Asymmetric TEM Horn Antenna for Improved Impulse Radiation Performance

#Hyeong Soon Park[1], Jae Sik Kim[1], Young Joong Yoon[1] and Ji Heon Ryu[2], Jin Soo Choi[2]
[1]The Electrical and Electronic Engineering Department, Yonsei University
Sinchon-dong, Seodaemun-gu, Seoul, South Korea, phsmicro@yonsei.ac.kr
[2]Agency for Defense Development, Daejeon, South Korea, rjh@add.re.kr

***Abstract* – A modified TEM horn antenna which has an asymmetric plates, two plates with different heights, has improved pulse radiation performance. This paper presents an optimized asymmetric TEM (AsyTEM) horn antenna and a same size of conventional exponentially tapered TEM (ETEM) horn antenna to verify the improvement of the impulse radiation performance. The AsyTEM horn antenna is shown to yield an enhanced reflection coefficient at the low frequency of the operation bandwidth. The results show that the AsyTEM horn antenna has reflection coefficient less than -10 dB in the frequencies from 2.6 GHz to over 20 GHz while the ETEM has 2.9 GHz to over 20 GHz. In the case of being compared with the ETEM horn antenna, it also had an improved impulse radiation gain which increased over 0.6.**

I. INTRODUCTION

The ultrawideband (UWB) antennas are recently attracting attention to satisfy the demand for a variety of applications. The UWB antennas provide many advantages, such as improved detection ability, adaptive ranging performance, the higher target resolution, and so on. Thus, the UWB antennas are used for the electromagnetic compatibility (EMC) measurement, the ground penetrating radar (GPR) system, and the broadband communication systems. Also the UWB antennas are applied to the transient radar cross section (RCS) measurements, the synthetic aperture radar (SAR) system for which the radiation of transient waveform is interesting through bandwidths exceeding one decade [1]. A lot of studies on the UWB antennas have worked and many types of the antennas which satisfy UWB characteristics are well established [2]-[4].

Specifically, the TEM horn antennas are widely used as the UWB antenna for having the merit of wideband, low dispersion, unidirectional pattern and easy construction [5]. Several researches have been preceded to improve the performance of the TEM horn antenna.

In this paper, the modified TEM horn antenna with the exponentially tapered asymmetric plates, two plates with different heights, has been designed.

When the TEM horn plates have the different heights, the TEM horn antenna can achieve an improved low frequency radiation ability. For a short pulse excitation, more pulse energy is distributed in the relatively low frequency range than that in the high frequency range. Improving the low frequency radiation means the improvement of the radiation efficiency [6].

To verify compatibility, the same size of the conventional exponentially tapered TEM (ETEM) horn antenna and the AsyTEM horn antenna are simulated. The simulated results show that the AsyTEM horn antenna exhibits the better reflection coefficient at the low frequency and the improved impulse radiation gain compared with the ETEM horn antenna.

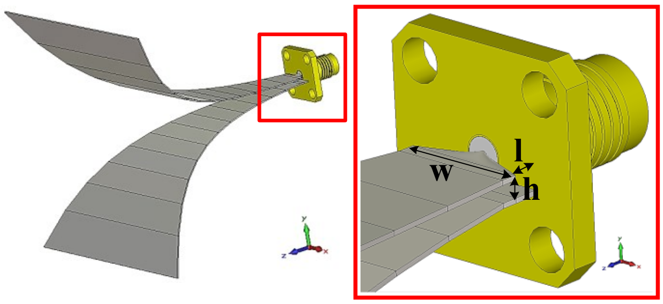
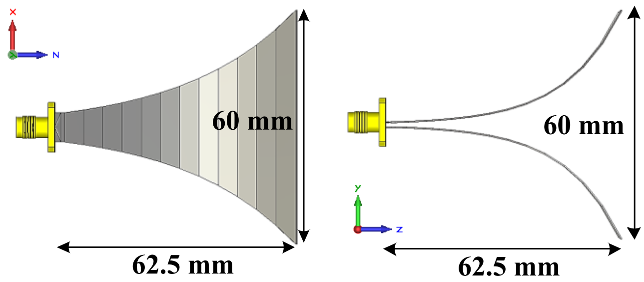


Figure 1. Feed transition of the TEM horn antenna



(a) Top view (b) Side view

Figure 2. the ETEM horn antenna geometry

II. ANTENNA DESIGN

A. *Feed Transition*

The TEM horn antenna is usually equipped with a balun structure at the feed position for guide a travelling wave without any impedance discontinuities. As shown in Figure 1, the smooth transition has been applied to pass from the inner conductor of the SMA connector to the upper plate and the lower plate is extruded to the SMA connector. The height (h), the length (l) and the width (w) of the transition structure is optimized to operating the 50 Ω line [7].

B. *Horn Profiles*

Figure 2 shows the geometry of the ETEM horn antenna including the transition structure. The main issue of the TEM

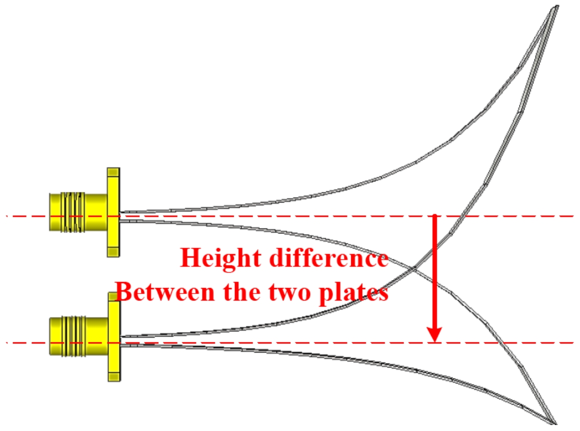


Figure 3. The size and geometry comparison of the AsyTEM and the ETEM horn antenna

horn design is matching the characteristic impedance of the guide from 50 Ω at feeding part to 120π Ω at the aperture. To smoothly varying characteristic impedance from feed to aperture, the tapered plates form of TEM antenna can be linear, exponential and Klopfenstein, etc. Linear tapered antennas can be built easily as compared with an exponentially taped antenna and Klopfenstein tapered antenna yield the smallest minor ripples characteristic in the reflection coefficient [8]. However, exponentially tapered plates have the advantage of the smooth impedance variations than the linear tapered and can be achieve more wideband characteristics in same size. Meanwhile, Klopfenstein tapered antenna has the disadvantage of the complicated design [9]. Thus, the exponentially tapered form is chosen to the basic structure shape. The TEM plates width is calculated by the means of equations for the parallel plate waveguide, as proposed in [9]. The designed ETEM horn antenna is 62.5 mm long, and the aperture size is 60X60 mm^2 respectively.

C. *Effect of the Asymmetric Plates*

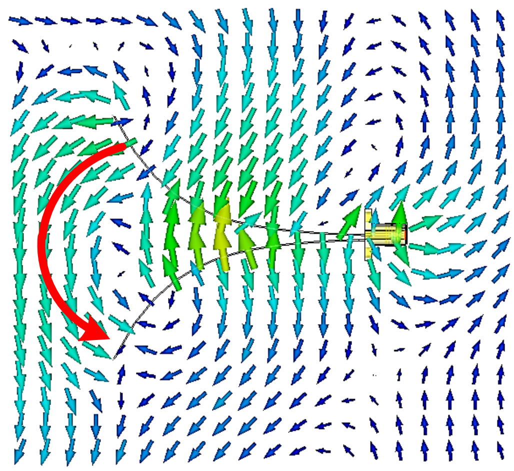
Usually the TEM horn antenna is a symmetrical structure to guarantee the end-fire radiation characteristic on main direction.

In [10], the asymmetrical anti-podal taper slot antenna (TSA) is introduced to further enhance the bandwidth of the conventional taper slot antenna. However, the asymmetrical TSA has inclined peak direction of the radiation pattern. To obtain the similar characteristic in [10], the three dimensions of the asymmetric plates are applied to the ETEM as shown in Figure 3. As illustrated in this Figure, the AsyTEM horn antenna has the same aperture size and antenna length as the ETEM horn antenna.

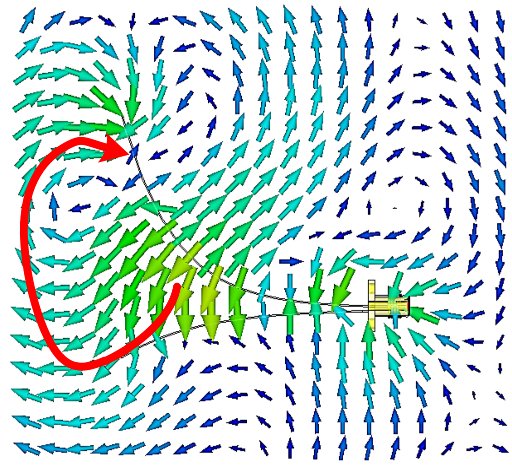
The AsyTEM horn antenna can be considered as a combination of the two different profiles of TEM horn antennas. To maintain the dimensions of the AsyTEM horn antenna as same as the ETEM horn antenna, the heights of the upper plate and the lower plate are complementary.

Figure 4 indicates the E-field distribution on near two antennas
at 2.6 GHz in the y-z plane. This figure shows that the contour path of the E-field vectors differs from each other.

The E-field vectors in the AsyTEM are not perpendicular to the edge of the each plate, which means that the equivalent aperture has been extended. Thus, the lower boundary of the resonant band can be downsized [10]. As expected, this result is the same as the analyzed phenomenon of the asymmetrical planar type TSA.



(a) E-field at 2.6 GHz of the ETEM horn antenna



(b) E-field at 2.6 GHz of the AsyTEM horn antenna

Figure 4.Simulated contour path of the E-field vectors

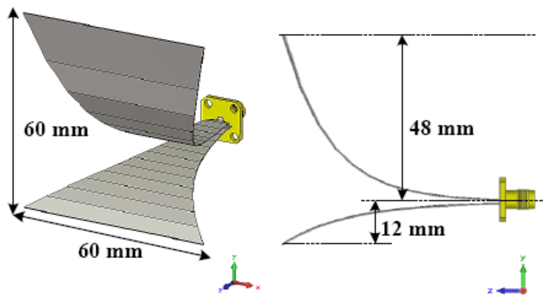


Figure 5. Final geometry of the AsyTEM horn antenna

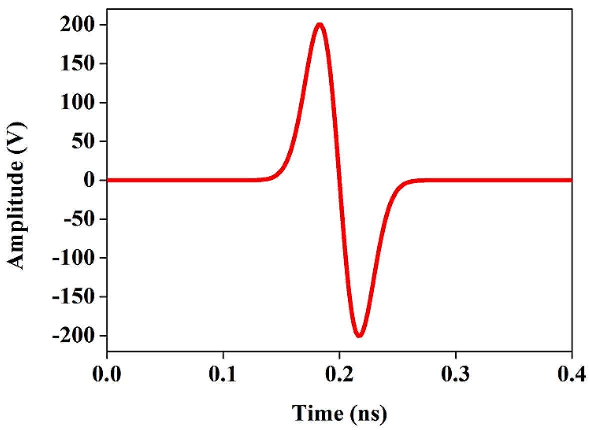


Figure 6. Input bipolar pulse in the time domain

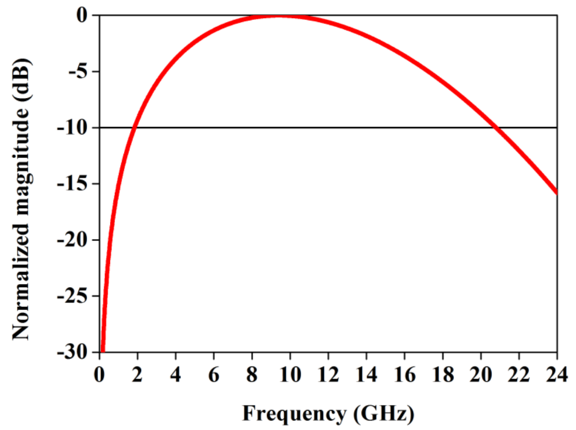


Figure 7. Power spectral density (PSD) of the input pulse

For optimum performance of the AsyTEM horn antenna, finding the optimized values of the different heights is preceded. The final values of the different heights have been founded with CST Microwave studio software using parameter sweep function.

The final geometry of the AsyTEM horn antenna is shown in figure 5. As shown in this figure, the horn length and the aperture size are the same as the ETEM horn antenna, but the height of the upper plate is 48 mm, the lower plate is 12 mm respectively.

III. Radiation Characteristics

First of all, the input voltage pulse is presented to simulate the radiated field of the two antennas. Figure 6 shows that pulse form is bipolar pulse with a null mean value.

Compared with the monopolar pulse, when received antenna receives pulse, the bipolar pulse can reduce pulse distortion. It also has several other advantages [11]. The basic Gaussian pulse is described analytically as [12]

$$v(t) = \frac{A}{\sqrt{2\pi\sigma}} \exp(-\frac{t^2}{2\sigma^2}) \quad (1)$$

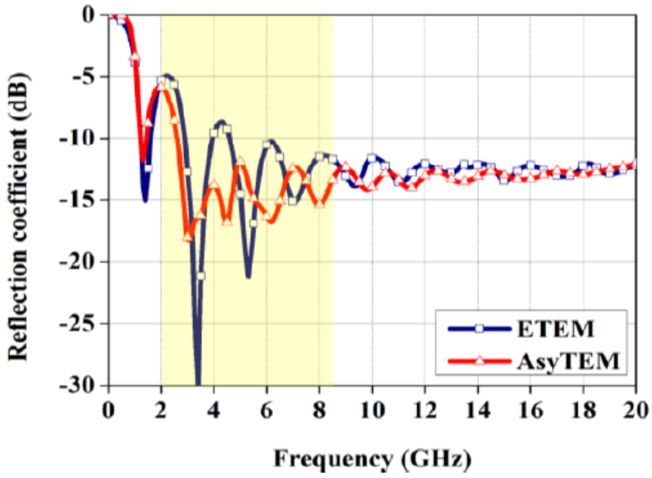


Figure 8. The reflection coefficient of the two antennas

The bipolar pulse is given by the first derivative of the Gaussian pulse

$$v'(t) = \frac{At}{\sqrt{2\pi\sigma^3}} \exp(-\frac{t^2}{2\sigma^2}) \quad (2)$$

Where A is the amplitude of the Gaussian pulse and σ defines the width of the pulse.

The peak value of the pulse is 200 V, the width of the input pulse is 150 ps and the rise time is about 24 ps respectively. The normalized power spectral density (PSD) of the input pulse is plotted in Figure 7. PSD spectrum can be achieved by Fourier transform of the input pulse. As shown in this figure, the bandwidth of the signal is about from 2 GHz to over 20 GHz and centered around 8 GHz. It is clear that the PSD of the input pulse meet the condition of the operating bandwidth of the two antennas.

Figure 8 shows the computed reflection coefficient as function of the frequency for the two antennas. Both antennas can cover the UWB characteristic. The bandwidth (S11<-10 dB) of the ETEM horn antenna is 2.6 to over 20 GHz and the AsyTEM horn antenna is 2.9 to over 20 GHz respectively.

The AsyTEM horn antenna has the enhanced bandwidth range at the low frequency. This result is already explained in the section II, figure 4. The AsyTEM horn antenna also has the better reflection coefficient compared with the ETEM horn antenna from about 2 to 8 GHz band. Mentioned in [6], improved low frequency characteristic makes the radiation efficiency better for a short pulse excitation. To obtain the transient radiated far-field result, E-field probe is 5 m away from the antenna in the simulation.

However, the AsyTEM horn antenna has difference length of the upper and the lower plates that cause the inclination of the peak direction in the radiation pattern. The farfield peak direction of the AsyTEM horn antenna rises up to about 13 degree in the elevation angle from the bore sight direction.

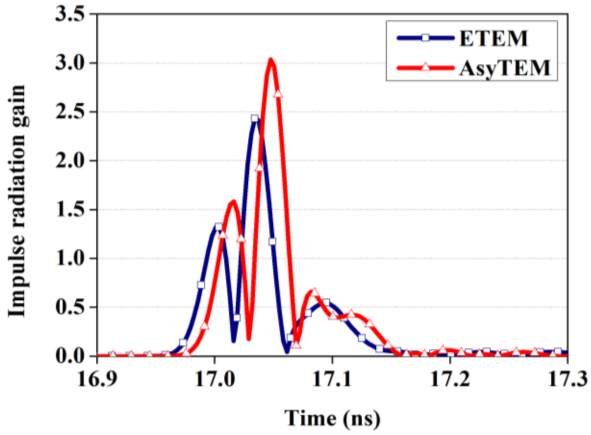


Figure 9. Impulse radiation gain of the two antennas

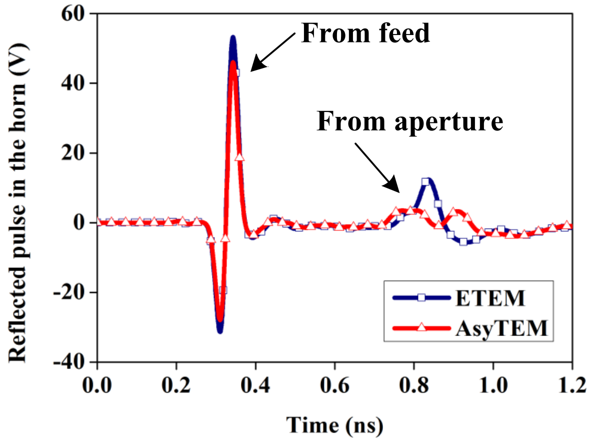


Figure 10. The reflected voltage in the horn

Thus, E-field probe to the AsyTEM horn antenna is located in the same distance and rises up to the peak direction for the correct comparison with the ETEM horn antenna.

Figure 9 indicates the impulse radiation gain of two antennas. The impulse radiation gain of the peak direction is defined as the ratio of the absolute level of a transient radiated far- field (E_r, unit : V/m) times the received distance (d, unit : m), and divided by the peak level of the voltage accepted by the antenna (V_{peak}, unit : V):

$$impulse\,radiation\,gain = \frac{|E_r \times d|}{V_{peak}} \quad (3)$$

As a result of this UWB improvement, it is obviously seen at the impulse radiation gain graph in figure 9 that both of the antennas show the low pulse dispersion. The AsyTEM horn antenna has the higher peak gain and the narrower received beam width than that of the ETEM horn antenna with the same physical size.

The maximum impulse radiation gain value of the ETEM horn antenna is 2.43 while the AsyTEM horn antenna is 3.03. Therefore, the AsyTEM horn antenna has improved impulse radiation gain which increased over 0.6 compared with the ETEM horn antenna.

The pulses reflected from the horn are given in Figure 10. In this figure, there is seen to be similar reflections between the two antennas. The biggest difference in the reflection occurs at the aperture. The ETEM horn antenna has the higher reflection voltage pulse from the aperture than the AsyTEM horn antenna. This result influences the radiated pulse from antenna that makes impulse radiation gain worse.

IV. Conclusion

The modified TEM horn antenna with the exponentially tapered asymmetric plates, two plates with different heights, is proposed to improve the impulse radiation performance compared with the same size of the exponentially tapered TEM horn antenna. To verify compatibility, the ETEM horn antenna and the proposed TEM horn antenna are simulated. The proposed antenna can improve the reflection coefficient at the low frequency range and low reflected pulse in the horn aperture. Therefore the impulse radiation gain of the UWB antenna system can be enhanced compared with the system with the conventional TEM horn antenna.

Acknowledgment

This paper was supported by Agency for Defense Development (ADD) under the contract number UD130008GD.

References

[1] Desrumaux L., Godard A., Lalande M., Bertrand V., Andrieu J., Jecko B., "An Original Antenna for Transient High Power UWB Arrays: The Shark Antenna," *IEEE Trans. Antennas and Propagation*, vol. 58, pp. 2515-2522, August 2010.

[2] Constantine A. Balanis, *Antenna theory - analysis and design*, 3rd ed., John Wiley & Sons, 2005, pp. 549-602.

[3] John DS. Kraus, Ronald J. Marhefka, *Antennas - For all applications*, 3rd ed., McGraw-hill, 2002, pp. 378-400.

[4] Sabath F., Giri D.V., Rachidi F., Kaelin A., *Ultra-wideband, Short Pulse Electromagnetics 9*, New york: Springer, 2010, pp. 189-294.

[5] Sara Banou Bassam, Jalil-Agha Rashed-Mohassel, "A Cheby-shev tapered Tem horn antenna," *Progress In Electromagnetics Research (PIER)*, vol. 2, pp. 706-709, 2006.

[6] Xiaolong Liu, Gang Wang, Wenbing Wang, "Design and performance of TEM horn antenna with low-frequency compensation," *Asia-Pacific Conf. of Environmental Electromagnetics*, pp. 306-309, November 2003.

[7] Godard,et al., "Size reduction and radiation optimization on UWB antenna," *IEEE Radar Conf.*, pp.1-5, May 2008.

[8] Klopfenstein R.W., "A transmission line taper of improved design," *Proceedings of the IRE*, vol. 44, pp. 31-35, January 1956.

[9] Kyungho Chung, Pyun S., Jaehoon Choi, "Design of an ultrawide-band TEM horn antenna with a microstrip-type balun," *IEEE Trans. Antennas and Propagation*, vol. 53, pp. 3410-3413, October 2005.

[10] Wenhua Chen, Yuan Yao, Zhijun Zhang, Zhenghe Feng, Yaqin Chen, "Design of unsymmetrical anti-podal taper slot element for array antenna," *IEEE Antennas and Propagation Society (AP-S)*, pp.1-4, July 2008.

[11] Diot J- C. et al., "Optoelectronic ultra-wide band radar system: RUGBI," *Radar Conf. EURAD*, pp.81-84, October 2005.

[12] Li Li, Pei Wang, Wu Xiao-dong, Zhang Jiakai, "Improved UWB pulse shaping method based on Gaussian derivatives," *IET international conf. CCWMC*, pp.438-442, November 2011.