

Directivity patterns features of antenna systems in regimes of ultra-short microwave pulses radiation

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Abstract. Directivity patterns of some antenna systems depend on duration of radiated microwave pulses. It is shown that for large enough two-dimensional systems the shortening of pulses leads to suppression of side lobe radiation. We propose to use a novel for two-dimensional antenna systems parameter – a correlation length which is useful for estimation of pulse shortening influence on antenna pattern. Correlation length depends both on the pulse duration and direction of radiation. The effect of side lobes suppression can be used for estimation of pulse duration.

1 Introduction

Recent advances in synchronisation of high power generators [1,2] open new opportunities in development of their arrays with record radiation pulse power. However, the extreme power of such generators (of the order of $10^8 - 10^9$ W) requires development of specific multichannel antenna systems. Horn antenna with vacuum output window on its aperture is appropriate, effective and widely used technical solution in high power microwave electronics. Dimensions of the output window of each generator cannot be less than a several wavelengths because of microwave breakdown on smaller apertures. It means that the distance between channels in the arrays of high-power generators are much greater than wavelength and side lobe levels in array directivity patterns are high (see [1,2] for instance). Another important parameter characterizing high-power generators is short or ultra-short pulse duration. It means that the pulses radiated by different channels in the array may not totally overlap which cause distortions in directivity patterns. In the paper we consider such effects in two-dimensional antenna systems and introduce a correlation length which is a useful parameter for estimation of short pulse effect on radiation patterns.

2 Theoretical model for simulations of arrays directivity patterns

Let us assume that microwave generators form planar array consisting of M columns and N rows (see Fig.1) and each generator radiates electromagnetic field with the structure of the fundamental Gaussian beam with linear polarization:

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$$E^f(x, y, z) = A^f \cdot \frac{-ika^2}{z - ika^2} \exp\left[ik \frac{x^2 + y^2}{2(z - ika^2)}\right] \exp(ikz), \quad (1)$$

where E^f is normalized (dimensionless) electric field; $k = 2\pi/\lambda = 2\pi f/c$ is a wavenumber; f is a frequency; c is a velocity of light; x and y are transverse and z is a longitudinal coordinates respectively; and a defines the transverse dimension of the beam waist.

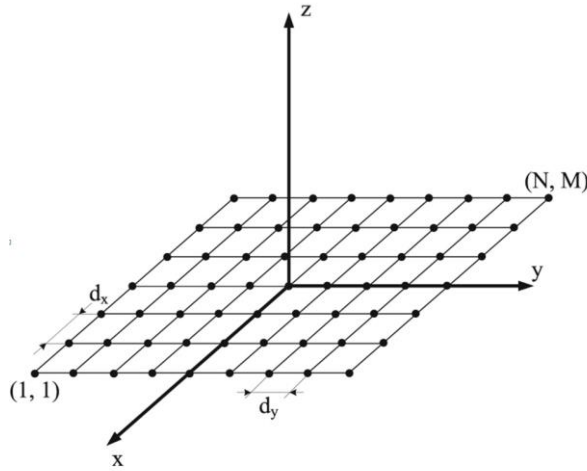


Fig. 1. Scheme of placement of generators in the array.

The fundamental Gaussian beam (1) is defined for fixed frequency f and for short microwave pulses Fourier transform is used to find electric field spectral components E^f of the microwave pulse. The total electric field of array radiating short pulses are found by inverse Fourier transform F^{-1} of the sum of all electric field spectral components of all generators in the array:

$$E(x, y, z, t) = \text{Re} \left[F^{-1} \left(\sum_{n=1}^N \sum_{m=1}^M \left\{ E_{n,m}^f \cdot \frac{-ika^2}{z - ika^2} \exp\left[ik \frac{(x - X_n)^2 + (y - Y_m)^2}{2(z - ika^2)}\right] \exp(ikz) \right\} \right) \right], \quad (2)$$

where $E_{n,m}^f$ is field spectral component of generator with indexes (n, m) in the array and (X_n, Y_m) are coordinates of generator with indexes (n, m) .

Directivity patterns have been considered for radiation of:

- i. short pulses with the central frequency f_0 and Gaussian envelope (see Fig. 2)

$$E_p = \text{Re} \left[\exp\left(-\frac{t^2}{2\tau^2}\right) \exp(i2\pi f_0 t) \right]; \quad (3)$$

- ii. CW signals with the same frequency f_0 .

For the short pulses the directivity pattern $D(x, y)$ is defined as a maximum of squared absolute value of electric field in the pulse transmitted through the point (x, y) in the far field cross section $z=Z_0$:

$$D(x, y) = \max_t |E(x, y, Z_0, t)|^2. \quad (4)$$

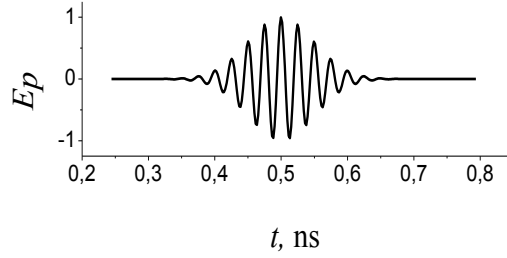


Fig. 2. Short pulse with the central frequency 40 GHz and Gaussian envelope.

For CW signals the directivity pattern $D_f(x,y)$ is equal to squared absolute value of electric field at central frequency f_0 at the same cross section (x,y,Z_0) :

$$D_f(x,y) = \left| \sum_{n=1}^N \sum_{m=1}^M \left\{ E_{n,m}^{f_0} \cdot \frac{-ika^2}{Z_0 - ika^2} \exp \left[ik \frac{(x - X_n)^2 + (y - Y_m)^2}{2(Z_0 - ika^2)} \right] \exp(ikZ_0) \right\} \right|^2. \quad (5)$$

3 Results and discussion

The delay of the signals from different parts of the array leads to distortion of directivity patterns. The side lobes in the pulse directivity pattern (see Fig. 3b) are noticeably smaller than those in the corresponding CW one (see Figs. 3a).

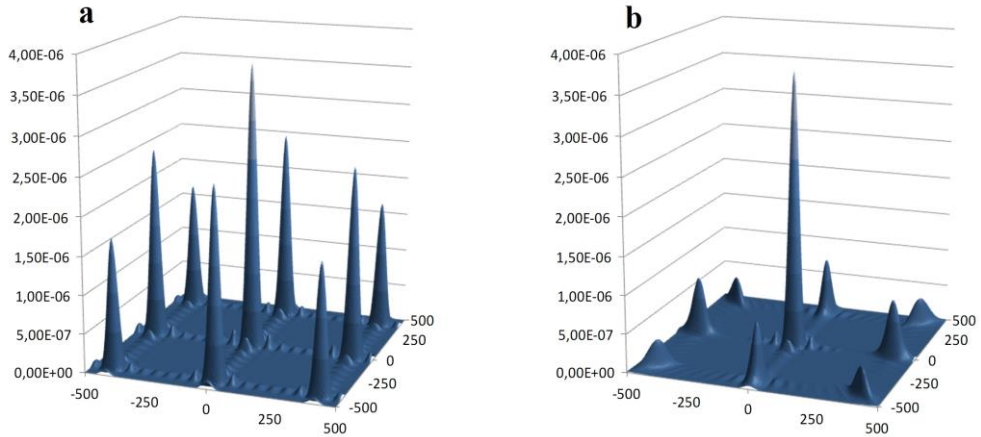


Fig. 3. Directivity patterns $D_f(x)$ and $D(x)$ of 8x8 array for CW signal (a) and for short pulses (b) respectively.

Pulse shortening does not affect the level and shape of the main lobe of the directivity patterns. For example, Figure 4 shows the cross sections ($y = 0$) of the pulse and CW directivity patterns for 8x8 array. It is clearly seen that the patterns practically do not differ within the main (i.e., maximum) lobe; and all side lobes in the pulse directivity pattern are smaller than in the CW one.

For one-dimensional arrays we introduced a correlation length [3],

$$L_{corr} = \frac{\tau_p \cdot c}{\sin \theta}, \quad (6)$$

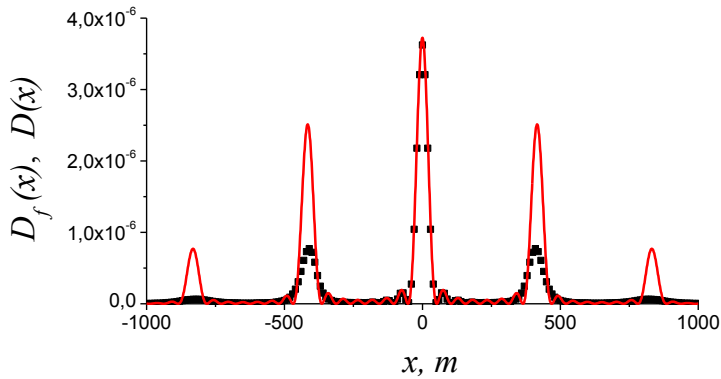


Fig. 4. Cross section ($y=0$) of directivity patterns $D_f(x)$ and $D(x)$ for CW signal (solid red line) and short pulses (black points) respectively.

which is also applicable for two-dimensional systems. Here τ_p is pulse duration and θ is an angle between z axis and the direction to the point of observation. The effect of side lobe suppression for short pulses can be used as a basis for a method for measurements of pulse duration.

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References

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