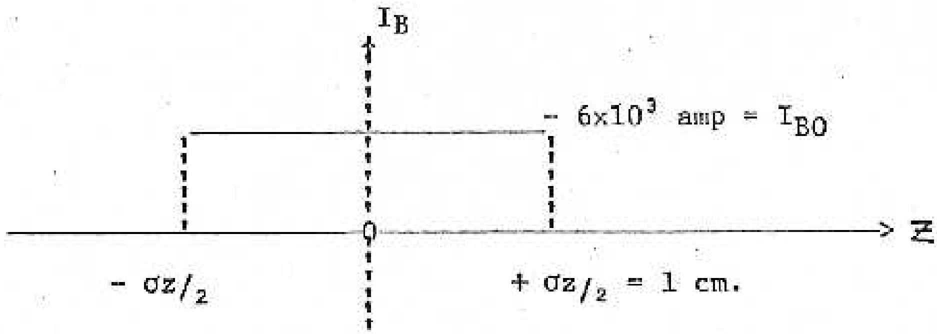
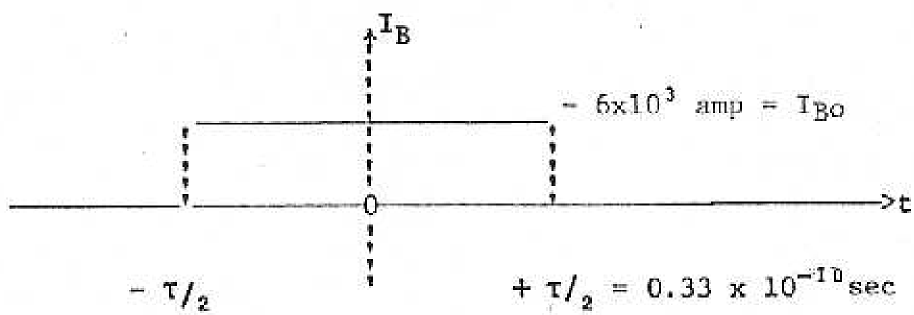
Beam Induced Electrical Noise In HRS

The periodic passage of PEP beam bunches through IR-6 will produce electric fields in the vicinity of our wire chamber detectors which could potentially cause signal wire noise problems. We were alerted to this matter by P. Wilson in PTM-189, 12/19/78. Wilson does an analysis based on image currents in the beam pipe and the resultant shielding effect. His results, based on a reasonable beam pipe wall thickness, are reassuring regarding the level of this noise in our drift-chamber wires. Since this could be an important matter, I have studied the problem from a different, but hopefully equivalent, approach in order to compare conclusions. Let me describe the situation.

The circulating electrons in the PEP ring constitute a current, I_B in the z direction when viewed from Intersection Region 6. Since the beam is bunched (1 to 3 bunches), this current has important a.c. components, and therefore generates an electric field, E_z, as Maxwell told us. Space and time-like representations of the beam are the following:





The zero of the z scale is the center of IR-6. The bunch width is $\sigma_z = 2$ cm. If there is only one bunch in the ring, the periodicity of this current pulse is $f_0 = 136$ KHZ. This is the worst case as far as noise is concerned and we will discuss this situation. The normal environment is 3 bunches which, of course, gives a periodicity of 408 KHZ. For design luminosity of $L = 10^{32}\text{cm}^{-2}\text{sec}^{-1}$ the average or d.c. circulating current is Idc = 55 ma. Therefore the amplitude of this current pulse is:

$$I_{BO} = \frac{c\ Idc}{f_0\ \sigma_z} = 6\text{x}10^3 \text{ amps.}$$

The Fourier components range from the fundamental, $\omega_0 = 2\pi f_0 = 0.85\text{x}10^6$ up to $m\omega_0$, where $m \simeq \frac{c}{\omega_0 \sigma z} = 1.76\text{x}10^4$. This corresponds to a maximum frequency of about 2.4 GHZ. The amplitude of the nth component is:

$$I_n = \frac{\omega_0 \sigma_z}{\pi c} I_{BO} = 2Idc$$

and its time derivative which we will need later is:

$$\frac{dIn}{dt} = 2n\omega_0 Idc$$

To find the electric field at a radial distance r from the beam, the easiest thing to do is first write down the vector potential $\vec{A}$

$$\vec{A} = \frac{\mu_0 I_B \sigma_z}{4\pi} \frac{\hat{z}}{r}$$

This is true when $r^2 >> \sigma z^2$. At the beam pipe ($r = 8$ cm and $\sigma_z = 2$ cm) this condition is met. The electric field then is:

$$\vec{E} = -\frac{\partial \vec{A}}{\partial t} = -\frac{\mu_0 \sigma_z}{4\pi} \frac{dI_B}{dt} \frac{\hat{z}}{r}$$

The amplitude of the nth harmonic is:

$$E_z(n\omega_0) = n \frac{\mu_0 \omega_0}{2\pi} \frac{\sigma_z}{r} \text{ Idc}$$

At the beam pipe and for design current Idc = 55 ma.

$$E_z(nw_0) = 2.2\text{x}10^{-3} n \text{ v/m}$$

Now if we put in the beam pipe, it will attenuate these fields by the factor $e^{-t/\delta}$, where t is the wall thickness and $\delta(n\omega_0)$ is the frequency dependent skin depth.

$$\delta = \left[\frac{2\rho dc}{n\omega_0\mu_0}\right]^{1/2}$$

The electric field just outside the beam pipe then becomes:

$$E_z(n\omega_0) = 2.2 \times 10^{-3}\ n\ e^{-t/\delta} \text{ v/m}$$

Let's look at some numbers to see what happens.

$$\rho_{Be} = 2.5\ \rho_{Ag} = 2.5 \times 1.63 \times 10^{-8}\ \Omega\text{-m}$$

$$\rho_{Be} = 4.08 \times 10^{-8} \Omega\text{-m}$$

$$\delta = 0.276\ \left(\frac{1}{n}\right)^{1/2} \text{ mm}$$

The beam pipe will be made of Berylium with t = .050" = 1.27 mm

n	δ	$e^{-t/\delta}$	$E_z(n\omega_0)$	f_n
	mm		μv/m	MHZ
1	0.276	1.0×10^{-2}	22	0.136
2	0.195	1.48×10^{-3}	6.5	.27
3	0.159	3.40×10^{-4}	2.2	.41
4	0.138	1.0×10^{-4}	0.88	.54
5	0.123	3.28×10^{-5}	0.36	.68
10	0.087	4.57×10^{-7}	.01	1.4
20	0.062	1.27×10^{-9}	6×10^{-5}	2.7

Oddly enough if there are three bunches instead of one, the situation is better, since now the fundamental is $3\omega_0$ and the largest electric field penetrating the beam pipe is ten times smaller than for only one bunch. For HRS we have further shielding of our spark chamber wires due to the Berylium tube of the inner-drift chamber assembly.

Incidentally, the way you find out how big the signal is at the end of your drift chamber wires due to these fields is from:

$$V\ sig = E_z l$$

Where E_z is the field at the wire and parallel to it and l is the length of the wire. This is a well-known antenna formula which is true when $l \ll \lambda$.

My analysis gives somewhat larger fields than Wilson's, but it appears that this source of noise will not be a problem for us. There will be other sources however.