TIME DOMAIN TAPERED SLOT ANTENNA ANALYSIS

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UDC 537.871.3

‰ 2002

A general modeling method for time domain analysis of aperture antenna pulse radiation is described. Non-synchronous excitation is the main feature of the proposed approach. As an example, it is applied to tapered slot antenna (TSA) pulse radiation. Some radiation patterns for TSA pulse radiation and their physical interpretation are represented.

Still growing attention to pulse signals is observed last decades. Such signals are more informative and cause less interference with the performance of other devices. Since conventional narrowband antennas are not suitable for short pulse radiation, new types of antenna have come. It is more convenient to treat these antennas in time domain (TD) rather than in frequency domain (FD) as it used to. In this work, we present a TD method for modeling the pulse radiation of apperture antennas. We apply this technique to analysis of TSA which is an end-fire antenna (see Fig. 1). This antenna has been thoroughly investigated in FD [1, 2]. But using these results to obtain impulse radiation characteristics by means of the inverse Fourier transformation requires significant calculation resources. Besides that, errors in the frequency domain can lead to a significant signal shape distortion. So an approximate consideration in the TD is more adequate.

In many cases, a pulse antenna can be adequately described by the current distribution on an aperture [3]. To generalize this approach, we consider an aperture with arbitrary current amplitude and time delay distribution and arbitrary exciting pulse shape. The field in the far zone can be obtained as follows [4, 5]:

$$\mathbf{E}(\mathbf{R}, t) = -\frac{\mu_0}{4\pi R_0}[[(\mathbf{e}_0 \times \mathbf{n}] \times \mathbf{n}] \iint_S A_j(\xi, \eta) \times$$

$$\times \frac{\partial}{\partial t} f\left(\tau - t_d(\xi, \eta) + \frac{x\xi + y\eta}{c R_0}\right) d\eta\, d\xi, \quad (1)$$

where $A_j(\xi, \eta)$ is the amplitude distribution [dimensionless]; $f(t)$ is the exciting pulse [A]; $t_d(\xi, \eta)$ is the time delay distribution [s]; $(\xi, \eta, 0)$ is a point on the aperture; $\mathbf{e}_0$ is the current unit vector (it determines polarization); $\mathbf{R} = (x, y, z)$ is the vector to a point of observation; $R_0 = |\mathbf{R}|$ $[m]$, $\mathbf{n} = \mathbf{R}/R_0$; $\tau = t - R_0/c$ is the retarded time [s]; μ_0 is the permeability of vacuum $[\mathrm{H} \cdot \mathrm{m}^{-1}]$. This is a general formula for aperture radiation analysis (in the far zone). The formula for the radiated field from a rectangular aperture with linear time delay distribution was obtained in [4] (for the H-plane):

$$E(R_0, t, \theta) = -\frac{\mu_0}{4\pi R_0}\frac{2bc}{\sin\theta - \alpha} \times$$

$$\times \left\{ f\left(\tau + (\sin\theta - \alpha)\frac{a}{c}\right) - f\left(\tau - (\sin\theta - \alpha)\frac{a}{c}\right)\right\}, \quad (2)$$

where $\alpha = c/\upsilon$, υ – the signal propagation velocity along $0x$, the co-ordinate origin is placed at the center of the rectangular aperture with dimensions $2a \times 2b$, θ is an angle in the H-plane ($x0z$-plane).

Let's now turn back to TSA. We can consider the slot as a number of rectangles (see Fig. 1) excited with a travelling wave, i.e., with linear time delay distribution. The exciting current amplitude and time delay is set for each one. We can find the full field

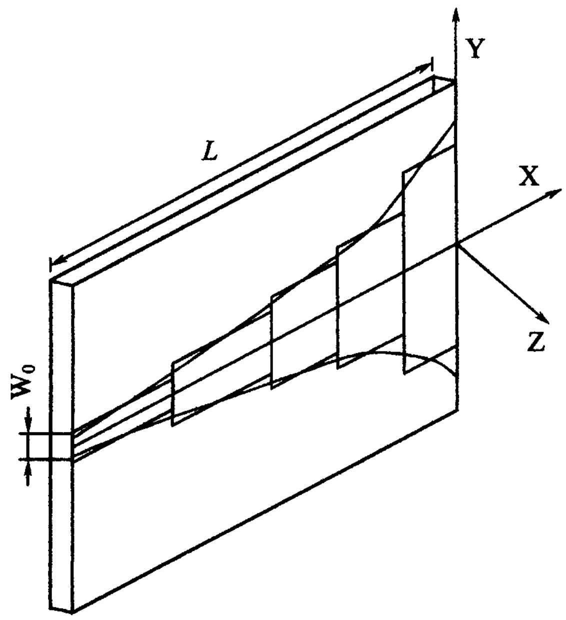

Fig. 1. Tapered slot antenna

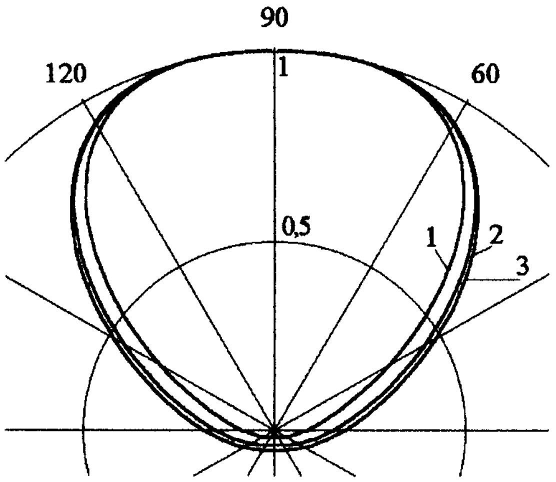

Fig. 2. Radiation patterns for $W_0 = 0.2L$, $\beta = 0.5$ (*1*); $W_0 = 0$, $\beta = 0.5$ (*2*); $W_0 = 0$, $\beta = 0$ (*3*)

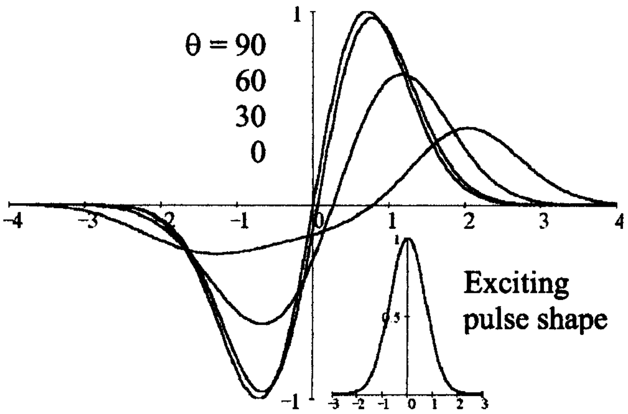

Fig. 3. Time shape of radiated field in far zone for $W_0 = 0$, $\beta = 0.5$

by summing fields calculated with (2) for every single rectangle. The amplitude of each section is as follows:

$$Z_0 I^2 = P = \text{const} \cdot e^{-2\beta x}, \quad I \approx \frac{e^{-\beta x}}{\sqrt{Z_0(x)}}. \tag{3}$$

This means that power decreases exponentially along the antenna because of radiation and conductive losses. For the decrement determination, extra theoretical and experimental investigation is needed. Z_0 is the wave impedance in the antenna; we use formulas from [1] to calculate it. The contribution of each section to the total field is determined by its area and current amplitude. For a constant antenna length, the pattern width is smaller for the more uniform distribution of a section contribution. So, as we know the Z_0 dependence on the slot width, we can in general optimize the antenna taper shape for the desirable radiation efficiency and pattern width. Some examples of calculated radiation patterns are presented in Fig. 2. These patterns are calculated for the linear tapered slot antenna excited by a Gaussian pulse for various initial slot widths W_0 and different decrements β, whereas the antenna length $L = 4cT$ is fixed ($2T$ is the pulse duration). One can see that the pattern calculated with taking into account losses is narrower than that calculated in the case of constant power. It is explained by the above-mentioned uniformity of section contributions. In Fig. 3, the time shape of the radiated field is plotted for various angles in the H-plane. The first derivative of the exciting pulse is radiated in the end-fire direction, whereas the time shape of a signal radiated in the side direction is distorted due to the different contributions from LTSA ends. This fact can be used to improve the pattern by using correlation after-processing in radar problems. It is worth mentioning that the source distribution described above affects only the H-plane pattern, whereas the E-plane pattern is determined mainly by the dipole-kind radiation from the abrupt end of the slot line [2].

The authors would like to thank N.N.Kolchigin for his attention to this work and useful discussion of the results.

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Received 10.12.01