Compact Tapered Slot Antennas for UWB Microwave Imaging Applications

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Abstract—: **This paper presents the design of compact Tapered Slot Antennas (TSAs) for application in an Ultra Wide Band (UWB) microwave imaging system. In the initial step, a conventional size-reduced TSA with an exponential taper for 3.1-10.6 GHz band is designed. From the radiation pattern analysis, it is found that this antenna exhibits poor directivity in the lower part of UWB. To overcome this shortfall, two modifications are investigated. One includes corrugations and the other one elliptical cuts on sides of the initial TSA. It is shown that the modified TSAs feature improved directivity while their UWB impedance characteristics are similar to the original TSA. The TSA with corrugations exhibits an almost constant directive radiation pattern across UWB. However, its gain oscillates with frequency leading to a pulse distortion. Therefore the size-reduced TSA with elliptical cuts in conducting sides looks to be the most attractive choice with respect to both directive properties and distortionless pulse transmission.**

Keywords- Ultra wideband antenna, slot antenna, directivity, radiation pattern.

I. INTRODUCTION

In 2002, Federal Communications Commission (FCC) of the United States released the unlicensed frequency band of 3.1 to 10.6GHz [1] for UWB applications. In order to achieve harmonious co-existence with current radio standards, UWB transceivers have to operate at low power levels of -41dBm/MHz. One of the challenges is a UWB antenna design. UWB antennas have to be small in size and preferably planar to achieve low manufacturing cost while providing desired radiation pattern and input impedance characteristics. In addition they have to support distortionless transmission of short duration pulses. Such characteristics are necessary for UWB radio and radar (i.e. Ground Probe Radar). With respect to the two application areas, main difference concerns the radiation characteristics. For UWB radio, antennas with omni-directional patterns are the preferable option. In turn for UWB radar, antennas with directional properties are the more preferable choice. The requirement of having small size, low profile and low cost UWB antennas with omni-directional pattern can be fulfilled with planar monopoles. The design of such antennas has been reported in many recent works. The design of small-size low profile UWB antennas with directive radiation patterns supporting distortionless pulse transmission seems to be more challenging. Our own interest is in the design of directive UWB antennas for microwave imaging. The design of compact but non-planar UWB antennas with directional properties for such application has been reported in [2-3]. An alternative to these designs is a planar Tapered Slot Antenna (TSA). In order for this antenna to have acceptable directive radiation pattern and ultra wide impedance bandwidth, it has to meet the minimum value of slotline aperture (H) and tapered length (L), as shown in [4].

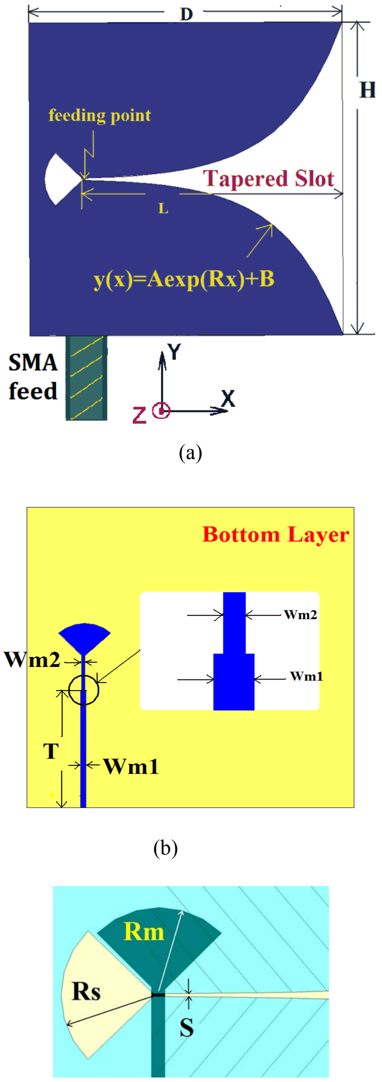
One shortfall of many TSA designs, according to the research in [5-6], is the drift of phase center with frequency, which results in pulse dispersion in the time domain. Usually, the larger-length TSAs exhibit a more unstable phase center. To overcome this problem, it is necessary to find a method to reduce the electrical-size of TSA without losing its UW impedance bandwidth and directional properties. The antenna literature includes a number of works [7-10] on how to improve performances of TSAs. However, they do not consider size reduction as one of their main objectives. In this paper, we investigate two approaches to improve directive properties of a size-reduced TSA aimed for operation in the 3.1-10.6 GHz band. In the first approach, we introduce a set of slots/corrugations while in the alternative approach we make elliptical cuts to conducting sides of the TSA.

The paper is organized as follows. Section II presents the conventional design of a size-reduced TSA. Section III describes modified size-reduced TSAs, one with variable size corrugations and the other with some conductor parts being removed. Section IV shows results and section V concludes the paper.

II. COMPACT TSA DESIGN

First, the conventional design of a reduced-size exponentially tapered slot antenna is presented. Aimed for operation in the 3.1-10.6 GHz band, this antenna named as ANT-A, is shown in Figure 1. As observed in Figure 1, the proposed TSA is located in the XY-plane. The slot is gradually tapered along the X-axis and is symmetric along the Y-axis. The upper half taper is defined by the function $y(x) = Ae^{Rx}+B$. where R defines the taper ratio. Other key parameters are the slotline aperture width (H) and the taper length (L). Our choice of this TSA is influenced by ease of manufacturing in comparison with the antipodal configurations reported in [9], [11]. This TSA is fed by a microstrip-line with a suitable microstrip-slot transition, as shown in Figure 1 b and 1c.

Following the guidelines in [4], the TSA dimensions are worked out and given in Table 1.



(a)

(b)

(c)

Fig.1 Configuration of size-reduced TSA (ANT-A)

(a) The top layer layout, (b) The feed microstrip (bottom layer), (c) The microstrip-slot coupling structure

Table 1: The design parameters of size-reduced TSA

L	Taper Length	30 mm
H	Taper Aperture	36 mm
D	Total Length (Include feed)	36 mm
Wm1	Microstrip Width (wide)	0.4 mm
Wm2	Microstrip Width (narrow)	0.6mm
T	Step Location	14mm
S	Slot Width in Feed	0.2 mm
R	Taper Ratio	0.15 mm^{-1}
Rm	Radius of Radial Stub 1	4.1 mm
Rs	Radius of Radial Stub 2	4.3 mm
εr	Permittivity of Substrate	10.2
K	Thickness of Substrate	0.64 mm

As shown later, this TSA antenna features non-directive properties in the lower part of UWB. This property is unwelcome when this antenna is to image a lossy dielectric object. The reason is that the lower portion of UWB does not efficiently enter an imaged object.

III. MODIFIED COMPACT TSAS

A. Compact TSA with Corrugations

In order to improve its directive properties, the TSA ANT-A is modified by adding slots/corrugations to its sides [10]. Figure 2 shows the antenna with variable-length corrugations. This antenna, named as ANT-B, provides an approximately constant directive radiation pattern across UWB.

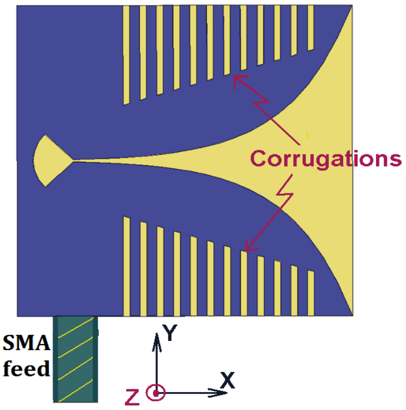


Fig. 2. TSA with variable-length corrugations.

B. Compact TSA with Some Conductor Removed

In an alternative approach, we remove some part of conductor forming the TSA ANT-A. The chosen conductor engraving is of elliptical shape. The resulting TSA antenna is named as ANT-C and is shown in Figure 3.

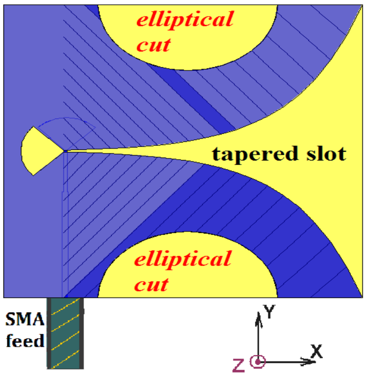


Fig. 3. TSA with some conductor removed.

The design and analysis of TSA ANT-A, ANT-B and ANT-C including SMA feeds is performed using full-wave electromagnetic software.

IV. RESULTS

Figure 4 shows the simulated return loss (S_{11}) of the three antennas for the frequency band between 3 and 11 GHz.

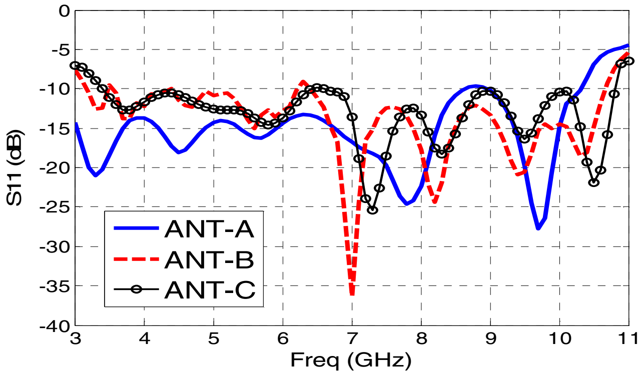


Fig.4 Simulation results for return losses of ANT-A, ANT-B and ANT-C

As observed in Figure 4, all three TSAs exhibit good return loss (RL) performance over UWB. Compared with ANT-B and ANT-C, ANT-A has a slightly better RL in the lower and middle part of UWB. The three TSAs have different gain characteristics and radiation patterns and offer different performances with respect to pulse transmission, as shown in Figures 5-11.

It can be seen in Figure 5 that both ANT-B and ANT-C have a higher gain than ANT-A in the lower part of UWB. The gain of ANT-A and ANT-C is gentle as a function of frequency while the gain of ANT-B is oscillating.

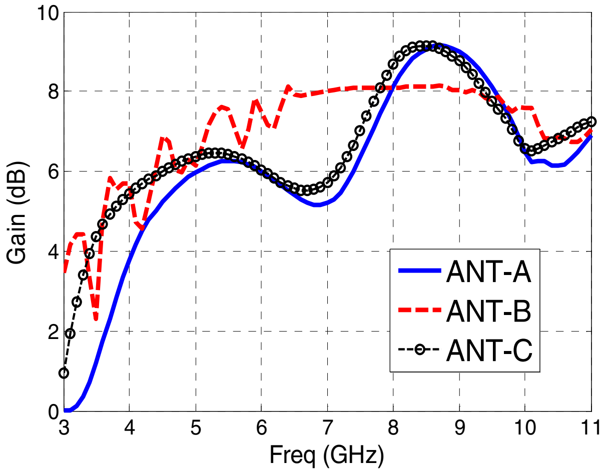


Fig.5 Simulation results for +X-axis gain of ANT-A ANT-B, and ANT-C.

The radiation pattern of ANT-A is non-directive in the lower part of UWB, as seen in Figure 6. ANT-C shows some improvement in terms of an approximately constant directive radiation pattern across UWB, as seen in Fig. 8, while ANT-B has an almost constant directive radiation pattern over UWB (Fig. 7).

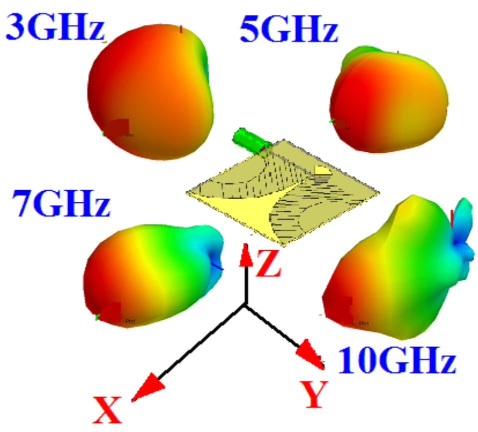


Fig.6 3-D radiation patterns for ANT-A at 3, 5, 7 and 10GHz.

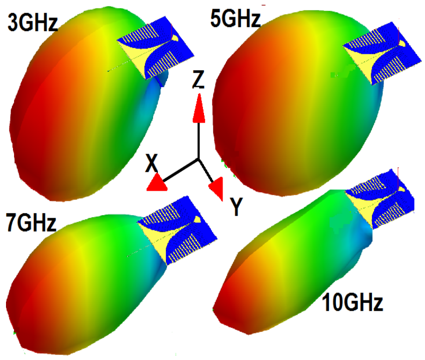


Fig7. 3-D radiation patterns for ANT-B at 3, 5, 7 and 10GHz.

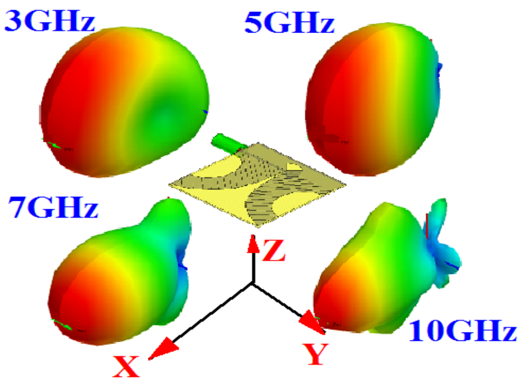


Fig.8 3-D radiation patterns for ANT-C at 3, 5, 7 and 10GHz.

However, this is at the expense of pulse distortion. As observed in Figures 9, 10 and 11, which show the results for pulse transmission between two identical TSA antennas spaced by 100mm, ANT-B is the worst performer, as it supports the longest ringing tail accompanying a Gaussian pulse. ANT-A offers the shortest ringing tail.

ANT-C seems to be best performer with respect to directive properties and distortionless pulse transmission.

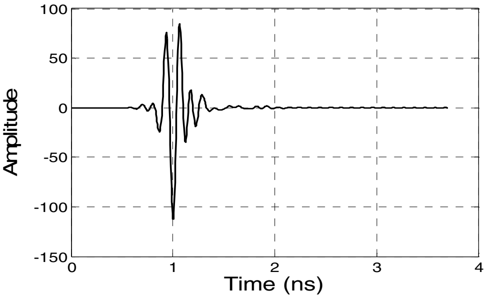


Fig.9 Received pulse for two co-polarized ANT-A antennas spaced by 100 mm.

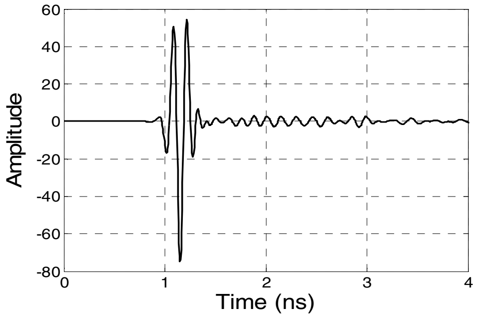


Fig.10 Received pulse for two co-polarized ANT-B antennas spaced by 100 mm.

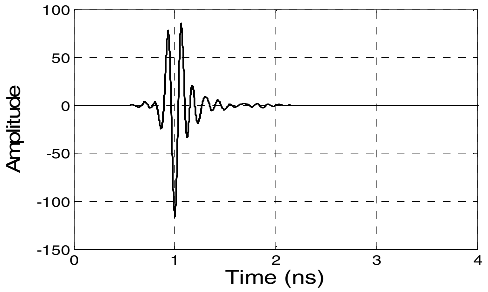


Fig.11 Received pulse for two co-polarized ANT-C antennas spaced by 100 mm.

V. CONCLUSIONS

This paper has reported the design of three compact Tapered Slot Antennas (TSAs) for operation in the ultra wide frequency band of 3.1-10.6 GHz. In the initial step, a conventional size-reduced TSA with an exponential slot taper has been designed. It has been shown that this antenna suffers from reduced directivity in the lower part of UWB. To overcome this shortfall, this TSA has been modified by adding a suitable pattern of corrugations or by introducing elliptical cuts in two conducting sides of TSA. It has been shown that the modified TSA antennas offer an approximately constant directive radiation pattern while preserving a UW impedance bandwidth of the original design. The size-reduced TSA antenna with elliptical cuts is the best performer with respect to directive properties and distortionless pulse transmission.

ACKNOWLEDGMENT

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REFERENCES

[1] C Report and Order for Part 15 Acceptance of Ultra Wideband (UWB) Systems from 3.1 – 10.6 GHz, F3-CC, Washington, DC, 2002.

[2] R. Khalaj, A. A. Trehan, and N. K. Nikolova," TEM Horn Antenna for Ultra-Wide Band Microwave Breast Imaging",Progress In Electromagnetics Research B, Vol. 13, 59-74, 2009.

[3] X. Li, S. C. Hagness, M. K. Choi and D. W. van der Weide, "Numerical and Experimental Investigation of an Ultrawideband Ridged Pyramidal Horn Antenna with Curved Launching Plane for Pulse Radiation", IEEE Antennas and Wireless Propag. Letters, vol. 2, pp. 259-262, 2003.

[4] B. Li , X. Che, "Application of Equivalent Circuit Method in Designing the Vivaldi UWB Antenna", Wireless Communications, Networking and Mobile Computing, 2008. WiCOM '08. 4th International Conference on12-14 Oct. 2008 Page(s):1 - 3.

[5] H.G, Schantz. "A Brief History of UWB Antennas", IEEE Aerospace and Electronic System Magazine, vol.19, no.4, pp.22-26, April 2004.

[6] W. Qun, B-S. Jin, B. Li; Y-M Wu; L-W Li, "An Approach to the Determination of the Phase Center of Vivaldi-based UWB Antenna"; Proc. IEEE Antennas and Propagation Society International Symposium 2006, Page(s):563 – 566, 9-14 July 2006

[7] K. Hettak, G.Y. Delisle, S. Tardif, G.A. Morin, M.G. Stubbs, "A Novel Wideband Chebychev Tapered Slot Antenna using Broadband CPW to Slotline Transition" Proc. IEEE Antennas and Propagation Society International Symposium, Page(s):1 – 4, 5-11 July 2008.

[8] J. Bourqui, M. Okoniewski, and E. Fear,"Enhanced Directivity of a Tapered Slot Antenna for Near-Field Imaging"; Antenna Technology and Applied Electromagnetics and the Canadian Radio Science Meeting, 2009. ANTEM/URSI 2009. 13th International Symposium on 15-18 Feb. 2009 Page(s):1 - 3.

[9] J. Bourqui, M. Okoniewski, and E. Fear, "Balanced Antipodal Vivaldi Antenna for Breast Cancer Detection"; Antenna Technology and Applied Electromagnetics and the Canadian Radio Science Meeting, 2009. ANTEM/URSI 2009. 13th International Symposium on 15-18 Feb. 2009 Page(s):1 - 3.

[10] V. Mikhnev and P. Vainikainen, "Ultra-wideband Tapered-slot Antenna with Non-uniform Resistive Loading," Proc. of the 6th Int. Conf. on Antenna Theory and Techniques (ICATT'07), Sevastopol, Ukraine, 17-21 September 2007, pp. 281-283.

[11] W. Khor, M. Bialkowski, A. Abbosh, N. Seman, and S. Crozier, "An Ultra Wideband Microwave Imaging System for Breast Cancer Detection", *IEICE Trans. Comm.*, vol. E85-A/B/C/D, no. 1, pp. 2376 – 2381, September 2007.