line — measurement.

than -10 dB from $f = 2$ GHz, however in the lower frequency range from 2 GHz to 4 GHz the measured values are about 2 dB higher than the simulated ones. This discrepancies may be due to the effect of SMA connector.

The measurements of the curved antenna were performed next. The antenna was curved around x and y axis with curvature radii $r = 100$ mm, 50 mm and 30 mm. The obtained results are presented in Figure 11.

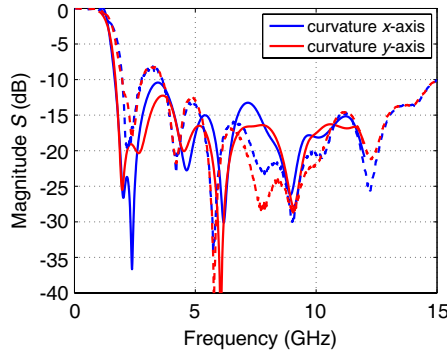


Figure 12. Magnitude of reflection coefficient for curved UWB antenna over cylindrical metallic cylinder. Antenna curvature radius $r = 70$ mm, metallic cylinder radius $r_g = 38$ mm. Solid line — simulations, dashed line — measurement.

As can be seen, besides the case of antenna curved around y axis with curvature radius $r = 30$ mm, the antenna reflection coefficients are below -10 dB in the frequency range from 2 GHz to 15 GHz.

In the last example we placed the curved antenna with curvature radius $r = 70$ mm in front of metallic cylinder with radius $r_g = 38$ mm. The antenna reflection coefficients for the cases of curvature around x and y axes are illustrated in Figure 12. Because the manufactured antenna has the reflection coefficient 2 dB higher in the frequency range 3–4 GHz than the simulated values, in the case of curved antenna placed on the metallic cylinder this effect is also visible.

4.2. Radiation Patterns

The measurements of the antenna radiation patterns were performed for three configurations of the analyzed antenna: planar antenna, curved antenna around x -axis with curvature radius $r = 70$ mm placed on the metallic cylinder with radius $r_g = 38$ mm and curved antenna around y -axis with the same curvature radius and cylinder radius.

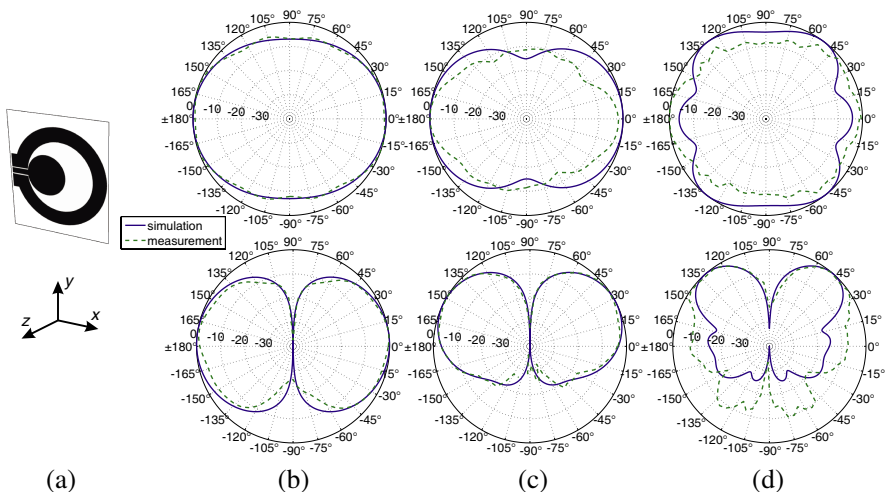


Figure 13. Planar antenna; (a) orientation of antenna, and radiation patterns at frequencies (b) 3 GHz, (c) 5 GHz and (d) 10 GHz. First row — yz plane for $x = 0$, second row — xz plane for $y = 0$.

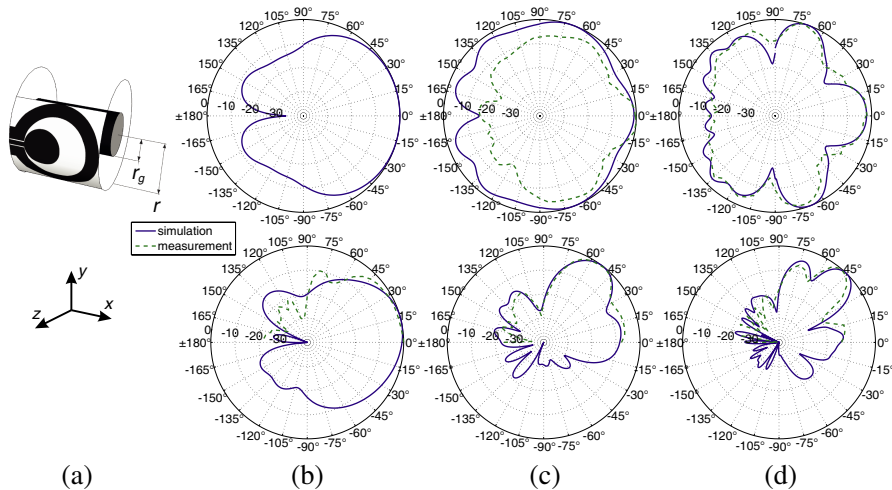


Figure 14. Curved antenna around x-axis on the metallic cylinder; (a) orientation of antenna, and radiation patterns at frequencies (b) 3 GHz, (c) 5 GHz and (d) 10 GHz. First row — yz plane for $x = 0$, second row — xz plane for $y = 0$.

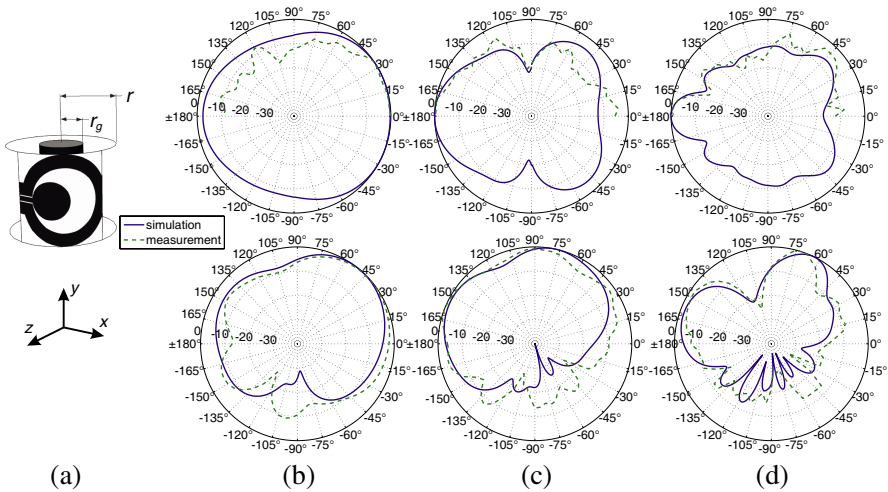


Figure 15. Curved antenna around y -axis on the metallic cylinder; (a) orientation of antenna, and radiation patterns at frequencies (b) 3 GHz, (c) 5 GHz and (d) 10 GHz. First row — yz plane for $x = 0$, second row — xz plane for $y = 0$.

All measurements were performed at frequencies 3 GHz, 5 GHz and 10 GHz. The results for planar antenna are presented in Figure 13, while for the curved cases are illustrated in Figures 14 and 15. Although, there are some discrepancies between the measured and simulated results the character of the patterns are similar and the obtained agreement is satisfactory.

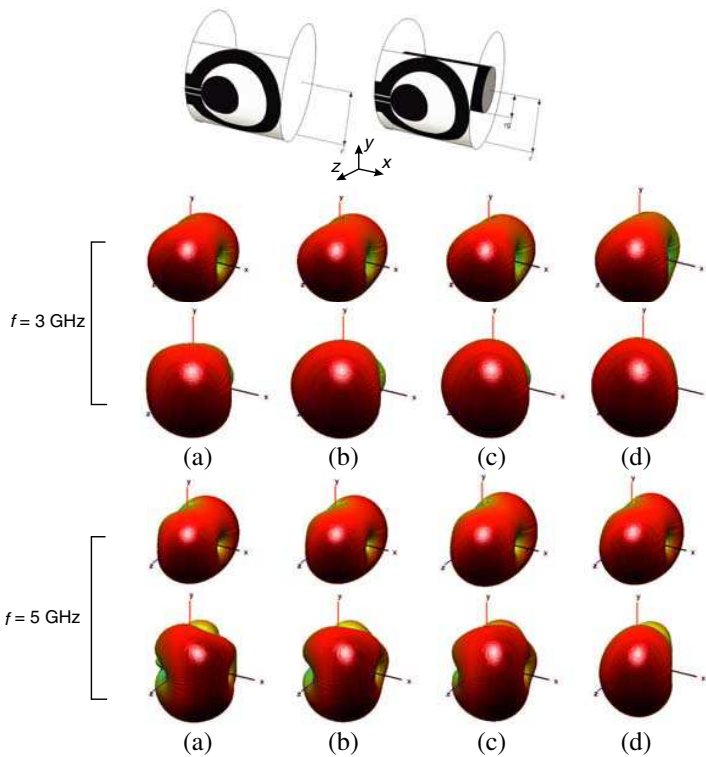
5. CONCLUSION

The investigation of finite ground CPW-fed UWB antenna and the influence of its curvature and the proximity of circular metallic screen on the reflection coefficients and radiation characteristics was presented. The investigated antenna was designed on a thin and flexible substrate which allowed its bending. The antenna configuration has been modeled and experimentally tested, showing good performance in 2–15 GHz frequency with return losses less than -10 dB. The antenna bending does not significantly affect its performance and therefore is suitable for the use in flexible electronic systems. The performed investigations allow us to formulate some rules concerning the antenna design for the curved surface application. In order to apply the antenna on curved surfaces or in the proximity

of metallic screen the base antenna structure (its planar version) should be well matched (the reflection coefficient should be lower than -13 dB in the entire frequency range) as its bending may deteriorate its performance. The distance of metallic screen should be greater than 20 mm in order to keep the reflection coefficient in the acceptable level in the entire frequency range. As the distance between metallic screen and the antenna affects the shape of its radiation patterns, especially at higher frequencies, the correct choice of the distance value should be made depending on the application.

APPENDIX A. 3D RADIATION PATTERNS

The 3D radiation patterns of antenna analyzed in Chapter 3 are presented here. Figures A1 and A2 present the results for curved antennas with and without the metallic screen as described in Chapter 3.



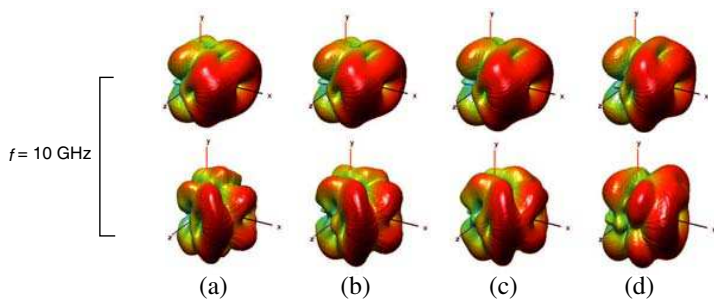
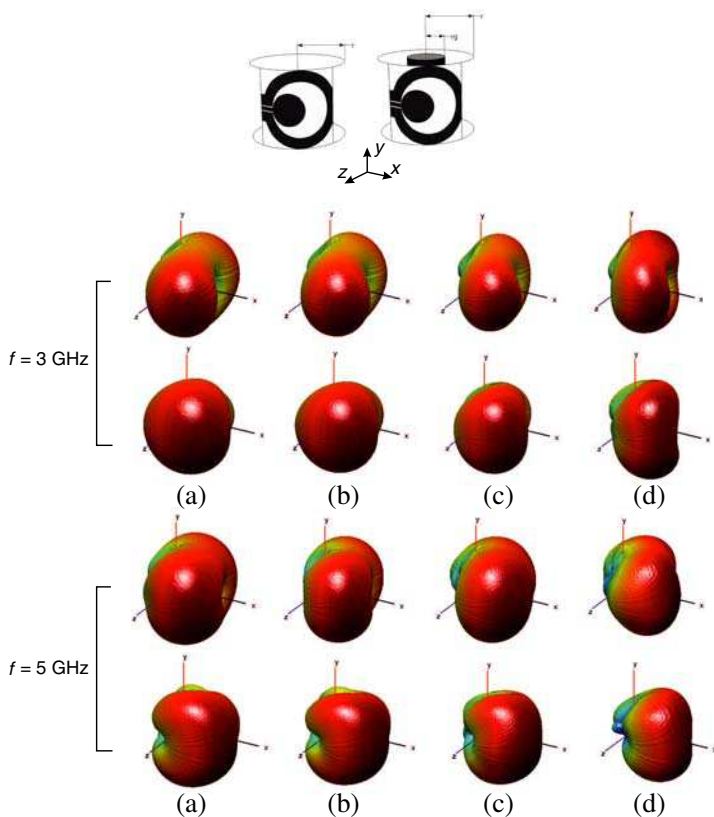


Figure A1. Radiation patterns of the investigated antenna at frequencies 3 GHz, 5 GHz and 10 GHz without (upper rows at each frequency) and with (lower rows at each frequency) metallic cylinder for antenna curvature and metallic cylinder radius, (a) $r = 100$ mm, $r_g = 70$ mm, (b) $r = 70$ mm, $r_g = 40$ mm, (c) $r = 50$ mm, $r_g = 20$ mm and (d) $r = 30$ mm, $r_g = 10$ mm.



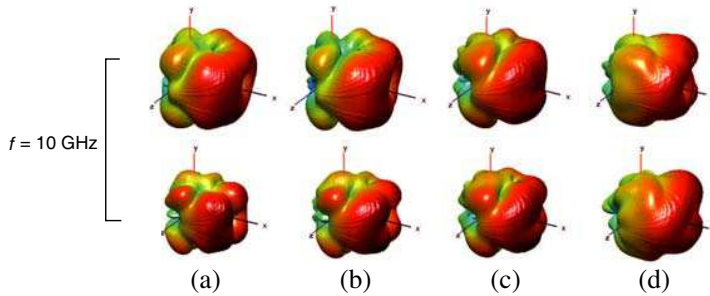


Figure A2. Radiation patterns of the investigated antenna at frequencies 3 GHz, 5 GHz and 10 GHz without (upper rows at each frequency) and with (lower rows at each frequency) metallic cylinder for antenna curvature and metallic cylinder radius, (a) $r = 100$ mm, $r_g = 70$ mm, (b) $r = 70$ mm, $r_g = 40$ mm, (c) $r = 50$ mm, $r_g = 20$ mm and (d) $r = 30$ mm, $r_g = 10$ mm.

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REFERENCES

1. "Rev. of Part 15 of the communications rules regarding UWB transmission systems," FCC, ET-Docket 98-153, FCC 02-48, 2002.
2. Yang, Y., Y. Wang, and A. E. Fathy, "Design of compact Vivaldi antenna arrays for UWB see through wall applications," *Progress In Electromagnetics Research*, Vol. 82, 401–418, 2008.
3. Zhu, F., S.-C. S. Gao, A. T. S. Ho, T. W. C. Brown, J. Li, and J.-D. Xu, "Low-profile directional ultra-wide band antenna for see-through-wall imaging applications," *Progress In Electromagnetics Research*, Vol. 121, 121–139, 2011.
4. Lazaro, A., D. Girbau, and R. Villarino, "Wavelet-based breast tumor localization technique using a UWB radar," *Progress In Electromagnetics Research*, Vol. 98, 75–95, 2009.
5. Lazaro, A., D. Girbau, and R. Villarino, "Simulated and experimental investigation of microwave imaging using UWB," *Progress In Electromagnetics Research*, Vol. 94, 263–280, 2009.
6. AlShehri, S. A., S. Khatun, A. B. Jantan, R. S. A. Raja Abdullah, R. Mahmood, and Z. Awang, "3D experimental detection and

- discrimination of malignant and benign breast tumor using NN-based UWB imaging system,” *Progress In Electromagnetics Research*, Vol. 116, 221–237, 2011.
7. Conceicao, R. C., M. O’Halloran, M. Glavin, and E. Jones, “Numerical modelling for ultra wideband radar breast cancer detection and classification,” *Progress In Electromagnetics Research B*, Vol. 34, 145–171, 2011.
 8. AlShehri, S. A., S. Khatun, A. B. Jantan, R. S. A. Raja Abdulah, R. Mahmood, and Z. Awang, “Experimental breast tumor detection using NN-based UWB imaging,” *Progress In Electromagnetics Research*, Vol. 111, 447–465, 2011.
 9. Chen, D. and C.-H. Cheng, “A novel compact ultra-wideband (UWB) wide slot antenna with via holes,” *Progress In Electromagnetics Research*, Vol. 94, 343–349, 2009.
 10. Xu, H.-Y., H. Zhang, K. Lu, and X.-F. Zeng, “A holly-leaf-shaped monopole antenna with low RCS for UWB application,” *Progress In Electromagnetics Research*, Vol. 117, 35–50, 2011.
 11. Zivkovic, I. and K. Scheffler, “A new inovative antenna concept for both narrow band and UWB applications,” *Progress In Electromagnetics Research*, Vol. 139, 121–131, 2013.
 12. Reddy, G. S., S. K. Mishra, S. Kharche, and J. Mukherjee, “High gain and low cross-polar compact printed elliptical monopole UWB antenna loaded with partial ground and parasitic patches,” *Progress In Electromagnetics Research B*, Vol. 43, 151–167, 2012.
 13. Zhang, Z. and Y. H. Lee, “A robust CAD tool for integrated design of UWB antenna system,” *Progress In Electromagnetics Research*, Vol. 112, 441–457, 2011.
 14. Liao, Z.-L., F.-S. Zhang, G. Xie, W. Zhai, and L.-N. Chen, “An omnidirectional and band-notched ultra wide band antenna on double substrates crossing,” *Progress In Electromagnetics Research C*, Vol. 22, 231–240, 2011.
 15. Sadat, S., M. Fardis, F. G. Geran, and G. R. Dadashzadeh, “A compact microstrip square-ring slot antenna for UWB applications,” *Progress In Electromagnetics Research*, Vol. 67, 173–179, 2007.
 16. Gong, B., J. L. Li, Q.-R. Zheng, Y.-Z. Yin, and X.-S. Ren, “A compact inductively loaded monopole antenna for future UWB applications,” *Progress In Electromagnetics Research*, Vol. 139, 265–275, 2013.
 17. Osman, M. A. R., M. K. A. Rahim, N. A. Samsuri, H. A. M. Salim, and M. F. Ali, “Embroidered fully textile wearable antenna for

- medical monitoring applications,” *Progress In Electromagnetics Research*, Vol. 117, 321–337, 2011.
18. Chen, M. and J. Wang, “Compact CPW-fed circular slot antenna for ultra-wideband applications,” *2008. 8th International Symposium Antennas, Propagation and EM Theory*, 78–81, Nov. 25, 2008.
 19. Marynowski, W. and J. Mazur, “Design of UWB coplanar antenna with reduced ground plane,” *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 13, 1707–1713, 2009.
 20. Pouyanfar, N. and S. Ahdi Rezaeieh, “Compact UWB antenna with inverted hat shaped resonator and shortening via pins for filtering properties,” *Progress In Electromagnetics Research Letters*, Vol. 33, 187–196, 2012.
 21. Zhang, S.-M., F.-S. Zhang, W.-Z. Li, T. Quan, and H.-Y. Wu, “A compact UWB monopole antenna with WiMAX and WLAN band rejections,” *Progress In Electromagnetics Research Letters*, Vol. 31, 159–168, 2012.
 22. Li, W.-M., T. Ni, T. Quan, and Y.-C. Jiao, “A compact CPW-FED UWB antenna with WiMAX-band notched characteristics,” *Progress In Electromagnetics Research Letters*, Vol. 26, 79–85, 2011.
 23. Levy, M., S. Bose, A. V. Dinh, and D. Sriram Kumar, “A novelistic fractal antenna for ultra wideband (UWB) applications,” *Progress In Electromagnetics Research B*, Vol. 45, 369–393, 2012.
 24. Tilanthe, P., P. C. Sharma, and T. K. Bandopadhyay, “A compact UWB antenna with dual band rejection,” *Progress In Electromagnetics Research B*, Vol. 35, 389–405, 2011.
 25. Lech, R., W. Marynowski, and A. Kusiek, “UWB microstrip antennas on a cylindrical surfaces,” *Progress In Electromagnetics Research Symposium Abstracts*, 496, Taipei, Taiwan, March 25–28, 2013.
 26. Hu, J., “Overview of flexible electronics from ITRIs viewpoint,” *28th VLSI Test Symposium (VTS)*, 84, Apr. 19–22, 2010.
 27. Nathan, A. and B. R. Chalamala, “Special issue on flexible electronics technology, Part 1: Systems and applications,” *Proceedings of the IEEE*, Vol. 93, No. 7, 1235–1238, Jul. 2005.
 28. Josefsson, L. and P. Persson, “Conformal array synthesis including mutual-coupling,” *Electronic Letters*, Vol. 35, No. 8, 625–627, Apr. 1999.
 29. Xu, Z., H. Li, Q.-Z. Liu, and J.-Y. Li, “Pattern synthesis of conformal antenna array by the hybrid genetic algorithm,”

- Progress In Electromagnetics Research*, Vol. 79, 75–90, 2008.
30. Si, W., L. Wan, L. Liu, and Z. Tian, “Fast estimation of frequency and 2-d DOAs for cylindrical conformal array antenna using state-space and propagator method,” *Progress In Electromagnetics Research*, Vol. 137, 51–71, 2013.
 31. Denidni, T. A. and M. A. Habib, “Broadband printed CPW-fed circular slot antenna,” *Electronics Letters*, Vol. 42, No. 3, 135–136, Feb. 2, 2006.