

A New TEM Horn Antenna Designing Based on Plexiglass Antenna Cap

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Abstract

Traditionally, more pulse energy is distributed in the relatively low frequency range than that in the high frequency range for a short pulse excitation. However, obtaining a well low-frequency performance for the relatively limited spatial volume of antenna is very difficult. The design of traditional transverse electric magnetic (TEM) wave antenna is irregular. Therefore, we propose a new TEM horn antenna based on plexiglass antenna cap in this paper. We determine the structure of new model through analyzing feed-in structure and the radiation characteristics. Then we use 3-dimension electromagnetic field simulator to build up antenna model and finish related structural parameters optimization. Through simulation, we realize the smaller feed-in reflection of fast pulse. This model has better time-frequency characteristic. Finally, we make antenna experiments, which shows that the new horn antenna has good time domain fidelity and feed-in reflection properties. It is suitable for ultra-wide band antenna.

Key Words: Transverse Electric Magnetic Wave Antenna, Plexiglass Antenna Cap, 3-dimension Electromagnetic Field Simulator

1. Introduction

In general, ultra wide spectrum and high power microwave is a kind of strong transient electromagnetic pulse, which has been used widely in electronic counter-measures, target detection and recognition. The research and design of ultra-wide band antenna has attracted more attention. TEM horn antenna is one of the important forms of ultra-wide band, because it is with simple structure, wide band wide, better direction and high efficiency. Upper and lower polar plate in TEM transmission line stretches forming an ultra-wide band antenna which can be called TEM horn antenna [1–3]. It will make characteristic impedance of antenna gradual change choosing proper opening angle, length and width. Then it can achieve a small port reflection. Because the antenna structure shape is similar to the horn antenna and it meets TEM wave transmission conditions. So this antenna type

is called TEM horn antenna. It can transmit nanosecond transient pulse broadband signals, are widely used in various fields such as high power microwave weapons, phased array radar and synthetic aperture radar [4–8]. It has some advantages such as simple structure, wide wave band, good directivity and high efficiency, which is a common ultra-wide band radiation and receiving antenna. Conventional TEM horn is in the form of opening angle. This paper designs a new TEM horn antenna based on plexiglass antenna cap and floor boarding structure. Its structure is more small and exquisite. while it also improves the environmental adaptability, the optimized antenna has good feed-in reflection and time-frequency characteristic, the final test results show that the TEM horn is fit for the ultra-wide band antenna. Because the TEM horn antenna has simple feeder structure, good directionality and modest gain advantages, it is used widely. Researchers have done many works to improve TEM horn antenna. Zhao [9] presented that a gigawatt (GW) transverse electromagnetic wave (TEM)-mode phase shif-

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ter (TPS) used to adjust the phase of output of high-power microwave was investigated. The phase shifter was composed of two identical coaxial TE₆₉₆₉ circular polarizers, and can adjust the output microwave phase in a range of 0°–360°. Abouelnaga [10] introduced a compact ultra wide band transverse electromagnetic UWB TEM horn antenna with microstrip-type balun feeding scheme. Yin [3] proposed a new directed radiation fast rising time electromagnetic pulse (FREMP) simulator scheme which is based on transverse electric magnetic (TEM) wave antenna of a wire edge curl structure. In antenna design and the actual manufacturing process, however, the distributed load applied to the TEM horn antenna is difficult to implement and expensive. So when designing TEM horn antenna, we should improve the structure of the antenna. In this paper, we design a new TEM horn antenna based on plexiglass antenna cap. We determine the structure of new model through analyzing feed-in structure and the radiation characteristics. Then we use 3-dimension electromagnetic field simulator to build up antenna model and finish related structural parameters optimization. Finally, the simulation results show that we realize the smaller feed-in reflection of fast pulse. This model has better time-frequency characteristic.

2. New TEM Horn Antenna Analysis

TEM horn antenna usually consists of two separated pieces of linear gradient or index gradient plates. Because the coaxial line characteristic impedance is not matched with TEM horn characteristic impedance, the current through the coaxial line is converted into electromagnetic wave outward radiation. Current in TEM horn antenna plates forms a magnetic field. And magnetic field direction parallels to the field symmetry plane.

There is voltage difference between TEM horn antenna plates, the electric field is formed and its direction is perpendicular to the symmetry plates. Hence, the magnetic field and electric field form TEM wave outward radiation.

As a receiving antenna, it should meet the directivity, bandwidth, small size and convenient using, etc. TEM horn antenna has the constant characteristics impedance within the wide wave band, which can easily transform plane wave into coaxial structure TEM mode.

When designing TEM horn antenna, it demands a small reflection in the bandwidth, and receiving antenna has the stable direction.

Standard TEM horn antenna is composed of 2 triangle plates, as shown in Figure 1. x, y, z are the direction in space rectangular coordinates. w is TEM horn aperture width. h is the distance between the end of wire grid edge curl TEM horn antenna. S is antenna plate length. L is the length of antenna. β is the angle between the two polar plates. α is aperture angle of antenna pad. Characteristic impedance of antenna is Z_c . Considering the antenna radiation mating faces needs a consistency, so the opening angle of the TEM horn antenna generally is small angle. For a small angle TEM horn antenna, its current distribution in board is mainly composed of longitudinal current along the x direction. When horn aperture height $h \ll \lambda / (2\pi)$, small angle TEM horn antenna can be seen as a terminal open circuit transmission line. The line will be divided into bits. Each a small transmission line is the combination of electric dipole and magnetic dipole. It will produce electromagnetic radiation under pumping signal. Through the integral of electric and magnetic dipole radiation, it gives radiation field on the main shaft of TEM horn antenna.

$$E(r, t) = \frac{h_a}{2\pi r c f_g} \cdot \frac{dV(t)}{dt} - \frac{c}{2l} M \quad (1)$$

where c is light speed. r is the testing distance on the spindle. $M = [V(t) - V(t - 2l / c)]$. $V(t)$ is antenna excitation signal. f_g is structure impedance factor (i.e., ratio of TEM horn antenna characteristic impedance Z_c and free space wave impedance Z_0). $h_a = h/2$ is effective height of antenna. l is the length of the horn along axis direction.

TEM horn antenna characteristic impedance can be calculated by:

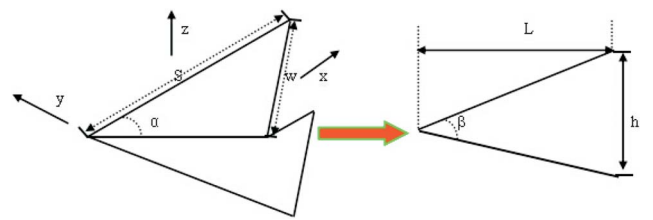


Figure 1. The structure of TEM.

$$Z_c = 120\pi[w/h + e + \ln f] \quad (2)$$

where w is TEM horn aperture width. e is a parameter. $f = w/h + 0.7$. h is TEM horn aperture height.

Through the analysis of the TEM horn antenna far-field radiation equation, it we want to increase the radiation field spectrum bandwidth, we can prolong the length of the TEM horn antenna. To increase the high-frequency cutoff frequency, we can reduce the opening angle and reduce diameter height.

3. New TEM Horn Antenna Design

According to the previous theoretical analysis, to design a TEM horn antenna receiving antenna, the length of the TEM horn plate and horn caliber height are the key parameters. To get a high bandwidth, low distortion degree in TEM horn antenna, it needs longer plate length, smaller horn aperture height, which can reduce low-frequency cutoff frequency, increase the high-frequency cutoff frequency and shorten the pulse response time of antenna. When designing TEM horn antenna, it also requires that the characteristic impedance of the antenna and feed-in coaxial cable characteristic impedance can match each other to reduce feed-in reflection, which needs the high technical requirements for TEM horn plate width and feed-in structure.

To facilitate the project implementation, the designed antenna is a new TEM horn antenna with floor boarding structure. 50Ω coaxial inner conductor connects the horn triangle plate vertices, coaxial outer conductor and ground plate are connected, coaxial connector chooses N type. In addition, we design an organic glass radome and install it on the ground flat. In the joint position, we use adhesive tape to seal it, which can effectively play a role in waterproof, dust prevention.

Feed-in structure is one of the key factors that affects the antenna performance. Feeder line insulating medium is teflon. Coaxial structure inner core exceeds floor directly connecting with the TEM horn positive plate. Inner core height is as low as possible to prevent producing the high order mode. Horn feed point structure can approximate to planar transmission line. There may be TE mode and TM mode in floor structure except transmit TEM mode. The lowest TE mode of flat structure is TE_{10}

mode, its cutoff wave length is only related to w of flat structure in feed point place. W is a correction component.

$$(\lambda_c)_{TE_{10}} = 2(W + 0.4h)\epsilon_r^{1/2} \quad (3)$$

The lowest TM mode of flat structure is TM_{01} mode, its cutoff wave length is only related to height h of the plate structure.

$$(\lambda_c)_{TM_{01}} = 2h\epsilon_r^{1/2} \quad (4)$$

For the high order mode in the plate structure surface waveform, it is unable to suppress, its cut-off frequency is zero.

4. Optimization Simulation of New TEM Antenna

After constructing antenna model, we use CST to make simulation calculation and optimize the antenna structure parameters. The main signal form of ultra-wide band antenna is transient pulse, so we should take antenna structure into consideration. Setting a quick rising edge, optimizing the antenna structure reflection, it can achieve the good spread of fast pulse in the antenna. Figure 2 shows that fast pulse in the feed point causes a small time-domain reflection, so feed-in structure is reasonable. Figure 3 and Figure 4 are antenna time domain and frequency domain response curve of TEM horn model respectively. What we can see is that the designed ultra-wide band antenna has a good time-domain characteristic, the waveform is very small, its tail is very short. The change of frequency response within 3 GHz is less

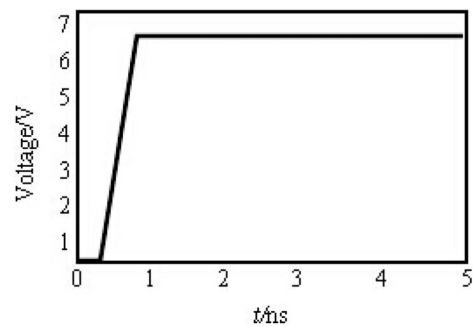


Figure 2. Reflection of fast pulse transmission.

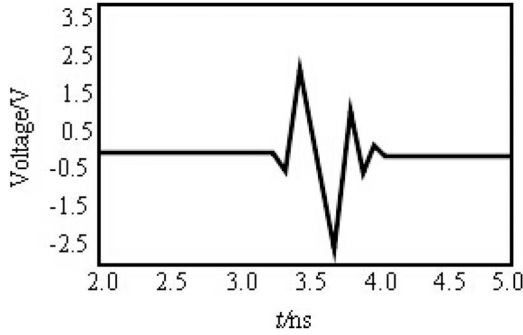


Figure 3. TEM horn time-domain character.

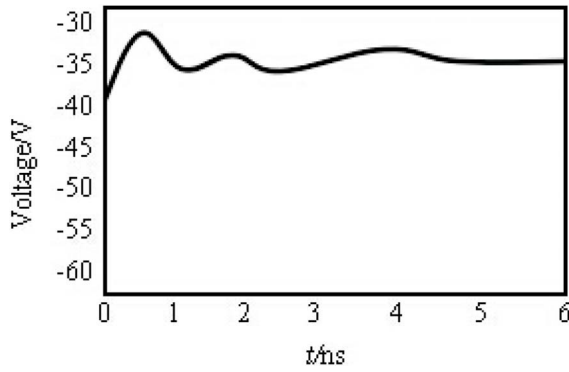


Figure 4. TEM horn frequency-domain character.

than 3 db, the new TEM keeps stability.

5. Experiments and Analysis

We first calibrate the standing wave coefficient through the network analysis instrument to test receiving characteristics as Figure 5. All the experience data satisfy IEC 61000-4-25, MIL-STD-464C and GJB 1389A.

Frequency range is 600 MHz–5 GHz, the antenna standing wave is less than 3, which suggests that the antenna is mainly used for high frequency radiation. Then we make radiation field transceiver test. Output pulse width of ultra-wide band signal source is 0.5 ns. We directly feed signal in TEM horn antenna through the cable. Within 3 m of transmitting antenna surface, we set a same TEM horn receiving antenna. Radiation field waveform can be approximate to differential form of feed-in impulse, so we can inspect receiving antenna time-domain characteristics by comparing the waveform differential consistency of TEM horn receiving pulse and feed-in impulsive as Figure 6. We can see that amplitude and pulse width of theory radiation field and the actual re-

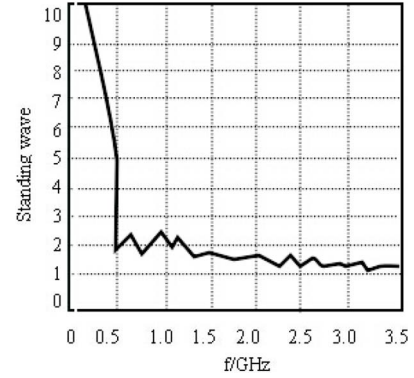


Figure 5. TEM horn standing wave.

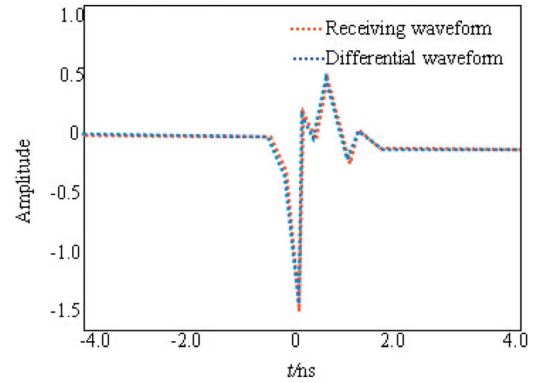


Figure 6. TEM horn standing wave.

ceiving radiation field are very consistent as well as the curve form. Therefore, it verifies the validity of the theory radiation calculation.

One important characteristic parameter of ultra-wide spectrum receiving antenna is the effective height, it needs to calibrate the antenna characteristic impedance. Ultra-wide band signal source sends 50 ns pulse and it is fed in antenna. Then we compute the ratio of reflection wave and source signal waveform amplitude, and we can get reflection coefficient R . $R = (Z_2 - Z_1)/(Z_2 + Z_1)$. Z_1 is feeder impedance. Z_2 is input impedance needed to solve. We make short circuit for TEM horn feed-in point and end of caliber plate respectively, and get the TEM horn antenna feed-in reflection, meanwhile, we make a comparison with state-of-the-art methods WMES [11], AMS [12] and get the results as Figure 7, 8, 9. So $R = (0.716 - 0.677)/0.677 = 0.058$. The output impedance of feeder line is 45Ω and antenna input impedance will be changed as 52Ω . Moreover, the comparison results show that our design is better than other methods.

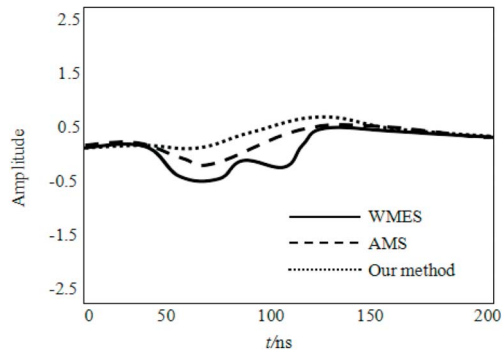


Figure 7. Short-circuit of feeding point of feed-in TEM horn antenna.

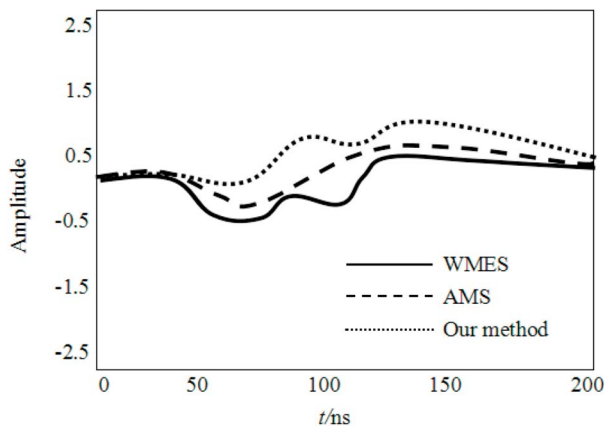


Figure 8. Short-circuit of end plate of feed-in TEM horn antenna.

After getting antenna characteristic impedance, we can get TEM horn receiving antenna transfer function frequency domain curve. It shows that frequency domain response is relatively stable within 3 GHz, about 0.03 m. Therefore, the effective height of TEM horn is $h = 0.03$ m more than half of antenna aperture height.

6. Conclusion

In this paper, we present a new TEM horn antenna based on plexiglass antenna cap. We realize the smaller reflection of fast pulse on the feed point and diameter, it has better time domain feature. Frequency domain response remains stable as a whole. Experimental results show that TEM horn has a good ultra-wide spectrum receiving characteristics. Time domain fidelity is good, feed-in reflection is very small. The antenna input impedance is 52Ω obtained by calibration. Transfer function within 3 GHz is relatively stable, effective height is

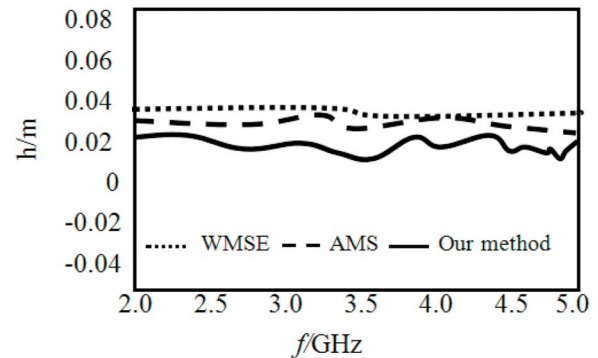


Figure 9. Feed-in reflection.

0.03 m, which is consistent with theoretical results. In the future, we will study more advanced TEM horn antenna designs to improve our paper.

References

- [1] Yin, S., Sun, Y. and Li, P., "A New Design of TEM Horn Antenna Based on Ultra-wide Band Broken Line," Progress in Electromagnetic Research Symposium, IEEE, pp. 4375–4378 (2016). doi: [10.1109/PIERS.2016.7735630](https://doi.org/10.1109/PIERS.2016.7735630)
- [2] Yin, S. and Li, H., "Time-domain Integration Method of Moments Used for Ultra Wideband Response of Monopole Antenna," Progress in Electromagnetic Research Symposium, pp. 1177–1180 (2016). doi: [10.1109/PIERS.2016.7734614](https://doi.org/10.1109/PIERS.2016.7734614)
- [3] Li, H. and Yin, S., "An Improved TEM Antenna Designing Used in Electromagnetic Pulse Directed Radiation," Progress in Electromagnetics Research Letters, Vol. 57, pp. 17–22 (2015). doi: [10.2528/PIERL15040205](https://doi.org/10.2528/PIERL15040205)
- [4] Zhao, X. L., Yuan, C. W., Liu, L., et al., "GW TEM-mode Phase Shifter for High-power Microwave Applications," IEEE Transactions on Plasma Science, Vol. 44, No. 3, pp. 268–272 (2016). doi: [10.1109/TPS.2016.2523122](https://doi.org/10.1109/TPS.2016.2523122)
- [5] Salari, M. A., Manoochchri, O., Darvazehban, A., et al., "An Active 20-MHz to 2.5-GHz UWB Receiver Antenna System Using a TEM Horn," IEEE Antennas & Wireless Propagation Letters, Vol. 16, No. 99, pp. 2432–2435 (2017). doi: [10.1109/LAWP.2017.2723318](https://doi.org/10.1109/LAWP.2017.2723318)
- [6] Shlager, K. L., Smith, G. S. and Maloney, J. G., "TEM Horn Antenna for Pulse Radiation: an Improved De-

- sign,” *Microwave & Optical Technology Letters*, Vol. 12, No. 2, pp. 86–90 (2015). doi: [10.1109/APS.1995.530002](https://doi.org/10.1109/APS.1995.530002)
- [7] Mahouti, P., Filiz, Güneş, Belen, M. A., et al., “Horn Antennas with Enhanced Functionalities through the Use of Frequency Selective Surfaces,” *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 26, No. 4, pp. 287–293 (2016). doi: [10.1002/mmce.20971](https://doi.org/10.1002/mmce.20971)
- [8] Arai, H., “Wide Band Electrical Parameter Measurement by Absorber Pasted Ridged Horn Antenna,” *European Conference on Antennas and Propagation*, IEEE (2015).
- [9] Zhao, X. L., Yuan, C. W., Liu, L., et al., “GW TEM-mode Phase Shifter for High-power Microwave Applications,” *IEEE Transactions on Plasma Science*, Vol. 44, No. 3, pp. 268–272 (2016). doi: [10.1109/TPS.2016.2523122](https://doi.org/10.1109/TPS.2016.2523122)
- [10] Abouelnaga, T. G. and Abdallah, E. A., “Microstrip-type Balun Compact TEM Horn Antenna for Time Domain Measurement System,” *International Journal of Microwave & Optical Technology*, Vol. 10, No. 1, pp. 13–19 (2015).
- [11] Collin, A., Merla, C., Perrin, A., et al., “A Wideband Microwave Exposure Setup for Suspended Cells Cultures: Numerical and Experimental EM Characterization,” *IEEE Antennas and Wireless Propagation Letters*, Vol. 15, pp. 278–281 (2016). doi: [10.1109/LAWP.2015.2440560](https://doi.org/10.1109/LAWP.2015.2440560)
- [12] Mirza, A. F., See, C. H., Danjuma, I. M., et al., “An Active Microwave Sensor for Near Field Imaging,” *IEEE Sensors Journal*, Vol. 17, No. 9, pp. 2749–2757 (2017). doi: [10.1109/JSEN.2017.2673961](https://doi.org/10.1109/JSEN.2017.2673961)

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