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Signal Identification by Means of Cross-Correlation Function

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Abstract: To estimate the input function on the correlator with high accuracy, the use of a rectangular pulse with varying position has been proposed. We used distribution functions in the form of a rectangular pulse, a pulse with a cosine vertex, a triangular and Gaussian pulse. Cross-correlation functions of all considered signals are represented by the Boltzmann model. Considered all the above signals, given 3,5,7,9,11,13,15 counts. It is shown that by differentiating the obtained dependences, it is possible to identify the studied signals and it is shown that the types of input and reconstructed signals coincide.

Keywords: signal identification, cross-correlation function, correlation coefficient

1. Introduction

Efficiency of Free Electron Lasers (FEL) is determined by the quality of accelerated electron beam including its bunch structure. That is why formation of dense relativistic electron bunches of subpicosecond durations and measurements of their parameters are key problems of physics of charged particle bunches. Electric field of a moving bunch may be represented as a sum of two fields, the Coulomb field and the radiation field. Each of these terms contains information on the temporal structure of the bunch. The radiation field is employed widely and effectively for the bunch diagnostics. A new single-shot multibeam cross-correlation technique is proposed for the measurement of a bunched electron beam temporal structure. As an optical laser pulse modulated by the Coulomb field of the electron bunch in an electro-optical crystal, it is proposed to use a non-uniform pulse modulated both in time and in space. In the proposed technique, measurement of the time profile is realized during a single laser shot. In this case, as a result of electro-optical modulation of a non-uniform femtosecond pulse, the information on the time profile of the Coulomb field is contained in only the spatially shifted spectral components of the modulated pulse.

The measurement of parameters of accelerated electron bunches is one of the interesting and actual problems. Let signal $x(t)$ defined experimentally obtained a distribution function of electrons along a bunch, that need to be approximated using a set of functions $\{r_n(t)\}$.

2. Metod

The block diagram of signal identifier by means of the cross-correlation function is represented in [1 -4] (See Fig. 1).

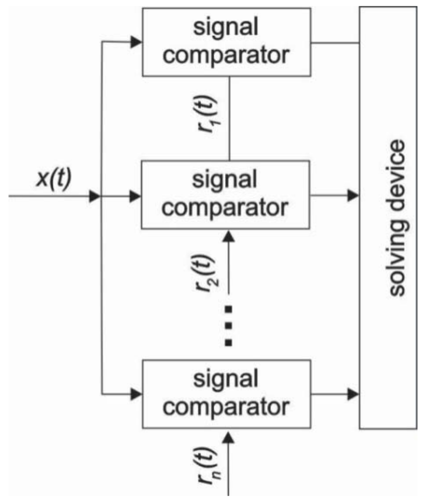

Fig.1. Block diagram of the signal identifier.

The measuring factor for signals is the energy of differential signal:

$$\varepsilon_{x,r} = \int_{-\infty}^{+\infty} \Delta_{xr}(t)\Delta_{xr}^{*}(t)dt, \tag{1}$$

where $\Delta_{xr} = x(t) - r(t)$. In the case when the signals coincide, the differential signal is zero [5]. Than lower the energy of the differential signal, the greater the similarity of the signals. Expression (1) can be written as

$$\varepsilon_{x,r} = E_x + E_r - E_{xr} - R_{rx}\,, \tag{2}$$

where E_x, E_r are the energies of signals, R_{xr} is the correlation coefficient of signals.

The correlation coefficient has a conjugate symmetry by its indices, and is equal $|R_{xr}| = \sqrt{E_x E_r}$ to the signal energy when $x(t) = r(t)$.The properties of the modulus of the correlation coefficient are similar to those of its real part, therefore, the modulus of the correlation coefficient can be used for identifying signals.

In this case the unknown signal $x(t)$ is compared to the test signal $r(t)$. The shortcoming of this method is that a large set of test signals $r_i(t)$ is required.

The possibility of $x(t)$ signal identification by the usage of one $r(t)$ standard test-signal (in the form of a rectangular pulse), travelling along the observed $x(t)$ signal is discussed (see Fig. 2).

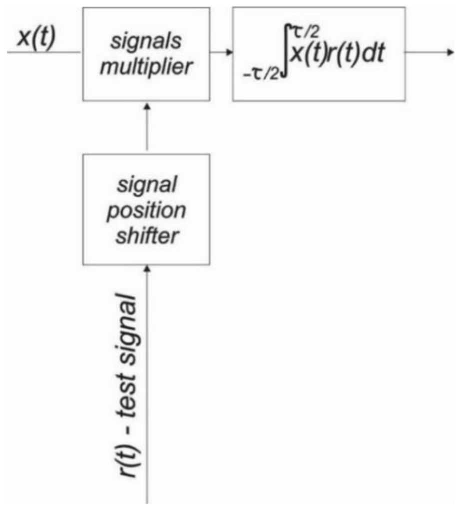

Fig. 2. Block diagram of cross-correlator.

3. Results and Discussions

The following set of normalized (height and duration) signals is depicted in the form of a rectangular pulse (Fig. 3a), a cosine-shaped pick pulse (Fig. 4a), a triangular pulse (Fig. 5a) and a Gaussian pulse (Fig. 6a). As a test-signal, a normalized rectangular pulse (Fig. 3a) is used, which is moving along the analyzed signal with a step 1. Based on that, the function R_{xr} is formed for all signals shown in Fig. 3a - Fig. 6a.

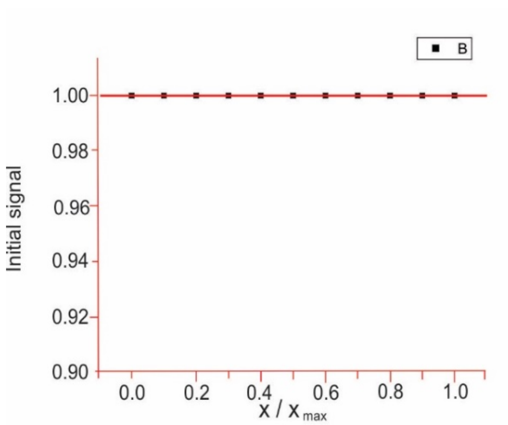

Fig.3a. A normalized rectangular pulse signal defined by 11 points.

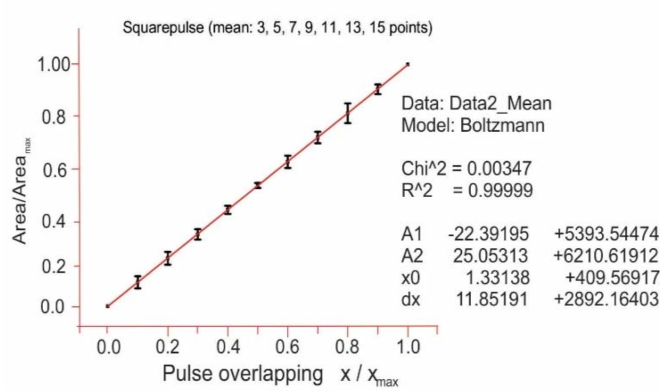

Fig. 3b. The cross-correlation function of a rectangular pulse, described by the Boltzmann model, hereR^2 = 0.99999, χ^2= 0.00347.

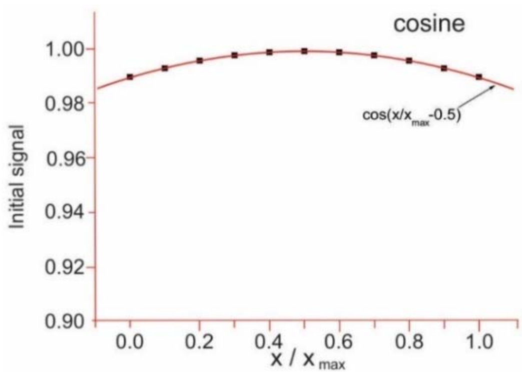

Fig. 4a. A normalized signal with a cosine-shaped pick function defined by 11 points.

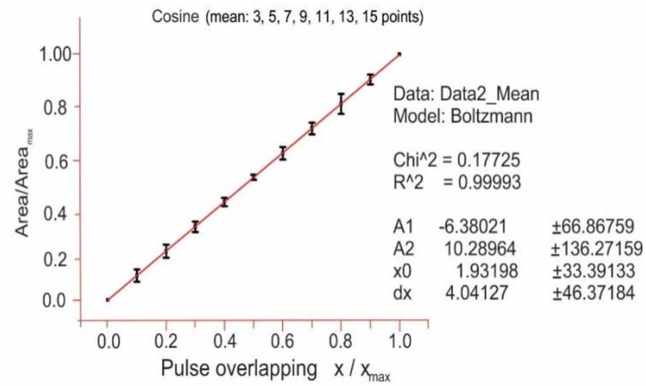

Fig. 4b. The cross-correlation function of a cosine-shaped pick pulse, described by the Boltzmann model, here $R^2 = 0.99993$, $\chi^2 = 0.17726$.

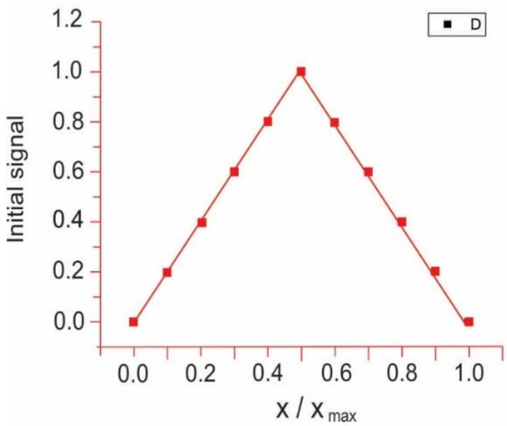

Fig. 5a. A normalized triangular pulse signal defined by 11 points.

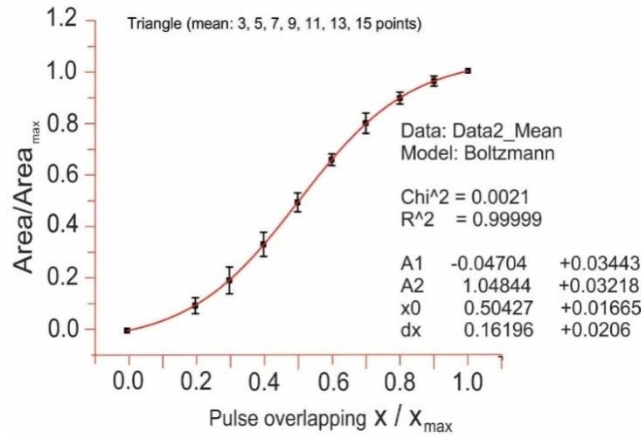

Fig. 5b. The cross-correlation function of a triangular pulse signal, described by the Boltzmann model, here $R^2 = 0.99999$, $\chi^2 = 0.0021$

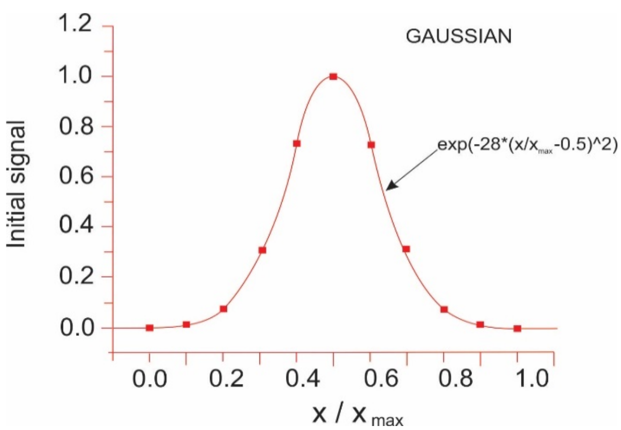

Fig. 6a. A normalized Gaussian pulse signal defined by 11 points.

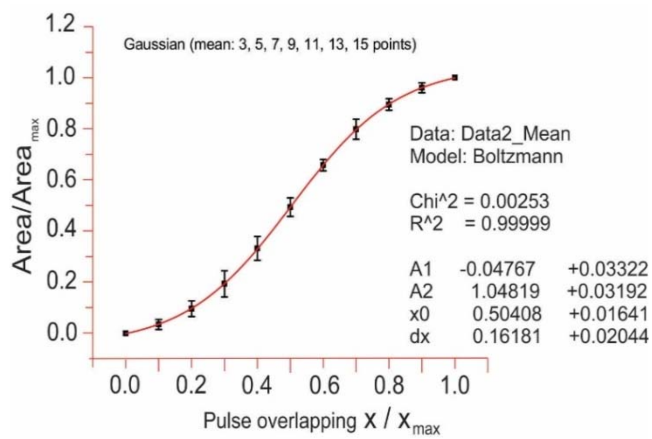

Fig. 6b. The cross-correlation function of a Gaussian pulse signal, described by the Boltzmann model, here $R^2 = 0.99999$, $\chi^2 = 0.00253$.

4. Boltzmann model

The definition of the Boltzmann model and the choice of parameters are shown in Fig.7.

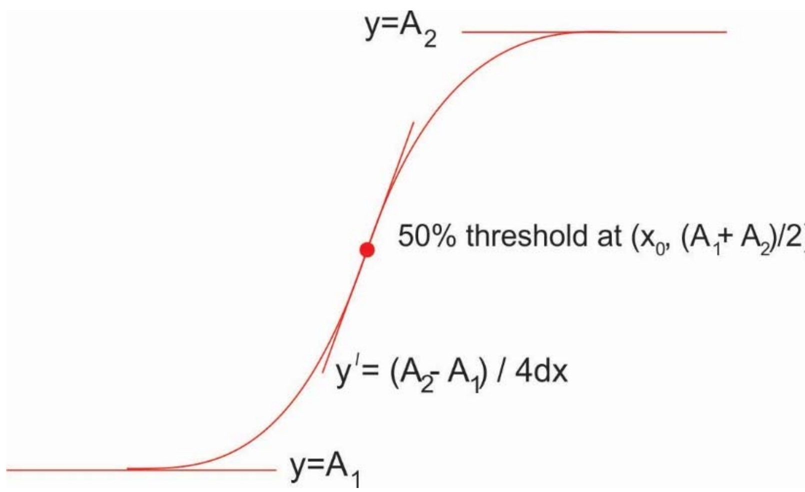

Fig. 7. Boltzmann model.

$$y = A_2 + \frac{A_1 - A_2}{1 + \exp[(x - x_0)/dx]}$$

where $R^2 - k$ determination, the closer R^2 is to one, the more faithfully the chosen model, χ^2 – is the Pearson criterion, the smaller χ^2, the more faithfully the chosen model. The characteristic parameters of the Boltzmann model are the point x_0 and the value of the derivative at this point, the values of which are given below [6].

PARAMETERS	UNIFORM	COSINE	TRIANGLE	GAUSSIAN
X_0	1.33138	1.93198	0.50427	0.50408
Dx	1	0.96682	2.1866	2.201

By differentiating the dependencies shown in Fig. 3b - Fig. 6b, the reconstructed signals are obtained.

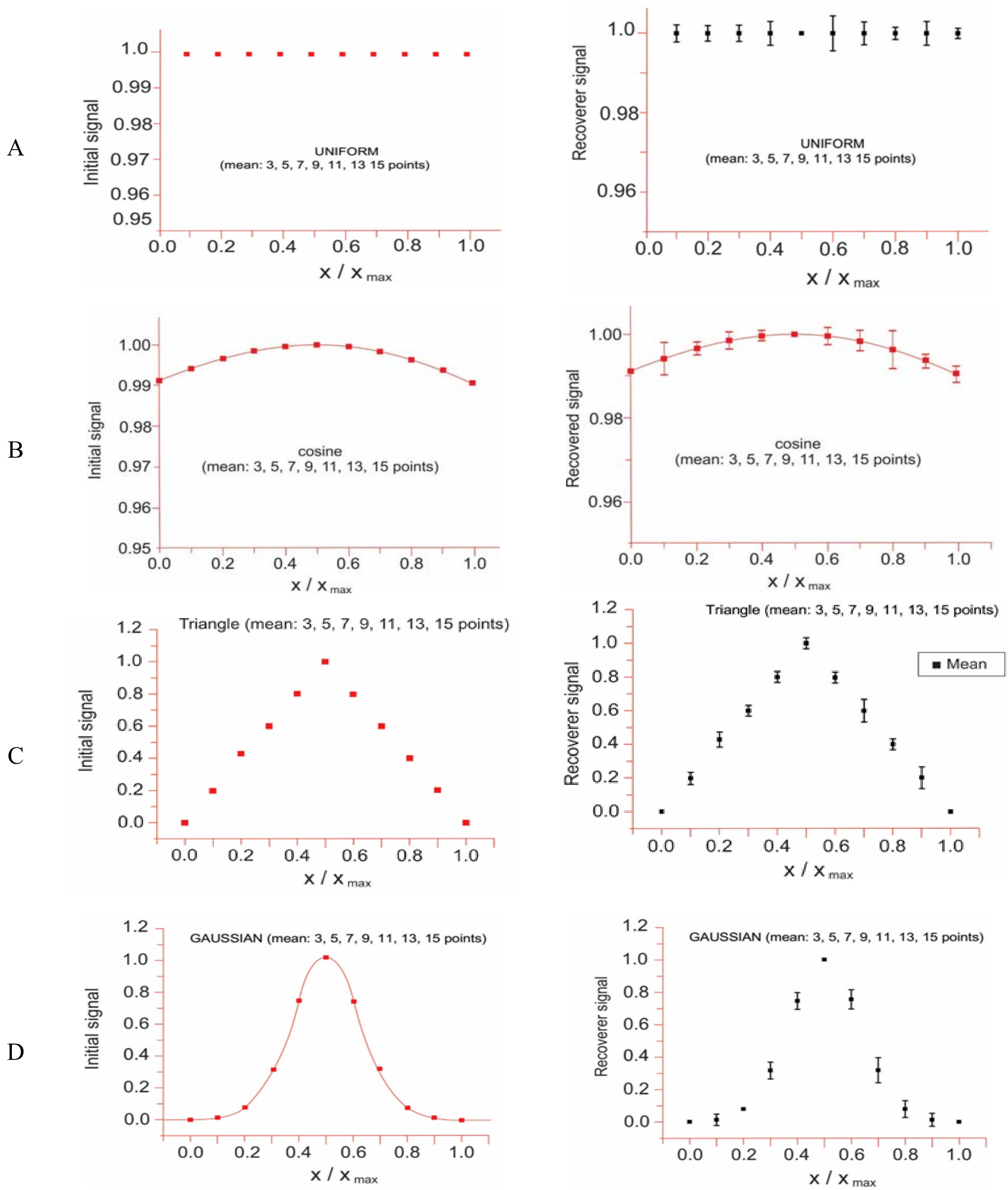

Fig. 8. The initial and reconstructed a - rectangular pulse signals,
b - cosine shaped pick signal, c - triangular pulse signal.
d - the reconstructed Gaussian pulse signal.

5. Conclusions

Thus, it is shown that the use of a rectangular pulse with a varying position allows us to estimate the input function on the correlator with sufficiently high accuracy with an appropriate choice of time samples. There by eliminating the need for a library of a large number of comparison functions and accordingly a large number of parallel correlators. The proposed method can be applied to determine the parameters of the beams.

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