Wave Beams of Short Radio Pulses Generated by Gigawatt Microwave Sources

A. V. Palitsin, M. B. Goykhman, A. V. Gromov, N. F. Kovalev

Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia, pal@appl.sci-nnov.ru

A rising interest to the generation of short pulses is observed lately [1-3]. In relativistic backward wave oscillators (BWO) operating in superradiance regime the peak power of output radiation may exceed the power of electron beam [1,2]. Such BWOs are effectively synchronized by the leading edge of accelerating voltage pulse so that the multi-channel systems can be built [1,2]. Radiation patterns of these systems consist of overlapping wave beams. The structure of each wave beam is usually close to the fundamental Gaussian beam with linear polarization. Dimensions of the output window of each channel exceed wavelength λ because of microwave breakdown on smaller apertures. It means that the distance between channels d is greater (typically much greater) than wavelength

$$d \gg \lambda \qquad (1)$$

and far field radiation pattern has many maximums.

In the report we analyze theoretically the peculiarities of such multi-channel systems in case of radiating the phase synchronized short pulses. Superposition of 2D scalar Gaussian beams (see Fig. 1) has been considered:

$$E = \mathrm{Re} \sum_{n=1}^{N} \left(\sqrt{\frac{-ika^2}{z-ika}} \exp\left[ik \frac{(X-X_n)^2}{2(z-ika^2)} \right] \times \qquad (2)$$
$$\times \exp(i2\pi ft - ikz) \right).$$

In (2): E is normalized (dimensionless) electric field; $k = \dfrac{2\pi}{\lambda} = \dfrac{2\pi f}{c}$ is a wavenumber; f is a frequency; c is a velocity of light; x and z are transverse and longitudinal coordinates respectively; X_n is a coordinate of the Gaussian beam with index n; and a defines the transverse dimension of the beam waist.

Patterns of energy flux density P in far field region have been considered for radiation of:
i. short pulses with the central frequency f_0 and Gaussian envelope

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

where 2τ is a pulse duration (see Fig. 2).
ii. CW signals with the same frequency f_0.

For the short pulses the radiation pattern $P_p(X)$ is defined as a peak value of energy flux density in the pulse transmitted through the point X in the far field cross section $z = L$. For CW signals the radiation pattern $P_f(X)$ is equal to energy flux density in CW signal at the same cross section $(X, z = L)$.
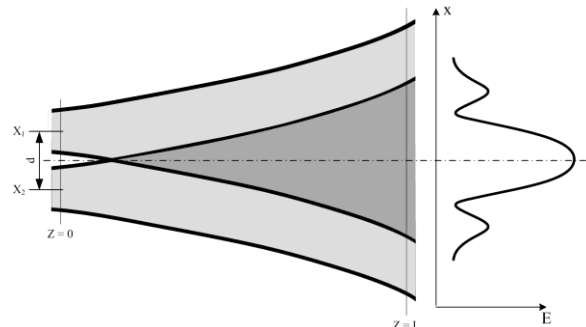

Fig. 1. Superposition of Gaussian beams and distribution of electric field at coordinate $z = L$ in far field region (shown schematically).
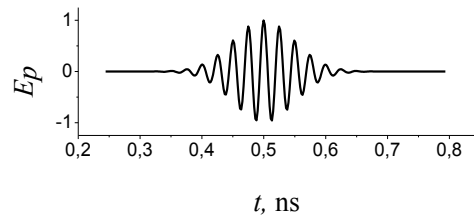

Fig. 2. Short pulse with the central frequency $f_0 = 40$ GHz (as an example) and Gaussian envelope.

Summation of two Gaussian beams resulted in small differences of radiation patterns for CW and short pulses signals as it is shown in Fig. 3. However, all maxima except the main one with highest amplitude are slightly reduced. In case of superposition of 8 Gaussian beams the suppression of side maxima becomes essential (see Fig. 4). Shapes of pulses outside the main maximum are distorted as it is shown in Fig. 5b.
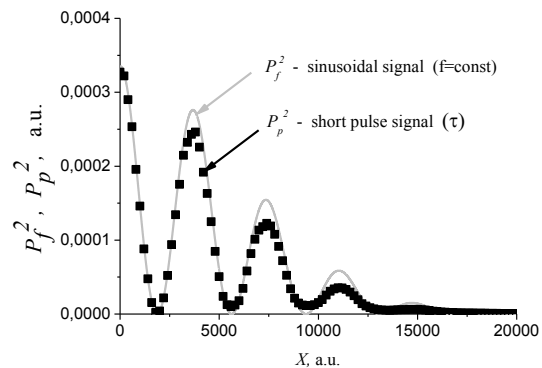

Fig. 3. Radiation patterns of CW (solid gray line) and short pulse (black dots) signals simulated for superposition of two Gaussian beams.
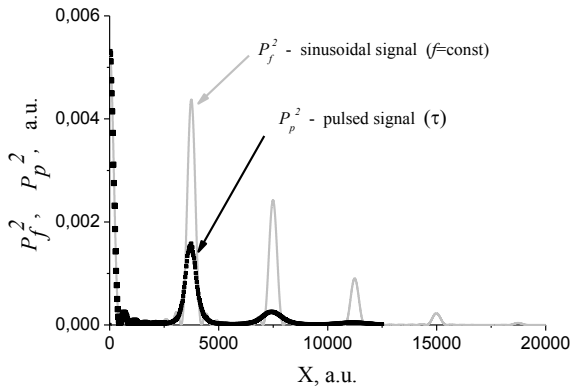
Fig. 4. Radiation patterns of CW (solid gray line) and short pulse (black dots) signals simulated for superposition of 8 Gaussian beams.
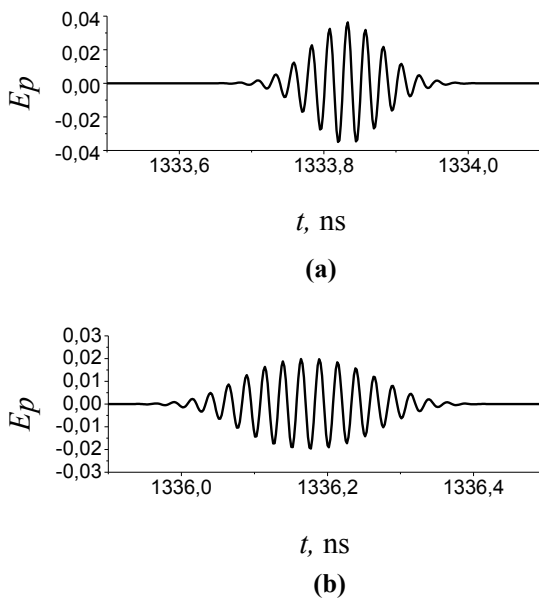

(a)

(b)

Fig. 5. Pulses in two points of far field cross section $z=L$. **a** - in the main maximum $X=0$ and **b** - in the first side maximum $X \neq 0$.

The reason of such distortion and accordingly the suppression of side maxima in radiation pattern is a delay of pulses transmitted in different wave beams and observed at the same point $(X \neq 0, z = L)$ in the far field region. It is appropriate to introduce a novel parameter for such multi-beam radiation systems

$$L_{corr} = \frac{2\tau \cdot c}{\sin(\theta)} \tag{4}$$

a correlation length. Here 2τ is the pulse duration and θ is an angle between z axis and the direction to the point of observation (see Fig. 6). For large enough numbers N of wave beams at any point of observation only pulses in wave beams with X_n from the range

$$\Delta X_n \leq L_{corr} \tag{5}$$

overlap and can be coherently summed. The number N_{corr} of such beams with overlapping pulses can be named as correlation number.
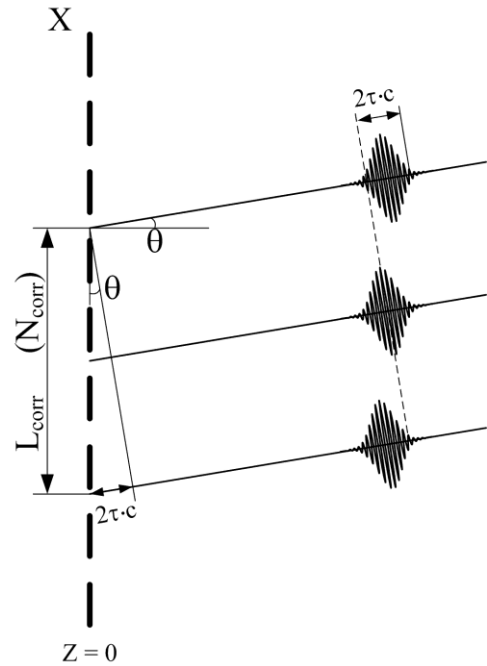

Fig. 6. Explanation for the correlation length L_{corr} and correlation number N_{corr}.

For the angle $\theta = 0$ pulses with any durations are overlapping because $L_{corr}(\theta = 0) = \infty$. It is a reason for invariability of main maximum in radiation pattern which is proportional to the square of the total number of wave beams N^2. For any side maximum ($\theta \neq 0$) the correlation length is finite (if the pulse duration is finite) and the amplitude of side maxima is proportional to N_{corr}^2 as electric fields only from N_{corr} wave beams are coherently summed. Consequently, for large enough numbers N of the beams the side maxima level of radiation pattern for short pulse signals can be suppressed as low as

$$\frac{N_{corr}^2}{N^2} \rightarrow \frac{1}{N^2} \tag{6}$$

as it is compared to side maxima of CW radiation pattern.

References

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