ACOUSTIC SPARK CHAMBER SYSTEM FOR BEAM MOMENTUM MEASUREMENT

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1. INTRODUCTION

In this note we describe an acoustic spark chamber system for momentum measurement of a particle beam. We intend to use the system at the Rutherford Laboratory in an experiment to investigate rare decay modes of the ω^0. The system is designed to produce parallel outputs, one of which is an actual value of momentum. The accuracy of this analogue circuit is rather high and for many types of experiment may be quite adequate. The other virtues of the system are the extreme simplicity of the spark chamber design and its flexibility.

2. SPARK CHAMBER DESIGN AND CONSTRUCTION

The use of circular foil chambers and modular construction gives important advantages in the precise location of the transducers and the stretching of the aluminium foil are both facilitated. Figure 1 shows the general appearance of a 3 gap chamber.

A foil module, shown in Fig. 2, consists of a perspex annulus with a 12 micron aluminium foil bonded onto each side. The foil must end before the earthed front plate of the transducer and in order to preclude edge sparking the edges of the foil slope away into a wedge shaped groove so that the gap separation at the edge is 50% greater than the normal gap separation. Before bonding the aluminium foil the perspex annulus is compressed in a hose clip. Unstretched foil is then bonded on to each side of the perspex ring along the sloping surface, with a toluene solvent expoxy resin (Araldite 107). When the bond is set, the clip is unscrewed and the perspex expands to normal size, stretching the foil. The flatness of surface obtained is limited only by the accuracy of the perspex surface. This method has been used successfully with both 18 cm and 28 cm diameter annuli. Thin frames show a tendency to bend out of a place and we have found that the annuli must be about 6 mm thick. There is a dead space of this amount between active gaps.

The transducer module also defines the gap separation. The 4 holes which hold the transducers (see Fig. 4) are drilled accurately with respect to the 16 locating holes. When a chamber is stacked and screwed up with studding through the locating holes, the transducers are accurately located (to 0.2 mm) one above the other. Figure 5 shows a section through a transducer. A 4 mm x 2 mm x 1 mm lead zirconate titanate crystal fits closely in the hole and location to the accuracy of the hole is possible. The hole is then filled with the damping material (tungsten- "Araldite" mixture). The output signal is taken from the back face of the crystal via miniature co-axial cable to a sub-miniature socket which is screwed on to the outside wall.

Partly because of the high mechanical coupling between the crystals and the chamber body itself, and partly because of reflections, it is found necessary to line the walls of the chamber with felt.

3. OPERATION AND PERFORMANCE

Small crystals (4 mm x 2 mm x 1 mm) have been found to be most satisfactory. Firstly, they approximate more nearly to point detectors and so enhance resolution. Secondly, it has been found that the angular response of a plain crystal transducer is a function of the crystal dimensions. Figure 6 shows a set of angular response curves obtained with crystals of 5 mm, 2 mm and 1 mm widths. The better response of the smaller crystals at large angles is probably due to diffraction. The crystals are mounted with their longest dimension normal to the foil. Measurements were taken to check on the linearity of the system and to measure the "effective spark size". The distance between the detector and a spark produced between 2 metal points was measured with a travelling microscope and the time delay was read off a scaler. The full width at half height of the histograms obtained was $\sim \frac{1}{2}$ μsec. The width is almost wholly determined by the clock frequency at which the scalers were operating.

Results were obtained with discharge capacities within the range 180 pF - 1000 pF, (spark energies 0.0025 - 0.01 joule), and the two extreme cases are plotted in Fig. 7. The intercept on the abscissa gives the effective spark size and under these conditions, with sparks in air, its value increases from 1.8 mm to 2.8 mm within the range of spark energies used.

As well as producing a small effective spark size, low energy sparks do little damage to the thin foils and since they are used here in conjunction with small crystals, large post amplification is required. A typical output voltage of 200 mV is obtained from the current sensitive transistor preamplifier with a spark energy of ~0.0025 joule. (Noise level is ~5 mV). A current sensitive preamplifier gives an acoustic signal with ~1 μsec front edge as opposed to ~2 μsec for a charge amplifier. The outputs of the preamplifiers are taken to standard types of discriminator circuits with a bias variable from 20 mV to 1 volt.

The spark chambers are located in two pairs on either side of a bending magnet quadrupole system such that the 2nd and 3rd spark chambers are at conjugate points. Thus, to 1st order, a measurement of spark position in each of these two chambers is sufficient to define the momentum.

The electronic logic system (Fig. 8) has been designed to be as flexible as possible. Since the system is to be used on a beam line the high particle flux may result in some old tracks in the spark chamber still having finite efficiency for spark production. This can be tolerated to some extent for a system in which all tracks are nearly parallel by taking the outputs of the sonic detectors through preamplifiers and discriminators to majority gates in order to select when at least a certain number (say 3 out of 4) of the gaps have fired at the same place. These logic systems plug in on a patch panel and the type of logic can be readily changed. The firing of a single gap or a pair of gaps at some other position would not be recorded and would not affect the results. The outputs from the majority gates are used as stop signals for scalers counting up to 5 Mc/sec clock pulses and for the analogue momentum display.

When the chamber is pulsed very high interference currents are generated and we use a clamping pulse to hold open the scaler gates regardless of discriminator pulses for the first 50 μsec or so. This seems more convenient than opening the scaler gates after a fixed time, and it avoids error arising from variation in this delay.

The analogue system has three uses:

1) Checking correct operation of spark chambers, preamplifiers discriminators and logic circuits.

2) Providing a reasonably accurate value for the momentum of each particle.

3) Enabling a spark chamber to be used for beam profile measurements. The system we describe will handle up to 10 particles in each machine pulse from Nimrod.

The formulae for x, y the coordinates of the spark, in terms of the times (t_1 and t_2) taken for the acoustic signal to reach two detectors which subtend on angle of 90° at the origin are :

$$x = \left\{ v^2 t_1^2 - \left[d + \frac{v^2}{4d} (t_1^2 - t_2^2) \right]^2 \right\}^{\frac{1}{2}} - d \, , \quad y = \frac{v^2}{4d} (t_1^2 - t_2^2)$$

(2d is the separation of the detectors).

In view of the much greater complexity of the calculation of x we use t_1 and t_2 to get y and t_2 and t_3 to get x using the formulae

$$x = \frac{v^2}{4d} (t_2^2 - t_3^2) \, , \qquad y = \frac{v^2}{4d} (t_1^2 - t_2^2)$$

The electronic system used to compute one cartesion coordinate is shown in Fig. 9, T_1 and T_2 are linear ramp current generators feeding into an integrating capacitor C. The pulses of duration t_1, t_2 from the bistable are fed on to the bases of transistors T_3 and G1 respectively. The value of the current is controlled by the emitter voltages on T_1 and T_2 and it increases linearly with time after t = 0, up to a maximum of t = 1 msec. When the gates G1 and G2 are closed then no current flows into C. In the quiescent state, T_1 and T_2 are virtually cut off and the voltage on C is clamped by S, a chopper transistor. At t = 0, the clamp is released, the gates are opened and current flows out of T_1 and into T_2. The charge on C does not alter substantially until one gate only is cut off. Then the charge on C is given by

$$Q = CV = \int_{t_2}^{t_1} I \, dt \approx \frac{K}{2} (t_1^2 - t_2^2)$$

A short time later, a read pulse samples the charge on C via gate G3. After the read cycle has finished, a reset pulse closes all gates and the integrating condenser is discharged.

The time of the read pulse and the slope of the ramp are capable of being altered so that the system can be used with different sizes of chamber.

Some sources of error could be:

1) Change in the velocity of sound. Since the electronic origin is at the centre of the spark chamber, this effect only alters the scale and will not be very serious.

2) Zero drift. The bottoming of the chopper transistor is very well defined and drift in the operational amplifiers is at the most 4mV/°C with ± 2.5 V peak output. Drift is, in fact, negligible.

3) Ramp non-linearity. Parabolic accuracy is excellent because of the cascode format of the squaring circuit. Any asymmetry in T_1 and T_2 can be monitored by replacing C with a resistance and measuring the current in it. First order corrections can be made by means of the variable resistance R_2 and the remaining error is very small.

The ramp should go through the origin $t = 0$ or if a correction for the effective spark size is needed, then through $t = 0 - \delta$. The correction can be provided by a small pedestal at the beginning of the run up.

Two of these circuits enable an x,y display on a cathode ray oscilloscope to be made. A multi-channel display can be obtained by using several circuits.

When using two chambers for a momentum analysis as described earlier, the momentum is immediately computed since a subtraction of two voltages is all that is required.

Momentum is proportional to $X_1 - mX_2$ where m (the magnification of the magnet system) is adjusted by varying the gradient of the ramp in one circuit. Extra information can also be fed in here and it is possible to do "missing mass" calculations in some favourable cases.

Figure captions

Fig. 1	3 gap acoustic spark chamber
Fig. 2	Plan view of foil module
Fig. 3	Section through foil module showing method of adhesion at foil edge
Fig. 4	Plan view of perspex annulus with transducers mounted on inside diameter
Fig. 5	Transducer mounting section through perspex annulus showing mounting of piezoelectric crystals
Fig. 6	Variation of angular response with size of piezoelectric crystal
Fig. 7	Distance versus time curves
Fig. 8	Block diagram of sonic electronic system
Fig. 9	The electronic system used to compute one cartesian coordinate

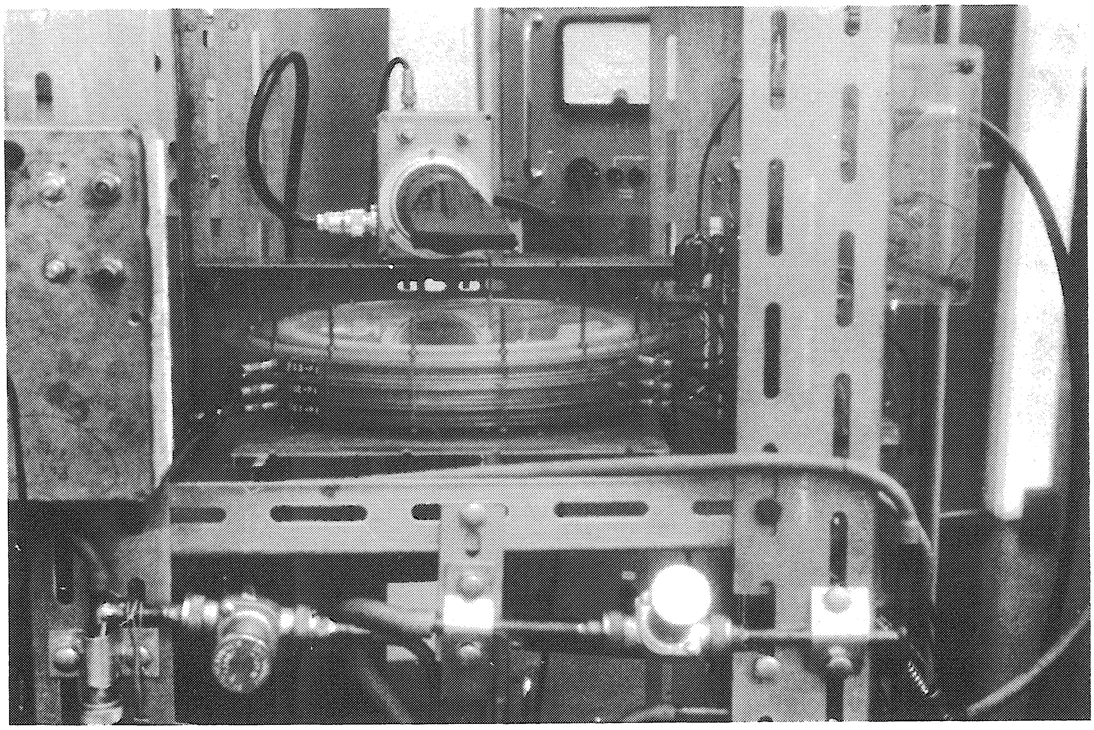


Fig 1. 3 GAP ACOUSTIC SPARK CHAMBER

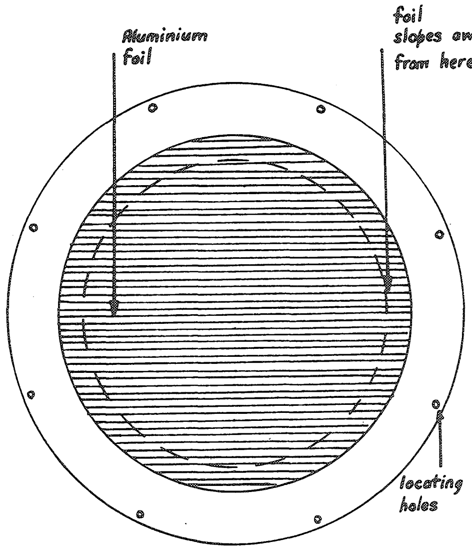


FIG. 2 PLAN VIEW OF FOIL MODULE.

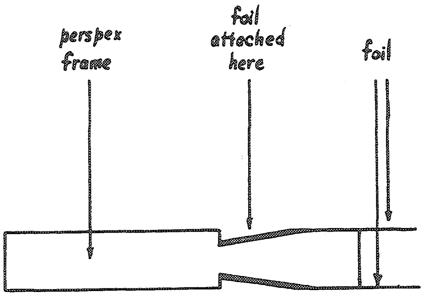


FIG. 3 SECTION THROUGH FOIL MODULE SHOWING METHOD OF ADHESION AT FOIL EDGE.

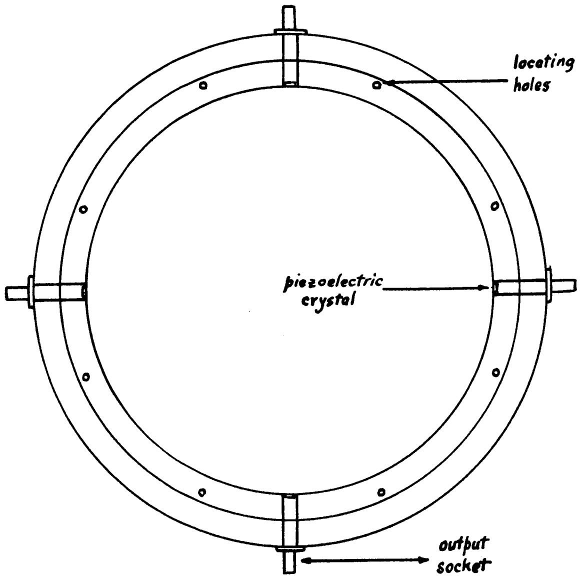


FIG. 4 PLAN VIEW OF PERSPEX ANNULUS WITH TRANSDUCERS MOUNTED ON INSIDE DIAMETER

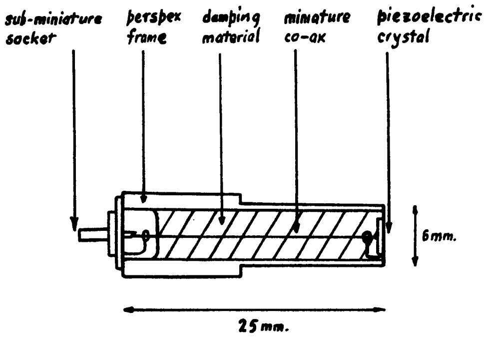
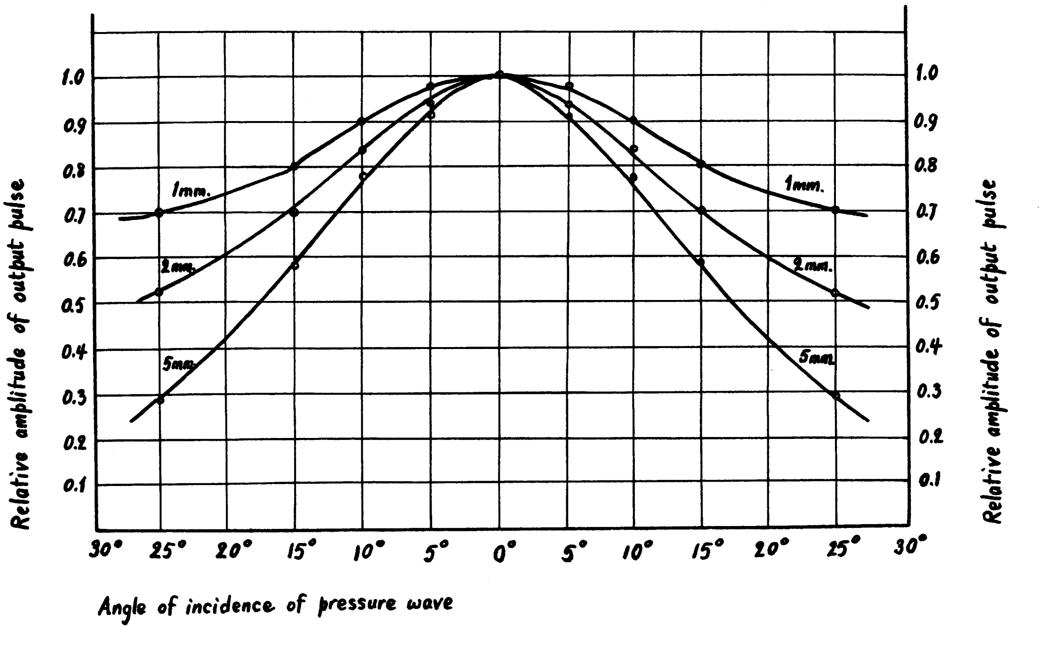
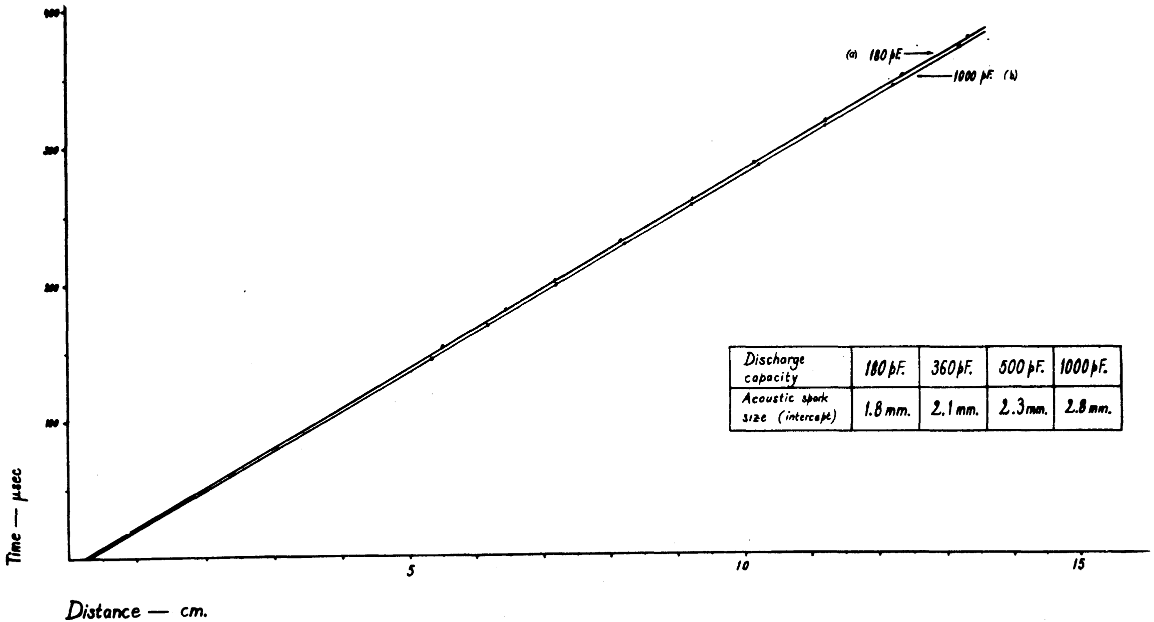


FIG. 5 TRANSDUCER MOUNTING
SECTION THROUGH PERSPEX ANNULUS
SHOWING MOUNTING OF PIEZOELECTRIC
CRYSTALS.

FIG. 6 VARIATION OF ANGULAR RESPONSE WITH SIZE OF PIEZOELECTRIC CRYSTAL





Discharge capacity	180 pF.	360 pF.	500 pF.	1000 pF.
Acoustic spark size (intercept)	1.8 mm.	2.1 mm.	2.3 mm.	2.8 mm.

Fig. 7 Distance versus time curves
(a) 180 pF Discharge capacity
(b) 1000 pF Discharge capacity

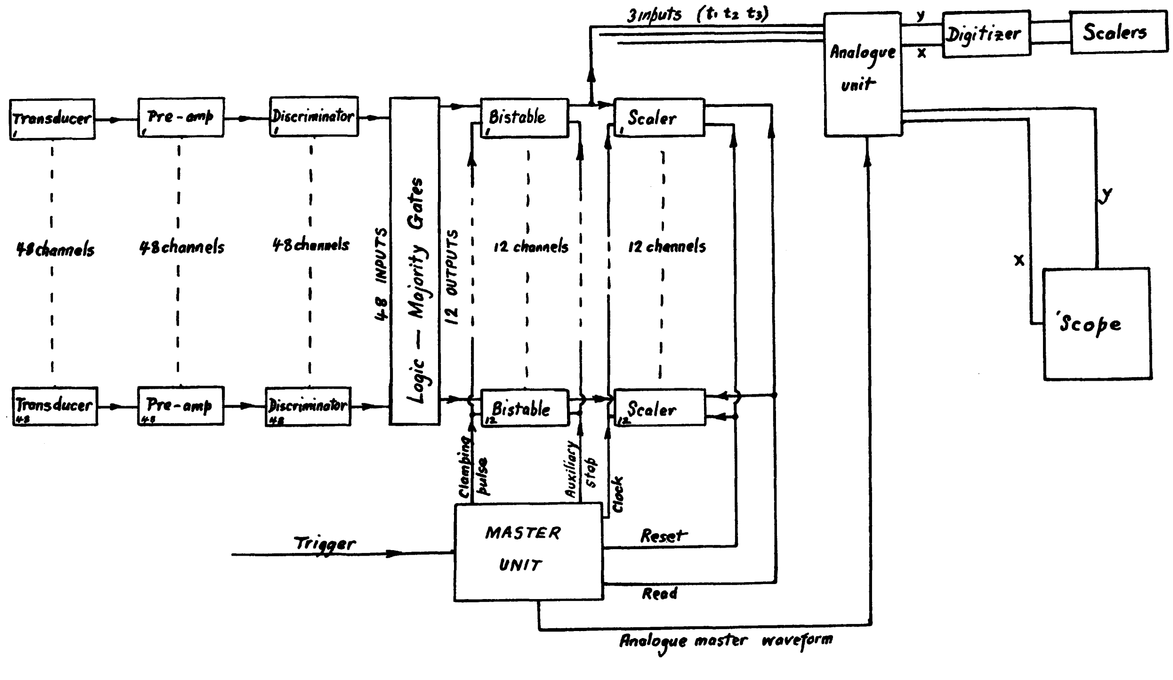


FIG. 8 BLOCK DIAGRAM OF SONIC ELECTRONIC SYSTEM

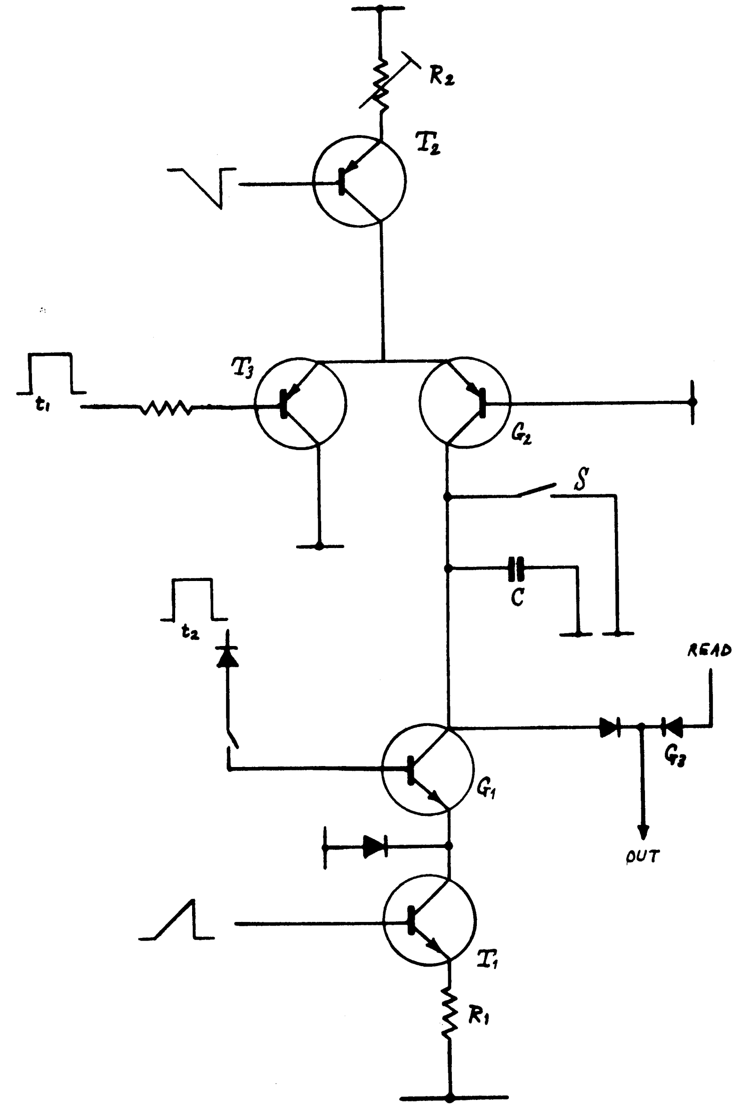


FIG. 9. THE ELECTRONIC SYSTEM USED TO COMPUTE ONE CARTESIAN CO-ORDINATE

DISCUSSION

PEREZ-MENDEZ: How do you propose to distinguish the ω from the ρ ?

ELLISON: We don't in this context. We actually want to examine what happens to decay reactions in the neighbourhood of the ω. In the decay we just want to identify the mass of the missing particle and look at decay modes of the ω.

BARDON: You have a remarkably low energy in your spark. Could you tell us please what is the gap size, the gas you use and also can you say anything about **repetition rates and efficiency** ?

ELLISON: I can't say anything at all about repetition rates. This is a thing that we shall be doing in the next few weeks. I can say that the gap is the normal 6 millimetres with 5 kilovolts applied. The gas used is a neon-helium mixture. Remember that our larger chambers have an effective diameter of about 28 cm whereas the smaller ones are 18 cm in diameter so they are rather small chambers. Because their self capacity is something like 30 pf we can therefore use 180 pf capacitors quite satisfactorily.

PIZER: If I understood you correctly the precision with which you measure a spark position is rather higher than what other people have been saying. Is that not so ?

ELLISON: I don't think so, no.

MAGLIC: What is the momentum resolution, $\Delta p/p$, you expect to get ?

ELLISON: About 0.1%.

MAGLIC: Could you describe how you measure the missing mass ?

ELLISON: The reaction is $\pi^- + p \rightarrow n + \omega$. We do neutron time of flight from a counter just before the target to an array of 6 scintillators 3 metres down the beam line from the target each at an angle of $\sim 4^\circ$. Since we are just above threshold, both the neutron and the ω go forward at the centre of mass velocity and therefore if one looks in the forward direction one can get away with a fairly crude momentum measurement and an accurate measure of the time of flight. One can then get the missing mass out rather simply.

MAGLIC: What is your resolution for the time of flight ?

ELLISON: We are hoping to get down to 1 nsec or slightly better.

MAGLIC: What is the percentage accuracy of the neutron momentum measurement ?

ELLISON: I can't quote this off-hand, I can quote what it comes to in ω mass- this is what really matters. It is about ± 4 or 5 MeV in ω mass.

MAGLIC: This is a remarkably low error.

ELLISON: Well it is just above threshold, the first few MeV. This is the great point. Of course the cross-section is very low.

AMALDI: I am quite surprised about the low value of the energy in your sparks. You showed a slide giving the acoustic spark size as the function of the capacity. Does the rise time of the pulses on the probes change or not depending on the capacity ?

ELLISON: It is about a microsecond for the different probes and varies very little with distance.

AMALDI: So you are sure to be far away from the shock wave region. This is very different from the results of other laboratories. Everybody uses much higher energies.

ELLISON: Well it is a factor of 10 or so. I think people should use lower energy sparks.

ROBERTS: If I understood you correctly, you said you were hoping to get a tenth of a percent momentum accuracy in a pion beam ? Could you give us more details of this ?

BINNIE: The method, in principle, is capable of a little better than that. If you simply use the sparks from the chambers on either side of the magnets in our beam then I think it is somewhat worse, but adequate for this purpose. Such a system has chromatic aberration in it because of the quadrupole focusing; this can be removed by using 3 sonic chambers and then the limit is probably somewhat better than 1 in a thousand.

ROBERTS: In that case I would like to hear what kind of scattering materials you have in a beam where you can get down to that kind of accuracy, because scattering in a couple of metres of air is enough to spoil that sort of precision.

ELLISON: There is a vaccum pipe in the system over a large fraction of the beam path. The actual chambers use half than (0.0005 in) foils.

VERNON: What is the momentum of the pions ?

ELLISON: 1.2 GeV/c.