Fast probe for short and high intensity pulses

A. Lorusso [a b], V. Nassisi[a b], M.V. Siciliano[c b]

[a]Department of Physics, Università del Salento, Lecce

[b]Istituto Nazionale di Fisica Nucleare sez. di Lecce,Italy

[c]Department of Material Science, University of Salento, Italy

The real time diagnostic of short current or voltage pulses is essential for good application with sophisticate and modern devices. Streak camera systems are able to detect sub ps pulses of particle or X-ray beams, but losing the possibility to use the beams during the detection. Besides, real time measurements of electromagnetic pulses offer a better control of the device functioning. Fast capacitive probes, which we will present in this work, are simple capacitors conceived like a transmission line. Such a probe is suitable for measuring fast voltage and current pulses propagating in coaxial structures of known characteristic impedance.

One of the last researches, e.g. free electron lasers (FEL), utilise electron bunches of the order of ten picoseconds [1]. In them, due to the absence of fast probe development for monitoring current or voltage in real time, the diagnostic is only performed on integrated output signal. In this way no exact information on the time evolution of the signal can be obtained and the exact time duration remains incognito. Various applications of short high voltage pulsers such as streak camera [2], Pockel cells [3] and optical modulator need of high voltage probes [4]. Inductive and/or capacitive probes of fast risetime can revolutionize the diagnostic methods which allow to record pulses in real time without disrupting of their propagation. The use of these probes is not very easy especially when incognito signals of short time duration must be detected. The design parameters of fast probes must be matched to the characteristics of the apparatus in order to reco rd pulses in real time. The successful is reached if very fast recording devices are disposable. Modern fast digitizing oscilloscopes have got sampling rate of more than 40 GS/s and bandwave up to 13 GHz which enhances the possibility to record fast pulses.

The response of an inductive divisor closed on a load of resistance R_L excited by a Heaviside function $I = I_0 u(t)$ is given by the following expression:

$$I_{out} = I_0 \frac{k\sqrt{L_1 L_2}}{L_2} u(t) e^{-t/\tau} \tag{1}$$

where L_1 and L_2 are the primary and secondary inductance, respectively, k is the coupling coefficient and τ is the relaxing time dictated by the ratio L_2/R_L. From Eq. (1) it is evident that the input signal will be derivate. Instead, for pulses of time duration $\tau_p < \tau$ the input signal becomes auto-integrated being $e^{-\tau_p/\tau} \approx 1$ and the response given from Eq. (1) reproduces the input signal. Instead, the more common devices utilised for voltage pulse diagnostic are the capacitive ones [5]. Both instrumentations are not invasive due to their high impedance values but their better risetime is 1 ns.

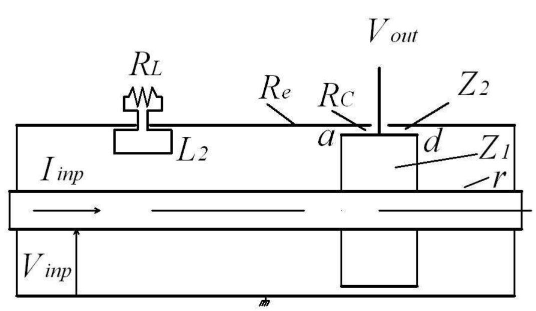

Figure 1. Experimental apparatus of a transmission line containing the current probe and the capacitive probe.

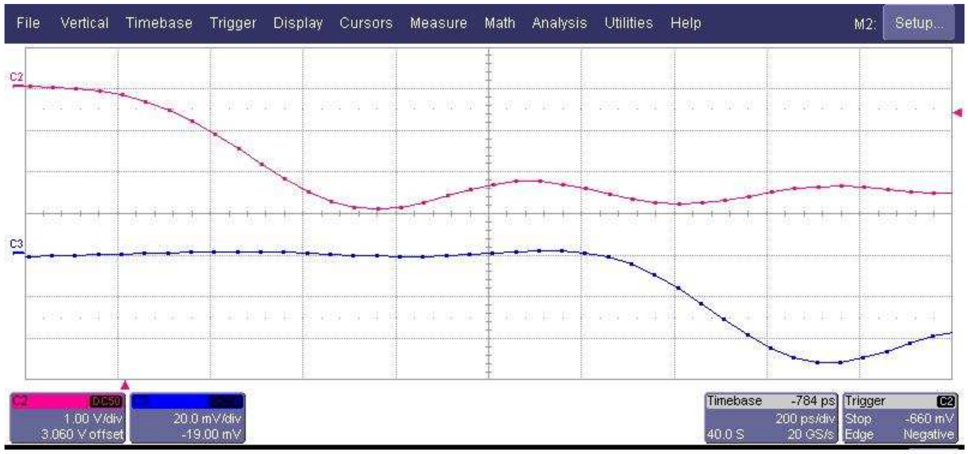

Figure 2. Experimental result. C2: input signal; C3: output signal.

Generally, the response of a capacitive divisor closed on a load resistor R_L and excited by a Heaviside function like $V = V_0 u(t)$ is given by the following expression:

$$V_{out} = V_0 \frac{C_1}{C_1 + C_2} u(t) e^{-t/\tau} \tag{2}$$

where C_1 is the capacitance of the input capacitor (between the inner conductor and the divisor electrode of radius R_C), C_2 is the one of the output capacitor (between the divisor electrode and the ground) and τ is the relaxing time given by $R_L(C_1 + C_2)$. Indeed in this case, for pulses of time duration $\tau_p < \tau$ the signal will be auto-integrated being $e^{-\tau_p/\tau} \approx 1$ and the Eq. (2) reproduces very well the input signal.

Fig.1 shows the schematic diagram of a generic transmission line containing an inductive auto-integrating divisor and a capacitive auto-integrating divisor. Let us call R_C the radius of the divisor electrode and approximating the divisor electrode with internal conductor to a short transmission line of a-d length, the characteristic impedance of this structure is Z_1. In the same way the divisor electrode with the external conductor forms an other short transmission line ever of a-d length by characteristic impedance Z_2.

Now, applying a voltage function by Heaviside waveform, $V_{inp} = V_0 u(t)$ on one extremity of the line, a voltage signal propagates, as well as a current one of $V_{inp}/(Z_1 + Z_2)$ intensity. Neglecting the thickness of the divisor electrode, the line impedance $Z_0 = Z_1 + Z_2$ and the propagating electric field will be divided; part of it will be in Z_1 line and part will be in Z_2 line. In this case closing the divisor electrode on a load resistive of $R_L \to \infty$, the potential of the divisor electrode will be:

$$V_{div} = \frac{\ln(R_e/R_C)}{\ln(R_e/r)} V_0 u(t) \tag{3}$$

In Fig. 2 we report the waveforms of the input signal (trace C2) and the output signal (trace C3). The amplification factor was $(3.6 \pm 0.1)x10^{-4}$. By these results it is noteworthy observe that the current attenuation factor was 56 ± 1 A/V, while the risetime of input and of the response attains at about 320 ps corresponding at the risetime of the oscilloscope.

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