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THEORETICAL AND EXPERIMENTAL RESEARCH OF A HORN ANTENNA NEAR FIELD

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Near field of horn antenna is considered by means of modelling and measuring in order to research its structure as it depends on a distance from antenna. A set of programs to calculate field characteristics with different input conditions has been developed. A semi-natural experiment is described of finding a distribution of equivalent currents on antenna radiating aperture. Images of the field on different distances from antenna are plotted.

Keywords: horn antenna, near field, moment method

1. Introduction

The horn antennas find broad application not only in radio equipments but also in certain microwave heating systems. In this connection the aim of this research is to examine structure of horn antenna near field, that by-turn give an opportunity to find certain initial conditions in order to calculate temperature distribution in a sample of the substance, which is radiated by this field.

Evaluation of the near field characteristics is one of the most difficult problems of antenna theory. Classical methods of electrodynamics allow us to find, at least, in principle, a strict solution that describes required field structure in arbitrary point of surrounding space [1]. However, it demands meaningful time and calculation expenditures.

For known amplitudes and phase distribution (APD) of equivalent currents in antenna aperture it would be calculate some integrals to find the radiated field. For these calculations method of moments (MoM) is applied [1-3], based on conception that the aperture is a two-dimensional antenna array. Solution is brought to the aperture segmentation by elementary areas (Huygens' elements) with following summation of separate elements vector fields. Compared to far field calculations this task for near field becomes more complex because of a necessity to take into account additional phase shifts due to unparalleled rays, coming from separate elements of the antenna array towards an observation point.

Using of numeric methods applying to horn antennas usually supposes that field in aperture is made by cylindrical or spherical wave. This defines type of a function that describes APD. In real conditions true APD may considerably differ from a theoretical one [4], due to influence of secondary fields reradiated by surrounding items, and it demands experimental specification [5].

The organization of the paper is as follows. In Section 2 some basics of a MoM application is described concerning horn antennas. In Section 3 the field calculation programs with results of their application are briefly considered, developed within computing environment MATLAB. In Section 4 we describe the method and results of experiments of measuring of equivalent currents amplitude distribution on a horn antenna aperture, and calculation of respective field structure. Section 5 contains conclusion and working deductions.

2. Operational Principle of a Horn Antenna, and a Moment Method

Horn antennas are of aperture antennas class, directed radiation of which is formed by a flat opening S surface. Simplest aperture antenna appears to be open end of a waveguide, though due to relatively small size of radiating aperture against a wavelength λ, such antenna has a weak directivity. Improvement of the latter can be achieved by a gradual extension of the opening size, due to which waveguide transforms into a horn antenna.

Directed features of a horn we can evaluate using method of Huygens-Kirchhoff, according to which a radiation field of any aperture antenna is formed in the issue of elementary area fields integration with $dS << \lambda^2$ sizes, placed continuously on a whole radiating surface. When using numeric methods, elementary area centres are placed discretely, and integration has to replace by a vector addition. This procedure gained a name of moment method.

Pyramid horn antenna is depicted on Figure 1. Detailed theoretical data about it are presented, for example, in [1, 2].

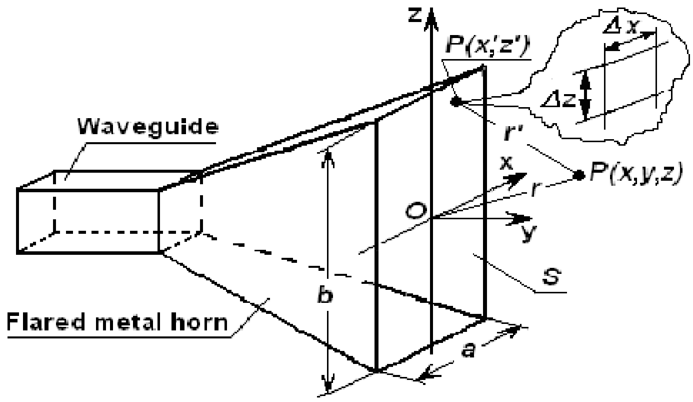

Figure 1. Pyramid horn antenna

Let us consider a MoM in details. Approximate rectangular aperture near field and Fresnel zone values may be obtained by source segmentation to the elements with size much smaller than λ. Example of certain segmentation is shown on Figure 1 in right hand isolated part.

If Δx and Δz are such small that respective discrete approximations of APD are precise enough, then the full field due to z – component of electric current of rectangular source may be found by summing up contributions of all elementary sources with a current

$$\dot{I}_z\left(z'\right) = \Delta x \dot{J}_z e^{-jkz'} , \tag{1}$$

where value of the current in case of both rectangular waveguide with wave H_{10} and respective horn, built on its base, does not depend on z.

The x – component of the current has analogous look:

$$\dot{I}_x\left(x'\right) = \Delta z \dot{J}_x e^{-jkx'} . \tag{2}$$

For the named waveguide and horn the value $I_x = 0$, and the I_z does not depend on z changing along x as a cosine function. Usually values Δx and Δz must not exceed $\lambda/8$.

Let us on the rectangular aperture APD is set only for z–component of a surface current J_z. It is necessary to find a field on a surface with. If a radiating source is segmented on the same elements with equal areas $\Delta x\Delta z$, then resulting field is defined by equation

$$\dot{E}_z = \sum_{\mathrm{m}=M_2}^{M_1} \sum_{\mathrm{n}=N_2}^{N_1} \dot{E}_{z\,\mathrm{mn}} \tag{3}$$

where are $M_{1,2} = \pm a/2\Delta x$, $N_{1,2} = \pm b/2\Delta z$. Values Δx and Δz would be selected in such a way as to amounts of the segments along x or z axes should be described by some odd numbers.

3. Numeric Realization of a Moment Method

Research of near fields was made with a help of a specially created package of applied programs, worked out for operation within computing environment MATLAB. It contains

1) the code to calculate components of an electromagnetic field of electrical dipole in arbitrary space point, with using of a cylindrical coordinate system;

2) the code to calculate components of a linear discrete array field with arbitrary APD, formed by elementary electrical dipoles that are situated in parallel.

3) the same – for aperture, presented as a matrix, each string of which is identical to linear array mentioned above.

Elementary electrical dipole (EED) in arbitrary point of space makes electromagnetic field, described by E_r, E_z and H_φ components where

$$\dot{\boldsymbol{E}}_z = \boldsymbol{A}\left(-\boldsymbol{i}\frac{\boldsymbol{z}_{r23}}{\boldsymbol{r}} + 2\pi\boldsymbol{z}_{r23} + \boldsymbol{i}4\pi^2\boldsymbol{r}(\boldsymbol{z}_{r2}-1)\right)\frac{\boldsymbol{e}^{-ikr}}{\boldsymbol{r}}, \tag{4}$$

$$\dot{\boldsymbol{H}}_\varphi = \frac{\boldsymbol{a}_m \boldsymbol{dl}\,\boldsymbol{R}}{4\pi\lambda\boldsymbol{r}^2}(1+\boldsymbol{ikr})\frac{\boldsymbol{e}^{-ikr}}{\boldsymbol{r}}. \tag{5}$$

In one's turn

$$\boldsymbol{A} = \frac{1}{8\pi^2\varepsilon_0\boldsymbol{c}\lambda}\boldsymbol{a}_m\frac{\boldsymbol{dl}}{\boldsymbol{r}}$$

– amplitude coefficient, $\boldsymbol{z}_{r2} = (\boldsymbol{z}/\boldsymbol{r})^2$, $\boldsymbol{z}_{r23} = 3\boldsymbol{z}_{r2} - 1$ – auxiliary quantities, a_m – equivalent current amplitude value, R – radius of coordinate line, coming through the observation point in cylindrical coordinate system, r – distance from dipole centre to this point, dl – length of the dipole, k – wave number, ε_0 – dielectric constant of free space, c – light velocity,

Having an opportunity to calculate EED field, it is not difficult to model a linear array field that consists of dipoles, by vector addition of these fields radiating by dipoles, in a required point of space. Below, as an example, the results have considered for modelling a process of separate radiators fields addition formed uniform amplitudes and null-phased antenna array 6λ length, in a point located from the antenna centre (see Fig. 1) at $y = 0.5\lambda$. The array is situated along x-axis.

On the left graph (Fig. 2) the complex plane is shown on which the trajectory have built that characterizes the evolution of the vector of summary field. It is supposed that observer sees the result of a gradual elongation of the linear array (increasing of dipoles number), starting from left end of this antenna.

The vector originates in the point with [0, 0] coordinates, and the second end of it slides on the shown trajectory, which appears to be a spiral of Cornu.

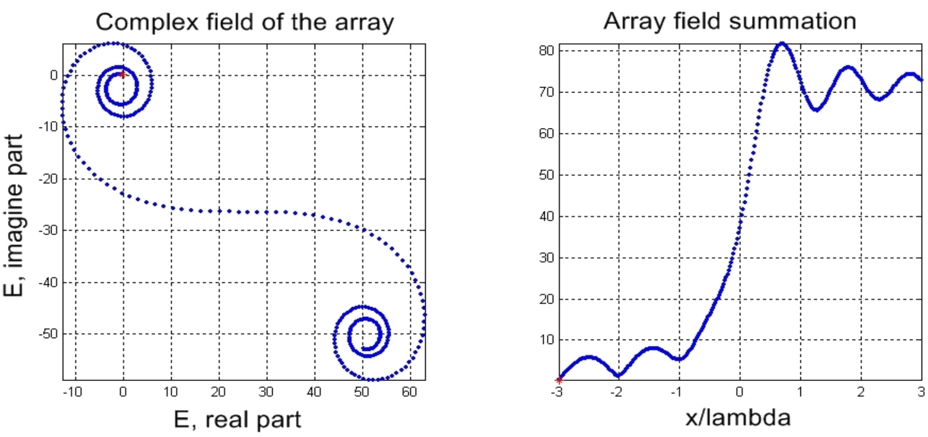

Figure 2. Calculation of the linear array field

Length of this vector and its inclination relative to the horizontal axis determine module and phase of a summary field, respectively. On the right graph dependence is shown of cumulative module of this field versus the gradually increasing antenna array length, which is counted off along the abscissa axis.

As opposed to elementary radiators, complex antenna structures, whose sizes are considerable in comparison to a wavelength, demonstrate a non-monotonic field reduction with increase of a distance from antenna. This is shown on Figure 3, where summary field strength module dependences are given on a shift of observation point along the y – axis (see Fig. 1) obtained for uniform amplitudes and null-phased linear antenna array with different lengths.

In generalized case behaviour of this function depends on the APD current in antenna. Positions of its extrema are determined by zeros of the derivative

$$\frac{d}{dy}\left|\sum_{n=1}^{N}\dot{E}_n[y, L/\lambda, \dot{I}(x)]\right| = 0 \tag{6}$$

of summary field, where N is the number of elements in the array.

As electrical length of array is increasing, number of local extremums is growing, but distances between them along y- axis become smaller. If amplitudes of currents in APD fall down in the direction of antenna edges, then considered dependence becomes smoother.

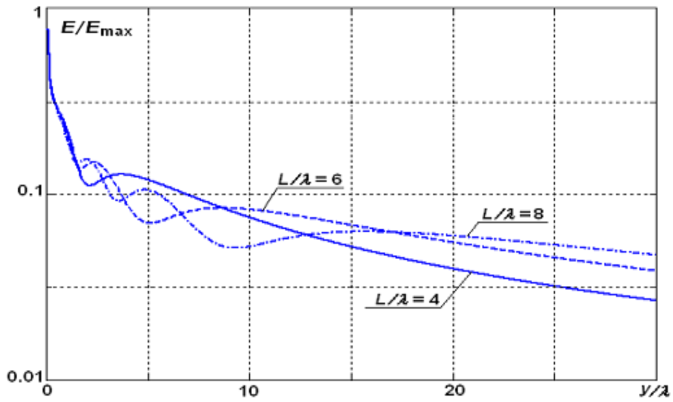

Figure 3. Fields of the linear arrays with different electrical lengths

Analogous features of a field structure are observed also for 2-dimensional arrays that model radiation of flat apertures. Relevant results there are displayed on Figure 4 for pyramidal horn with size of aperture $a/\lambda = 2.5$, $b/\lambda = 1.5$ that are typical for microwave heating devices.

It is supposed that the equivalent source of a spherical wave is located in an imaginary top of pyramid (Fig. 1), amplitudes distribution of the current along wide a and narrow b horn walls is repeating the distribution produced by H_{10} wave in a cross-section of the feeding waveguide, and phase distribution is of a quadratic character.

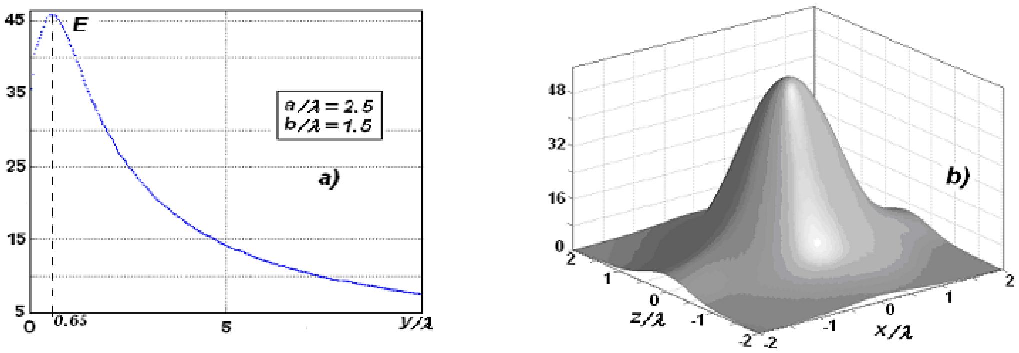

Figure 4. Horn antenna field: a) versus a distance from the aperture centre;
b) field relief on a surface parallel to aperture ($y/\lambda = 0.65$).

With such APD behaviour of a module in dependence on a distance is characterized by a single maximum (Fig. 4 *a*) that is located on a $y/\lambda = 0.65$ distance from the horn aperture. If some surface is placed on that distance being transversely to y-axis, then a field strength module distribution around a surface centre may be displayed as a field relief, i.e. 3-dimensional picture that is shown on Fig. 4 *b*. In average, while distance is increasing some narrowing of a main maximum as well as some growth of the side lobes level take place, at least as far as the inequality $y/\lambda < (2L/\lambda)^2$ is satisfied. Here L is the biggest aperture size that defines a relative border of a far zone.

4. The Experiment and Its Results

Purpose of the experiment was to measure APD of equivalent currents on the aperture of horn antenna model ($a/\lambda = 2.5$, $b/\lambda = 1.5$) applied in the microwave heating experiments. Unfortunately, phase distribution probing was not yet carried out, as certain necessary equipment was absent.

To find amplitudes distribution there was assembled the plant, which is seen on Figure 5. It consists of the microwave generator *5* with 2,45 GHz frequency, used in the Wats 2002 device; tested antenna *1*, and the receiving part manufactured by own strength and consisting of field probe (vibrator antenna) *2* united with microwave signal detector; amplifier *3*; and indication device *4*. Horn opening is closed by the foam plastic sheet with a coordinate grid that serves to show the probe positions.

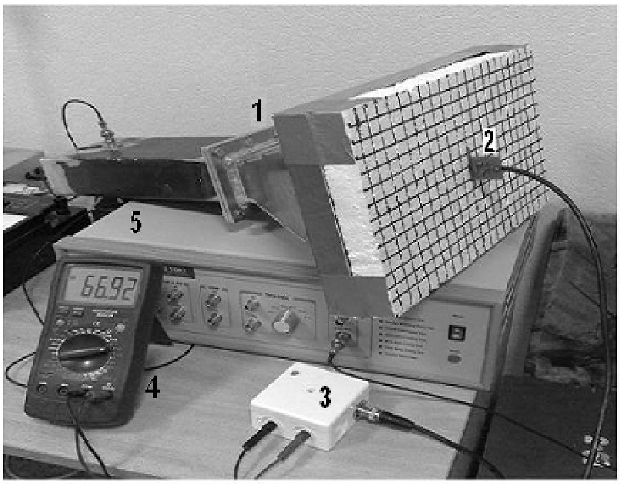

Figure 5. Experimental plant: 1) horn antenna with the feeding waveguide, 2) field sensor with detector, 3) amplifier, 4) indication device, 5) microwave generator

Several measurements have been carried out during the experiment. As a result it was determined that the equivalent current module distribution on the aperture is noticeably different from the expected one, which behaviour should have been close to the currents on the surface of waveguide open end with H_{10} wave feeding. This is shown on Figure 6 *a* where the module of current z – components versus displacements along wide and narrow horn walls are displayed on the higher and lower graphs, respectively. On Figure 6 *b* the relief of named current module distribution on the aperture is plotted.

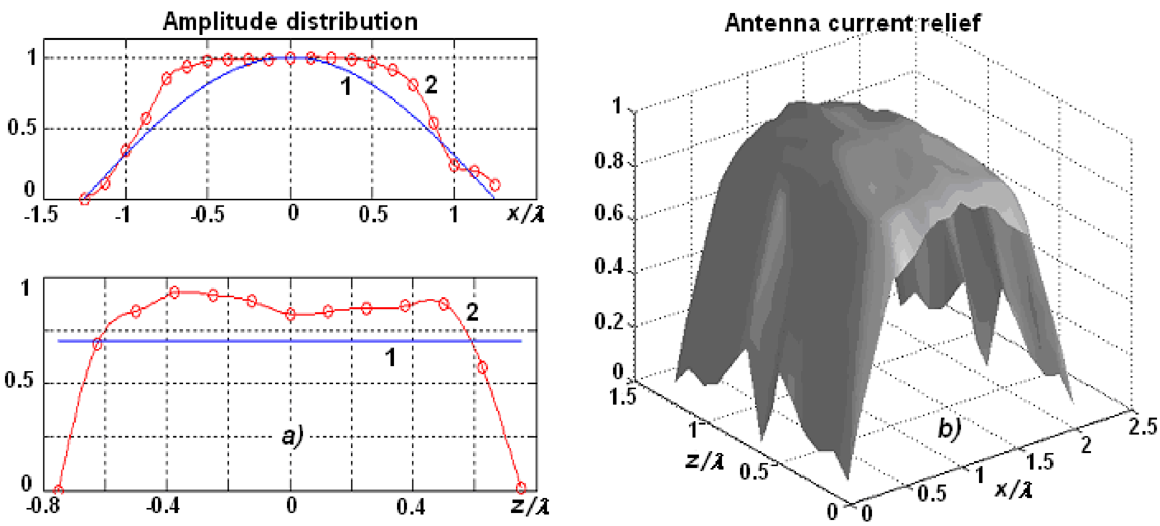

Figure 6. a) Equivalent current module distribution on the horn aperture versus shifts along both the wide and narrow horn walls (1 - theory , 2 – experiment); b) relief of the distribution

Main reasons of the discrepancies may be apparently explained by: 1) waves of high modes should be participate in forming of certain field structure within the waveguide that is fed the horn antenna; 2) influence of secondary fields reradiated by items which are located within immediate environment of the laboratory plant [5]. The latter was confirmed by a series of measurements carried out with different location of the horn antenna relative to these items.

It should remark that there are indirect methods to reconstruct a current distribution in antenna aperture starting from near field measurement data [6].

Based on gained results, with a help of a computing program set described in Section 3 it is possible to track near field character features depending on a distance to the antenna. When microwave heating devices are modelled, these data can be used as boundary conditions to calculate a temperature distribution in a sample of certain substance, being radiated by electromagnetic field.

5. Conclusions

Main results of the work are as follows:

- non-monotonic changing of the near field characteristics relative to distance allows formulating the problem of choice of the most efficient place to locate a heated object in order to minimize reflected waves;
- the experimentally found current distribution on the aperture permits to indirectly estimate on the reasons of the expected field picture distortion.

Possible efforts of a further research may be oriented to an improvement and revision of the developed computing programs package in order to solve a problem of modelling non-stationary current distributions on the aperture caused by a pulse operation mode of the antenna.

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