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memorandum

Los Alamos Neutron Science Center
LANSCE-1, Accelerator Physics and Engineering

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SUBJECT: EM Analysis of SNS Capacitive Probes

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The memo summarizes an analysis performed for the SNS diagnostic elements – the energy and phase detectors (capacitive probes), which are intended for time-of-flight measurements. The study was initiated by Jim O'Hara's request to check the electromagnetic properties of the existing design of the SNS capacitive probes.

The EM code package MAFIA [1] is applied to the analysis of electromagnetic characteristics of the SNS capacitive probes. The characteristic impedances of transmission lines are computed in the static limit. The signal phase dependence on the beam transverse position is studied at the SNS bunch repetition frequency f_b=402.5 MHz using time-domain simulations with a beam. The approach is similar to that used for the EM analysis [2] of the APT diagnostics elements and relies on some of its results.

SNS Capacitive Probes

The capacitive probe (phase detector) consists of a ring inside a shallow cavity on a beam pipe, see Fig. 1. It has two 50-Ohm coaxial connections at the diametrically opposite locations (not shown). The probe dimensions [3] correspond to the beam pipe radius of 15 mm.

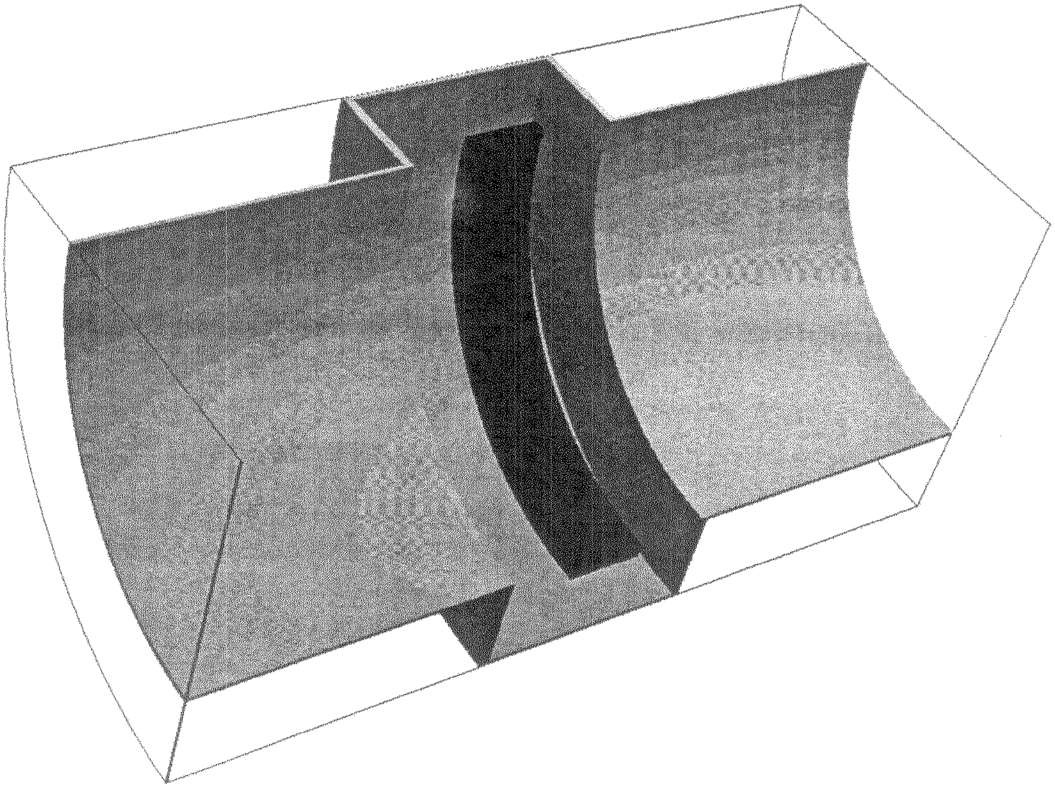

Figure 1: Capacitive probe model (one-quarter cut).

Static analysis

For 2D electrostatic calculations we assume a flat symmetric geometry with the same cross section as the longitudinal cut of the probe. It gives the characteristic impedance Z_c=96.3 Ω for the mesh Δr=0.25 mm, Δz=0.5 mm. Since two halves of the probe are connected in parallel, this leads to the line impedance close to 50 Ω.

To calculate Z_c from 3D electrostatic results one needs to know the electric length of the transmission line from one connection to the other. If we assume it to be equal to the average half-circumference, so that $r_{eff} = (r_{rout}+r_{cav})/2$=18.5 mm, we obtain Z_c=110.5 Ω for the same mesh. An assumption of the electric length being equal to ring length, i.e. $r_{eff} = (r_{rout}+r_{rin})/2$=15.875 mm, leads to Z_c=94.8 Ω. Facing this uncertainty, we prefer to use the electric length found from the time-domain simulations (see below): r_{eff} = 17.1 mm, which gives us the line characteristic impedance Z_c=103.6 Ω.

Dynamic analysis

Direct time-domain computations with an ultrarelativistic beam bunch passing the capacitive probe at the axis or parallel to the axis have been performed. MAFIA T3 code calculates the beam wakes and the voltages seen at the probe connections, which are simulated by discrete 50-Ohm resistors. We use a Gaussian bunch with the charge Q=1 Coulomb and the rms length σ=5 mm, with a varying transverse displacement d from the beam axis. Figures 2-3 show the voltages recorded at the upper (closer to the beam) and lower terminations as the bunch passes the structure.

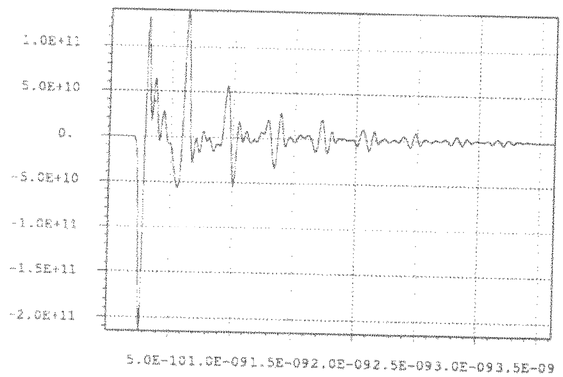

Figure 2: Voltage at the upper port (V per 1 Coulomb of the bunch charge) versus time (sec) for the beam displaced half-aperture up.

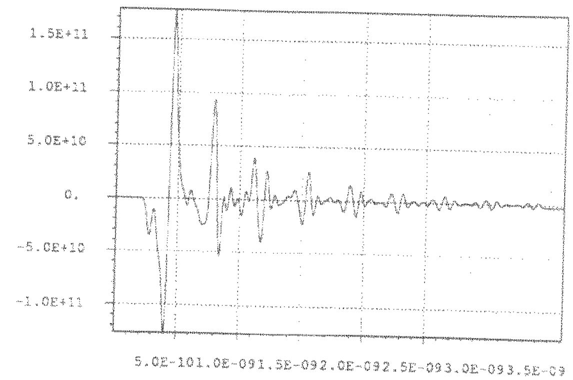

Figure 3: Voltage at the lower port (V per 1 Coulomb of the bunch charge) versus time (sec) for the beam displaced half-aperture up.

One can see from Fig. 2 that the first peak (beam signal) is stronger for the closer (upper) port. The repeating peaks in Fig. 2 correspond to this pulse as it travels along the transmission line coming back to upper port turn after turn. On the opposite, for the lower port, which is farther from the beam, the first peak (beam signal) is small, but the next, larger peak is due to strong pulse that came from the upper port in the half-turn.

We are interested in phases of these signals with respect to the phase of a centered beam at the probe working frequency, f_b=402.5 MHz. Therefore, we cut out the signal time range Δt= $1/f_b$=2.4845 ns and perform the FFTs of the cut-out signals. Figures 4-5 show the signal phases in the frequency range of interest when the beam is half-aperture displaced. The phase difference at 402.5 MHz is about 4.85° for this case.

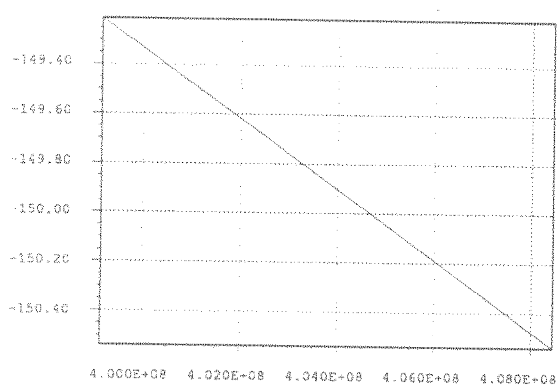

Figure 4: Phase of the upper-port signal (degrees) versus frequency (Hz) for the beam displaced half-aperture up.

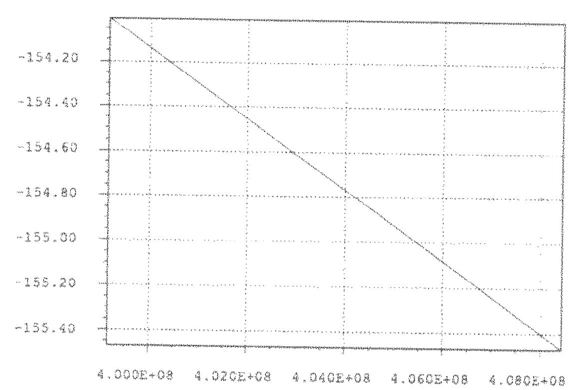

Figure 5: Phase of the lower-port signal (degrees) versus frequency (Hz) for the beam displaced half-aperture up.

The phases φ_u and φ_d at the both ports, and the phase difference $\Delta\varphi=\varphi_u - \varphi_d$ versus beam displacement are presented in Table 1. One can see that the phases are approximately symmetric with respect to that of the centered beam. In agreement with the analysis [2], the phase difference is approximately linearly proportional to the beam displacement.

Table 1: Signal phases at 402.5 MHz versus beam transverse deflection

Displacement-to-aperture ratio, *d/r*	0	1/4	1/2
φ_u,°	-152.15	-150.90	-149.68
φ_d,°	-152.15	-153.41	-154.53
$\Delta\varphi$,°	0	2.51	4.85

Like in the previous case [2], the both phases behave monotonically near f_b, and similar to each other. The phase difference $\Delta\varphi$ versus frequency is shown in Fig. 6, and Fig. 7 shows the phase of a signal produced by the centered beam.

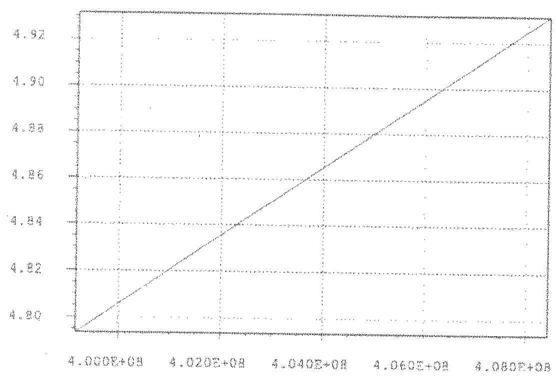

Figure 6: Phase difference $\Delta\varphi$ (degrees) of the port signals versus frequency (Hz) for the half-aperture displaced beam.

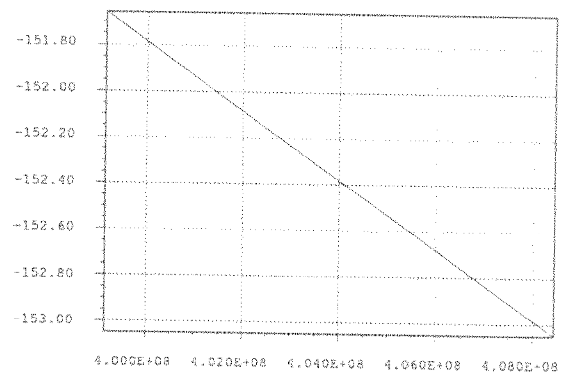

Figure 7: Phase of the port signal (degrees) versus frequency (Hz) for the centered beam.

References

1. MAFIA Release 4.00, CST, Darmstadt, 1997.
2. S.S. Kurennoy, LANSCE-1 memo 98-77, March 1998.
3. J.F. O'Hara, Private communication, May 1999.