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RAPID COMMUNICATION

A fast electro-optic high-voltage sensor

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Abstract. This communication describes the construction and testing of a fast electro-optic high-voltage sensor, intended for use in a variety of pulsed-power applications. A 150 kV coaxial high-voltage cable is adapted to form an adjustable voltage divider, with the voltage across the lower section of the divider being measured with the aid of a Pockels cell. As developed, the sensor has been employed to measure 15 kV pulses with a rise time of less than 3 ns, and work is in hand to extend the pulse voltage measurement into the megavolt region.

Modern pulse-power techniques are encountered in areas such as the generation of bursts of high energy x-rays, or when explosive flux compressors are used as a short-term high-energy high-current source [1]. The instrumentation required includes an accurate and reliable method of measuring transient voltages that may rise to several megavolts in a few nanoseconds. The high level of electromagnetic noise created means that schemes using conventional voltage dividers [2] cannot readily be used, as problems associated with ground loops at the remote and inaccessible sites, where much of the experimental work is undertaken, and the provision of adequate shielding of the useful low-voltage signal are difficult to overcome. Existing high-voltage schemes based on electro-optic sensors [3, 4] are not easily adapted, because of the necessarily long distance between the sensor and the measuring equipment, the intense electric field produced and the loss of the transducer during each experiment. This communication describes a sensor in which many of these objections are overcome, and which is simple, inexpensive and can be coupled via optical fibres to the measuring equipment. Results are presented for a sensor measuring voltages rising to about 15 kV in a few nanoseconds, as a step towards a megavolt device.

The measurement system being developed includes both electrical and electro-optic sections, with the former being a fast capacitor voltage divider based on a length of 150 kV polyethylene dielectric coaxial cable as shown in cross section in figure 1. A high-voltage electrode HV which can be moved vertically replaces the normal central conductor, while an aluminium electrode E_1 together with mylar foil I_2 and an earthed copper electrode E_2 surround the cable dielectric I_1. Vertical movement of HV alters the capacitance between HV and E_1, but not between E_1 and E_2, and with the low-voltage output taken between E_1 and E_2 this enables the voltage ratio of the divider to be varied. The unit was tested in a 100 kV DC circuit, with the small quantity of transformer oil O above the central electrode introduced to prevent corona discharge. Figure 2(*a*) illustrates the response of the voltage divider to a step input change of 15 kV, by comparing the output signals obtained with a 100 MHz bandwidth oscilloscope fed via both an appropriate high-voltage probe with a bandwidth of 75 MHz and the voltage divider followed by the matching resistor and panel jack shown in figure 1. Extremely close correspondence is evident between the two recorded traces.

Figure 1 shows the electro-optic Pockels cell mounted within the output electrodes E_1 and E_2 of the voltage divider. Polarized light is received from a 5 mW HeNe laser positioned 10 m from the cell, with detection of the light output achieved, again about 10 m from the cell, using a 700 MHz bandwidth opto-electronic converter followed by a 100 MHz oscilloscope. When the voltage divider is energized, the action of the Pockels cell is to cause a change in the light received by the converter (and therefore in the deflection of the oscilloscope), which is directly dependent on the output voltage of the capacitor divider. Both the laser and the converter and oscilloscope are contained in Faraday cages and, where necessary, optical fibres can be used to provide the optical path.

Figure 2(b) compares the output from the optical sensor recorded on the oscilloscope with that obtained via the high-voltage probe, and shows clearly that a faster sensing signal is obtained. The relative permittivity of the cable insulation was 2.25, and with the cable length of 120 mm this gave a rise time of 1.2 ns [5] for the high-voltage arm of the voltage divider. Together with the 0.4 ns [6] and the 0.5 ns introduced respectively by the Pockels cell and the opto-electronic

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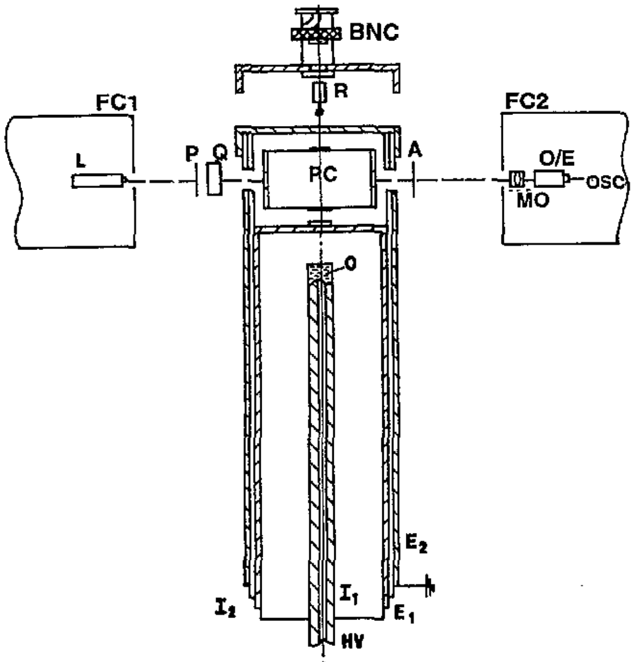

Figure 1. Experimental unit (not to scale). L, 5 mW HeNe laser; FC, Faraday cages; A, analyser; P, polarizer; Q, $\lambda/4$ plate; PC, Pockels cell; HV, high voltage electrode; O, transformer oil; MO, microscope objective lens; R, matching resistor; OSC, 150 MHz oscilloscope; O/E, 700 MHz opto-electronic converter; BNC, panel jack; I, insulators (I_1 polyethylene, I_2 mylar); E, electrodes (E_1 aluminium, E_2 copper). Supplementary insulation at the input not shown.

converter, the estimated rise time of the overall sensor is between 2 and 3 ns. This compares favourably with the 4.6 ns rise time of the high-voltage probe and the less than 3.5 ns of the oscilloscope. The noise appearing on the optical signal is inherent in the converter when insufficient light is provided to its 50 μm diameter input, and could be almost eliminated by using a 50 mW laser as the light source. Based on the success so far achieved, a larger unit suitable for use with megavolt pulses is under development.

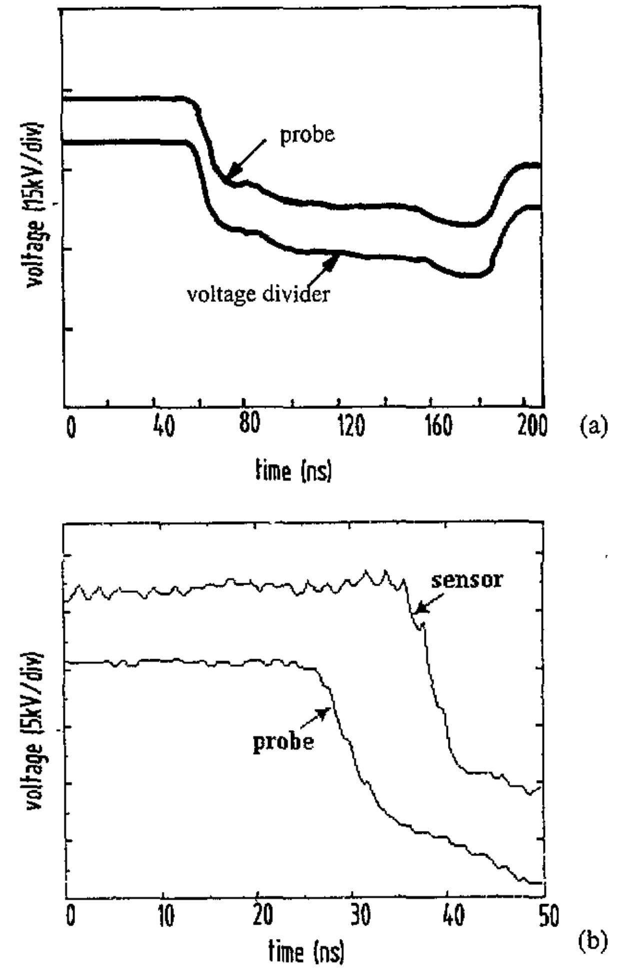

Figure 2. Output response of (a) voltage divider and (b) sensor both for a 15 kV step input, compared with the corresponding high voltage probe signals.

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