Ultrawideband Elliptical Microstrip Antenna Using Different Taper Lines for Feeding

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Abstract:- In this paper, a printed elliptical slot antenna fed by different tapered microstrip line with U-shaped and Circular ring-shaped tuning stub is proposed for ultra-wideband (UWB) applications. The tapering aids in minimizing the reflection at the interface between the microstrip feed line and the tuning stub. Introduced is a new tapering profile that minimizes the reflection and hence enhances the bandwidth. The tapering profile is based on the Willis–Sinha profile. The design parameters for achieving optimal performance are investigated. The operation and the performance of the proposed antenna are also analyzed. Good agreement between simulated and experimental results is obtained.

Key-Words: Microstrip line, printed antenna, elliptical slot antenna, tapered lines, circular polarization (CP), ultrawideband (UWB).

1 Introduction

Microstrip patch antennas have been widely employed in many practical applications for several decades [1] because of their many advantages such as low profile, light weight, low cost, conformability, ease of fabrication, and integration with RF devices. However, the main drawback of microstrip radiators is their narrow bandwidth. Several techniques have been appeared in the last years to improve the bandwidth such as: capacitive compensation [2-3], thicker substrates [4], and stacked-patches [5].

For wideband applications, different slot antennas with microstrip line feeding are presented in [6-10]. In [6], a round corner rectangular wide slot is used, which can achieve a –10 dB bandwidth of 6.17 GHz. In [7], an impedance bandwidth of 1.1 GHz has been obtained using a printed wide slot antenna with a fork-like tuning stub. A T-shaped microstrip line fed wide slot antenna, which has a wide bandwidth of 1.2 GHz is presented in [8]. The use of a cross-shaped microstrip fed slot is presented in [9], the experimental bandwidth of the antenna is 3.156 GHz.

Recently, printed elliptical/circular slot antennas that fed by either a coplanar waveguide (CPW) or a microstrip line are proposed for ultrawideband (UWB) applications [10]. In both designs, a U-shaped tuning stub is introduced to enhance the coupling between the slot and the feed line so as to broaden the operating bandwidth of the antenna.

Bandwidth enhancement is achieved by using a short linear tapered feed line. The measured bandwidths of elliptical/circular slot microstrip fed line antennas are 2.6-10.22 GHz and 3.46-10.9 GHz, respectively. For CPW, the measured bandwidths are 3.1-10.6 GHz and 3.75-10.3 GHz, respectively.

In this paper, a novel circular-ring tuning stub elliptical slot antenna with an enhanced bandwidth is proposed for UWB applications, where the circular-ring tuning stub is connected to the microstrip fed line by a long Willis-Sinha tapered line [11, 12]. This antenna has also been used to achieve circular polarization (CP). Furthermore, the bandwidth of elliptical microstrip fed line slot antenna proposed in [10] is enhanced by increasing the outer radius of the U-shaped tuning stub. The rest of the paper is organized as follows: Section 2 discusses the different tapered lines, reflection patterns of these tapered lines are obtained to find the optimum lengths of the tapered line that gives zero or minimum reflection coefficient. In section 3, the performance of the elliptical microstrip line fed slot antenna of [10] with the optimum tapered lines lengths is evaluated. Section 4 describes the novel antenna geometry, where the U-shaped tuning stub is replaced by a circular-ring tuning stub. The antennas performances are evaluated in section 5. Measured results are introduced in section 6 and the Conclusions are given in section 7.

2 Tapered Lines

Microstrip taper line acts as matching sections between two microstriplines of different characteristics impedances $(z_1 \; and \; z_2)$. The most famous tapered lines are exponential [13], parabolic [14], hyperbolic [15], linear [16], and Willis-Sinha. Table 1 shows the impedance profiles for these tapered lines. The reflection coefficient ρ_i at x = 0 is given by [17]

$$\rho_i = \int_0^L \frac{1}{2} \frac{d\left[\ln z_o(x)\right]}{dx} e^{-j2\beta x} dx \tag{1}$$

where L is the tapered line length, z_o is the characteristics impedance at a point situated at a distance x from the beginning of the taper, and β is the propagation constant.
We have obtained the reflection coefficient of each taper by substituting its impedance profile into Equation (1) and solving it numerically, the results are plotted in Fig.1. This figure presents the normalized values of the reflection coefficient magnitude for the tapers as a function of L/λ_s, where λ_s is the guide wavelength (λ_s =33.84mm), ρo is the value of the reflection coefficient when the taper is removed and is equal to:

$$\rho_o = \frac{(z_2 - z_1)}{(z_2 + z_1)} \tag{2}$$

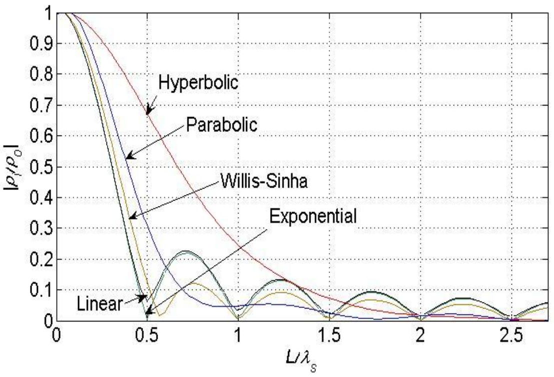


Fig.1 Reflection pattern of different types of tapered line

It is noticed that for the cases of the exponential, linear, and Willis-Sinha tapers, the reflection pattern consists of a major lobe which is followed by a series of minor lobes of reducing amplitudes as the frequency or the taper length is increased. The reflection pattern in the case of the exponential taper doesn't depend on the values of the end impedances z_1 *and* z_2; the zeroes take place at $L = 0.5\lambda_s$, λ_s, $1.5\,\lambda_s$, ... *etc.* For the linear tapered the reflection pattern has minimum and not zeroes at the same points. The first zero in the case of Willis-Sinha taper is shifted to 0.56 λ_s which means that a longer taper is needed, but it has the advantage that the minor lobes are much reduced as compared with the minor lobes of the exponential and linear tapers. The reflection coefficient for the parabolic and hyperbolic tapers reduces gradually as either of the taper length or the frequency increases and hence the performances are less sensitive to frequency.

Table 1
Impedance profiles for different tapered lines

Tapered line	**Impedance profile** L= Tapered line length, z_1=Input impedance of T.L. z_2= Input impedance of antenna, and x= Incremental section of length.
Exponential	$z_0(x) = z_1 \exp[(\frac{x}{L})\ln(\frac{z_2}{z_1})]$
Linear	$z_0(x) = z_1[1 + (\frac{z_2}{z_1} - 1)(\frac{x}{L})]$
Parabolic	$z_0(x) = z_1 + 3(z_2 - z_1)(\frac{x}{L})^2 - 2(z_2 - z_1)(\frac{x}{L})^3$
Hyperbolic	$z_0(x) = \frac{z_2 + z_1}{2} + \frac{z_2 - z_1}{2}\tanh[6(\frac{x}{L} - 0.5)]$
Willis-Sinha	$z_0(x) = z_1 \exp\left\{\left[\frac{x}{L} - \frac{0.2405}{2\pi}\sin\left(\frac{2\pi x}{L}\right)\right]\ln\left(\frac{z_2}{z_1}\right)\right\}$

3 Performance Enhancement by the Optimum-Length Tapers

In previous work [10], an elliptical microstrip line fed slot antenna with a linear taper of length 0.092 λ_s resulted in a high normalized reflection coefficient. The achieved bandwidth was 2.6 to 10.22 GHz. However, the optimum length of the taper that gives a minimum normalized reflection coefficient is 0.5 λ_s when using linear or exponential tapers, and 0.56 λ_s when using Willis-Sinha as shown in Fig.1. For the parabolic and hyperbolic tapers the minimum normalized reflection coefficient occurs at lengths 1.7 λ_s *and* 2.5 λ_s, respectively.

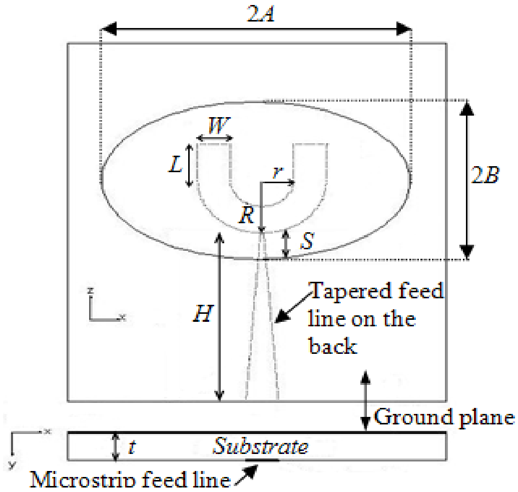
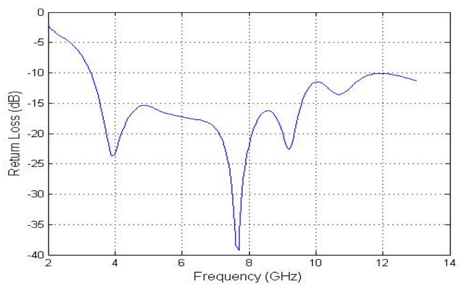


Fig.2 Geometry of printed elliptical slot antenna fed by microstrip line

Since the optimum length of the parabolic and hyperbolic tapers is large, the complexity and size of the antenna will increase, and thus they were excluded from the simulation.

The geometry of the printed elliptical slot antenna fed by microstrip line is shown in Fig.2. The slot and the feeding line are printed on different sides of the dielectric substrate. Bandwidth enhancement could be achieved by using the optimum length of tapers. The antenna is modeled numerically by using Zeland IE3D software [18] which utilizes the method of moment technique. It should be noted that the antenna was simulated over the full range of frequencies (0-13GHz) which is the limit of the software. Fig.3 shows the return loss when using linear, exponential, and Willis-Sinha tapers respectively. Their lengths are chosen to be the optimum lengths, i.e., the lengths that give a minimum reflection coefficient.



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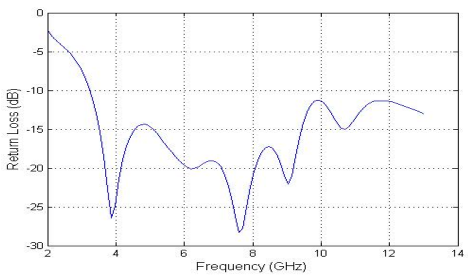

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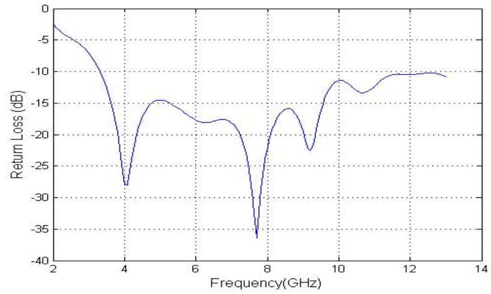

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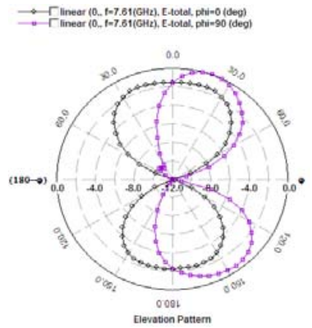
Fig.3 Simulated return loss curves of printed elliptical slot antenna using (a) Linear (b) Exponential and (c) Willis-Sinha taper with U-shaped tuning stub.

Table 2 summarizes the achieved performance when using the three tapers with their optimum lengths. Fig.4. shows the radiation pattern for three cases at the optimum resonant frequency for each case.

It is observed from Fig.4 (and Fig.7) that the radiation pattern is not exactly broadside. Also, there is an increase in the front-to-back ratio (F/B) due to the embedded slots in the ground plane and the decreased ground-plane size in wavelength. One way to eliminate the F/B is using a reflector.

Table 2
Performance of Microstrip Antenna with U-shaped Tuning Stub for Different Tapers.

Characteristics	Linear	Exponential	Willis-Sinha
Optimum length (H)	0.5 λ_s	0.5 λ_s	0.56 λ_s
S (mm)	1.8	1.6	1.2
Simulated -10dB Bandwidth	3.27-13	3.26-13	3.3-13
f_r (GHz)	7.61	7.61	7.72
Gain (dBi)	4.40	4.38	4.51
Directivity (dBi)	6.25	6.31	6.43
Antenna Efficiency (%)	65	64	64
Maximum Radiation Pattern (deg)	20	20	20



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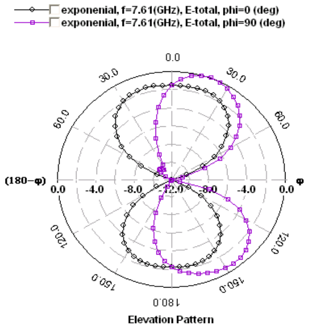

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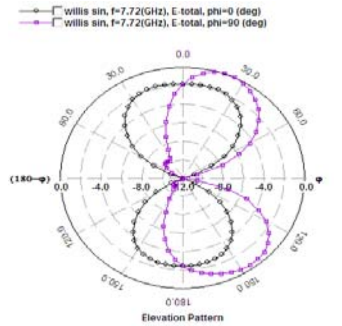

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Fig.4 Simulated radiation pattern of microstrip line fed elliptical slot antenna (a) Linear taper at f_r=7.61 GHz (b) Exponential taper at f_r =7.61 GHz (c) Willis-Sinha taper at f_r = 7.72 GHz

4 Geometry of the Proposed Antenna

The configuration of the proposed antenna is shown in fig.5. The elliptical radiating slot has a long axis radius *A* (*A=16mm*) and a short axis radius *B (B=11.5mm).* It is etched on a rectangular dielectric FR4 substrate of thickness *h* = 1.5mm and a relative permittivity of 4.7. The 50 Ω microstrip-fed line with circular ring shaped-tuning stub is printed on the opposite side of the substrate of size (42mm×42mm) and placed symmetrically with respect to the centerline of the elliptical slot; the microstrip line width is 2.74 mm.

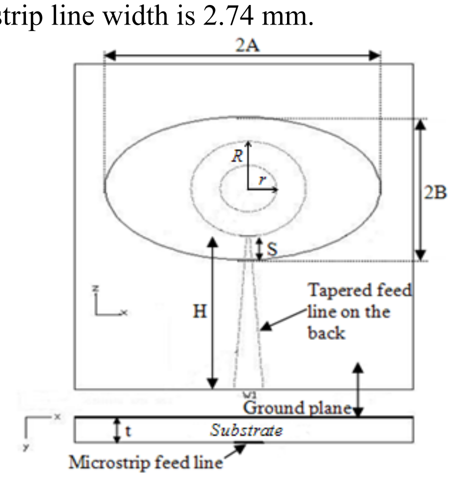
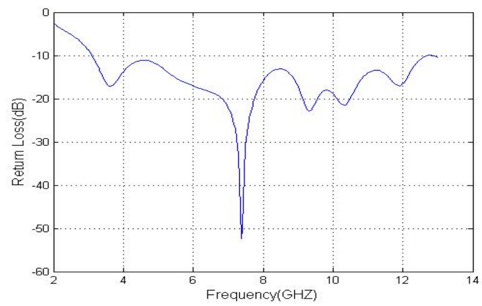


Fig.5 Geometry of printed elliptical slot antenna fed by microstrip line.

For the taper, linear, exponential, and Willis-Sinha are used to connect with the Circular Ring shaped-tuning stub, which consists of a circular ring section with an outer radius *R* of 7.5mm and an inner radius r of 2.9mm. *S* represents the distance between the bottom of the circular ring shaped-tuning stub and the lower edge of the elliptical slot.

5 Performances evaluation of the proposed antenna

The simulations reveal that the UWB characteristics of the slot antenna results from the multiple resonance introduced by the combination of the elliptical slot and circular ring shaped-tuning stub. It is also shown that the performance of the antenna is critically dependent on the outer radius *R* of circular ring shaped-tuning stub and the distance S between the bottom of the tuning stub and the lower edge of the slot and the width of the slot (axis radius *A* and a short axis radius *B*). So these parameters should be optimized for maximum bandwidth. Figur.6 shows the simulated return loss for different tapers.



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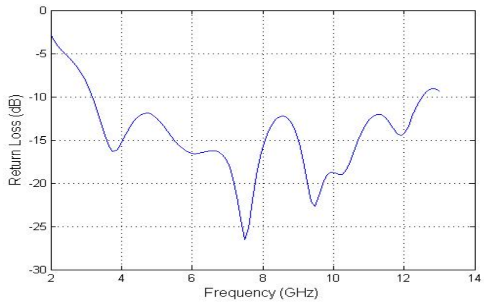

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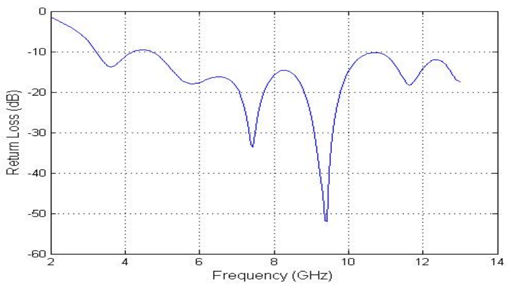

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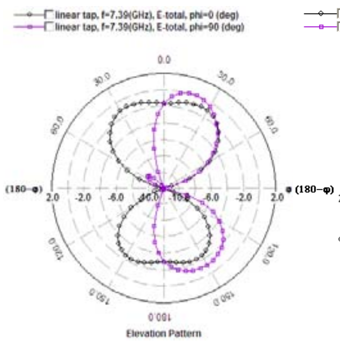
Fig.6 Simulated return loss curves of printed elliptical slot antenna using (a) Linear (b) Exponential and (c) Willis-Sinha taper with Ring-shaped tuning stub.

Table 3 summarizes the achieved performance when using the three tapers with their optimum lengths. Fig.7. shows the radiation pattern for the three cases at the optimum resonant frequency for each case.

Table 3
Performance of Microstrip Antenna with Ring-shaped Tuning Stub for different Tapers.

Characteristics	Linear	Exponential	Willis-Sinha
Optimum length (H)	0.5 λ_s	0.5 λ_s	0.56 λ_s
S (mm)	1.5	1.3	1.4
Simulated -10dB Bandwidth	3.1-13	3.2-12.78	3.21-13
fr (GHz)	7.39	7.39	9.37
Gain (dBi)	4.16	4.13	5.66
Directivity (dBi)	6.15	6.11	8.82
Antenna Efficiency (%)	63	63	48
Maximum Radiation Pattern (deg)	20	20	45



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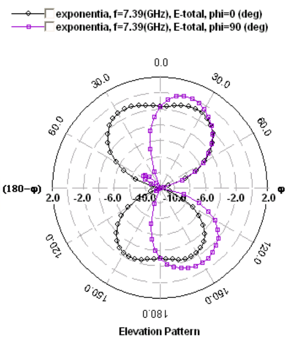

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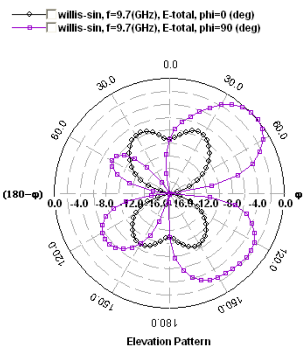
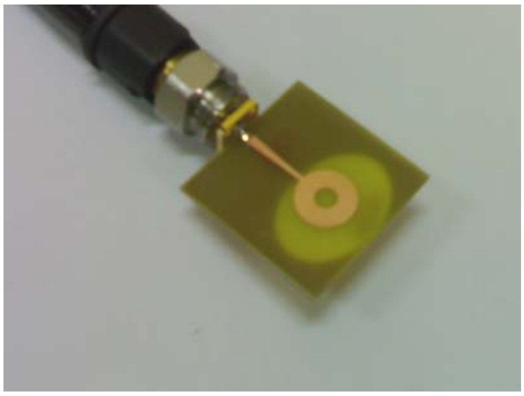


(c)

Fig.7 Simulated radiation pattern of microstrip line elliptical slot antenna (a) Linear taper at f_r=7.39 GHz (b) Exponential taper at f_r =7.39 GHz (c) Willis-Sinha taper at f_r = 9.37 GHz

6 Measured Results

An elliptical slot microstrip antenna with Ring Circular shaped tuning stub fed by Willis-Sinha taper was fabricated and tested (Fig.8). The simulated and measured return loss is shown in Fig.8(c). The fundamental resonant mode is at 8.5GHz and 9.37GHz for the measured and simulated results, respectively. The -10dB impedance bandwidth is 2.9-13GHz for the measured antenna and 3.21-13GHz for the simulated antenna.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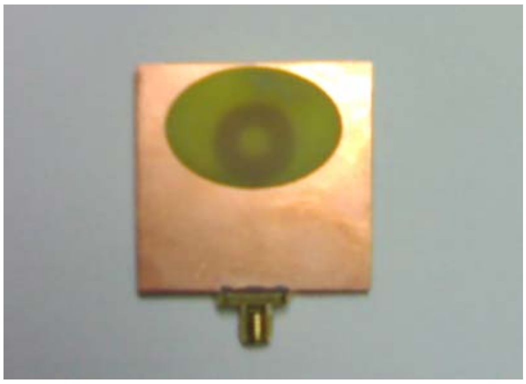
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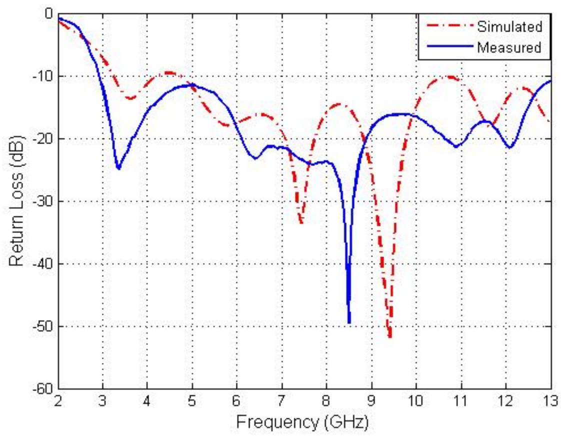

(c)

Fig.8 (a) Ring-shaped Tuning stub antenna connected to Willis-Sinha Tapered line. (b)Elliptical slot antenna at ground plane (c) simulated and measured return loss of antenna.

7 Conclusion

A planar elliptical slot antenna fed by different tapered microstrip lines with a circular ring shaped-tuning stub is presented and investigated. The slot dimension, the distance S, and the optimum tapered length with minimum reflection coefficient are the parameters that should be optimized for maximum bandwidth. The Ultra-wide bandwidth of 10.1GHz (2.9GHz-13GHZ) was achieved. Experimental results reveal that the antenna shows very good UWB performance, which makes it useful in UWB applications due to their relative small size.

References:

[1] C. A. Balanis, “*Antenna Theory Analysis and Design”*, 2nd ed: John Wiley & Sons, Inc., 1997.

[2] James, J. R. and P. S. Hall (eds.), *“Handbook of Microstrip Antennas”*, Peter Peregrinus, UK, 1989.

[3] Gao, S. and S. S. Zhong, *“Analysis and design of dual-polarized microstrip arrays”*, International Journal of RF and Microwave CAE, Vol. 9, No. 1, pp. 42–48, 1999.

[4] Pozar, D. M. and D. H. Schaubert (eds.), *“Microstrip Antennas, the Analysis and Design of Microstrip Antennas and Arrays*”, IEEE Press, New York, NY, 1995.

[5] P. S. Hall, “*Probe compensation in thick microstrip patches”,* Electron Lett., vol. 21, pp 606-607, 1987.

[6] H. L. Lee, H. J. Lee, J. G. Yook and H.K. Park. *"Broadband planar antenna having round corner rectangular wide slot"* Proc. IEEE Antennas and Propagation Society, vol.2.pp.460-463. Jan. 16, 2002.

[7] J.Y. Sze and K.L. Wong, *“Bandwidth enhancement of a microstripline-fed printed wide-slot antenna,” IEEE Trans. Antennas Propag.*, vol. 49, no. 7, pp. 1020–1024, July 2001.

[8] M. K. Kim, K. Kim, Y. H. Suh, and I. Park, *“A T-shaped microstripline-fed wide slot antenna,”* in *Proc. IEEE Int. Symp. APS*, pp. 1500–1503, July 2000.

[9] Y. W. Jang, *“Broadband cross-shaped microstrip-fed slot antenna,” Electronics Letters*, vol. 36, no. 25, pp. 2056–2057, Dec. 7, 2000.

[10] P. Li, J. Liang and X. Chen,*"Study of Printed Elliptical / Circular Slot Antenna for Ultrawideband Applications"* IEEE Transaction on antenna and propagation, Vol. 54. No.6. June 2006.

[11] E.A.F. Abdallah and M.B. Saleh, *" Theory, Design and Fabrication of microstrip tapers for impedance matching sections ",* **pulliten of the** National research center, Dec. 1983.

[12] Willis, J. And Sinha, N. K., Proc. IEE, vol. 103B, pp.166, 1956.

[13] Michael ides, M., Mullard Tech. comm. pp. 116, 170, 1972.

[14] Yang, R. F. H., Proc. IRE, vol. 43, pp. 1010, 1955.

[15] Scott, H.J., Proc. IRE, vol. 41, pp. 1654, 1953.

[16] Rustogi, O. P., IEEE Trans. Microwave Theory and Tech. vol. 17, pp. 166, 1969.

[17] Collin, R.E., *" Foundation for Microwave Engineering"*, Mc Graw-Hill Book Company, Inc., New York, p. 237, 1966.

[18] IE3D Zeland software version 11.54