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LETTERS TO THE EDITOR

ON THE OPTIMIZATION OF THE CAPACITIVE BEAM PICK-OFF*

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Tests with the capacitive pick-off used with a time-of-flight system are described, and the optimization of the parameters is discussed.

The use of a capacitive pick-off for generating timing signals from beam pulses is well known. The purpose of this note is to describe the system in use with the University of Michigan's time-of-flight facility, and in particular to indicate how the signal-to-noise ratio and pulse rise time are optimized.

The beam line consists of an aluminum duct of diameter $D = 6''$. A brass cylinder of length l and diameter d is mounted coaxially in and insulated from the beam duct just upstream of the target near a focus of the ion-optical system. Conducting irises with axial openings of diameter d' are mounted a distance l' in front of and behind the brass cylinder as shown in fig. 1 The charge induced on the cylinder by the approach of beam pulses results in a voltage signal which is direct-coupled to a high-input-impedance amplifier mounted in the duct physically close to the cylinder. To minimize jitter in the derived timing signal, it is important to match the amplifier to the pulse shape and to minimize noise.

The duty cycle is short, the beam pulses being approximately triangular in shape of width $t_p \approx 2$ ns at the base and separated in time by the order of 1000 ns.

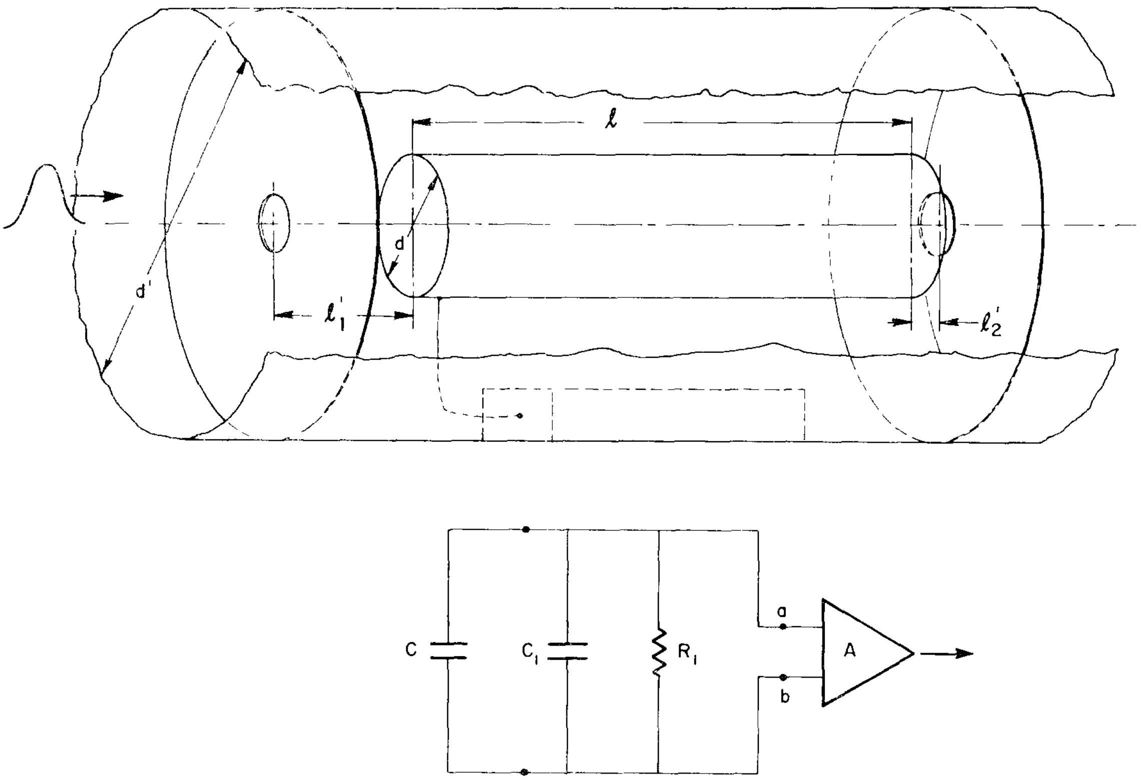

Fig 1 The geometry of the capacitive pick-off and the equivalent input circuit of the amplifier

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Typically the average current is $I_0 \approx 0.2\ \mu$A, thus the peak current is $I_p \approx I_0 \times 2T/t_p \approx 0.2$ mA, the charge per pulse is $Q = I_0 \times \frac{1}{2} t_p \approx 2 \times 10^{-13}$ C, and the pulse travels down the beam line with $\beta = (v/c) \approx (2T/E_0)^{\frac{1}{2}} \approx 0.15$. Each pulse has a spatial extent therefore of about $S = vt_p \approx 9$ cm. Provided the inner cylinder is long compared to S, each beam pulse induces a charge $-Q$ on the inner surface of the cylinder, and provided the time constant associated with the capacitance is long compared to l/v, a charge $+Q$ on the outer surface. The rise and fall times of the potential across the capacitance $C = 0.2416\ l/\log(D/d)$ pF will be relatively long since the induction process begins as the charge approaches from infinity and will become significant at distances of the order of a few D. These times can be reduced by inserting irises in the beam line as shown in fig. 1 to shield the inner cylinder from the electric field of the charge until it approaches to within about d'. The peak voltage induced across the input terminals (a, b) of the amplifier of input impedance $[R_i \| C_i]$ is $V = Q/(C + C_i)$ provided only that the time constant $R_i(C + C_i)$ is long compared to the rise time ($\tau \approx 2$ ns) of the pulse. To reproduce the rise time, the upper half power point of the amplifier (assuming RC coupling) must be about $f_h \approx 0.35/\tau \approx 180$ MHz. MOSFET's are now available having very large gain–bandwidth products with input impedances of the order of $10^{11}\ \Omega$ in parallel with a capacitance of a few pF. (An amplifier has been constructed with a gain of 30 and a rise time of 1.7 ns.) A droop in the pulse of 5% for a pulse width of 10 ns is more than adequate, thus the lower half power point of the amplifier can be at a relatively high frequency, $\sim 10^6$ Hz. This permits the main noise power to be shifted below the band pass of the amplifier. It should be noted that the timing signal should bear a definite relation to the mean charge distribution, thus the use of resonant responses is to be avoided.

The total mean-square thermal-noise voltage across the terminals (a, b) of the amplifier input, consisting of $[R \| (C + C_i)]$, is $\overline{V_t^2} = kT/(C + C_i)$, but for an amplifier having upper and lower half power points f_h and f_l the mean-square noise voltage referred to the input (a, b) is

$$\overline{V_{ab}^2} = \frac{2kT}{\pi(C+C_i)}[\tan^{-1} 2\pi R(C+C_i)f_h - \\ - \tan^{-1} 2\pi R(C+C_i)f_l]$$

$$\approx \frac{kT}{\pi^2 R(C+C_i)^2}\left(\frac{1}{f_l} - \frac{1}{f_h}\right),$$

$$\text{for } f_h, f_l > [2\pi R(C+C_i)]^{-1}.$$

The signal-to-noise ratio is $V_s/V_n = \pi Q[Rf_l/(kT)]^{\frac{1}{2}}$ and the improvement in signal to noise over dc coupling is $\pi[R(C+C_i)f_l]^{\frac{1}{2}}$. Thus if the lower cut-off is 2×10^6 Hz and $R = 10$ mΩ, $(C + C_i) = 16$ pF, the signal to noise is improved by a factor of 56. Of course, increasing f_l also decreases noise due to pick-up.

The signals obtained for three different arrangements of the geometry of fig. 1 are shown of fig. 2. In each case $D = 15.2$ cm and $d = 5.0$ cm. In fig. 2a, $l = 35$ cm, and in figs. 2b and 2c, $l = 17.8$ cm. Also figs. 2a and 2b are without and fig. 2c is with irises. The photographs were taken using a dc-coupled amplifier (gain 30, rise

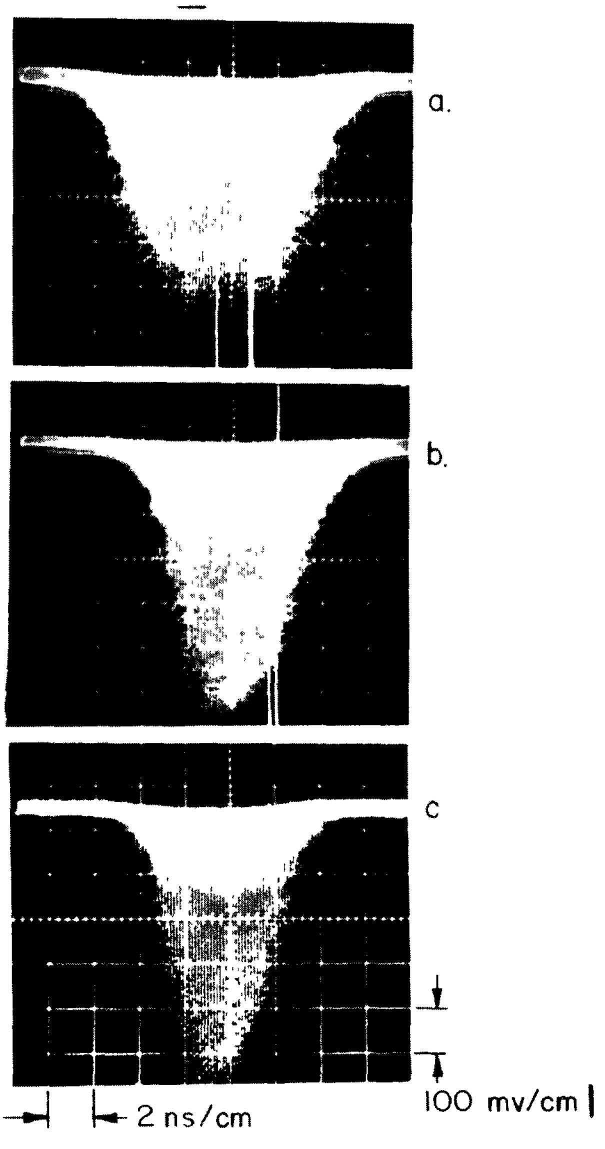

Fig. 2. The pick-off signals generated by the beam pulses. See text for description.

time 1.7 ns) and a Tektronix sampling scope. The time scale is 2 ns/cm and the voltage scale is 100 mV/cm. In fig. 2a the 4 ns flat top is consistent with the pulse length $S = 9$ cm and velocity $v \approx 4.5 \times 10^9$ cm/s for which the flat top should be 3.8 ns. The rise and fall times (3–4 ns) are symmetrical and the peak amplitude is about 450 mV. In fig. 2b the flat top has disappeared, again consistent with $S = 9$ cm, $v = 4.5 \times 10^9$ cm/s, the rise and fall times are essentially symmetrical (again 3–4 ns) and the amplitude is about 600 mV. In fig. 2c with irises ($d' = 2.2$ cm, $l'_1 = 5$ cm, $l'_2 = 1$ cm), the rise and fall times are more nearly 2.5–3 ns, and the half width of the pulse is approximately 1 ns less than for fig. 2b. The pulse height is essentially the same as for fig. 2b indicating that the irises add little to the capacitance. The pulse heights in figs. 2a and 2b are consistent with the measured total shunt capacitance at the input of the amplifier, being about 14 pF and 21 pF, respectively.

When used for timing, the signal from the 50 Ω output of the amplifier is sent through RG8/U foam coax to the data room, through a LeCroy Model 133B amplifier of gain 4 and clipping time constant approximately 0.1 μs, to an Ortec Model 453 constant-fraction timing discriminator. The output of the discriminator is used as the stop signal for the time-of-flight system.