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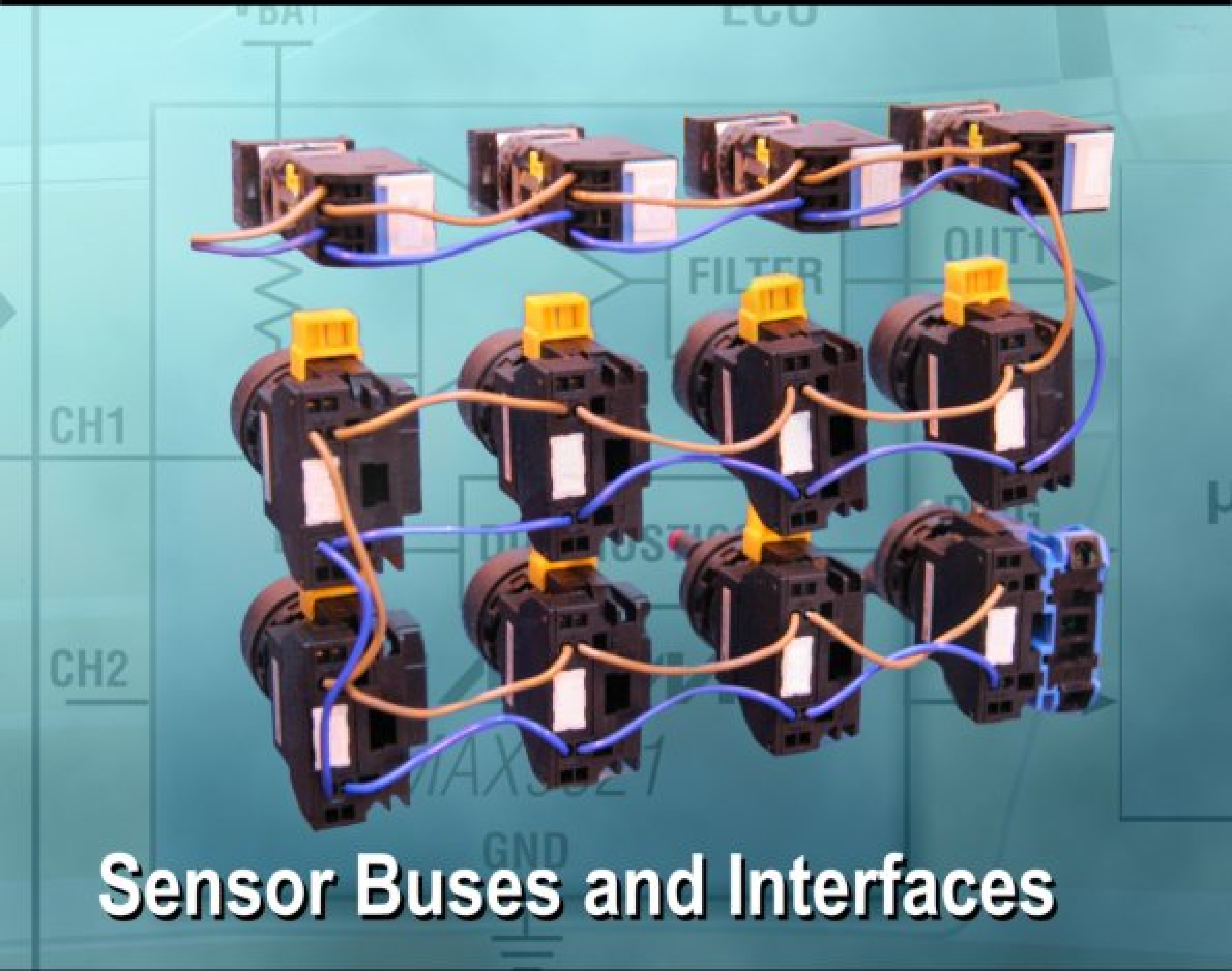

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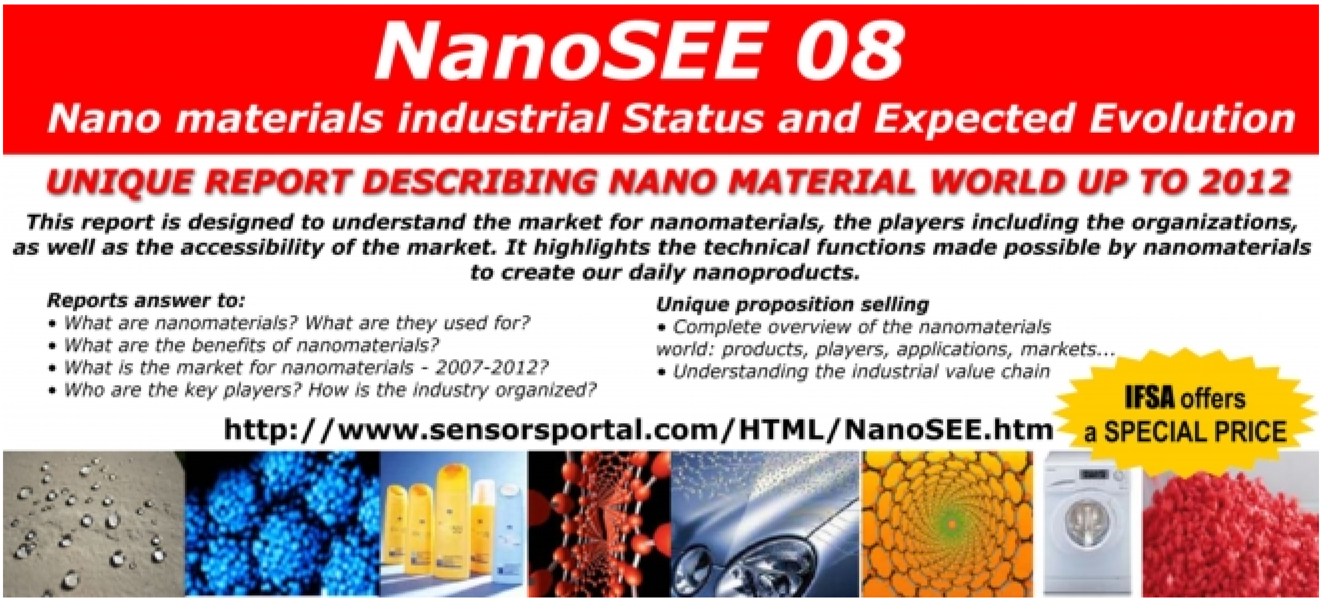
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Ultra High Voltage Surge Waveforms Measurement Using an Optical Transducer

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Abstract: Ultra high voltage surge waveforms measurement by means of a portable optical transducer is presented. The sensor system uses a transducer element based on the longitudinal electro-optic effect with a double pass configuration to obtain a better sensitivity. The transducer head is allocated to one meter of distance from the generating element of electric field and it is able to measure waveform surges from 515 kV up to 1090 kV with fast response. It is demonstrated that the telemetry of ultra high voltage surge waveforms can be successfully done by means of this proposed optical transducer. *Copyright © 2010 IFSA.*

Keywords: Electro-optic device, Pockels effect, Optical transducer, Ultra high voltage, Voltage surge waveform

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1. Introduction

One of the main problems to carry out tests in electrical equipment is the ultra high voltage surge waveform measurement. Traditional techniques for ultra high voltage surge measurement include among others, as sparkover of sphere gaps and the methods using transformer and potential dividers.

Techniques based on sphere gaps are reliable for calibration purposes and they are not convenient to carry out routine measurements because the breakdown does not occur at exactly the same value of voltage each time. Methods based on transformers and potential dividers are rough and with low accuracy due to the undesirable currents and discharges since in some cases the corona effect is present [1, 2]. Another traditional technique used for ultra high voltage waveforms estimation is based on the Litchenberg patterns obtained by using a Klydonograph. However, none of the techniques reported up to now allow us to measure surge waveforms and estimate their amplitudes with high accuracy.

Electric field sensors based on electro-optic modulators are attractive for ultra high voltage measurement applications because they offer great advantages with respect of traditional techniques [3, 4]. The absence of any conducting element allows us to obtain advantages such as electrical isolation, immunity to electromagnetic interference and electrical and thermal noise.

The use of the electrophysical phenomenon well-known as the Pockels effect, has been demonstrated for electric field measurements long time ago [5], and the first voltage sensor system using optical fibre technology was reported some years ago [6-13]. A transducer based on optical fibre with an electro-optic longitudinal modulator using a $Bi_{12}TiO_{20}$ crystal has been proposed, with a good sensitivity (modulation depth of 0.145 % for 1 Vrms) [14, 15]. This electric field transducer has been assembled and inserted into a non conductive cylinder with dimensions of 39 mm of longitude and 13 mm of diameter coupling two pieces of multimodal fibre jacketed with 100 mts. of length.

In this paper, we show that ultra high surge waveforms can be estimate using an optical transducer based on optical fibre and an electro-optic element. In section 2 we describe the configuration of the sensor system. In section 3 we describe the experimental details. Finally, in section 4 we present the conclusions and remarks. Our main aim is to show that the ultra high voltage surge waveform can be estimated with this linear, portable and with high sensitivity optical sensor system proposed.

2. Transducer's Scheme

Fig. 1 shows the photo and the configuration of the optical transducer and its optical path used. A beam out coming from a 670-nm non-polarized superluminiscent light emitting diode (SLED) SUPERLUM^{TM} SLD-26-HP with FHWM 30 nm and 5mW allocated in the processing unit together with the temperature and current controller PILOT-2^{TM}. The processing unit is coupled to the transducer head through two pieces of 100 meters of multimode jacketed fiber (62.5 / 125 μm) and a couple of selfoc lenses. Inside the transducer head, the polarization state of the light after the addition of the polarizing prism changes 45 degrees with respect to the axes of the electric field which is induced by the crystal's birefringence. The linear polarized light goes through a $Bi_{12}TiO_2$ cubic crystal, i.e. we consider a uniform crystal without any own intrinsic birefringence. Meanwhile, if we impose electric field on the crystal, the $Bi_{12}TiO_2$ crystal becomes uniaxial [16]. The value of the induced birefringence is proportional to the imposed electric field due the Pockels effect. Thereby, the light in the crystal will be propagates as a linear combination of two waves: the first one for a "fast axis" and the other one for a "slow axis". That is, two waves with different velocity can be considered. Therefore, the relative phase retardation between these waves is proportional to the linear induced birefringence. Then, the sensitivity for this transducer is given by the rate between the retardation phase of the light from the SLED and the magnitude of the electric field. Therefore, to obtain the largest amount of retardation per unit electric field for this 5 mm × 5 mm × 2 mm $Bi_{12}TiO_{20}$ crystal, both the electric field and the optical path are chosen normal to the (100) crystallographic plane.

Polarized light returns to the crystal after two reflections from the surface of the backreflecting prism made of BF7 glass (refractive index $n = 1.575819$ @ $\lambda = 670$ nm), thus, adding a phase shift of $\pi/4$ to obtain circular polarization. In this case, the polarizer prism acts like an analyzer, that is, change the polarization modulation into intensity modulation and returning by another fiber coupled with a Selfoc lens. Finally, the light is collected by a photodetector inside the processing unit. It should be noticed, that phase shift is linearly proportional to the electric field straight [15].

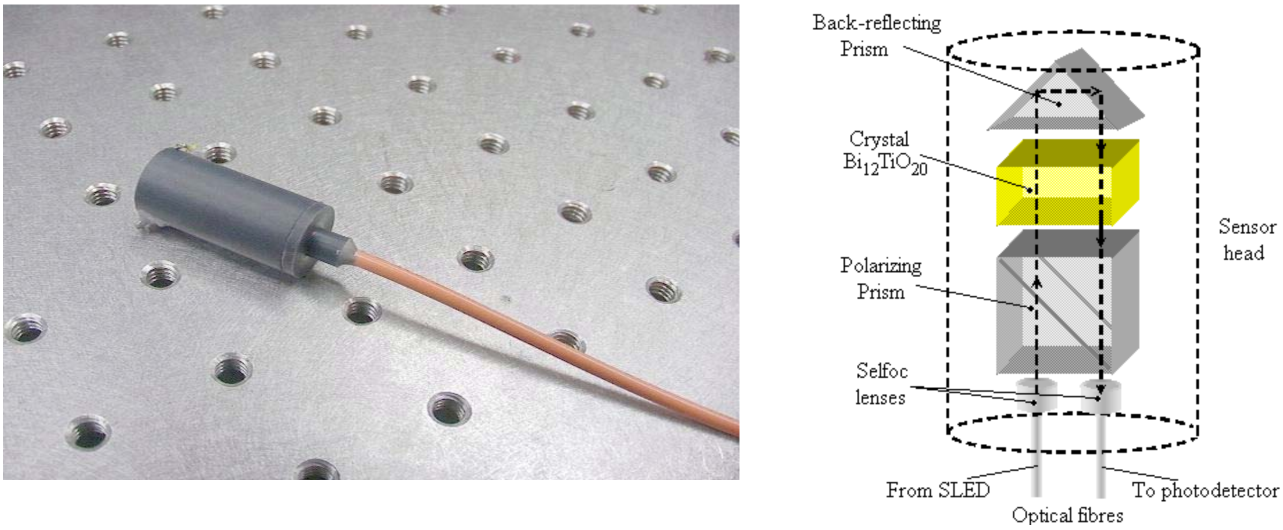

Fig. 1. Photo and scheme of the optical transducer; SLED is the superluminiscent light emitting diode.

The transmission function of the optical transducer can be obtained from the 2×2 Jones matrix formalism of each element as [16],

$$I = \left| P \times R(-45^o) \times C_{ref} \times R(45^o) \times R(-45^o - \vartheta) \right.$$

$$\times W \times R(45^o + \vartheta) \times R(-45^o) \times C_{inc} \tag{1}$$

$$\left. \times R(45^o) \times E \right|^2 ,$$

where, E denotes the Jones vector of light at the input of the crystal after the polarizer, $R(...)$ is the rotation matrix, C_{inc} is the Jones matrix of the $Bi_{12}TiO_{20}$ crystal for the incident light, W is the Jones matrix of the back-reflecting prism, C_{ref} is the Jones matrix of the $Bi_{12}TiO_{20}$ crystal for back-reflected light and P is the Jones matrix of the analyzer.

As it is shown in Fig. 2, the transmission function of the transducer is highly non linear. However, it is possible to choose a part of the transmission function that has an approximately linear behaviour (for example from 1 up to 2.35 radians). The alignment of the vertical axes of the reflecting prism and the polarizing prism guarantees a phase difference between the fast and slow waves that approaches to 1.57 radians. Therefore, we expect that the sensor will be working in the linear part of its transmission function.

3. Experimental Details

Ultra high voltage surge waveform measurements were carried out to an element V(t) constituted of an aluminium tube with 15 centimetres of diameter. The V(t) was connected to an ultra high voltage surge generator based on the charge and discharge of capacitors and the transducer head was allocated one meter of distance from the voltage element. We defined the vertical plane as the normal plane to the physical ground that includes the transducer head and the voltage element V(t). The circular surface of the transducer was placed in the perpendicular position to the electric field vector because the transducer head was designed as a longitudinal electro-optical modulator [14]. Then, several ultra high voltage surges were applied to the voltage element, from 500 kV up to 1100 kV.

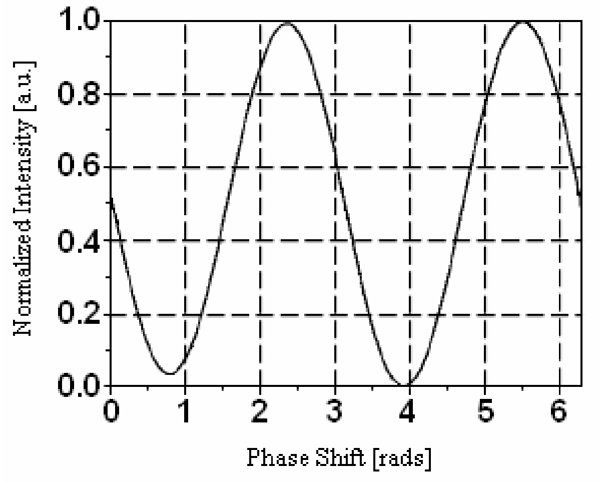

Fig. 2. Transducer's transmission function.

We observe the sensor system response in an oscilloscope (HP^{TM} model 54603B, 60 MHz) and surge waveforms were recorded by an optical spectrum analyzer (ANDO^{TM} AQ 6312B) connected at the amplified output of the processing unit. We carry out the ultra high voltage surge measurements for the horizontal plane as well as for the vertical plane and we do not appreciate some difference. This is logical since the system electric field generation has a cylindrical symmetry [17].

4 Results and Discussions

To determine the linear response of the sensor system, a transmittance curve was obtained, in which, the output voltage versus applied voltage is plotted. We register the amplified voltage output of the processing unit after 1 ms in order to prevent the wavetail time of the signal [1]. We registered the values for each one of the measurements corresponding to the ultra high voltage and we plotted in Fig. 3. Analyzing the results by means of the error theory, we obtained the following calibration equation:

$$V_{measured} = 10^4 \times \left(V_{sensor}[V] - \frac{0.028}{1.91} \right) \quad (2)$$

The plot of the calibration equation is shown in continuous line in Fig. 3. It is thus seen that the sensor transmission function has a linear behaviour as we expected.

The fast response and the high sensitivity of the transducer in the surges measurement is demonstrated in the Fig. 4 (a, b and c). We can observe the behavior of the negative transitory part clearly for 699, 898 and 1090 kV taking the runing of the system from 10 μs before and up to 10 μs after that the ultra high voltage discharge is generated.

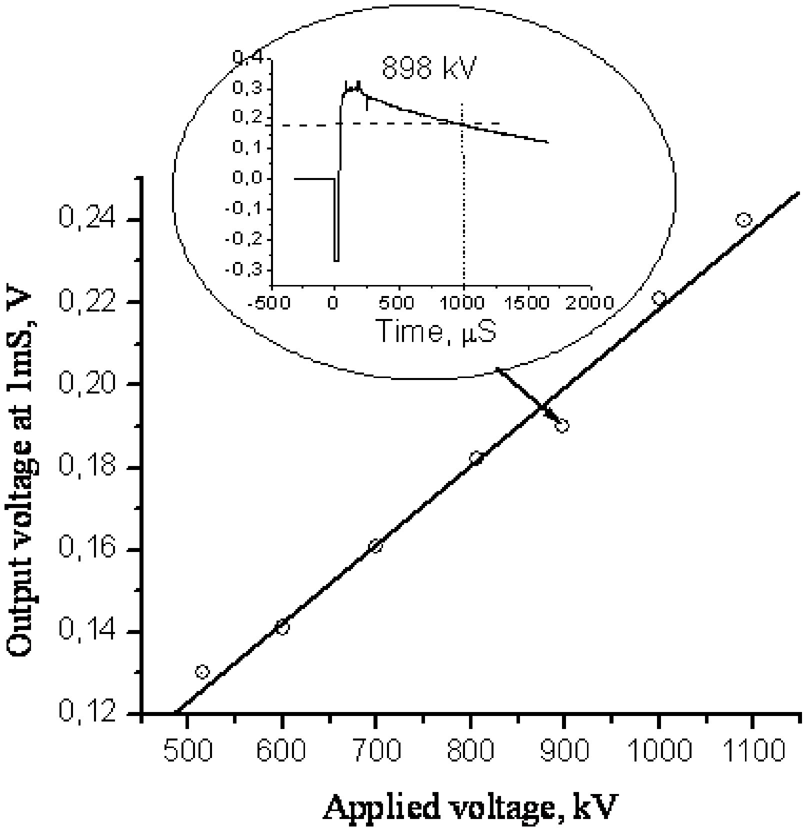

Fig. 3. Ultra high voltage surge waveforms detected from 1meter of the voltage element V(t).

These graphs show in diferent scales of time, the behavior of the surge and his waveform captured with this technique proposed.

Making use of the Fourier transform, we analize the transitory part of each signals obtaining a maximum frequency of 300 MHz. Transitory part is due to the generation mechanism of the surges and it is not possible to solve it with another measurement techniques reported previously.

4. Conclusions and Remarks

The surge waveform is a unidirectional impulse of nearly double exponential in shape. As we can see in the graphs, this new technique proposed to estimate the ultra high voltage surges can fulfils standards as 1/50 and 1.2/50 μs waveforms. Moreover, this new technique has been successfully done without the potential dividers broadly used for this purposes.

The feasibility of ultra high voltage surge waveforms measurement from 515 kV up to 1090 kV using a portable, remote, and robust optical sensor system based on an optical transducer has been demonstrated. The double pass of the light in the crystal enhances the performance of the sensor by increasing the sensitivity with fast response detecting variations of 300 MHz. Measurements also show a good behaviour of the modulation depth besides a linear response. Finally, this technique of measurement is suitable to carry out studies in the generation and telemetry of ultra high voltage surges.

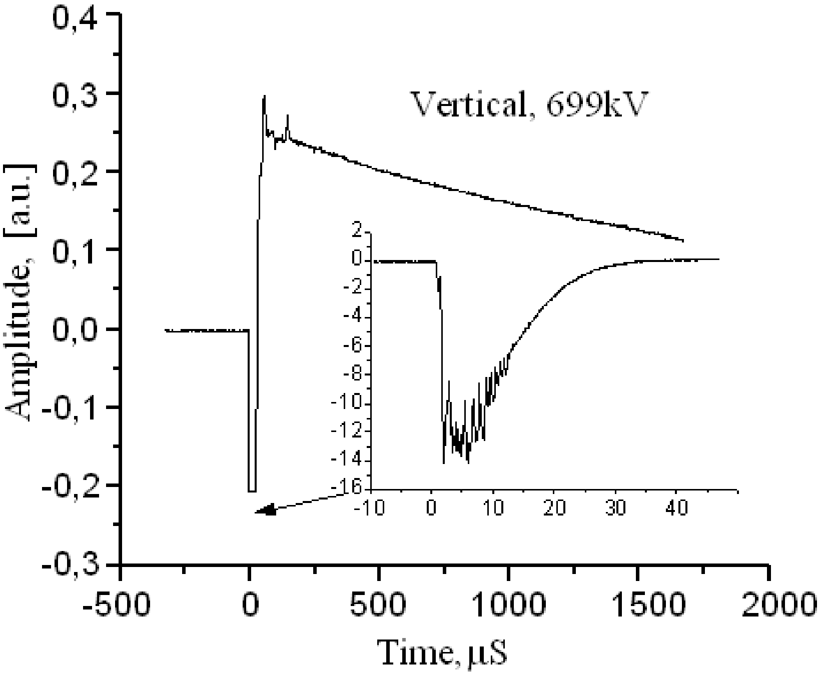

Fig. 4a. 699 kV surge waveform.

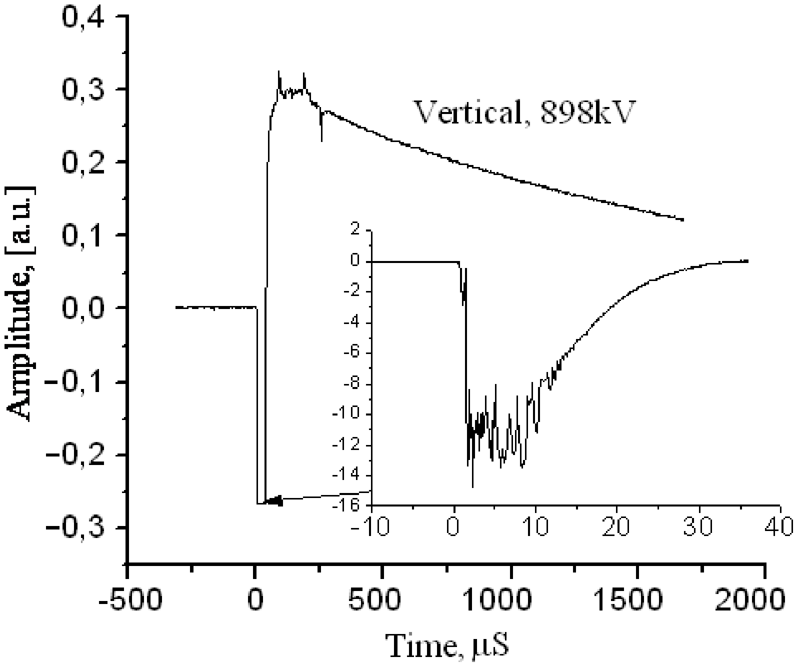

Fig. 4b. 898 kV surge waveform.

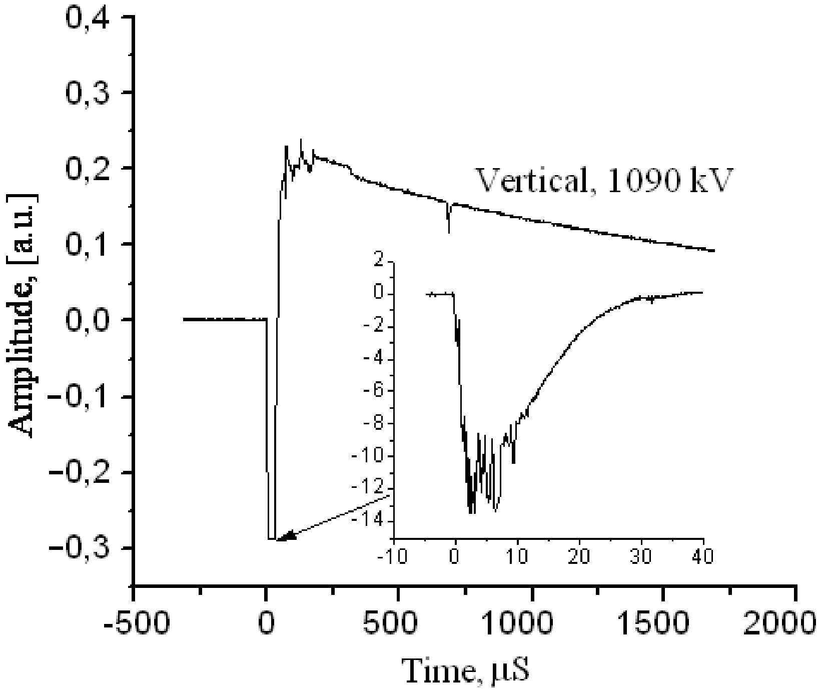

Fig. 4c. 1090 kV surge waveform.

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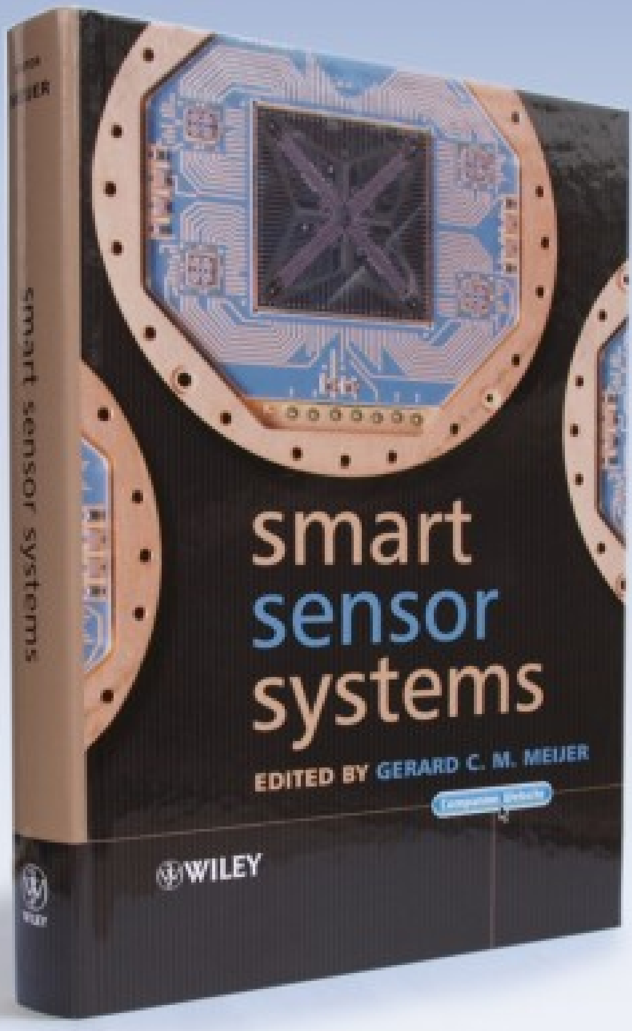

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