Matching of a Piece-Wise Linear TEM Horn

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Abstract

Three techniques to match a piece-wise linear UWB TEM horn are proposed. Two of them are based on the characteristic impedance technique and the asymptotic theory using Sommerfeld solution for plane wave scattering by a wedge. The third theory uses the edge wave scattering pattern from the modified Weinstein solution for scattering by an open end of a flat waveguide. The results of analytical and numerical simulations show that the third theory gives calculations with a high accuracy of the coefficient of reflection near -10 dB level. This allows us to use the third theory to optimize a piece-wise linear UWB TEM horn with the aim of minimizing the lower frequency of matching with the given overall dimensions. The samples of analytical optimization are given.

1. Introduction

Regular (linear) TEM horns and irregular (curved) TEM horns are widely used as UWB antennas. Optimization of the shape of plates of irregular horns allows to obtain lower frequency of matching in comparison with the regular UWB TEM horns of similar dimensions [1]. In this paper we consider the problem of piece-wise linear TEM horn matching. This horn (Fig. 1) is easy to manufacture and to optimize due to the finite number of geometric parameters. Optimization of parameters L_j, β_j (see Fig. 1) may be carried out using various numerical methods. However, optimization requires much time and significant computational resources when a piece-wise linear TEM horn has a large number of sections, and the optimization has to be made over a wide band of frequencies.

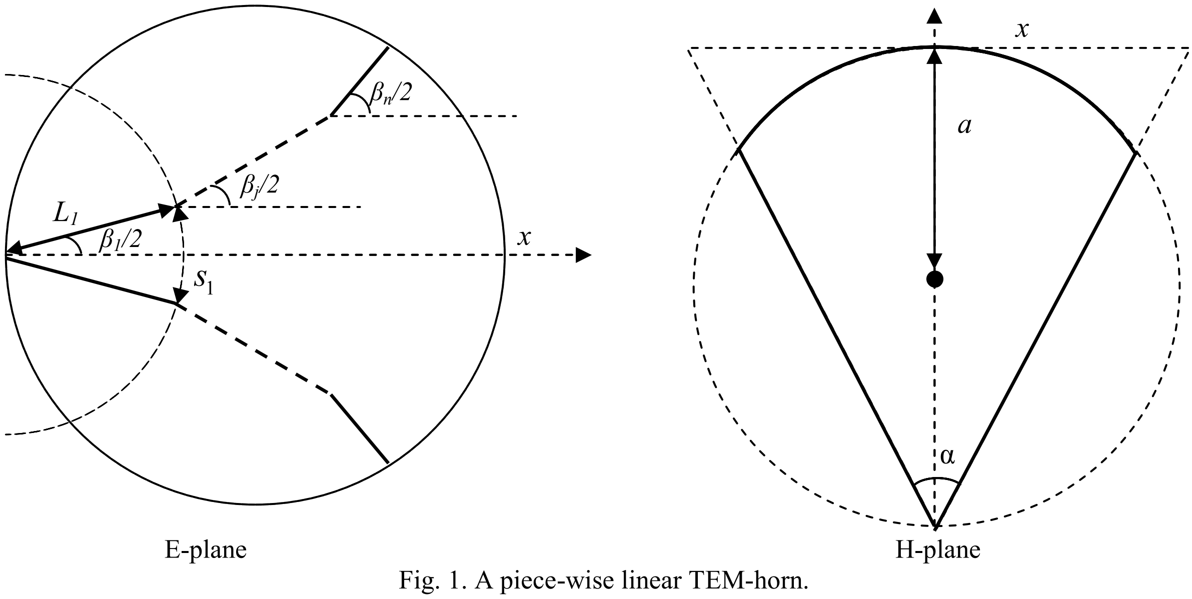

Fig. 1. A piece-wise linear TEM-horn.

2. Characteristic Impedance and Asymptotic Technique

A numerical-analytical procedure for optimizing geometrical parameters of TEM horns with the given bandwidth was proposed in [1]. This method is based on two principles. The technique of the transverse sections characteristic impedance is used inside the irregular TEM horn. And the asymptotic theory for the reflection coefficient from a junction of two horns [2] is applied to take into account the reflection from the end of the horn. The characteristic impedance of the tangent regular horn and the numerical results obtained in [3] are used to calculate the characteristic impedance in each section of the irregular horn. The spline interpolation of numerical results is used to construct the analytical model. The similar techniques can also be used for piece-wise linear TEM horn. The total reflection coefficient of an irregular TEM horn includes the sum of contributions to the reflection of individual horn sections with their their own phase shifts phase shifts. As a result, the expression for the reflection coefficient of the piece-wise linear TEM horn can be written as:

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$$R = \sum_{j=0}^{n} \frac{Z_j - Z_{j+1}}{Z_j + Z_{j+1}} \exp(2Ik\sum_{i=1}^{j} L_i) + \frac{g(0,0,2)}{2ks_n} \exp(I\frac{\pi}{2} + 2Ik\sum_{j=1}^{n} L_j) , \tag{1}$$

where Z_0 is the feed line impedance, Z_j is the horn section impedance, k is the wave number, L_j is the horn section length, n is the horn section number, $s_j = \beta_j \sin^{-1}(\frac{\beta_j}{2})\sum_{i=1}^{j} L_i \sin(\frac{\beta_i}{2})$ is the arc length between the horn section edges, $g(\alpha,\beta,c) = g^- + \varepsilon g^+$, $g^{\pm}(\alpha,\beta,c) = \frac{1}{c}\sin\frac{\pi}{c}(\cos\frac{\pi}{c} - \cos\frac{\alpha \pm \beta}{c})^{-1}$ is the diffraction coefficient (scattering pattern) in the Sommerfeld solution for the plane wave scattering by a wedge, $c_j = \frac{\varphi_j}{\pi}$, $\varphi_j = \frac{\beta_j}{2} - \frac{\beta_{j+1}}{2} + \pi, 1 < j < n$. For the last horn section: $j = n$, $\varphi_n = 2\pi$. Angles β_j are shown on Fig. 1.

Another technique uses the asymptotic theory [2] to take into account the reflection from the joints of adjacent sections as well as the reflection from the end of the horn. The result is:

$$R = \frac{Z_0 - Z_1}{Z_0 + Z_1} + \sum_{j=1}^{n} \frac{g(0,0,c_j)}{2ks_j} \exp(I\frac{\pi}{2} + 2Ik\sum_{i=1}^{j} L_i) , \tag{2}$$

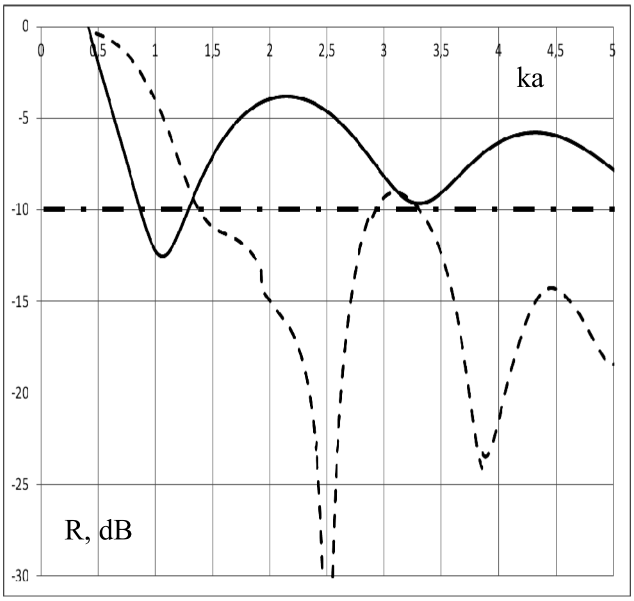

Fig. 2. The dependence of the reflection coefficient on the electric size of the sphere obtained by the formula (1)

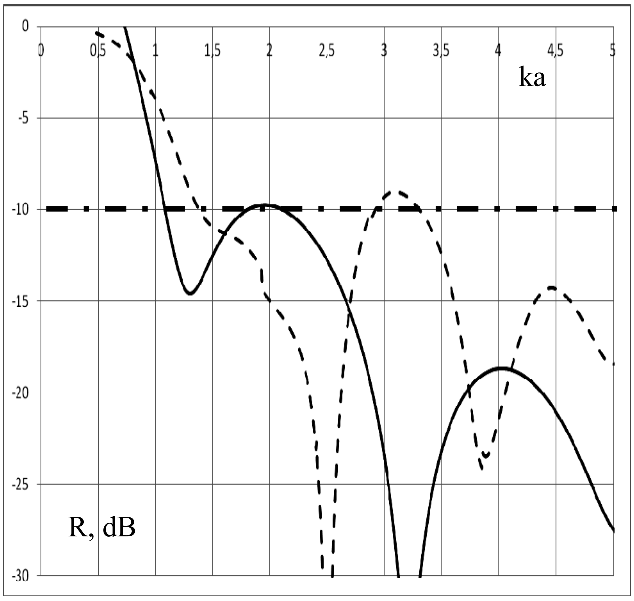

Fig. 3. The dependence of the reflection coefficient on the electric size of the sphere obtained by the formula (2)

The formula (1) has been used to calculate the reflection coefficient of the piece-wise linear TEM horn of 8 sections with the following parameters: $\alpha = 90°$, $\beta_1 = 16.6°$, $\beta_{j+1} - \beta_j = 10°$, $L_j = L_1$, $j > 1$. The dependence of the reflection coefficient on the electric size of the radius of the TEM horn circumsphere is shown on Fig. 2 as a solid line. The dashed line shows the results of numerical simulation of the reflection coefficient for the same horn using finite element method (FEM). Dash-dotted line shows the level of -10 dB. The horn excited by the 50Ω coaxial line. The parameters of the first section of the horn are selected so that it has the 50Ω impedance as well.

The same dependence for the same horn was calculated using the formula (2). The result is shown on Fig. 3 as a solid line. The dashed and dash-dotted line show the results of numerical simulation and the level of -10 dB respectively as earlier.

Obviously, the result of calculations according to the formulas (1) shown in Fig. 2 cannot be considered acceptable. The result of calculations in Fig. 3 is rather satisfactory though it is still not precise enough. Therefore, one more model has been proposed for simulation of a piece-wise linear TEM horn.

3. Modified Asymptotic Technique

The proposed analytical model is based on the asymptotic theory [2] modified by replacing the scattering pattern of a plane wave by a wedge with the scattering pattern of an edge wave from the Weinstein solution for scattering TEM mode by an open end of a flat waveguide [4]. This expression is multiplied by the ratio of edge wave scattering patterns in problem of a plane wave diffraction by wedges with different angles β_i. Adding the last factor is caused by the need to modify the solution [4] so that it matched wedges instead planes. As a result, we obtain:

$$R = \frac{Z_0 - Z_1}{Z_0 + Z_1} + \sum_{j=1}^{n} \frac{g(0,0,c_j)}{g(0,0,2)} \exp(I\frac{\pi}{2} + 2Ik\sum_{i=1}^{j} L_i - \pi\frac{kd_j}{2}) \quad (3)$$

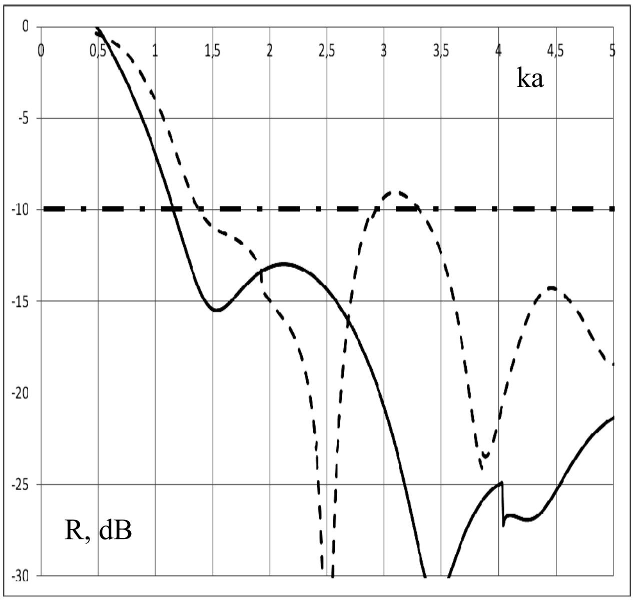

Fig. 4. The dependence of the reflection coefficient on the electric size of the sphere (formula (3), n = 8)

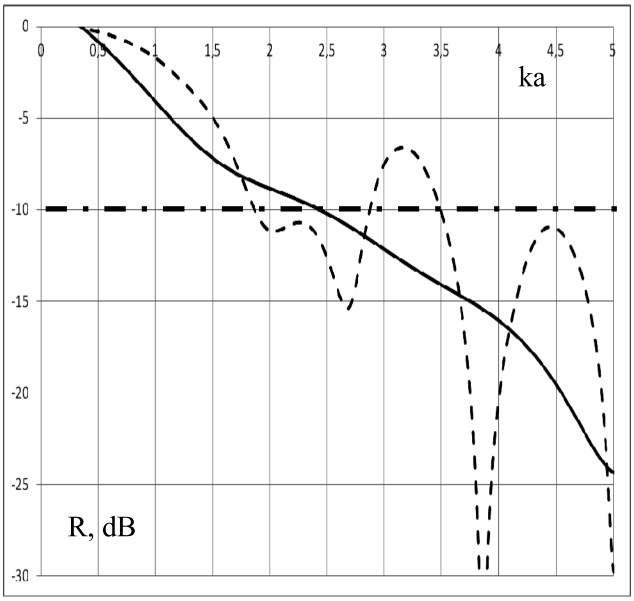

Fig. 5. The dependence of the reflection coefficient on the electric size of the sphere (formula (3), n =4)

The dependence of the reflection coefficient on the electric size of the radius of the TEM horn circumsphere calculated using formula (3) is shown by the solid line on Fig. 4 and Fig. 5 for 8 sections horn and 4 sections horn respectively. Parameters of the 4 sections horn are: $\alpha = 90°$, $\beta_1 = 16.6°$, $\beta_{j+1} - \beta_j = 10°$, $L_j = L_1$, $j > 1$. Parameters of the 8 sections horn are described above. The dashed line shows the results of numerical simulation of the reflection coefficient using FEM. One can see good coincidence of analytical and numerical results near -10 dB level. So we can try to use formula (3) to minimize a lower frequency of matching on this level. The results of angles β_j optimized for 8 sections horn and 4 sections horn are shown on Fig. 5 and Fig. 6.

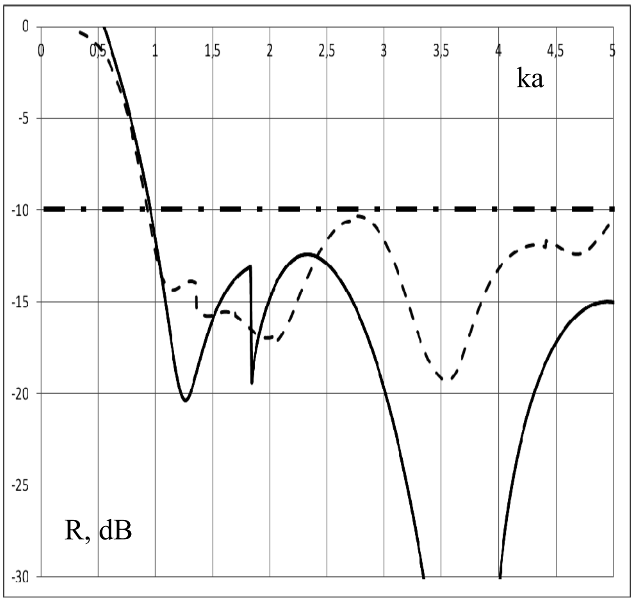

Fig. 6. The dependence of the reflection coefficient on the electric size of the sphere (formula (3), n = 8)

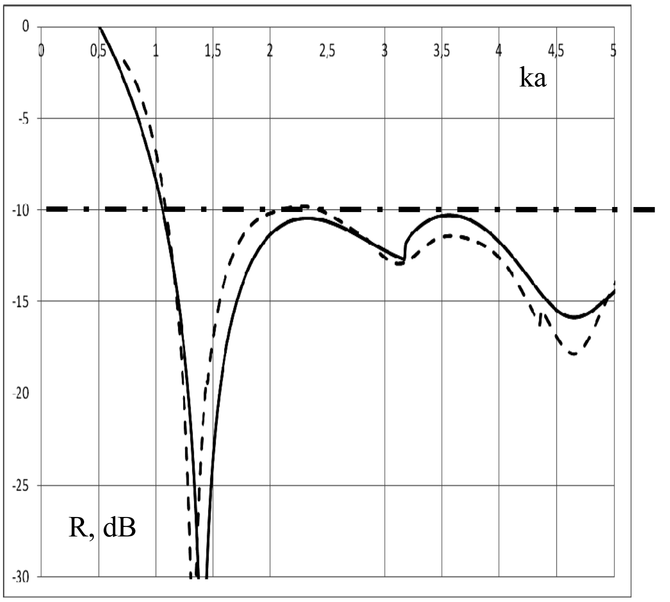

Fig. 7. The dependence of the reflection coefficient on the electric size of the sphere (formula (3), n = 4)

It is interesting that the results of analytical and numerical simulations (solid and dashed lines on Fig. 6 and Fig. 7) coincide better for the optimized horns than in a general case (Fig. 4 and Fig. 5).

4. References

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