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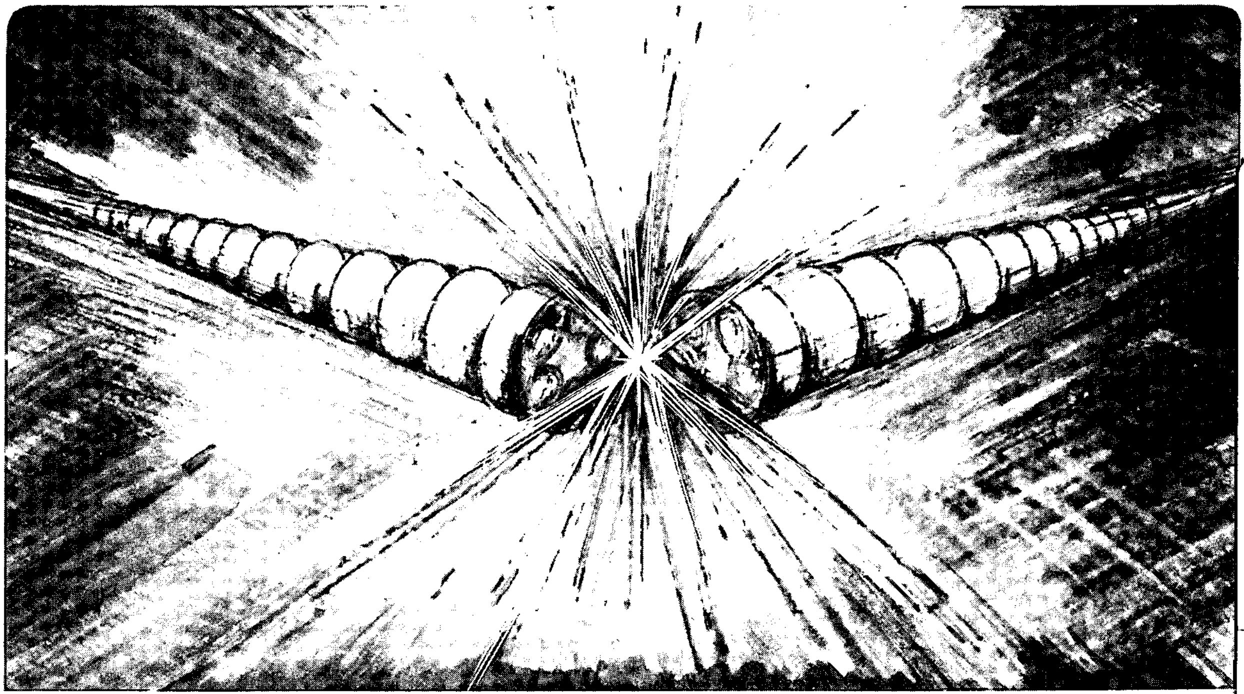

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CONSTRUCTION OF A SETUP FOR DETERMINATION OF LONGITUDINAL PROFILE AND DURATION OF ULTRASHORT ELECTRON BUNCHES*†

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ABSTRACT

A setup for determination of the longitudinal profile and duration of ultrashort electron bunches is proposed. The key idea is based on the connection between charge distribution in the bunch and time shape of a transition radiation (TR) flash. The short light pulse is generated through TR and is stretched using a special linear device, by a known algorithm, after which it is intensified by a linear amplifier and further processed by a corresponding algorithm. As a result the initial light pulse is recovered. An experimental device for registering a single super short light pulse has been developed and is now operating. With this device, the shape of the above mentioned laser pulse of duration ~20 ps was reconstructed, achieving a pulse structure time resolution of about 50 fs.

INTRODUCTION

The well-known optical TR generated by electron beams [1] is used for measurement of beam parameters [2-4] and for determination of bunch length [5]. We propose a setup which will allow the determination of the longitudinal profile and length of picosecond and sub-picosecond electron bunches.

THE TIME PROFILE OF TR FLASH

The question we pose here is: What will be seen by the observer when a uniformly moving charge q at velocity $\bar{v}$ crosses the boundary interface to two media?

From merely qualitative considerations it follows that the dependence of TR intensity contains information on the function of charge distribution in the bunch. This supposition inspires us with hope to implement the determination of longitudinal profile of picosecond bunches and its lengths [6].

Indeed, the TR arises precisely at the moment when the charge passes through the boundary and the number of emitted quanta is proportional to the charge. This circumstance allows us to assert that by determination of the shape of the time dependence of the radiation light flash intensity one can reveal an unambiguous correspondence with the function of charge distribution in the bunch, as was previously shown [6].

To begin with, we'll restrict ourselves to the simplest case, when a point-like charge moving along the Z-axis traverses normally the boundary vacuum and ideally conductive surface (Fig. 1).

In this case the TR field in the stationary phase approximation will be of the form

$$\bar{E}(R,\theta,t) = \frac{q\beta}{J_1 cR} U(\theta)\delta(\frac{R}{c} - t)\bar{e}_\theta \tag{1}$$

where $U(\theta) = \sin\theta / (1 - \beta^2 \cos^2\theta)$ is the angular distribution of the "backward" TR — in the opposite direction to the particle velocity (z<0). We choose a polar coordinate (R, θ, φ) and denote by R the distance from the point of intersection to the point of observation.

In the case of oblique incidence the "backward" radiation fields for two polarizations -- in the plane of incidence ($E_{\|}$) and normal to it ($E_{\perp}$) -- have the forms

$$E_{\|} = \frac{q\beta}{c\pi R} U(\theta)\varphi(\frac{R}{c} - t)\cos(\varphi),$$

$$E_{\perp} = \frac{q\beta}{c\pi R} U(\theta)\varphi(\frac{R}{c} - t)\cos(\varphi), \tag{2}$$

where the angle θ is counted off from the direction of "geometro-optical reflection" from the boundary. One can see that the total field remains linearly polarized.

For the narrow frequency band from $\omega - \Omega to - \Omega$ lying in the optical range $(\Omega / \omega_o << 1)$ we must make the substitution in the expression of radiation fields

$$\delta(\frac{R}{c} - t) \rightarrow \frac{\sin\Omega\frac{R}{c} - t}{\Omega(\frac{R}{c} - t} \exp\left\{ i\omega_o(\frac{R}{c} - t) \right\}. \tag{3}$$

Such an approach is sufficiently correct, since for the narrow frequency band in the optical range we have every reason to neglect dispersion and consider the surface ideally conductive.

Now we turn to the finite-size bunch case. Instead of the point-like charge the boundary is traversed by a bunch with the charge density distribution in the form

$$\rho(z,t,\Phi) = qZ(\frac{z}{d})R(\tau,\Phi), 0 \le \tau \le a; 0 \le \Phi \le \pi. \tag{4}$$

where a is a quantity that defines the bunch transverse dimensions, d defines its longitudinal dimension, $Z(\frac{z}{d})$ is the charge distribution along the axis, and $R(z,\Phi)$ is the charge distribution for the cross section.

Now we refer to the case of oblique entrance of the bunch. For ultra-relativistic particles $(\gamma = (1-\beta^2)^{-1/2} >> 1)$, as known, the radiation energy concentrates near the angles $\theta \sim 1/\gamma$, where θ is counted off from the "geometro-optical reflection" direction. Actually we are interested in the case when the longitudinal dimension of the bunch is much greater than its transverse ones. Then, taking into account also that $\Omega / \omega_o << 1$ we can describe the detected TR intensity of the quasi-linear bunch $(a \sin\theta / d << 1)$as [6].

$$I(R,t) = \frac{q^2\beta^4}{2\pi^2} G_\perp Z^2\left(\frac{L}{d}\right)U^2(\theta) \tag{5}$$

where the term $G_\perp$ characterizes the transverse structure of the bunch, $L = \beta R - vt$.

The measurement error due to the finiteness of transverse dimensions of the bunch at a sin d~.01 will make up a few percent. Hence, the measurement of intensity I(R,t) will enable one to unambiguously define the charge distribution along the bunch $Z\left(\frac{L}{d}\right)$ and the light flash time-profile.

THE SETUP FOR DETERMINATION OF TIME PROFILE AND ENERGY OF PICOSECOND LIGHT FLASH OF TR.

To detect the time profile of intensity of TR flash in the optical band, one can use the well known methods of measurements of ultrashort light pulses. The conventional streak-camera can be used directly for pulses longer that 3-5 ps irrespective of degree of coherence of light pulse. The nonlinear methods -- the correlation technique -- have limiting resolution up to .05 ps and are applied in measurements of a sufficiently coherent laser radiation. This means that neither of the cited methods can be used for the determination of the TR flash intensity time shape. In the first case because of insufficient time resolution, and in the second because of a low degree of coherence.

To solve this problem, we propose the following method of measurement (Fig. 3). To TR light pulse is preliminary converted by a special linear device which executes its time broadening by a known algorithm in such a way that the shape of the broadened and converted pulse has unambiguous correspondence with the shape of the initial pulse. The converted pulse is intensified by a wide-band optical amplifier whose amplification factor varies from 100 to 1000. The intensified light pulse is detected by a time-analyzing streak-camera. The information from the streak-camera is introduced to the computer which performs preliminary processing and recovery of the time profile of the TR pulse. The mentioned procedures are executed using specialized software. The measurement error will not exceed 20%.

Calibration of the setup consists in the measurement of the standard laser pulse whose shape is preliminarily measured on the device for determination of the time-profile of laser pulses with the resolution of 50 fs. The standard pulse parameters: wavelength .53 μm, duration 7-8 ps, pulse energy $\sim 10^{-4} J$. The data on the pulse shape are introduced into the memory of the PC placed at the output of the measuring setup.

Then the standard pulse via the attenuator (filter) with the absorption coefficient $5x10^3 - 10^4$ is directed to the setup. Results of the measurement are compared with the data on the shape of the standard pulse and, according to the comparison results, the system readiness instruction is given.

Calibration of the tract of measurement of energy parameters of TR pulses is not necessary because the radiometer used for this purpose is self-calibrating. In the measurement of the shape of ps TR pulses the value of the "pedestal" is about 15-17% of the maximum value of pulse intensity.

PROTOTYPES AND DEMONSTRATION PROGRAM OF DEVICES WHICH WE PROPOSE TO USE AT SET-UP

We are developing a prototype of a time profilometer for a single laser pulse of 15-20 ps with nearly 50 fs time resolution. A prototype of the device determining the shape of a light pulse of 15 ps duration will be demonstrated. It will be shown how the pulse converts when passing through the time broadening unit. The duration of the converted pulse will make up about 150 ps. It will also be shown how the converted pulse is detected by the streak-camera. On the basis of the results of photometric measurement of the detected pulse a reconstruction of the initial pulse will be demonstrated [7-8].

We are also making a computer simulation of a measuring device for a time profile of TR flash intensity of duration from .3 to 3 ps, including:

- the reconstruction of the time profile of the TR pulse
- the conversion of the time profile of TR pulse at output of the (a) unit of time broadening, (b) intensity amplifier, (c) streak-camera
- the estimation of correctness of the pulse shape reconstruction and errors values.

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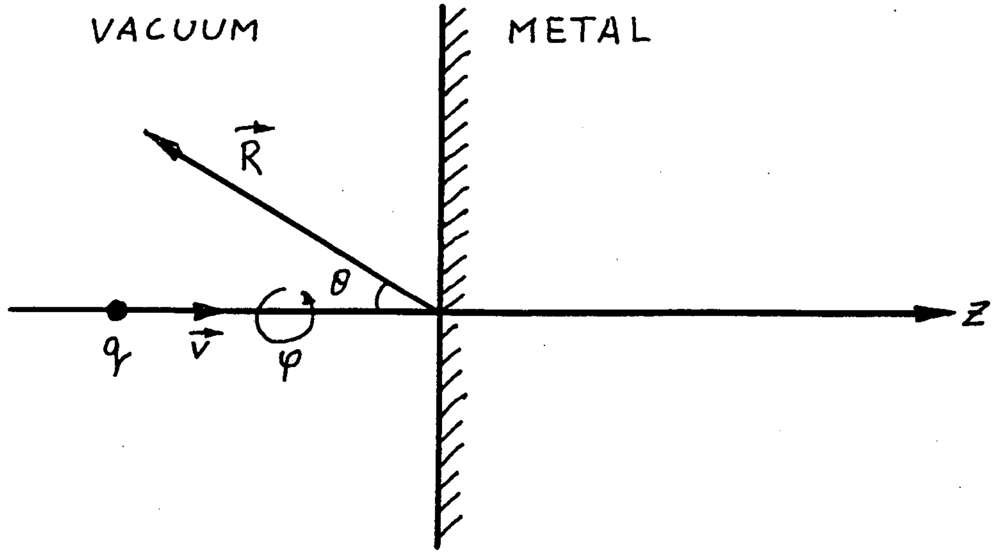

VACUUM
METAL
$\vec{R}$
θ
q
$\vec{v}$
φ
z

Fig. 1

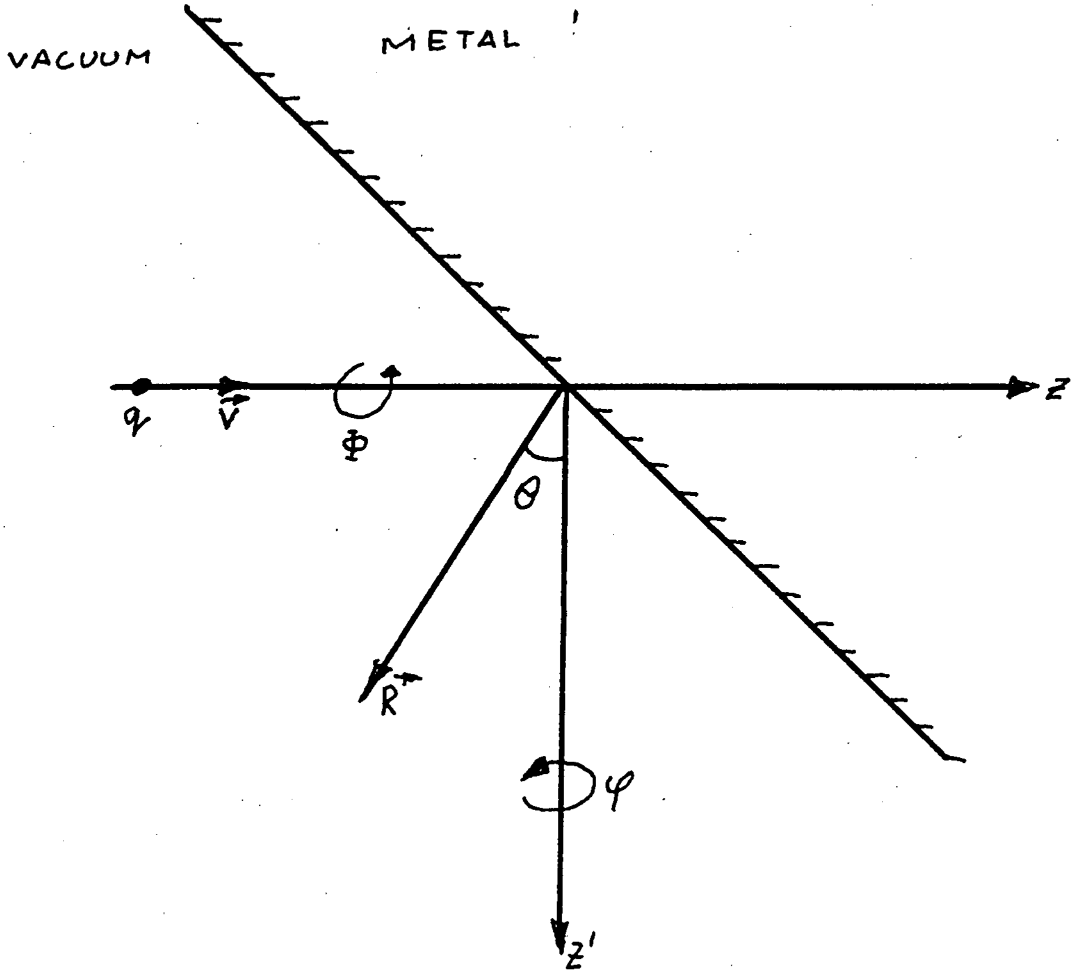

VACUUM
METAL
q
$\vec{v}$
Φ
θ
z
$\vec{R}$
φ
z'

Fig. 2

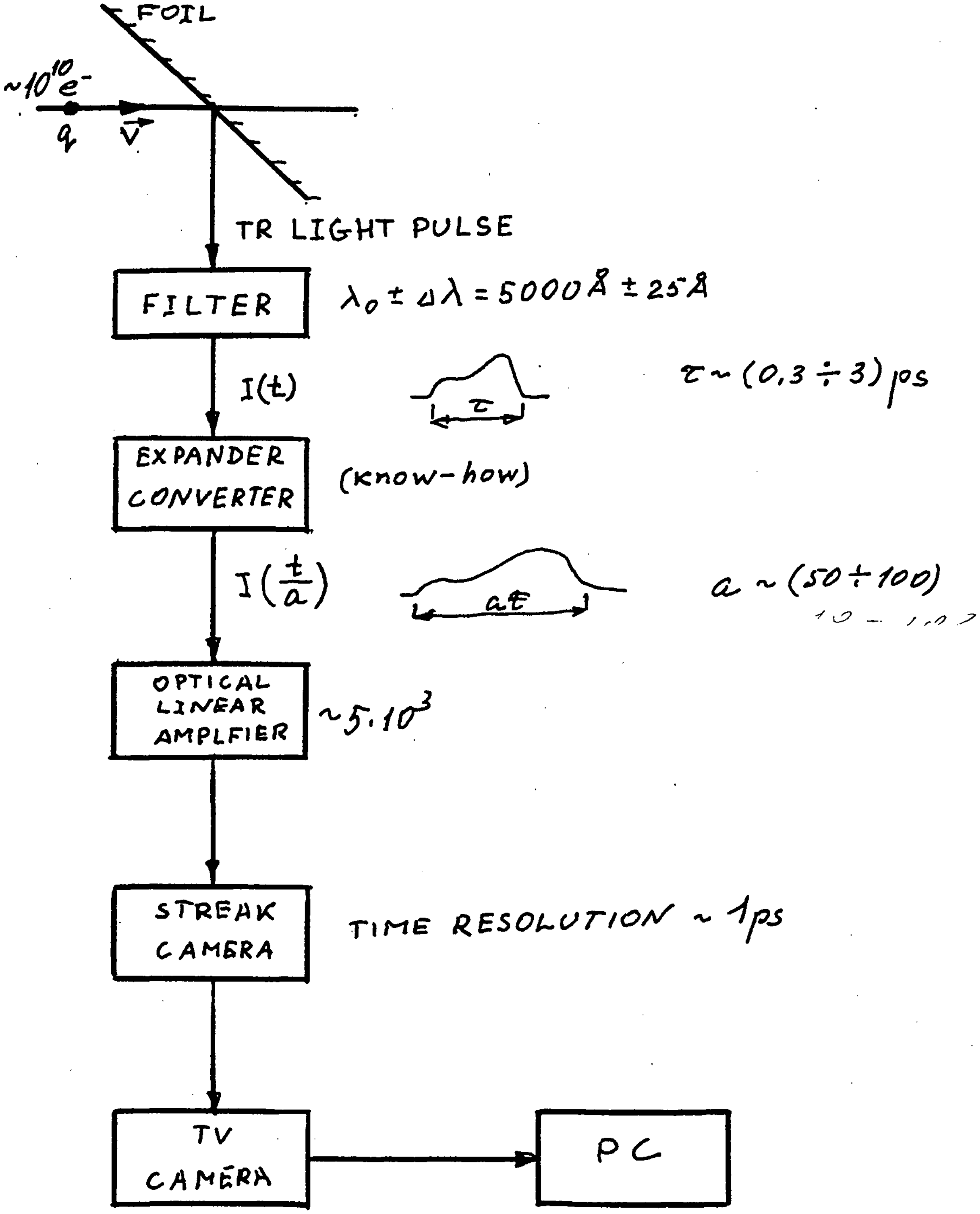
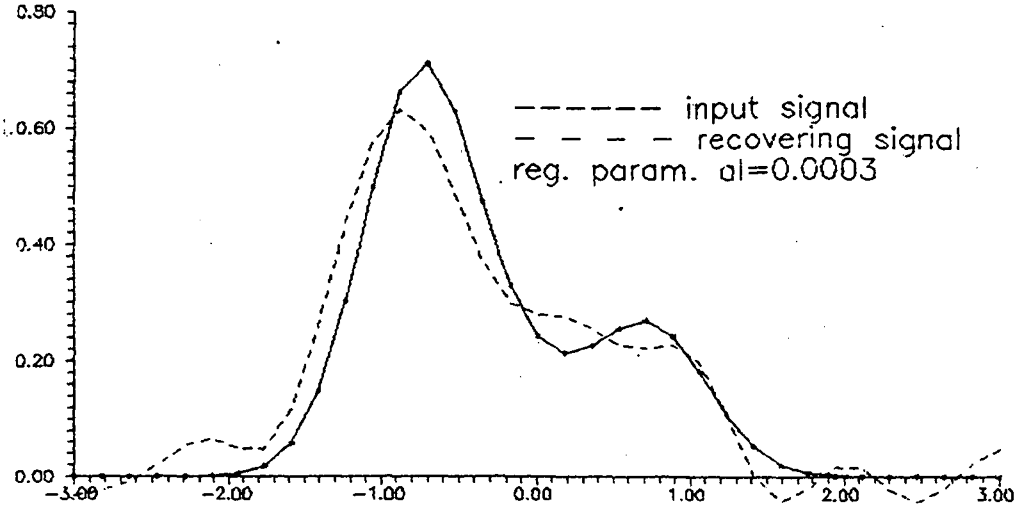
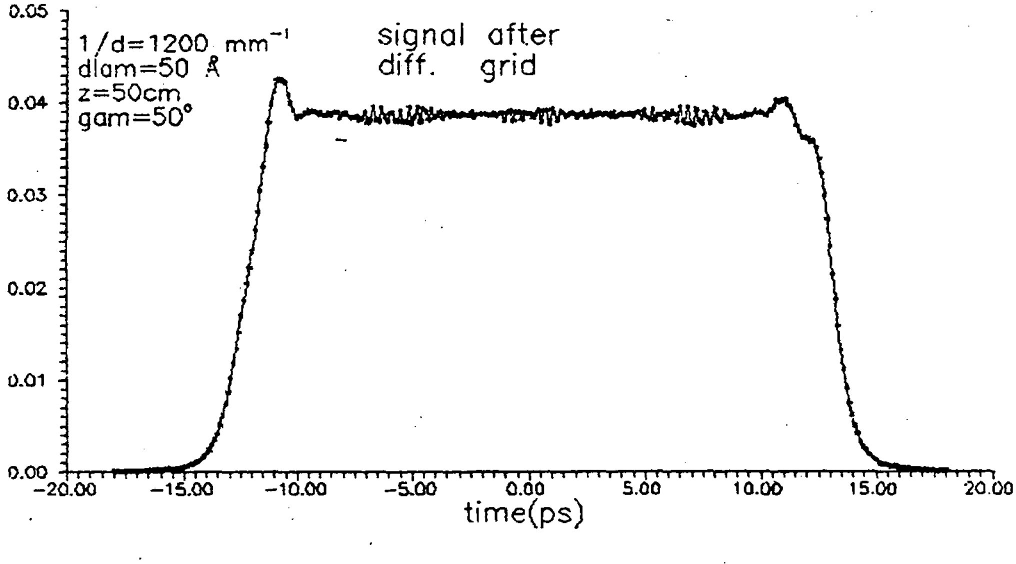
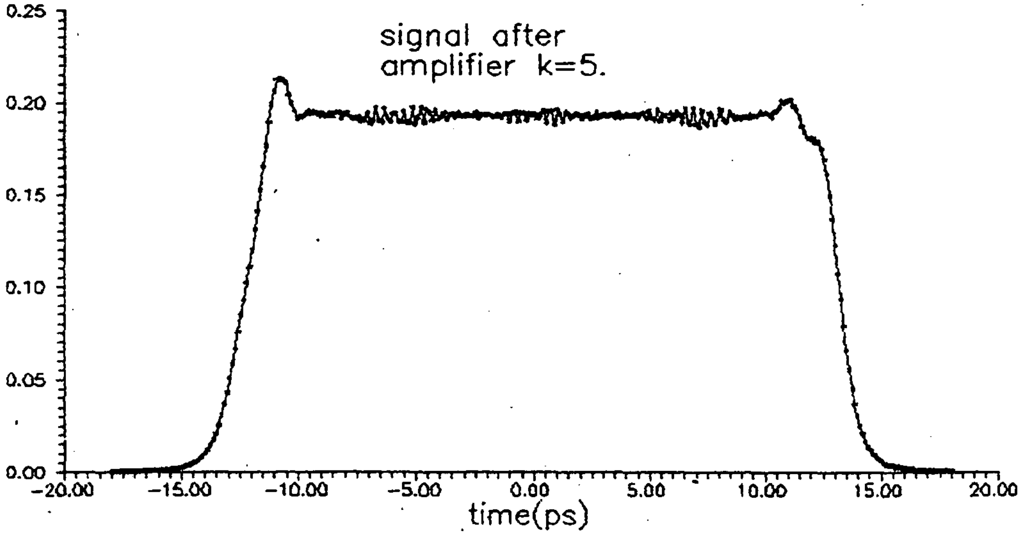
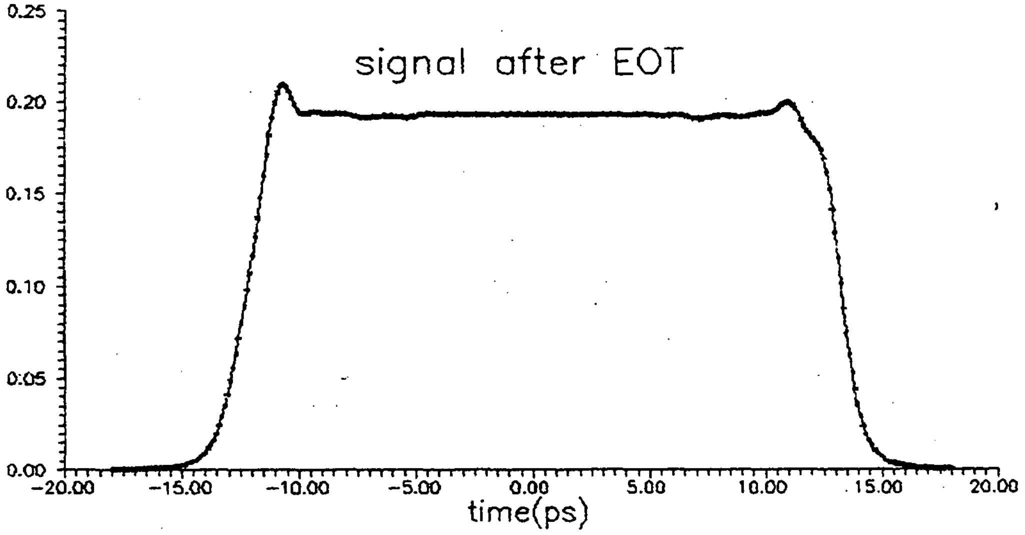

FOIL
~10^10 e^-
q
v
TR LIGHT PULSE
FILTER
λ0 ± Δλ = 5000Å ± 25Å
I(t)
τ
τ ~ (0,3 ÷ 3) ps
EXPANDER CONVERTER
(know-how)
I(t/a)
aτ
a ~ (50÷100)
10 ÷ 100
OPTICAL LINEAR AMPLFIER
~5·10^3
STREAK CAMERA
TIME RESOLUTION ~ 1ps
TV CAMERA
PC

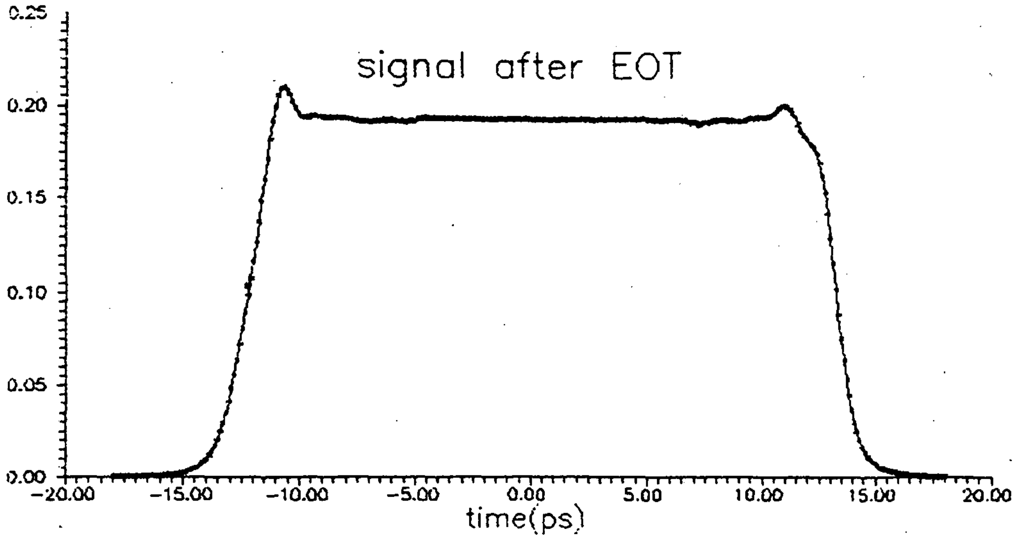
Fig. 3

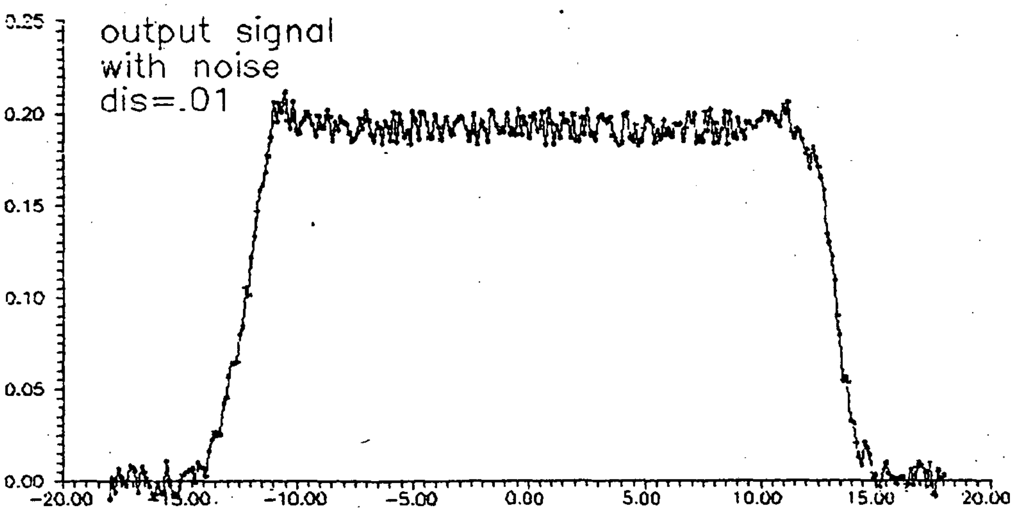

0.80
0.60
0.40
0.20
0.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
input signal
recovering signal
reg. param. al=0.0003


0.05
0.04
0.03
0.02
0.01
0.00
1/d=1200 mm^{-1}
dlam=50 Å
z=50cm
gam=50°
signal after
diff. grid
-20.00
-15.00
-10.00
-5.00
0.00
5.00
10.00
15.00
20.00
time(ps)


signal after
amplifier k=5.
0.25
0.20
0.15
0.10
0.05
0.00
-20.00
-15.00
-10.00
-5.00
0.00
5.00
10.00
15.00
20.00
time(ps)


signal after EOT
0.25
0.20
0.15
0.10
0.05
0.00
-20.00
-15.00
-10.00
-5.00
0.00
5.00
10.00
15.00
20.00
time(ps)


signal after EOT
0.25
0.20
0.15
0.10
0.05
0.00
−20.00
−15.00
−10.00
−5.00
0.00
5.00
10.00
15.00
20.00
time(ps)


output signal
with noise
dis=.01
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0.20
0.15
0.10
0.05
0.00
−20.00
−15.00
−10.00
−5.00
0.00
5.00
10.00
15.00
20.00

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