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MODIFIED DIRECTIONAL WIDE BAND PRINTED MONOPOLE ANTENNA FOR USE IN RADAR AND MICROWAVE IMAGING APPLICATIONS

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Abstract—This paper presents a modified design of directional monopole antenna with parabolic-shaped ground plane. To increase the directivity, axis of parabola in the ground plane is rotated 45 degrees (in comparison with the previous antenna) to extend throughout the direction of the substrate's diagonal. Consequently, vertex of the parabola is placed at the optimum point in the corner of the substrate. The aim of this attempt is to design an extended and symmetrical ground plane around the patch, with more clarity, to maximize its capability as a reflector. Directivity is further improved by inserting parabolic-shaped slots at the corners of the ground plane. Simulation and measurements show that the proposed antenna has stable directional radiation pattern and higher gain compared to the previous directional monopole antennas. Impedance bandwidth of the antenna covers the frequency range of 4–9 GHz. Measured HPBW is among the degrees 54–22 between 4 and 9 GHz. Gain and HPBW of the antenna are improved 1.3–3.1 dB and 5–15 degrees, respectively among the bandwidth in comparison with previous antenna. Results confirm the good characteristics of the antenna for use in microwave imaging, where high resolution is required.

1. INTRODUCTION

Currently there are increasing demands for directional antennas, especially for the Ultra Wide Band (UWB) applications. Radars and microwave breast cancer imaging systems are the main examples where the directive antennas are required. Directional antennas are used to optimize Half Power Beam Width (HPBW), more clearly, to increase the radiation intensity in a favored direction by converging radiation

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pattern. In radars, antenna's HPBW is one of the main parameters determining the radar's resolution; finer details can be resolved by using a narrower beam. In the case of long range applications, it is required to minimize the HPBW in order to cover the long distances [1, 2]. On the other hand, a directional beam of an antenna is desirable for Body-Worn Devices used in Wireless Body Area Network (WBAN), to reduce the effects of human body to electromagnetic radiation [3]. Nevertheless, most of the wide band and UWB antennas like planar monopoles, which are in use, have almost Omni-Directional radiation pattern [4–6]. Directivity can be achieved if the antenna is large in a desired direction, such as Horn or Vivaldi antennas [7, 8]. In other types, antenna includes cavity or shielding plane behind itself, or uses the absorbing materials in order to obtain directivity. On the other hand, such approaches cause either increment in the antenna size or decrease in the antenna efficiency as well as complication in the production process [3, 9]. Some other directional antennas such as conventional slot antennas have limited operating frequency range [3, 10], while Vivaldi type antennas have a good bandwidth and directional radiation pattern [11]. Printed disc monopole antennas with an L-shaped or parabolic-shaped ground plane are introduced as a directional antenna for various applications [2, 12]. In these studies it has been shown the effect of ground plane optimization on obtaining the desired directional characteristic of the antenna.

The aim of this paper is to design a modified antenna structure which is convenient especially in the use of near field near surface measurement applications, such as microwave breast cancer imaging. Therefore, HPBW of the antenna must be small enough in order to detect the smaller details. The proposed antenna is a modification of the antennas given in [2, 12], which is more directive compared to the previous types. Directivity is improved by extending the axis of the parabolic shape of the ground plane throughout the direction of the substrate's diagonal, and subsequently, by inserting parabolic slots on the ground plane. Then, the presented planar antenna is composed of a disc-monopole fed by a $50\,\Omega$ microstrip line printed on a FR4 substrate. Both simulations and measurements confirm that the proposed antenna has a stable radiation pattern versus frequency, improved directivity of 5–15 degrees and improved gain of 1.3–3.1 dB in the frequency range of 4–9 GHz compared to conventional monopoles such as given in [2, 12].

The paper is organized as follows. In Section 2, design and structure of the antenna is presented. In Section 3, parametric study and characteristics of the antenna are demonstrated; moreover simulation and measurements are presented and compared with each other.

2. DESIGN AND CHARACTERISTICS OF THE ANTENNA

The purpose of this design is to propose an antenna which has the impedance bandwidth between 4 and 9 GHz, with a highly directional radiation pattern throughout the desired bandwidth, for use in near field near surface imaging applications. Geometry of the proposed antenna is illustrated in Fig. 1, including the top and bottom metal layers. In order to maintain a trade-off between the gain in the favored bandwidth and the size of the antenna, it is designed on square FR4 substrate with dimension of 50 mm, where dielectric constant is $\varepsilon_r = 4.4$. Thicknesses of the dielectric (d) and conductor layers are 1.6 mm and 35 μm, respectively. The top layer in Fig. 1 consists of a circular patch element with 50 Ω microstrip feed. The Parameters r, w and h are the radius of the patch, and the width and length of the feed line, respectively. In the other side of the substrate there is a parabolic-shaped ground plane.

The oil-colored part of Fig. 1 on the bottom of the substrate acts as a parabolic reflector. A prominent feature of this antenna is the carefully designed ground plane that improves the directivity. Main edge of the reflector which is shown by (1) in Fig. 1, is inserted based on Equation (1):

$$y - y_1 = \frac{(x - x_1)^2}{4c_1} \tag{1}$$

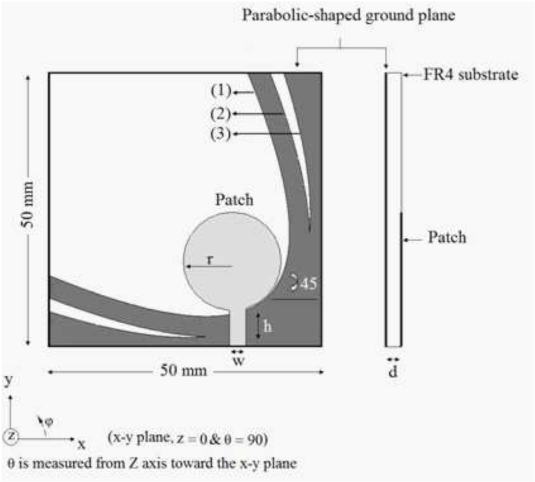


Figure 1. Top and side views of the antenna.

where, x_1 and y_1 are measured with regard to the coordinate system which is shown in Fig. 1. The factor $1/(4c_1)$ appearing in Equation (1) is defined as the concavity factor of the curve, where c_1 is the length between the focal point and vertex point of the parabola which is known as the focal length. Parabolic curve which is based on Equation (1) is rotated 45 degrees in order to extend the axis of the parabola merely in the direction of the substrate's diagonal. Also the vertex point of the parabola is considered to the nearest place of the substrate's diagonal. To maintain optimum trade-off between the reflection coefficient and directivity throughout the bandwidth of 4–9 GHz, the optimal values of x_1 and y_1 are determined as 40.4 mm and 9.3 mm, respectively. Radius r is chosen as 9 mm in order to obtain the desired reflection coefficient bandwidth. Center point of circular patch is inserted in 33.6 mm and 15.5 mm respectively in x and y directions. Width of the microstrip feed is selected 3 mm to obtain 50 Ohm impedance, while the center of w is inserted at 34.6 mm in the x direction. Consequently, length of the feed line h is chosen 6.9 mm. Focal length of c_1 is recognized as 5.4 mm to obtain the optimum concavity for curve (1) according to the location of the circular patch, that is to say, locating the patch exactly on the focus of the curve (1).

Furthermore, in order to improve the reflection of radiation pattern from the ground plane, two parabolic slots are inserted at the corners of the ground plane. These slots are formed by subtracting the area between the curves:

$$y - y_2 = \frac{(x - x_2)^2}{4c_2} \tag{2}$$

$$y - y_3 = \frac{(x - x_3)^2}{4c_3} \tag{3}$$

from the ground. All the parameters in Equations (2) and (3) are defined as the same as in Equation (1). Both vertex points of the curves (2) and (3) are inserted at the same point. Both parabolic curves, based on Equations (2) and (3), are rotated 45 degrees to locate the axis of the parabolas in the direction of the substrate's diagonal. Focal lengths of c_2 and c_3 must be chosen longer than $c_{1,}$ due to the reduced concavity of curves (2) and (3) compared to the curve (1). Therefore, the optimum quantities of $x_{2,3}$ and $y_{2,3}$ are determined as 42.4 mm and 7.3 mm, respectively. In order to obtain the optimum concavity for curve (3) to improve the directivity, focal length of c_3 is recognized as 8 mm. Also focal length of c_2 is determined as 6.4 mm, to optimize the dimensions of the slots.

A prototype with the mentioned optimum parameters has been fabricated. In Fig. 2 the photo of the antenna is shown. On the left, the side of the antenna with the parabolic-shaped ground plane is observable, while on the right we have the other side with the circular patch and the microstrip line.

3. RESULTS AND DISCUSSION

Ground plane of the antenna consists of a symmetrical parabolic curve, whose axis is extended along the direction of the substrate's diagonal. Advantage of this extended and symmetrical reflector around the circular patch is a symmetrical and optimum convergence of the radiation. The electrical field distribution beyond the ground plane is shown in Fig. 3, which demonstrates that the ground plane, expressed by Equation (1), reflects the radiation throughout its surface. Especially reflectance at the end of the reflector's edge is noticeable,

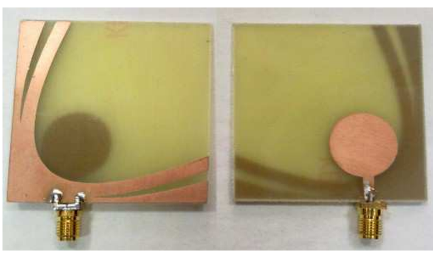


Figure 2. A photograph of fabricated antenna.

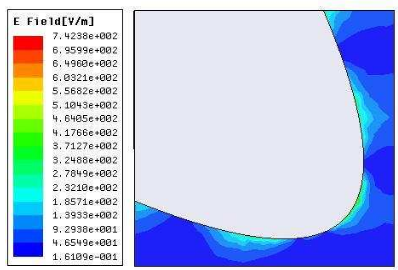
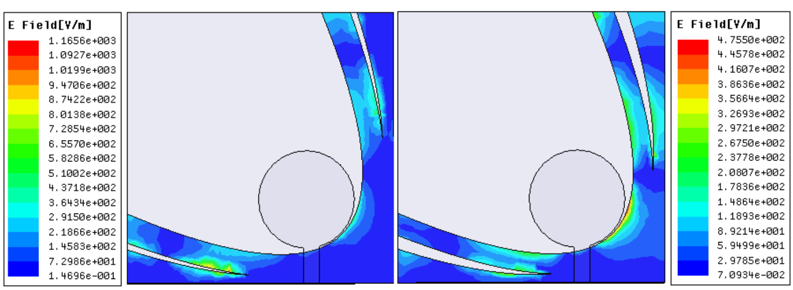


Figure 3. Electrical field distribution around the ground plane at 6 GHz.



(a) (b)

Figure 4. Electrical field distribution around the ground plane at freq. of 6 GHz, (a) $c_2 = 7$ mm and (b) $c_2 = 6.4$ mm, optimum.

which is a benefit of optimum use of the reflector's length. Effects of this design on the directivity, and consequently gain, are shown in Fig. 7. Compared to the antenna presented in [2], gain of the antenna is remarkably improved, among 1–2 dB between 4 and 9 GHz.

The ground plane acts as a reflector with its own original design. The second edge of the ground plane which is created by inserting the slots, behaves as an additional reflector which increases the directivity. The effect of inserting parabolic slots on the field distribution around the ground plane is demonstrated in Fig. 4. Other reflection occurs at the second parabolic edge which in return raises the reflectance of the ground plane. Along with, optimizing the slots causes the reflector to improve the directivity. Besides inserting the circular patch on the focal point of the reflector, another crucial design consideration is the size of the reflector's width throughout the different parts of the ground plane. Amount of the reflected radiation is depends on the proportion of the reflector's width to the wavelength. Focal length c_2 is used to optimize the reflector's width directly, and c_3 is not used due to the fact that c_1 and c_3 are already optimized according the concavities of curve (1) and (3), where the ground plane reflections occur both from. Fig. 4 shows the distribution of the surface fields at the frequency of 6 GHz for two values of $c_2 = 7$ mm, and $c_2 = 6.4$ mm (optimum), for constant values of c_3.

As a result, Fig. 5 shows that effect of the varying amounts of c_2 to the gain of the antenna for different frequencies. Therefore, we can use different values for c_2 depending on the frequency of application.

Considering Fig. 5 for an application with center frequency of 6.5 GHz, $c_2 = 7$ mm will give the optimum solution. In this antenna, for the frequencies between 4 and 9 GHz, $c_2 = 6.4$ mm is identified as an optimum value. The effect of varying amount of c_2 on the reflection coefficient is also shown in Fig. 6; $c_2 = 6.4$ mm is also determined to

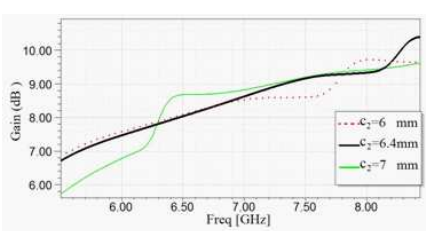


Figure 5. Simulated gain at Theta = 90 degrees and Phi = 131 degrees for $c_2 = 6$, 6.4 and 7.

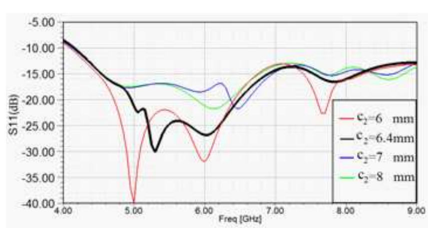


Figure 6. Simulated reflection coefficient for $c_2 = 6, 6.4,$ 7 and 8.

obtain the desired impedance bandwidth.

Compared to the antenna demonstrated in [2], gain of the antenna is improved among 1–2 dB, between 4 and 9 GHz, without slots; Parabolic-shaped slots further improve the gain between 0.1 and 1.1 dB. Consequently, Gain of the antenna is improved among 1.3–3.1 dB through the bandwidth of 4–9 GHz. Results are shown in Fig. 7(a), between 5.5 and 9 GHz at $\theta = 90$ and $\phi = 131$ degrees where, θ and ϕ are measured with regard to the coordinate system

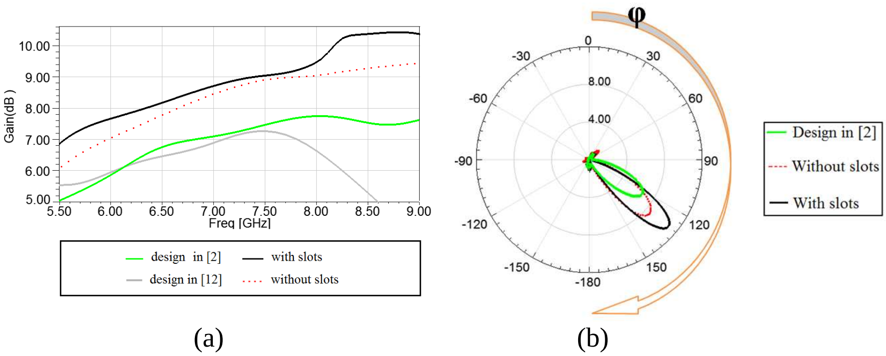


Figure 7. (a) Simulated gain of the antenna compared to [2] and [12]. (b) Simulated radiation pattern (linear scale) of the antenna compared to [2] at the frequency of 8.5 GHz at $\theta = 90$, x-y (E) plane.

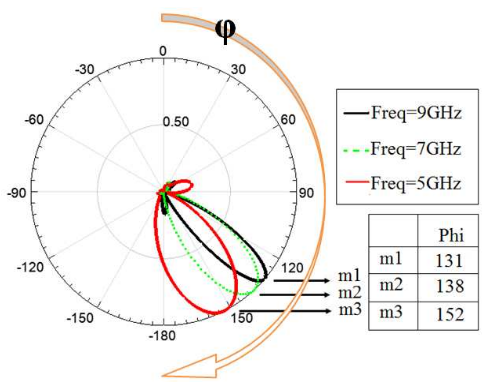


Figure 8. Radiation pattern of the antenna (in linear scale). m_1, m_2 and m_3 are the direction of maximum gain at the frequencies of 9, 7 and 5 GHz, respectively. $\theta = 90$, x-y (E) plane. $\phi = 0$ is the reference point which is shown in Fig. 1 according to the position of the antenna.

which is shown in Fig. 1. Considering Fig. 7(a), the gain is improved 1.3–3.1 dB and 1.2–5 dB through the bandwidth in comparison with [2] and [12], respectively. Also related radiation pattern in linear scale at the frequency of 8.5 GHz in x-y (E) plane is shown in Fig. 7(b), where, $\phi = 0$ is the reference point which is shown in Fig. 1 according to the position of the antenna. Simulated HPBW of the antenna for this frequency is 26 degrees with slots, while HPBW is 31 degrees without slots and also for the antenna designed in [2] is 38 degrees. This confirms a 33% improvement in HPBW, which is considerable in order to increase the resolution of a Radar-Based imaging system. Between the frequencies of 4 and 9 GHz, HPBW changes among 56 degrees and 25 degrees, respectively.

Direction of radiation pattern of the antenna moves between Phi = 131 degrees and Phi = 152 degrees among 5–9 GHz (Fig. 8), that confirms a good stability of the antenna's beam versus frequency.

Radiation pattern of the antenna in 3 dimensional at the frequency of 8 GHz is presented in Fig. 9. As it can be seen from this figure, beam of the antenna in x-z (H) plane is isotropic in one side, Consequently, $\theta = 90$ (x-y, E) plane of the beam of the antenna is considered for study as a directional beam, in order to use in radar-based imaging applications.

All simulations were done in HFSS v.11, using finite element method, where, the rate of convergence maximum delta S is taken as 0.005. Radiation boundary is located 25 mm ($\lambda/4$ for 3 GHz) away from edge of the antenna in all directions. Then simulations compared to the measurements, which were done using Agilent N5230A network analyzer in the anechoic chamber with dimensions 6 × 7 × 3.3 m and working frequencies 80 MHz to 20 GHz constructed at Istanbul Technical University. Full 2 port SOLT calibration is done where IF

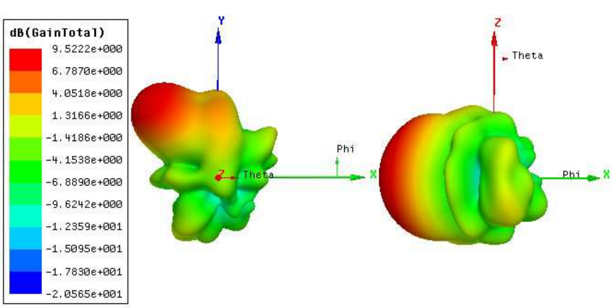


Figure 9. 3D beam of the antenna in two (x-y) and (x-z) plane at the frequency of 8 GHz.

band is 10 Hz for 8 frequencies between 5.5 GHz–9 GHz. After the radiation pattern measurements, the antenna gain was also calculated. The measurement was performed with gain comparison method, using reference gain antenna which is calibrated pyramidal horn. Antenna Under Test (AUT) was in receive mode. Maximum signal level of -32 dB is measured for S_{21}. Radiation pattern levels normalized according to that value.

Good agreement is observed between the simulations and measurements. Fig. 10 shows the simulated and measured beam of the antenna in two (6 and 8.5 GHz) frequencies in $\theta = 90$, x-y (E) plane, where, $\phi = 0$ is the reference point which is shown in Fig. 1 according to the position of the antenna. At 6 GHz, measured HPBW is 41 degrees and simulated HPBW is 44 degrees, also for the frequency of 8.5 GHz obtained HPBW is 23 degrees compared to the simulated

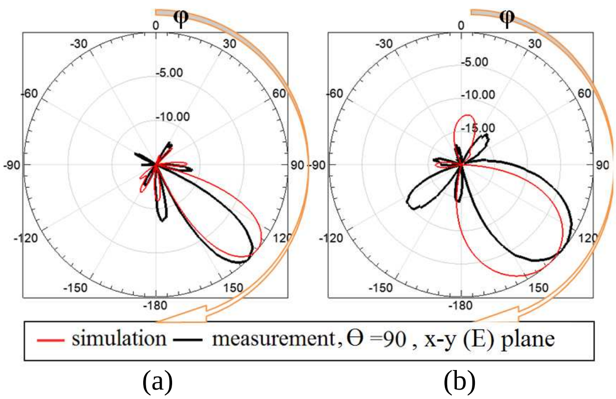


Figure 10. Simulated and measured normalized beam of the antenna at (a) frequency = 8.5 GHz and (b) frequency = 6 GHz in logarithmic scale.

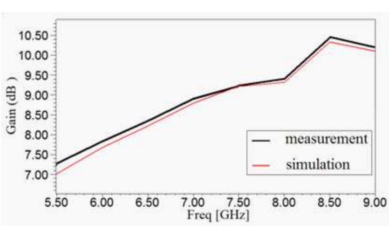


Figure 11. Simulated and measured gain of the antenna.

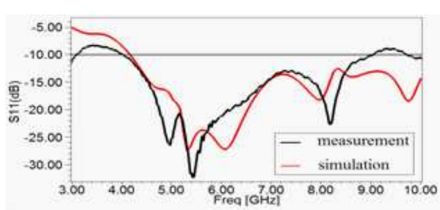


Figure 12. Simulated and measured reflection coefficient.

HPBW which is 26 degrees. There are 10 degrees and 5 degrees tilts between simulated and measured patterns at the frequencies of 6 and 8.5 GHz, respectively. Gain of the antenna also is shown in Fig. 11, which shows a good agreement between the simulated and measured gain at Theta = 90 degrees and Phi = 131 degrees.

Finally, simulated and measured reflection coefficient is shown in Fig. 12 which confirms a good characteristic of the antenna in the favored bandwidth.

4. CONCLUSION

Modified design of directional wide band monopole antenna with parabolic-shaped reflector has been presented for use in microwave breast imaging. Directivity is the most important characteristic to obtain high resolution. Two operations were used to improve the directivity. Firstly, to create a symmetrical and extended reflector around the circular patch, axis of the parabola was extended throughout the direction of the substrate's diagonal. This led to an improvement in the ability of the reflector to converge the radiation. Furthermore, directivity of the antenna is improved by inserting the corrective slots. Also parametric design of the antenna allows constructing it with different dimensions of the slots for desired frequencies. Measurements confirm that reflection coefficient is under −10 dB throughout 4–9 GHz. Furthermore, measured HPBW is among 54–22 degrees between 4 and 9 GHz which is improved between 5 and 15 degrees compared to [2]. Gain of the antenna improved between 1.3 and 3.1 dB throughout the bandwidth, compared to the antenna presented in [2] and 1.2–5 dB in comparison with [12].

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REFERENCES

1. Stutzman, W. L. and G. A. Thiele, *Antenna Theory and Design,* 2nd Edition, John Wiley & Sons, 1998.
2. Mokhtaari, M. and J. Bornemann, "Directional ultra-wideband antennas in planar technologies," *Proceedings of the 38th European Microwave Conference,* 885–888, 2008.

3. Klemm, M., I. Z. Kovcs, G. F. Pederson, and G. Troster, "Novel small-size directional antenna for UWB WBAN/WPAN application," *IEEE Transactions on Antennas and Propagation*, Vol. 53, No. 12, Dec. 2005.
4. Chan, K. C. L., Y. Huang, and X. Zhu, "A planar elliptical monopole antenna for UWB applications," *IEEE/ACES International Conference on Wireless Communications and Applied Computational Electromagnetics,* 182–185, Apr. 2005.
5. Liang, J. X., C. C. Chian, X. D. Chen, and C. G. Parini, "Study of a printed circular disk monopole antenna for UWB systems," *IEEE Transactions on Antennas and Propagation,* Vol. 53, 3500–3504, Nov. 2005.
6. Mazinani, S. M. and H. R. Hassani, "A novel omni directional broadband planar monopole antenna with various loading plateshapes," *Progress In Electromagnetics Research*, Vol. 97, 241–257, 2009.
7. Shafieha, J. H., J. Noorinia, and C. Ghobadi, "Probing the feed line parameters in Vivaldi notch antennas," *Progress In Electromagnetics Research B*, Vol. 1, 237–252, 2008.
8. 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.
9. Yarovoy, A. G., "Antenna development for UWB impulse radio," *Eur. Microwave Week*, Amsterdam, Netherlands, Oct. 2004.
10. Lu, Y., Y. Huang, and H. T. Chattha, "Size reduction of a wideband slot antenna," *3rd European Conference on Antennas and Propagation, EuCAP 2009*, 1455–1458, Mar. 23–27, 2009.
11. John, M., M. J. Ammann, and P. McEvoy, "UWB Vivaldi antenna based on a spline geometry with frequency band-notch," *Antennas and Propagations Society International Symposium*, 1–4, Jul. 2008.
12. Locatelli, A., D. Modotto, F. M. Pigazzo, S. Boscolo, E. Autizi, C. DeAngelis, A.-D. Capobianco, and M. Midrio, "Highly directional planar ultra wide band antenna for radar application," *Proceedings of the 37th European Microwave Conference*, 1421–1424, Oct. 2007.