Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2008, Article ID 267197, 9 pages
doi:10.1155/2008/267197

Research Article

Parametric Study of Ultra-Wideband Dual Elliptically Tapered Antipodal Slot Antenna

Xianming Qing, Zhi Ning Chen, and Michael Yan Wah Chia

Institute for Infocomm Research, 20 Science Park Road, #02-21/25 TeleTech Park, Singapore 117674

Correspondence should be addressed to Xianming Qing, qingxm@i2r.a-star.edu.sg

Received 29 April 2007; Accepted 11 November 2007

Recommended by Hans G. Schantz

Parametric study of the impedance and radiation characteristics of a dual elliptically tapered antipodal slot antenna (DETASA) is undertaken in this paper. Usually, the performance of the DETASA is sensitive to the parameters, the effects of major geometry parameters of the radiators and feeding transition of the DETASA on antenna performance are investigated across the frequency range of 1–18 GHz. The information derived from this study provides guidelines for the design and optimization of the DETASAs which are widely used for UWB applications.

1. INTRODUCTION

The cochannel interference and multipath effects of wireless communication systems can be reduced by using directional antennas [1–4]. Some of the current point-to-multipoint systems are using horn antennas for this reason, but the horn antennas are too bulky to be integrated with the rest of the wireless packages and suffer high cost of fabrication. Tapered slot antennas (notch antenna, Vivaldi antenna) have been widely used in phased and active arrays for radar systems for many years [5, 6]. They are good candidates for multifunction communication applications because of their stable directional patterns and consistent impedance matching over a very broad operating frequency range without any tuning elements as well as low profile and unobtrusive planar structures. Therefore, they have been proposed for emerging UWB wireless communications and radar applications [7–10].

The dual elliptically tapered antipodal slot antenna (DETASA) [11, 12] is a modified version of the antipodal Vivaldi radiator [13]. It differs from the conventional antipodal Vivaldi antennas since the inner and outer edges of the slotline radiator of the DETASA are elliptically tapered. The slotline radiator is fed by a pair of parallel strip lines which are transformed from a microstrip line. The variations of antipodal Vivaldi antennas were studied both analytically and experimentally [14, 15]. However, the reports hardly discuss effects of antenna parameters on the impedance and radiation characteristics of the DETASA, which is vital for an engineer to design and optimize the antenna.

Therefore, this paper investigates the effects of major geometrical parameters of the DETASA on the impedance matching, gain, and radiation patterns to provide engineers with a clear design guideline. First, Section 2 shows a design as a reference for the following discussion. The geometry of the DETASA as well as comparison of simulated and measured results is introduced. Then, Section 3 demonstrates the effects of the antenna parameters on the impedance matching. After that, Section 4 discusses the impact of the antenna parameters on the radiation characteristics including gain, cross-polarization levels, and radiation patterns in both E- and H-planes. Finally, conclusions are drawn in the last section.

2. ANTENNA CONFIGURATION

Consider a typical DETASA antenna shown in Figure 1. It comprises two main parts: tapered slotline radiator and feeding transition, which are usually printed on a piece of PCB. The tapered slotline radiator shown in Figure 1(b) is configured by two conducting arms which are symmetrically on opposite sides of a substrate with respect to the y-axis. The

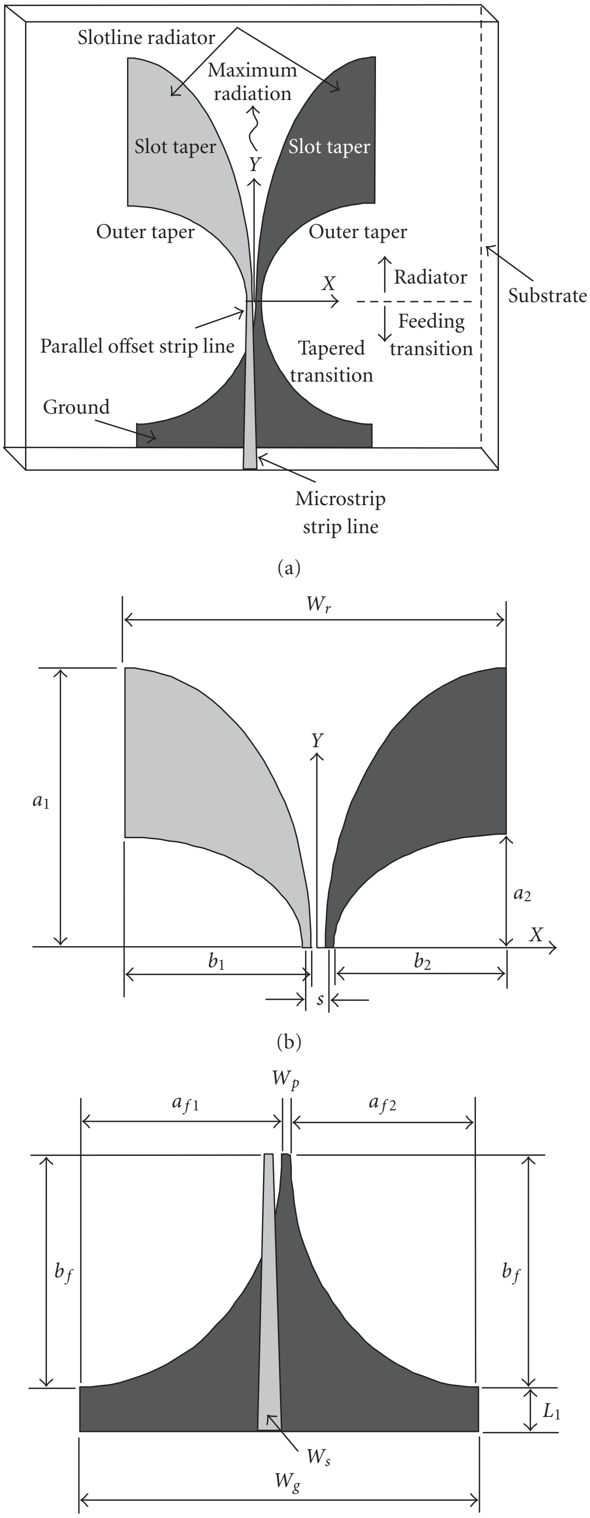


Figure 1: Geometry of a typical DETASA: (a) overall view, (b) tapered slotline radiator, and (c) feed line transition.

slot tapers of the conducting arms follow the outline of a quarter ellipse with major axis a_1 and minor axis b_1; the outer tapers are also elliptically tapered, and take the profile of a quarter ellipse with major axis a_2 and minor axis b_2. Tapering the outer conductor edge provides the convenience for antenna feeding and additional design degrees of freedom for optimizing antenna impedance and radiation performance. It is known that the lower frequency limit of this type of antenna is determined by the cutoff mechanism of the flare, namely, at the lowest operating frequency, the aperture (W_r) is $\lambda_s/2$, where λ_s is the wavelength of the slotline [5, 11, 16]. The feeding transition is shown in Figure 1(c) where a 50-Ω microstrip line (strip width, W_s, and ground width, W_g) is transformed to a parallel offset strip line (width W_p, offset S) to feed the tapered slotline radiator. The strip line is linearly tapered, while the ground plate is elliptically tapered. The profile of the ground taper takes the outlines of two quarter ellipses which are determined by major and minor axes (a_{f1}, b_f), and (a_{f2},b_f), respectively.

The E-plane of the DETASA shown in Figure 1 is on x-y plane ($\theta = 90^\circ$), and the H-plane is on y-z plane ($\phi = 90^\circ$). The maximum radiation will be in y-direction ($\theta = 90^\circ$, $\phi = 90^\circ$). The parametric studies will be carried out over a frequency range of 1–18 GHz, where the parameters a_1, a_2, W_g, b_f, S, and W_p will be considered. When a selected parameter is investigated, the rest of the parameters are unchanged. For comparison, the aperture W_r of the slotline radiator is fixed during the study to fix the lower edge of the operating frequency range. The parametric study will be conducted by the aid of using commercial software XFDTD [17] which is based on FDTD method.

To validate the simulation results, a DETASA prototype was simulated by using the XFDTD software first; the prototype was then fabricated and measured. The parameters of the reference design are $a_1 = 50$ mm, $b_1 = 25$ mm, $a_2 = 20$ mm, $b_2 = 24$ mm, $W_g = 51$ mm, $W_s = 1.86$ mm, $W_p = 1.0$ mm, $S = 0.5$ mm, $a_{f1} = 26$ mm, $a_{f2} = 24$ mm, $b_f = 25$ mm; substrate = RO4003, thickness = 0.8128 mm, $\epsilon_r = 3.38\text{-j}0.002$. The simulated and measured results in terms of return loss, gain, and radiation patterns are illustrated in Figures 2 and 3. It is found that the agreement is very good. Therefore, the using of simulated results for further parametric study is viable.

3. PARAMETRIC STUDIES: IMPEDANCE CHARACTERISTICS

Figure 4 shows the return loss of the DETASAs with varying side intercepts, $a_1 - a_2$, of the slotline radiator. It is seen that compared with the reference design with $a_1 = 50$ mm and $a_2 = 20$ mm, the larger side intercepts ($a_1 = 70$ mm, $a_2 = 20$ mm, and $a_1 = 50$ mm, $a_2 = 10$ mm) degrade impedance matching characteristic in particular at the lower edge of the bandwidth. The smaller side intercepts ($a_1 = 30$ mm, $a_2 = 20$ mm, and $a_1 = 50$ mm, $a_2 = 40$ mm) lead to the worse results than the larger. The reason is that the small-side intercepts bring the outer edges of the slotline radiator close to the slot edges, which makes the conducting arms too narrow to maintain the slotline characteristics, especially at lower frequencies.

Figure 5 illustrates the impact of the feeding transition on the impedance matching. Figure 5(a) shows that the

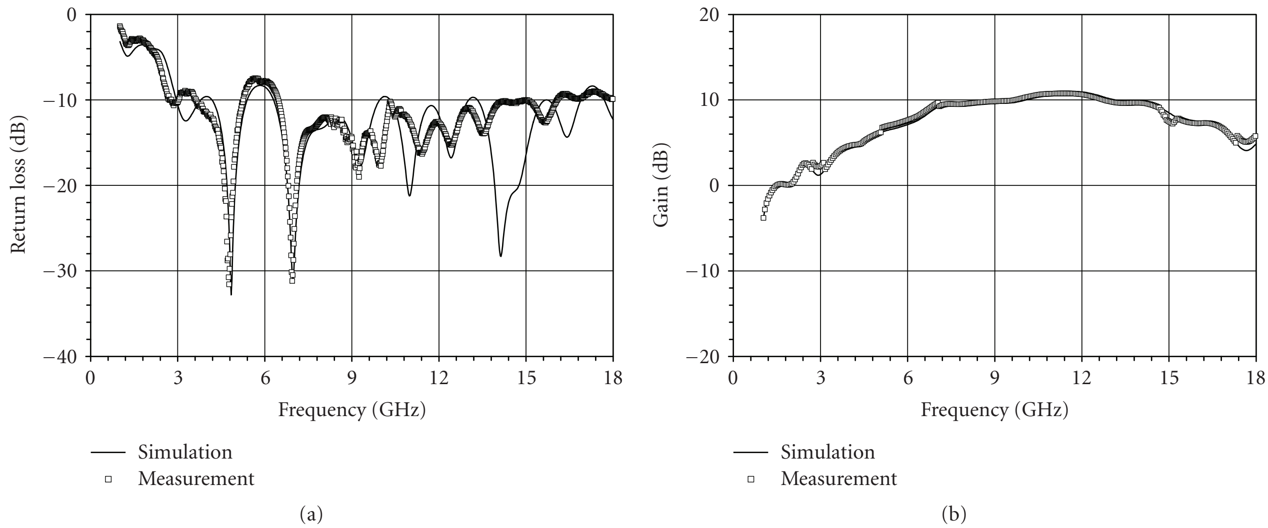


FIGURE 2: Comparison of simulated and measured return loss and gain of the reference DETASA shown in Figure 1; (a) return loss, (b) gain.

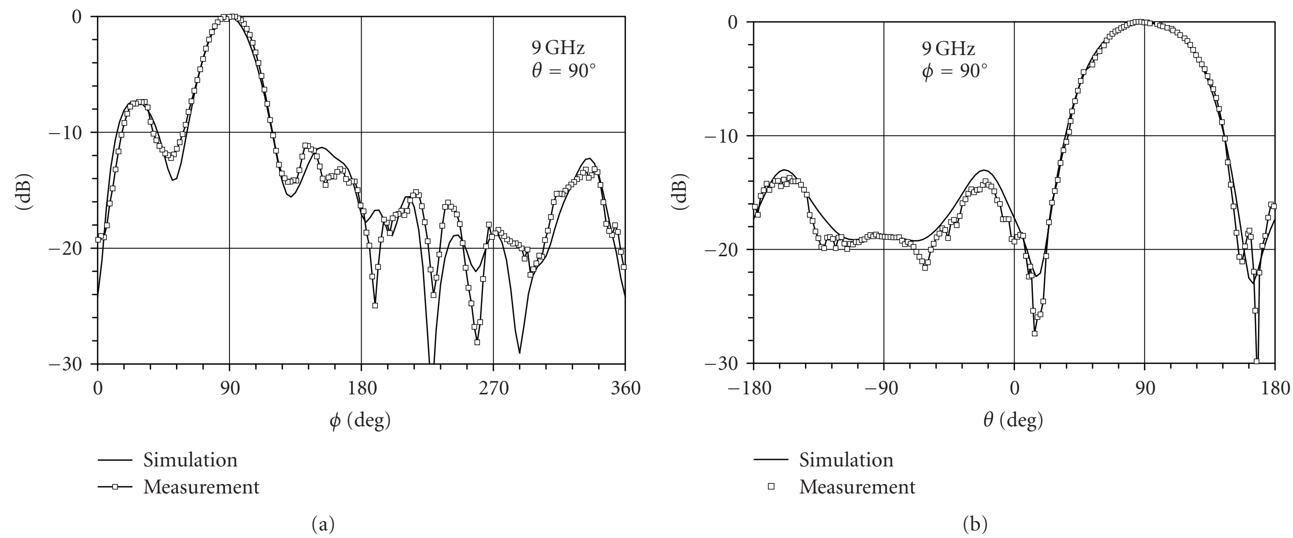


FIGURE 3: Comparison of simulated and measured radiation patterns of the reference DETASA shown in Figure 1; (a) E-plane, (b) H-plane.

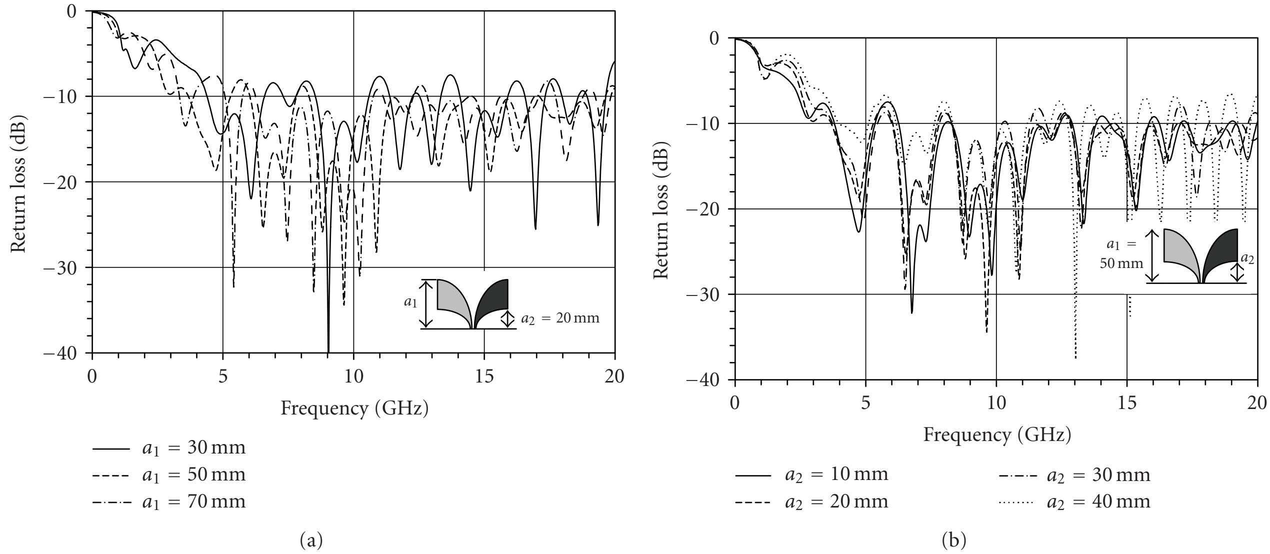
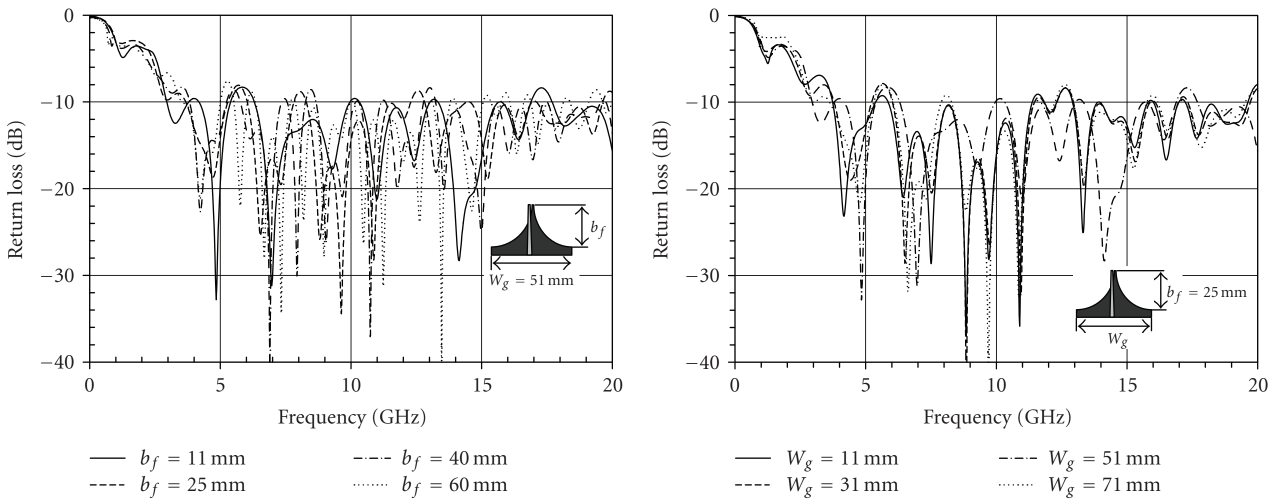
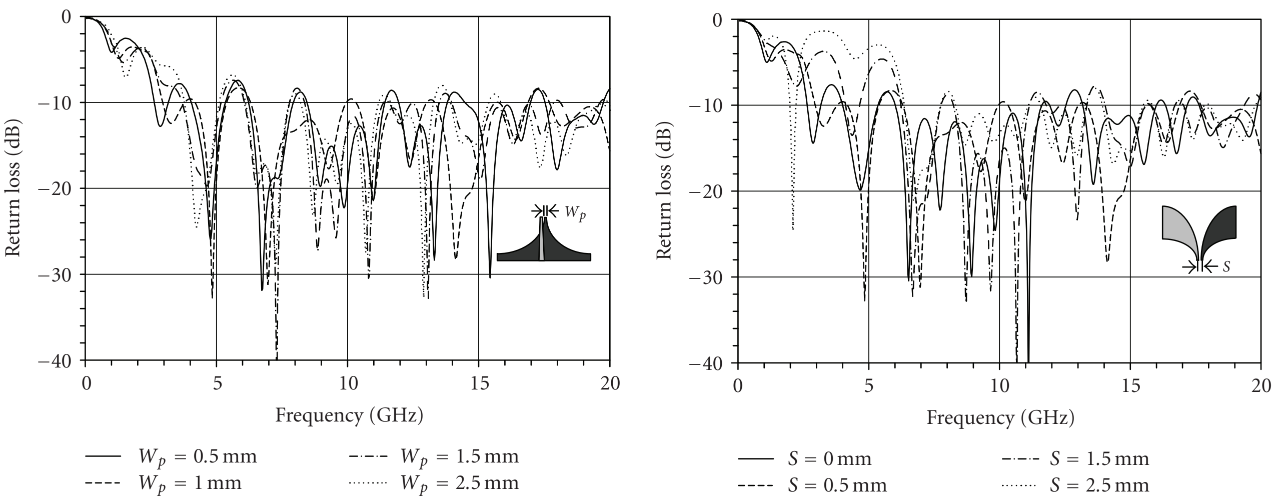


FIGURE 4: Return loss for varying the side intercepts, $a_1 – a_2$, of the slotline radiator.



(a) (b)

FIGURE 5: Return loss for different feeding transition configuration.



(a) (b)

FIGURE 6: Return loss for varying parallel strip lines.

impedance matching is slightly affected by the length of the transition over 1–18 GHz. The similar phenomena can be observed when changing width of the tapered ground plate, W_g, as shown in Figure 5(b). Therefore, it is concluded that the length of the feeding transition and the width of the tapered ground plate have little impact on the impedance matching of the DETASA. From impedance matching point of view, a compact DETASA can be realizable by using a miniaturized feeding transition.

Figure 6 shows the return loss of the DETASAs for different parallel offset strip lines by varying the width, W_p, and the offset, S. From Figure 6(a), it is found that the effect of the strip width to impedance matching is limited. Smaller W_p is preferable for better impedance matching at lower frequencies. Figure 6(b) shows that the offset of the parallel strip line, S, has a significant impact on the return loss of DETASA; larger offset degrades the impedance matching a lot below 7 GHz. It suggests that smaller W_p and S are adequate in DETASA design for better impedance matching, especially for lower frequencies. Furthermore, W_p and S can be optimized for specific DETASA configuration.

4. PARAMETRIC STUDIES: RADIATION CHARACTERISTICS

In this section, we will address the impact of the geometry parameters of the DETASA on its radiation characteristics: gain, cross-polarization, radiation patterns including main beam, side lobe, and back lobe levels. Note that the gain addressed in this paper is the realized gain which includes the mismatching loss of the antenna.

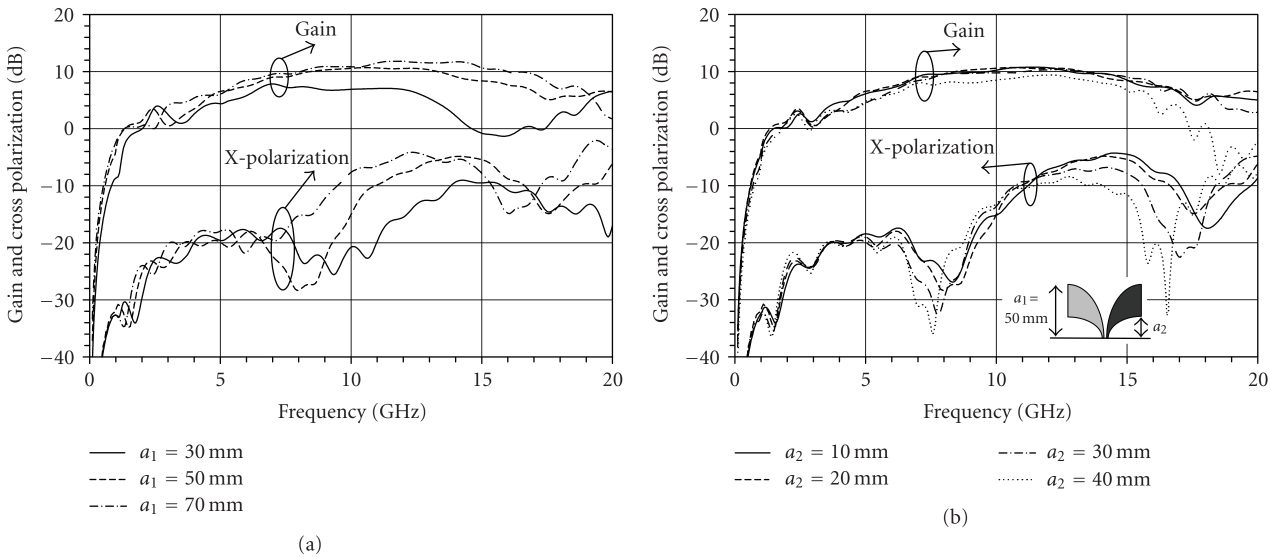


Figure 7: Gain and cross-polarization levels for varying the length of slot taper, a_1, and outer taper, a_2, of the slotline radiator.

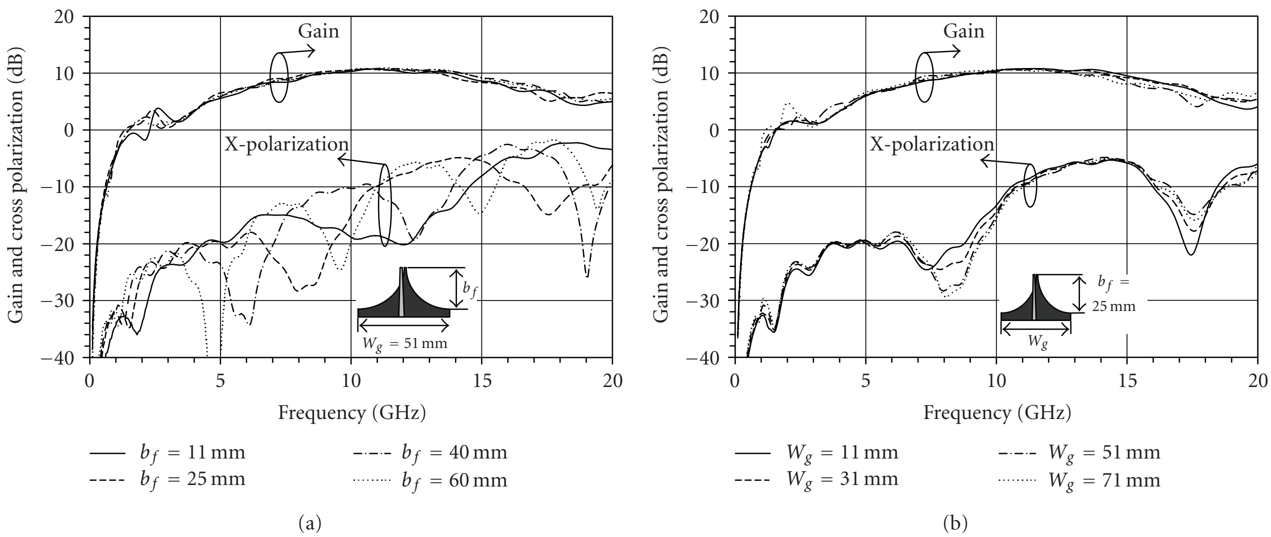


Figure 8: Gain and cross polarization with different ground profiles of feeding transition.

Figure 7 shows the impact of varying lengths of slot taper and outer taper of the slotline radiator on gain and cross-polarization levels. Figure 7(a) shows that the increase in the length of slot taper, a_1, for the fixed outer edge (a_2 = 20 mm) results in higher gain and cross-polarization levels in particular at higher frequencies. The gain drops significantly when a_1 is reduced to 30 mm because the narrow conducting arms cause the slotline radiator to not operate well. From Figure 7(b), we can find that the outer taper primarily affects the cross-polarization levels. Larger a_2 offers lower cross-polarization level. Again, the narrower conducting arm (a_1 = 50 mm, a_2 = 40 mm) reduces the gain especially at the frequencies higher than about 15 GHz.

As shown in Figure 8, it is found that the gain of the DETASA is almost unaffected by the feeding transition. The length of the tapered ground, b_f, has a great effect on the cross-polarization levels of the antenna as the operating frequency is higher than 5 GHz as shown in Figure 8(a) whereas the width of the tapered ground, W_g, hardly affects the cross-polarization level as can be seen in Figure 8(b).

Figure 9 shows the gain and cross-polarization levels of the DETASAs for changing parallel offset strip lines. It is clear that width of the strip lines, W_p, and offset of the strip lines, S, have little effect on the gain. Also, W_p does not affect the cross-polarization level below 12.5 GHz but the increasing W_p lowers cross-polarization levels at higher frequencies. Figure 9(b) shows that the increasing S results in lower cross-polarization levels at higher frequencies.

In general, all cases suffer higher cross-polarization levels at higher frequencies. The reason is the inherent asymmetrical features of antipodal structures, namely, two conducting arms of the DETASA are positioned at opposite sides

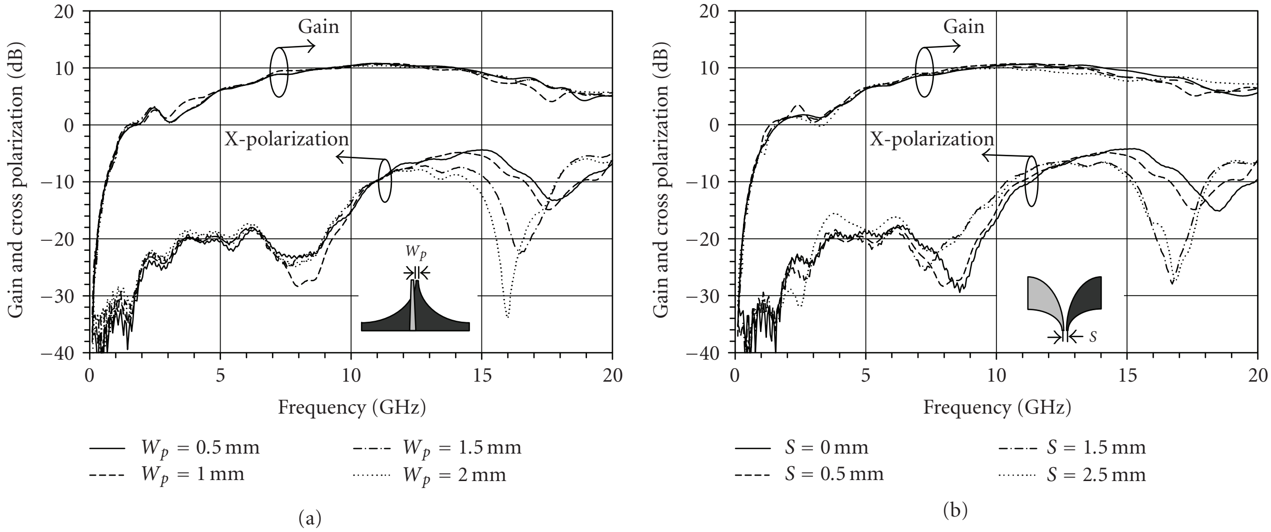


Figure 9: Gain and cross-polarization levels for parallel strip lines.

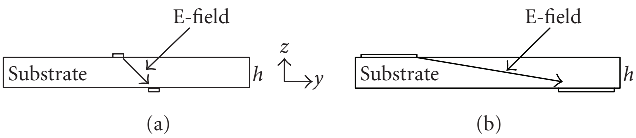


Figure 10: Cross-section view of the DETASA: (a) cross section of the DETASA next to the feeding transition, (b) cross section of the DETASA close to the aperture.

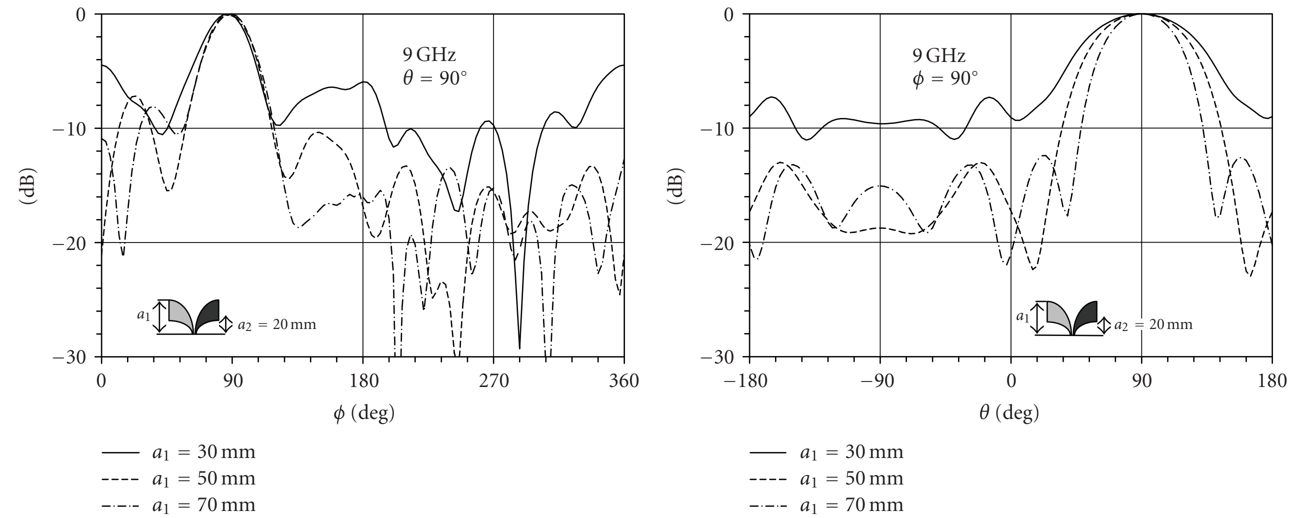
of the substrate, which causes the fields in slotline to be skew as shown in Figure 10. The skewness of the field in the slotline is more serious in the starting area which corresponds to radiation at higher frequencies. In the area close to the aperture, the separation of the conducting arms become larger so that the skewness of field is brought down and lower cross-polarization is observed at lower frequencies. Higher cross polarization at higher frequencies is the drawback of the microstrip-line-fed DETASA, the effective way to reduce cross polarization of such antenna has been reported yet.

The characteristics of radiation patterns in E- and H-planes are investigated in terms of the beamwidth, sidelobe, and backlobe levels. Figure 11 compares the radiation patterns of the DETASAs at 9 GHz for varying length of slot taper, a_1. Figures 11(a) and 11(b), respectively, show the patterns in the E- and H-planes. The E-plane patterns are asymmetrical because of the instinct of the antipodal structure. The length of the slot taper is found to have a slight effect on the beamwidth in the E-planes but a significant impact on the sidelobe and backlobe levels. Figure 11(b) demonstrates that the length of the slot taper has the largest effect on the beamwidth, sidelobe, and backlobe levels in the H-planes. The longer the length a_1 is, the narrower the main beam is. The angular locations of the peaks and nulls of sidelobes as well as the shape and levels of backlobes are changed as well. It should be noted that with $a_1 = 30$ mm, the sidelobes, and backlobes increase a lot in both E- and H-planes.

Figure 12 discusses the effects of varying length of the outer edge, a_2, on the radiation characteristics of the DETASAs. Figure 12(a) shows the radiation patterns in the E-plane. The outer taper mainly affects the sidelobe and backlobe of the patterns. The smaller a_2 leads to lower sidelobe levels. The influences of the outer taper on H-plane patterns are shown in Figure 12(b). Again, the outer taper has a great effect on the sidelobe and backlobe levels of the patterns. The angular location and the level of sidelobe as well as backlobe change significantly for varying a_2. Therefore, the length of outer edge, a_2, can be optimized for desired sidelobe and backlobe performance in both the E- and H-planes.

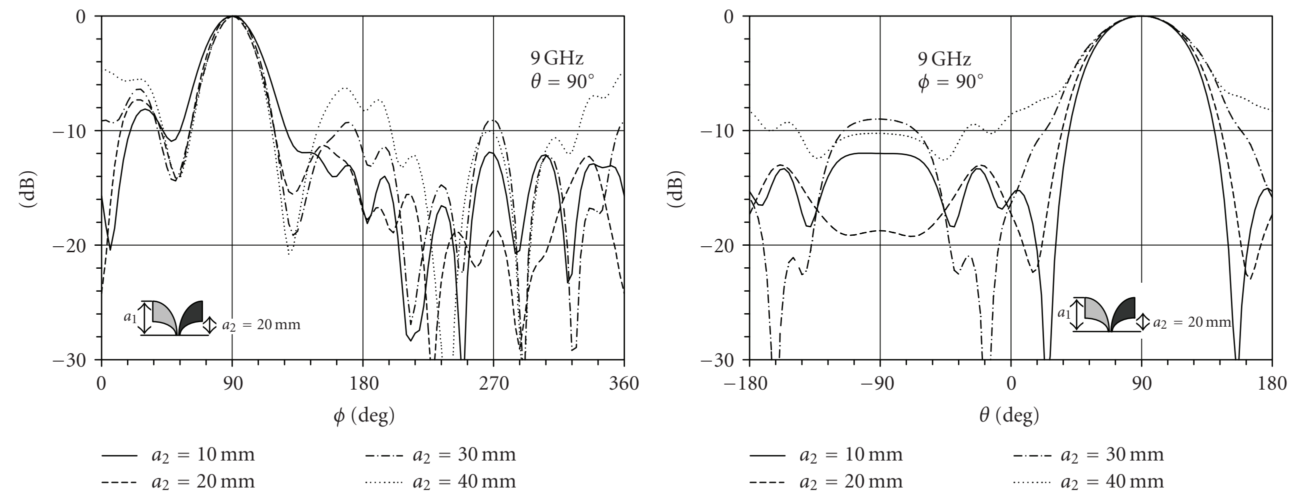
For further understanding the radiation characteristics of the DETASA, the current distribution on the conducting arms is calculated by using IE3D [18] which is based on moment method. Figure 13 shows the currents of two DETASAs with different slotline radiator configurations. For the DETASA which has large side intercept, $a_1 - a_2$ (shown in Figure 13(a)), the currents along the edges of the slot taper are large in quantity so they dominate the radiation of the antenna. The currents along the outer edge are oppositely directed and small in quantity so that they contribute less to the radiation. However, when conducting arms becomes very narrow, that is, the side intercept is very small (shown in Figure 13(b)), the currents along the inner and outer edges of the slot taper are similarly directed and almost equal in quantity. The radiating structure does not behave as a Vivaldi radiator but more like a V-shaped dipole. This is the reason of those DETASAs, which have small side intercepts, demonstrate lower gain, higher sidelobe and backlobe levels.

Figure 14 illustrates the radiation patterns of the DETASAs in the E- and H-planes for changing length of tapered ground, b_f. Refer to Figure 14(a), the length of the tapered ground has main effect on sidelobe and backlobe of the E-plane patterns. The pattern becomes more symmetrical when



(a) (b)

Figure 11: Radiation patterns of DETASAs for varying length of slot taper, a_1, in (a) E-plane and (b) H-plane.



(a) (b)

Figure 12: Radiation patterns of DETASAs for varying length of outer taper, a_2, in (a) E-plane, (b) H-plane.

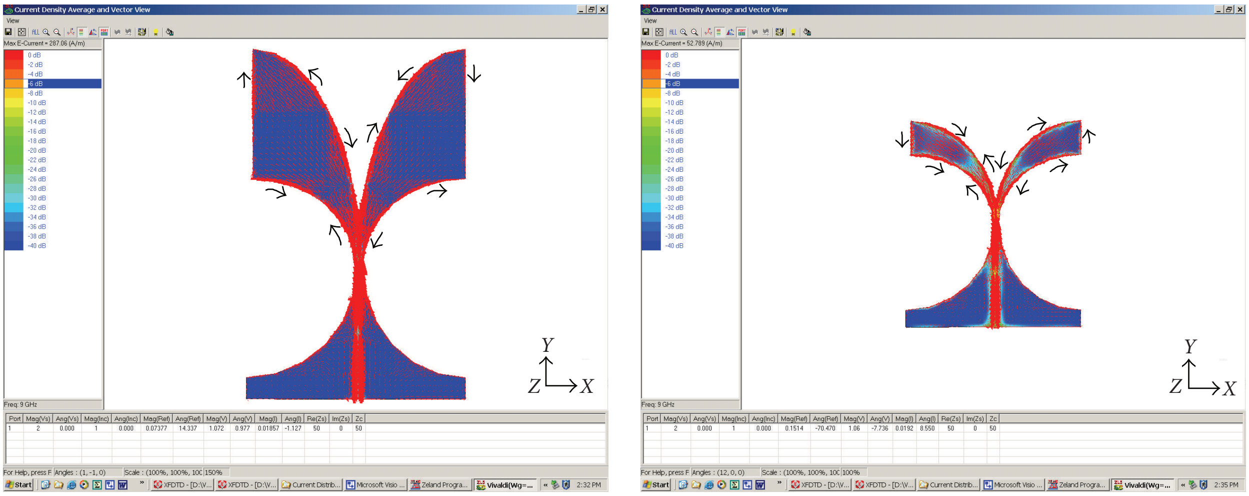
tapered ground is longer. In H-planes, no significant impact is observed but the low backlobe is achieved for a specified ground length, $b_f = 25$ mm.

Figure 15 presents the E-plane and H-plane patterns of the DETASA with the width of the tapered ground, W_g, varying from 11 mm to 71 mm. Again, the width of the tapered ground affects the sidelobe and backlobe levels in the E-planes and the backlobe levels in the H-planes. Conclusively, a small width W_g is conducive to the symmetry of E-plane patterns.

It is concluded that the effect of the feeding transition to the radiation patterns is limited to the sidelobe and backlobe. As shown in Figure 13, the currents on the tapered ground plate are small and mainly along the tapered edges. For those feeding transitions which are longer in length, for example, $b_f = 60$ mm or smaller in width, for example, $W_g = 11$ mm, the antenna structure tends to be more symmetrical with respect to the y-axis; furthermore, the direction of the currents on the ground plate tends to y-direction so that they cause less distortion to the radiation, the antenna patterns becomes more symmetrical in E-plane.

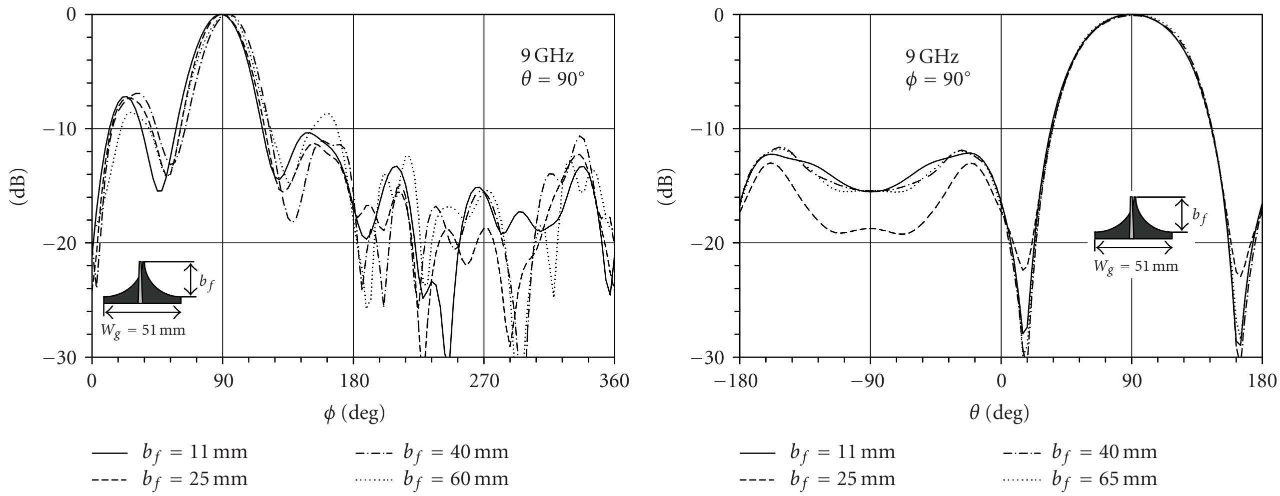
5. CONCLUSIONS

This paper has investigated the effects of major geometry parameters on the impedance and radiation performance of the DETASA. The investigation was conducted to explore the general behavioral trends of the DETASA rather than to design a specific antenna. The parametric study has been done over 1–20 GHz band and yielded a wealth of information which will benefit antenna engineers for their design and optimization of the DETASA.



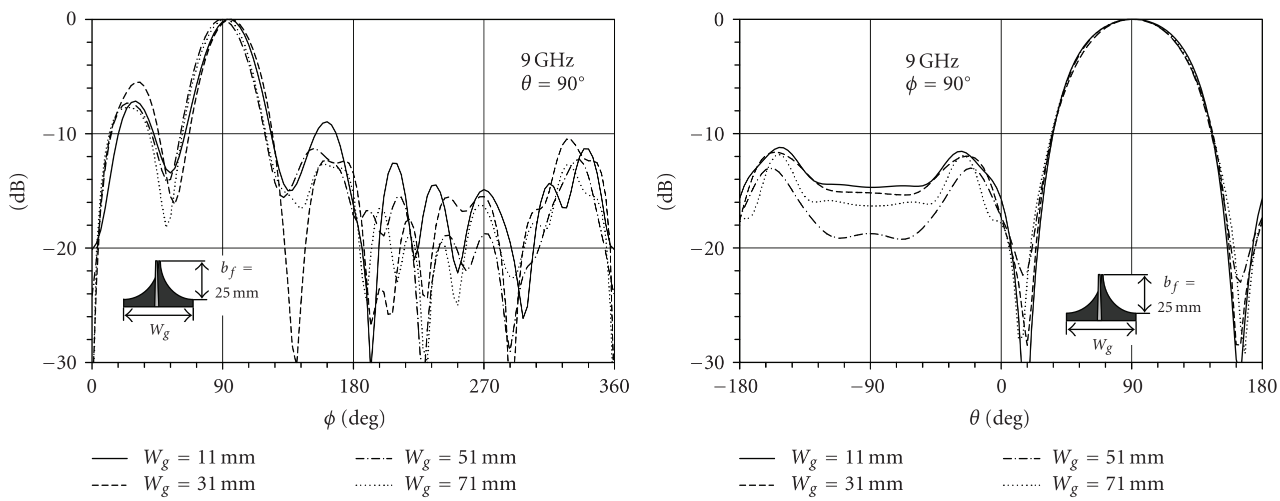
(a) (b)

Figure 13: Current distribution for DETASAs with different profile of slotline radiator: (a) a_1 = 50 mm, a_2 = 20 mm, (b) a_1 = 30 mm, and a_2 = 20 mm.



(a) (b)

Figure 14: Radiation patterns of DETASAs for changing length of tapered ground, b_f, in (a) E-plane, (b) H-plan.



(a) (b)

Figure 15: Radiation patterns of DETASAs for changing width of tapered ground, W_g, in (a) E-plane, (b) H-plane.

From the study, we can conclude the following points, which can be used as a guideline for the design of the DETASA.

(1) The side intercepts, a_1-a_2, of the slotline radiator and separation of the parallel offset strip lines, S, have major effects on the impedance matching characteristic. Large-side intercept and small separation result in good impedance matching especially at lower frequencies. The profile of the tapered ground plate has a slight effect on impedance matching.

(2) The length of the slot taper, a_1, mainly controls the gain of DETASA. Usually, longer slot taper offers higher gain but results in higher cross-polarization levels. The outer edge shows little impact on the gain. The feeding transition has shown very little effect on antenna gain but somewhat on the cross-polarization levels

(3) The length of the slot taper, a_1, has shown a significant effect on main beam of the H-plane patterns, while the main beam of the E-plane patterns is nearly unaffected. The longer the slot taper is, the narrower the H-plane beamwidth is. The length of the outer taper, a_2, has little effect on the main beam but affects the sidelobe and backlobe levels. Therefore, it can be optimized to suppress sidelobe and backlobe levels.

(4) The size of the feeding transition primarily affects the sidelobe levels of E-plane patterns. Longer or smaller feeding transitions offer more symmetrical radiation patterns in E-plane.

REFERENCES

[1] W. C. Y. Lee, *Mobile Communcations Design Fundamentals*, Wiley, New York, NY, USA, 1993.

[2] T. Manabe, Y. Miura, and T. Ihara, "Effects of antenna directivity and polarization on indoor multipath propagation characteristics at 60 GHz," *IEEE Journal on Selected Areas in Communications*, vol. 14, no. 3, pp. 441–447, 1996.

[3] S.-S. Jeng, G. T. Okamoto, G. Xu, H.-P. Lin, and W. J. Vogel, "Expérimental evaluation of smart antenna system performance for wireless communications," *IEEE Transactions on Antennas and Propagation*, vol. 46, no. 6, pp. 749–757, 1998.

[4] P. Cardieri and T. S. Rappaport, "Application of narrow-beam antennas and fractional loading factor in cellular communication systems," *IEEE Transactions on Vehicular Technology*, vol. 50, no. 2, pp. 430–440, 2001.

[5] P. J. Gibson, "The vivaldi aeriel," in *9th European Microwave Conference*, pp. 101–105, Brighton, UK, October 1979.

[6] R. Janaswamy and D. H. Schaubert, "Analysis of tapered slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 35, no. 9, pp. 1058–1065, 1987.

[7] W. Sörgel, C. Waldschmidt, and W. Wiesbeck, "Transient responses of a Vivaldi antenna and a logarithmic periodic dipole array for ultra wideband communication," in *IEEE International Antennas and Propagation Symposium and USNC/CNC/URSI North American Radio Science Meeting*, vol. 3, pp. 592–595, Columbus, Ohio, USA, June 2003.

[8] S.-G. Kim and K. Chang, "Ultra wideband exponentially-tapered antipodal vivaldi antennas," in *IEEE Antennas and Propagation Society Symposium 2004 Digest held in Conjunction with: USNC/URSI National Radio Science Meeting*, vol. 3, pp. 2273–2276, Monterey, Calif, USA, June 2004.

[9] M. Manteghi and Y. Rahmat-Samli, "A novel UWB feeding mechanism for the TEM horn antenna, reflector IRA, and the Vivaldi antenna," *IEEE Antennas and Propagation Magazine*, vol. 46, no. 5, pp. 81–87, 2004.

[10] Y. Yunqiang, Z. Cemin, L. Song, and A. E. Fathy, "Development of an ultra wideband vivaldi antenna array," in *IEEE Antennas and Propagation Society International Symposium and USNC/URSI Meeting*, vol. 1 A, pp. 606–609, Washington, DC, USA, July 2005.

[11] J. D. S. Langley, P. S. Hall, and P. Newham, "Balanced antipodal Vivaldi antenna for wide bandwidth phased arrays," *IEE Proceedings: Microwaves, Antennas and Propagation*, vol. 143, no. 2, pp. 97–102, 1996.

[12] J. A. N. Noronha, T. Bielawa, C. R. Anderson, D. G. Sweeney, S. Licul, and W. A. Davis, "Designing antennas for UWB systems," *Microwaves and RF*, vol. 42, no. 6, pp. 53–61, 2003.

[13] E. Gazit, "Improved design of the Vivaldi antenna," *IEE Proceedings H: Microwaves, Antennas and Propagation*, vol. 135, no. 2, pp. 89–92, 1988.

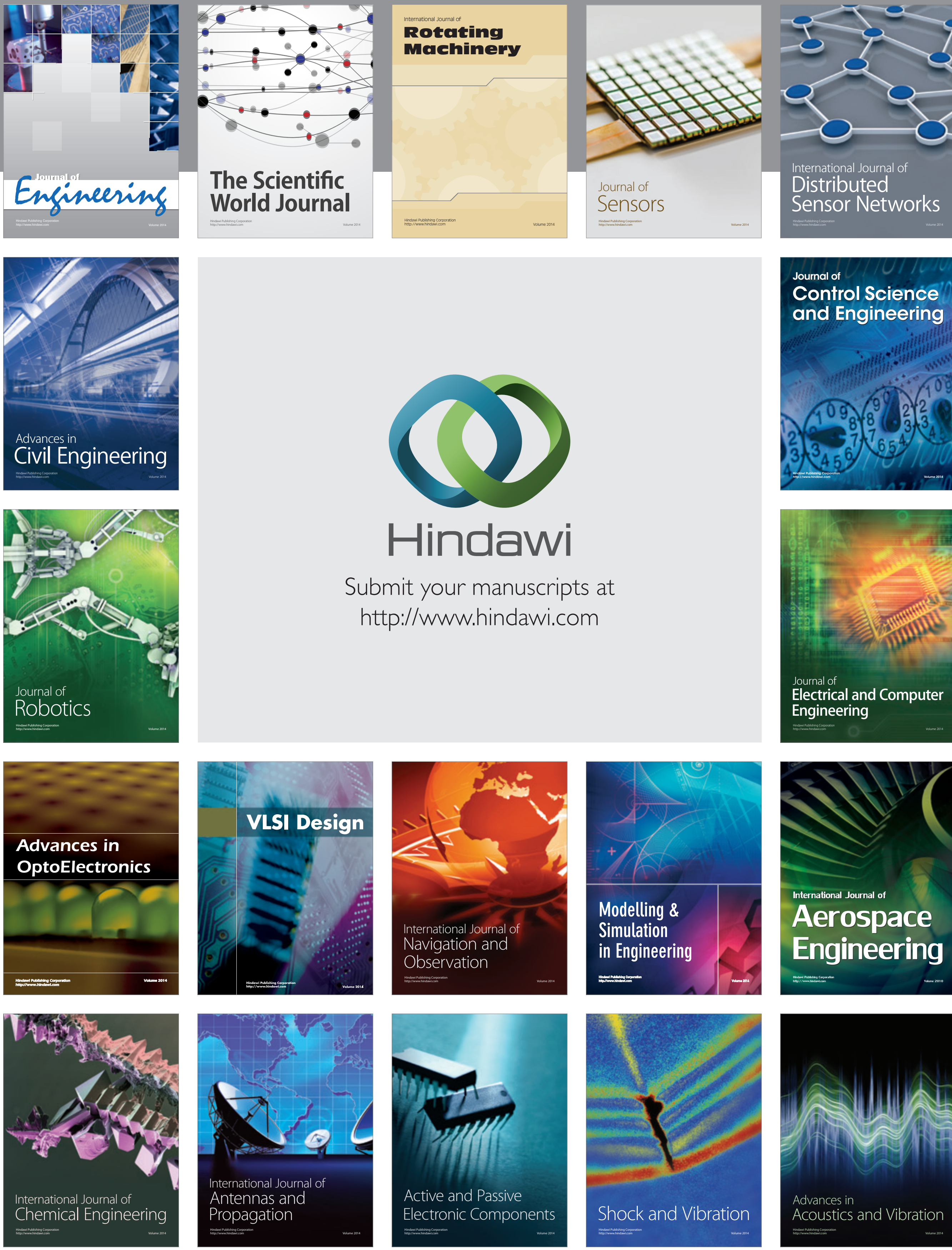
[14] N. Fourikis, N. Lioutas, and N. V. Shuley, "Parametric study of the co- and crosspolarization characteristics of tapered planar and antipodal slotline antennas," *IEE Proceedings H: Microwaves, Antennas and Propagation*, vol. 140, no. 1, pp. 17–22, 1993.

[15] M. C. Greenberg, K. L. Virga, and C. L. Hammond, "Performance characteristics of the dual exponentially tapered slot antenna (DETSA) for wireless communications applications," *IEEE Transactions on Vehicular Technology*, vol. 52, no. 2, pp. 305–312, 2003.

[16] K. S. Yngvesson, D. H. Schaubert, T. L. Korzeniowski, E. L. Kollberg, T. Thungren, and J. F. Johansson, "Endfire tapered slot antennas on dielectric substrates," *IEEE Transactions on Antennas and Propagation*, vol. 33, no. 12, pp. 1392–1400, 1985.

[17] "XFDTD version 6.1," Remcom, Inc., Pennsylvania USA.

[18] IE3D version 11, *Zeland Software, Inc.*, Fremont, Calif, USA.


Journal of Engineering
The Scientific World Journal
International Journal of Rotating Machinery
Journal of Sensors
International Journal of Distributed Sensor Networks
Advances in Civil Engineering
Journal of Control Science and Engineering
Hindawi
Submit your manuscripts at
http://www.hindawi.com
Journal of Robotics
Journal of Electrical and Computer Engineering
Advances in OptoElectronics
VLSI Design
International Journal of Navigation and Observation
Modelling & Simulation in Engineering
International Journal of Aerospace Engineering
International Journal of Chemical Engineering
International Journal of Antennas and Propagation
Active and Passive Electronic Components
Shock and Vibration
Advances in Acoustics and Vibration