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AGS WIDE BAND WALL CURRENT MONITOR

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AGS DIVISION TECHNICAL NOTE

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Introduction

If one wished to observe with maximum fidelity longitudinal structure of proton bunches in the AGS--the variation of charge density with time at a fixed azimuth in the ring--one would probably be directed to the assembly of hardware which senses the beam's image current at the F-20 straight section. This note describes that hardware and argues that the signal observed has only modest distoration for frequencies in the bunch below 1 GHz.

Description

This beam detector is a wall current monitor. A bunch of protons mvoing within the vacuum chamber drags with it an image charge on the inside wall of the chamber. If the chamber wall is interrupted by a resistive ring, the image current will create a voltage drop across the ring while the bunch passes, proportional to the local current in the bunch. The frequency fidelity of the device is expected to be high simply because the lengths inherent to the device are small--the resistive break can be a few centimeters wide (too narrow and the gap capacitance gets too large), while even a very tight bunch is 10 ns (or 300 cm) long. A fairer parameter for estimating the frequency response is the vacuum chamber radius. One might expect resonant phenomena with $\lambda \sim$ diameter = 15 cm, or frequency $\simeq c/15\ \mathrm{cm} \simeq 2$ GHz. We shall see that extracting, transporting and displaying the signal in the main control room cause distortion before this frequency is reached.

It should be stated early on that the device described is a copy, in thought if not in execution, of a similar type monitor which exists in each of the booster rings at CERN.[1]

The resistive ring is realized by first breaking the vacuum chamber and inserting an insulating ring, and then bridging the break with fifty 1/4 Watt 250Ω resistors, mounted in parallel, and equally spaced around the break. The voltage across the ring is coupled to a single 50Ω coaxial cable by ten short symmetrically located 50Ω coaxial cables. Each short cable connects to five of the 250Ω resistors bridging the break using tapered copper fingers. The ten cables fan together to a single cable using a passive resistive matching unit. Some diagrams of this construction are shown in Figure 1. In the limit that the impedances at the gap and at the fan in are pure resistive and if the beam applied equal pulses to each resistor, this set up would be perfectly matched. These assumptions get poorer as the frequency increases and some resonant coloration of the output is expected. The length of first importance is that of each of the ten connecting cables-necessarily of order the beam chamber diameter. From bench tests, to be described later, the frequency response variation due to this coupling fluctuates by at most 6 db over frequencies below 1.2 GHz.

Once the signal is on the single cable it is carried to the main control room, a distance of 320 feet from the closest practical point in the ring, the straight section following the F-20 magnet. Air-dielectric, 7/8" diameter coaxial cable is used, this being small enough to run in (with difficulty), yet giving an acceptable attenuation at 1 GHz of about 4 db. Figure 2 gives the cable attenuation taken from the cable spec. sheet.

Finally, the signal is displayed on an oscilloscope. Two are available--a Tektronix 7834 storage scope, whose frequency response has fallen by 3 db at 400 MHz, and a Tektronix 7104 oscilloscope, with a 1 GHz 3 db point. The various pieces in the system are reasonably matched frequency-wise.

Band Width Tests

Frequency response study falls into two categories: (1) bench testing of the pick-up and its associated cabling and (2) observation, and comparison with other pick-ups, of the AGS beam. The second type is more interesting and relevant, but the first is more controlled.

The fan-in network connecting the ten cables from the pick-up to the single high frequency cable was tested first. Two such units were constructed and a signal was fanned out in one and then recombined in the other. Input was compared with output as the signal frequency was varied. Typical results are shown in Figure 3. The "Δf" in the figure is the frequency change needed to change the number of wavelengths on the connecting cables by $\lambda/2$. The effect of the cable resonances is evident as is a much higher frequency resonance, perhaps the metal cans containing the resistive summing networks. Next, the pick-up with its cables was inserted into a 50Ω coaxial system--a cable; an adaptor to a 6" diameter coaxial tube, split for the pick-up; and another adaptor back down to a cable. A signal then could be applied to the system, observed at the terminated output, and compared to the pick-up signal (see Figure 4). The results from this test are shown in Figure 5. The distortions with frequency are quite similar to Figure 3, presumably due again primarily to the coupling system, and display a 6 db variation within the frequency range of test. From the fan-in result mentioned above, it would be reasonable to expect an even larger distortion at $\sim$ 1.6 GHz.

In the ring, the situation is somewhat different from the coaxial structure set-up, especially with respect to the low frequency end of the spectrum. In a coaxial structure the response from the monitor extends to dc, while in the ring, the vacuum chamber is electrically broken between magnets, and so the image current cannot have a dc component. The low frequency behavior is determined by the return path available to the bunch image charge. This problem is handled in the CERN design, and indeed will be in our device, by enclosing the resistive ring in a conducting shield which contacts the vacuum chamber electrically upstream and downstream, hence providing a dc return path, and incidentally shielding the pick-up from external rf fields. This shield also shorts the signal frequency components below that at which the effective impedance (inductive) of the shield path becomes of the order the 2.5Ω resistance of the gap. The low frequency cut off is supressed by increasing the inductive coupling to the signal shield path, which is accomplished by putting ferrite rings around the vacuum chamber under the shield. The shield is esthetically pleasing and is being added to the F-20 pick-up. The ferrite rings, taken from a pre-conversion AGS rf cavity, sawed in half to ease assembly, have been tested using the 50Ω coaxial set-up mentioned above to assure that their permeability falls sufficiently slowly with frequency to keep the impedance of the shield path large over the entire range above the frequency cut-off. Ten of these rings, each with an ID of 20 cm, an OD of 35 cm, and a thickness of 2.1 cm, will be placed around the chamber, supressing the low frequency cut-off (3 db) to 50 Kilohertz, hence causing a 15% base line distortion in a square bunch 50 ns long.

In fact, the unshielded pick-up appears not to suffer an rf noise problem, nor, if care is taken to keep the downstream break in the vacuum chamber several meters away from the pick-up, is the low frequency response unacceptable.

Turning then to results from the pick-up as it is presently installed in the ring, it is interesting to first look for the 200 MHz structure in the injected beam from the linac. Figure 6 shows the result with the 200 MHz structure clearly present, riding on the stored beam. The storage scope is triggered at 1μs intervals during the AGS multi-turn injection.

The AGS has an electrostatic wide band pick-up located in the E-20 straight section. Its frequency response has been bench tested to 200 MHz.[2] In order to gain confidence in F-20, the two should agree within their bandwidths. The new pick-up has approximately 10 times the gain of the E-20 pick-up to a given beam pulse. This explains the relative clarity of the 200 MHz linac structures. The bunches in Figure 6 would be of only 1 mV amplitude in E-20 and, hence, difficult to see. The E-20 pick-up has been used for measuring bunch lengths in several recent AGS studies. One of the motivations for the wider band pick-up was to confirm the measurements made with E-20. Figure 7 shows pictures of the same bunch on successive cycles of the machine, in the F-20 and E-20 pick-ups. The two agree, provided the tail on the E-20 picture is ignored.

One of the worrysome characteristics of the E-20 pick-up is a high frequency (approximately 800 MHz) ringing around the "transition" energy at high intensity (approximately 10^{13} protons) which continues after the bunch is no longer between the electrodes. Figure 8 shows the phenomenon using the 1 GHz scope. The F-20 pickup also sees the 800 MHz structure, but only when protons are present (Figure 9). Perhaps the E-20 pick-up and the bunch interact at this frequency, and F-20 documents resulting bunching within the bunch. This observation suggests further study which will be undertaken when the AGS returns to high intensity running.

Many people have helped with this project. Sal Giordano contributed long and very constructive discussions, as well as his experienced hand during the bench testing. Al Maschke and Gene Raka provided helpful orientation. Erwin Rodger provided engineering know-how. Flemming Pedersen outlined the entire device.

References

1. G. Gelato, PSB Wide Band Observation System Survey of Options and Proposed Solution, SI/Note EL/70-5 31.8.1970.

2. Private communication, J.G. Cottingham.

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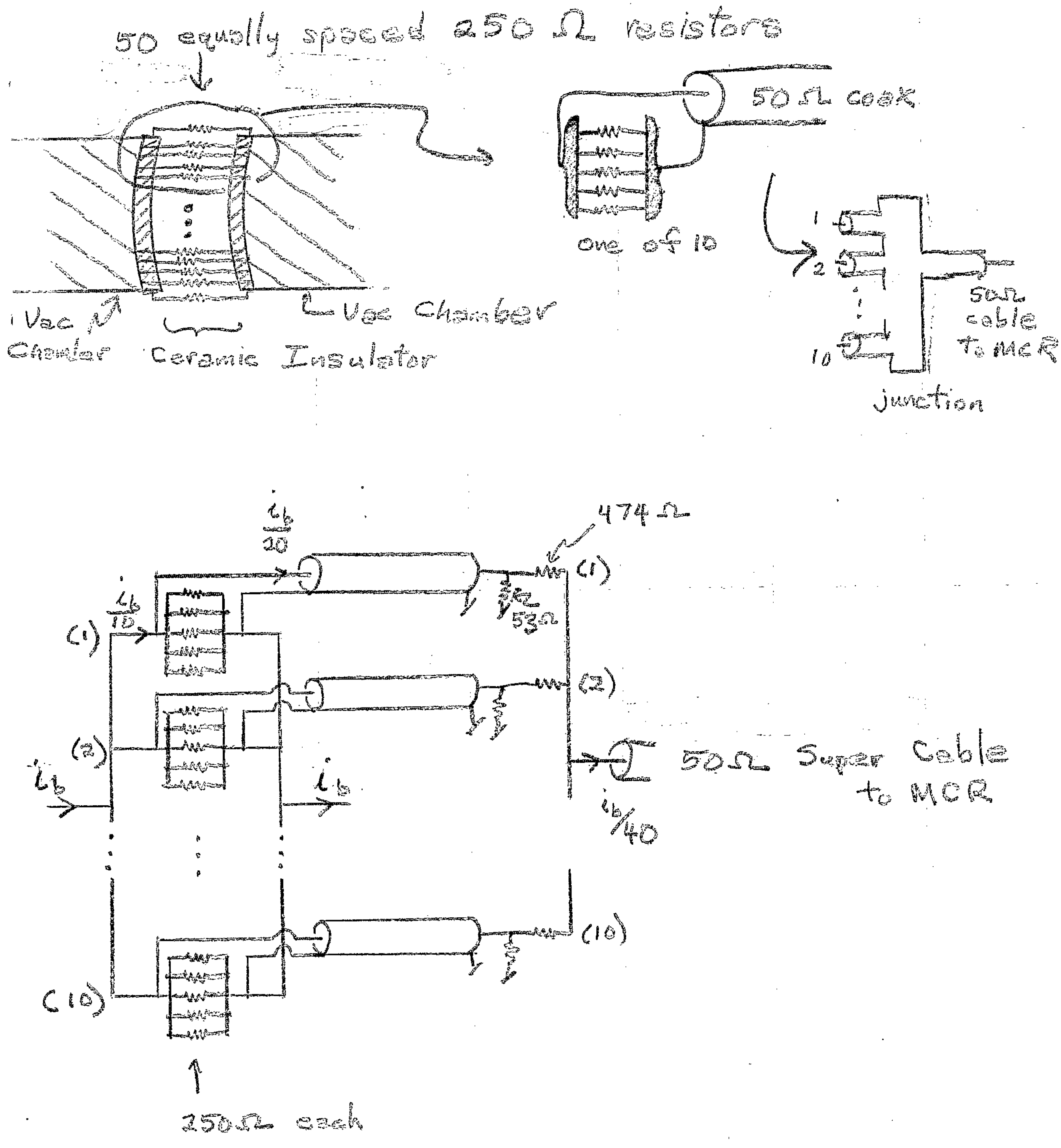


Schematic of F-20 image current pick-up

Fig 1

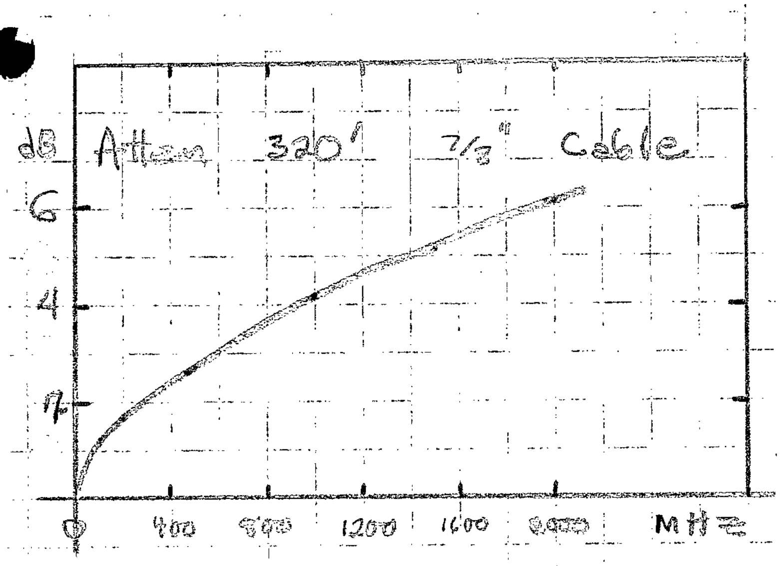
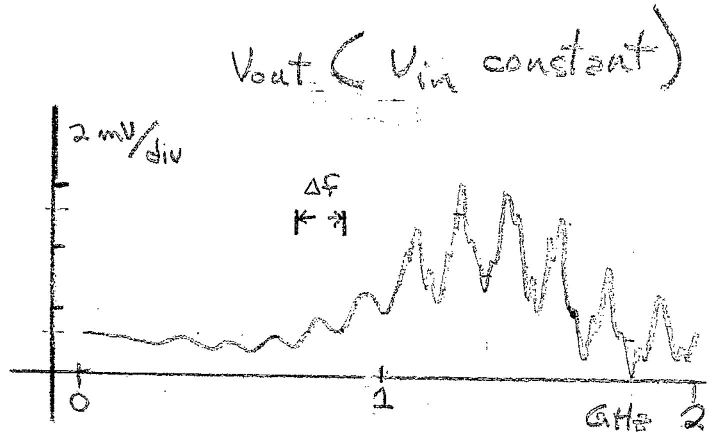


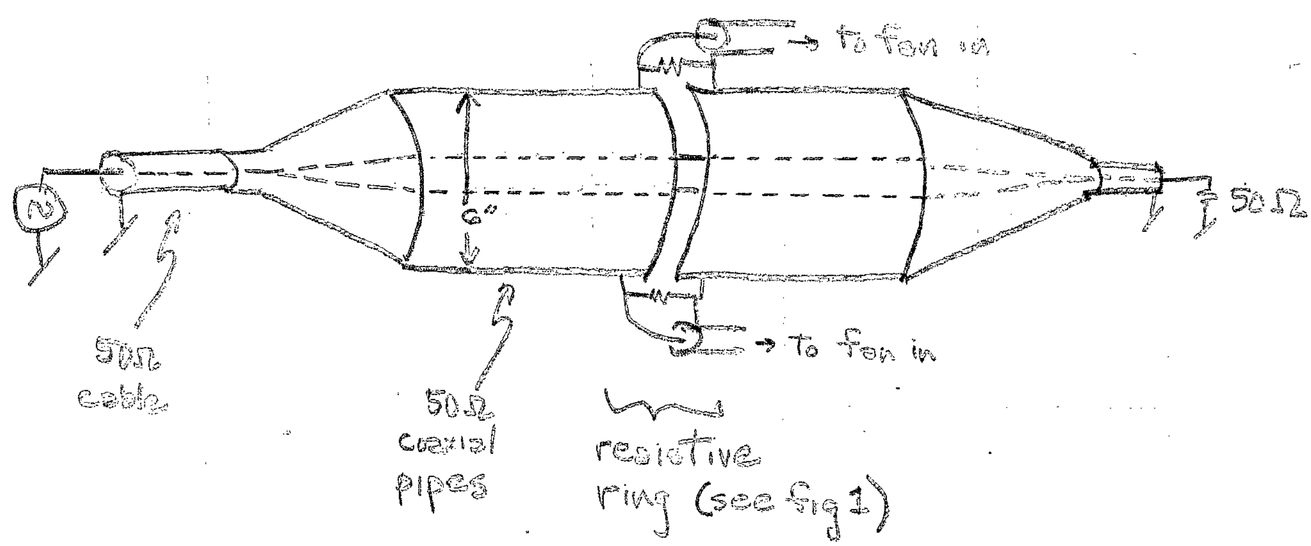
Fig 2 cable freq response



Frequency Response
fan-out → fan-in network

1037A

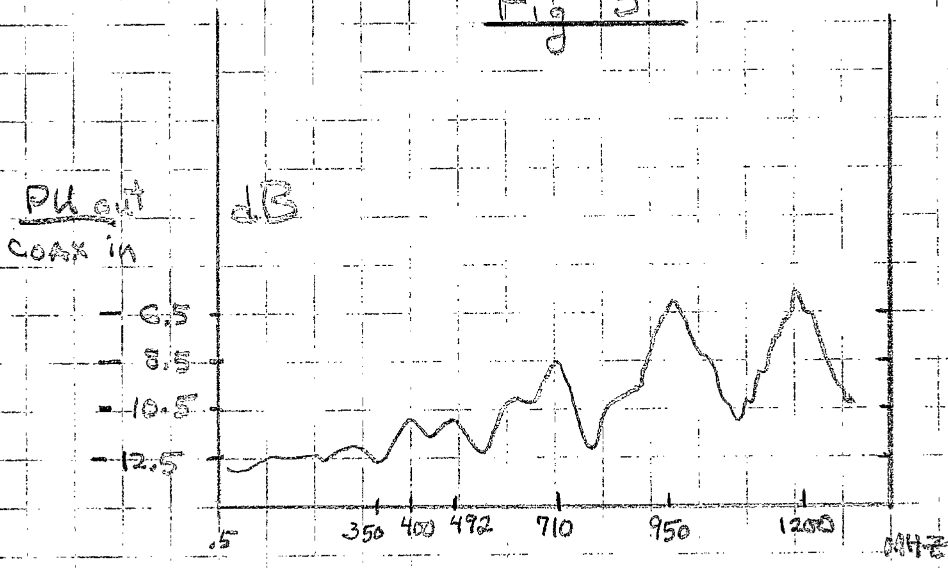
Fig 3



50 Ω coaxial bench test set-up

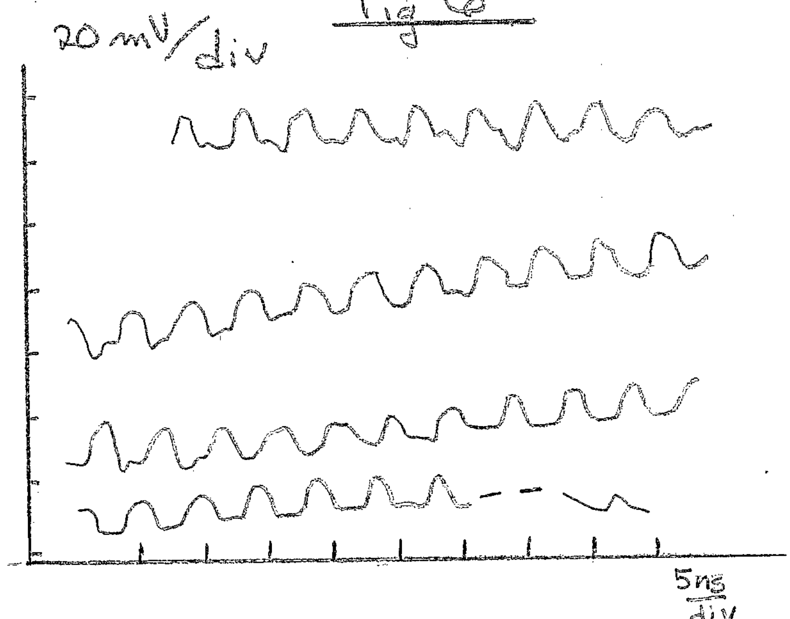
fig 4

Fig 5



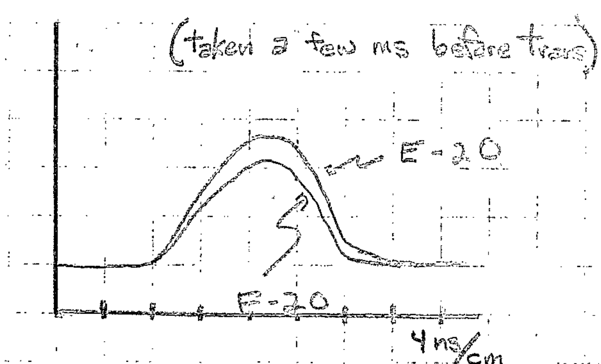
"E-20" bench test frequency response using 50Ω coax set-up

Fig 6



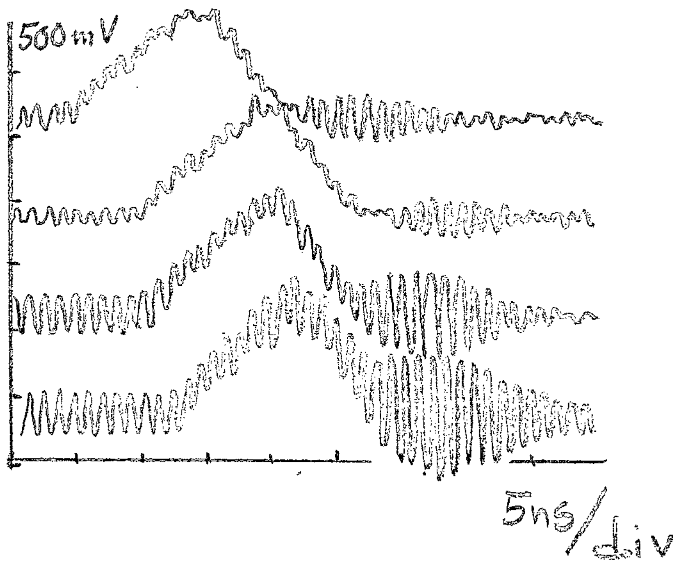
200 MHz structure in the injected beam

Fig 7



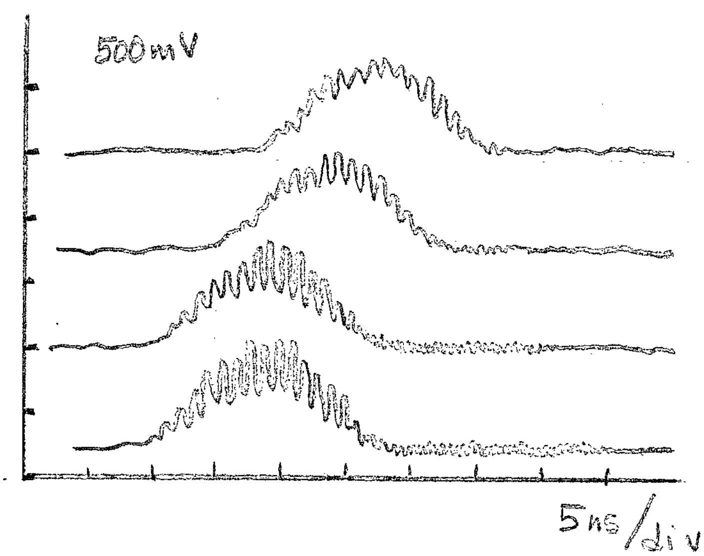
same bunch, spaced by one revolution in time (arbitrary amplitude)

Fig 8



E-20   500 μs after "transition"
200 μs delay between traces

Fig 9



F-20   same conditions as in figure 8, not same bunch