高保真超宽带TEM喇叭的分析与设计

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摘　要　本文讨论了波形保真的TEM喇叭分析和设计问题。本文提出了两个新论点：1）喇叭的开口端阻抗不能看作真空波阻抗，它与喇叭尺寸、张角有关；2）冲激脉冲有时序性，反射只与局部结构有关。因此，波形保真喇叭不同于普通的宽带喇叭。本文按此思想设计了一个宽张角圆锥TEM喇叭，实验表明波形保真良好。

关键词　TEM喇叭，超宽带，天线，冲激脉冲

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Analysis and Design of UWB TEM Horn with Waveform High Fidelity*

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Absteact The TEM horn for transmitting and receiving narrow pulse or impulse waveform has been discussed in this paper. A novel design concept and calculation method have been presented. According to this concept, a ridged conical TEM horn has been designed and fabricated. The experiment results show that its performance is excellent, so it is very valuable for the study of transient field and ultrawideband (UWB) radar

Key words TEM horn, antenna, UWB rader, impulse

1 Introduction

TME horn is an ultrawideband antenna which is widely applicated in the transmitting and receiving system of impulse waveforms. so far many theory analysis and design for this type of antenna have been presented[1~3], but they are limited to frequency domain. This is correct in some degree. For air medium, it is considered that TEM wave propagation is indenpendent of frequency. By using Fourier transform, many charateristics such as transverse field distribution and wave impedence, can use straightforwardly in time domain, but when discussing impedence match, it is inaccuraty if we also use the concept of frequency domain. For example, many researchers think that the reflection is the least by using Chebisiv or Butterwords impedence transform in the internal of the horn, but they have ignored an important feature, namely time order of the narrow pulse. Above mentioned methods of impedence transform are constituted in the condition of stationary sinusoidal wave, all of the reflection wave at the impedence ladder join in the superposition procedure. However, the impulse wave will be reflected only when the pulse have arrived the impedence ladder, we should consider the time order of the superposition, generally speaking only a small section of the ladder take part in superposition,

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so that above mentioned transform design has lost grounds in the condition of narrow pulse. Some authors think that the impedence of the horn aperture is the air wave impedence (120π), and take it as load impedence of the horn when they do impedence transform design. Sometimes this will bring on a disastrous results, a pulse train which is almost equal amplitude will be appered. In fact, the match concept is not so simple, wave mode theory should be used for analysis strictly, as shown in Fig. 1. If we expand radiation wave of the horn in space spherical mode wave function[4], then we will notice that it is in terms of a infinite sets, and expressd as

$$\begin{cases} \Sigma a_n(E_n^+ + \Gamma_n E_n^-) = \Sigma b_m E_m^+ \\ \Sigma a_n(H_n^+ - \Gamma_n H_n^-) = \Sigma b_m H_m^+ \end{cases} \quad (1)$$

In the above expression, the left indicate wave guide mode, supercript "+" means the external travelling wave, "−" means reflection wave, n is the mode ordinal number, a_n is the nth mode amplitude, Γ_n is its reflection coefficent. The right indicate the sum of space mode, and the symbol is as same as the left. The wave impedence for each mode not only relate to wave type, but also distance. In the very short distance, the impedence value of thelow mode have closed to that of free space, the higher the wave mode is, the farther therequired distance is. However, their wave impedence either tend towards zero or infinite on the short distance. Obviously, the wave impedence as a design value will relate to the size of the horn and its flared angle. Although it is difficult to compute it strictly, we should point out that the wave impedence of the horn will be more and more close to that of freespace if the length of the horn is lengthened and its flared angle is enlarged, hence the reflection of the aperture will be reduced.

2 Theory

The radiation waveform of a TEM horn is required to have good fidelity, that is to say it is required to have little reflection. These relection include that of the aperture, interanal transmission, and feed terminal. It is defficult to calculate these reflection of the aperture, even though in frequency domain, there is no yet ready formula that can be available. But we know that the reflection is little when the ratio of the size of the horn aperture to wavelength is large in frequency domain. It is not difficult imagine that there issimilar case in time domain, when the horn aperture size is more large than the pulse width (to measure by light meter). TEM transmission line charateristic impedence is unmeaning for discussing the match between a horn and free space, for example, the charateristic impedence of two wire could be 377 Ohms when their distance is very close. yet it is almost utter reflection.

The reflection will be arised in the process of wave transmission in the horn. Here we should use the concept of charateristic impedence. For an impulse, the transmission line segment that wave arrived will have effect and the transmission line that the wave unarrived will be "invisible", so that only a very short transmission line segment that wave have arrived will arise reflection for each instant, and the remain parts afterwards thd segment can be taken as a matching load, as shown in Fig. 2. If the reflection coefficent is constant, then the transmission coefficent is also constant, so the pulse waveform will be not distorted. This is the basic concept to discuss the impedence matching in time domain.

We take $Z_0(0)$ which is the start terminal impedence of the TEM horn as the normalized value. Suppose the normalized characteristic impedence of transmission line is z(x), then the reflection coefficient of each point in the process of the wave march forward is

$$\Gamma(x) = \frac{z(x+\Delta x) - z(x)}{z(x+\Delta x) + z(x)} \tag{2}$$

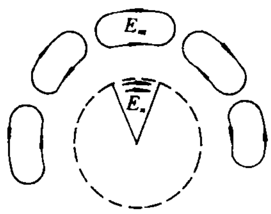

Fig. 1 Internal and external wave mode representation of TEM horn

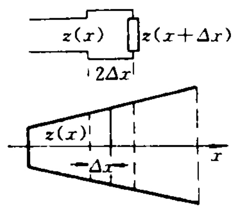

Fig. 2 Discontinuity equivalent circuit of the TEM horn

Where $z(x+\Delta x)$ is the average characteristic impedence of the segment that wave have arrived, $2\Delta x$ is the length of the segmint. For the impulse waveform, the segment is more less thanthe all length of the horn, namely it is a minute—sized. So the change of the characteristic impedence of the segment can be regarded as linear, and their average value is namely the middle value. From it we have

$$\Gamma(x) \approx \frac{1}{2}\frac{\left(\frac{\mathrm{d}z}{\mathrm{d}x}\right)}{z(x)}\Delta x = \frac{1}{2}\frac{\mathrm{d}\ln z}{\mathrm{d}x}\Delta x$$

that is

$$z(x) = e^{a\Gamma(x)x} \tag{3}$$

where $a = \frac{2}{\Delta x}$

Thus it can be seen that if let the $\Gamma(x)$ equals a constant, then the TEM horn should be exponentially flared, and when $\Gamma(x)=0$ the TEM horn characteristic impedence is constant. This is more simple than the wideband impedence matching in frequency domain.

There are many methods, such as variation method and conformal mapping method can be used to compute the characteristic impedence of the TEM horn. For a complex shape horn, it is the most convenient and reliable to use the integral equation method. fig. 3 shows the cross section of a ridged conical TEM horn, its top plate and low plate are equal potential surface, the potential equation can be written as

$$\varphi(\vec{r},\theta) = \int_s G(\vec{r},\vec{r}')\rho(\vec{r}')\mathrm{d}s \qquad (4)$$

where $\vec{r}'$ is source point, $\vec{r}$ is field point, ρ is the density of line charge, $G(\vec{r}, \vec{r}')$ is Geree function of potential

$$G(\vec{r},\vec{r}') = \frac{1}{2\pi}\varepsilon\ln\left|\frac{\vec{r}'' - \vec{r}}{\vec{r}' - \vec{r}}\right| \qquad (5)$$

where ε is the permittivity, $\vec{r}''$ is the mirror point of $\vec{r}'$ against the x axis.

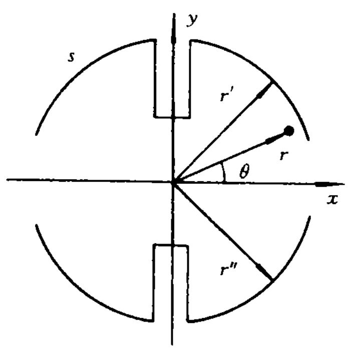

Fig. 3 Cross section coordinate of ridged conical TEM horn

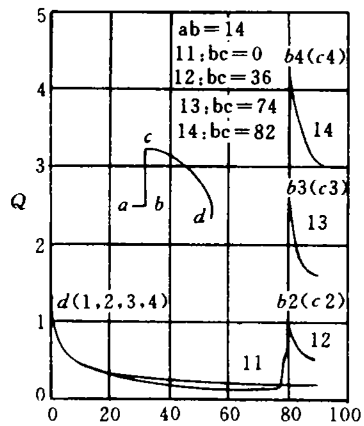

Fig. 4 Charge distribution of the TEM

In the expression (4), ρ is unknown function. since the conductor is equal potential, we can let the $\varphi(\vec{r},\theta)=1$, on s, thus integral equation can be written as

$$\int_s G(\vec{r} - \vec{r}')\rho(\vec{r}')\mathrm{d}s' = 1, \qquad on\ s \qquad (6)$$

The moment method can be used to solve integral equation into a matrix equation, and the charge density $\rho(\vec{r}')$ can be evaluated, so the total charge will be obtained by integration on s

$$Q = \int_s \rho(\vec{r}')\mathrm{d}s' \qquad (7)$$

The distribution capacity of the horn is

$$c = \frac{Q}{2} \qquad (8)$$

Thus characteristic impedence can be found as