Recent Developments in High Energy Counter Experiments

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New Detector Developments

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It is a great pleasure for me to be here. I am very much honored to have been invited here. And, I am grateful for the warm hospitality and attention that I am receiving on this, my first, trip to Japan.

I am pleased also to have this opportunity to visit this new laboratory. I look forward to being able to get a closer look at the activities here, and I expect that this will be a very exciting place to be over the next few years as the laboratory is gradually built and the accelerator starts to operate.

In discussing detectors, I would first like to review the characteristics of the most common detectors in use in high-energy physics.

1. Scintillation counters. Their spatial resolution is dictated, usually, by the size of the piece of scintillator used. Typically the scintillator size is from 0.5 cm to 100 cm. (Occasionally, by using two photomultiplier tubes on the same scintillator much better spatial resolution is obtainable. For example, see Reference 1.) The great usefulness of scintillation counters is attributable not to the space resolution, but to the time resolution, typically 10^{-8} to 10^{-9} seconds. Such good time resolution allows coincidence counting under favorable conditions (with low rates of accidental coincidences).

2. Spark chambers. They have space resolution, usually, of 1 mm to 2 mm. Their resolving time is about 10^{-6} seconds. Thus, they have better space resolution, but poorer time resolution, than scintillation counters. Spark chambers also have a dead time associated with them, associated with the time needed to recharge condensers, and, perhaps, advance the film (for optical spark chambers) or read out the spark information by magnetostrictive ribbon.

3. Bubble chambers. Bubble chambers have a spatial resolution of perhaps 0.2 mm, but a relatively poor time resolution, perhaps 10^{-3} sec.

4. Cherenkov counters. They have space and time resolution similar to scintillation counters, but they are usually used only where their sensitivity to particle velocity is important. Only particles moving faster than the

velocity of light in an optical medium emit Cherenkov radiation, and then the light is emitted in a well defined cone of directions.

Table I lists the properties we have reviewed, as well as an estimate of the allowable repetition rate with which information can be read out from the various detectors.

Table I. Properties of the most common particle detectors.

Detector type	Typical space resolution	Typical time resolution	Typical maximum repetition rate
Scintillation counters	5 mm to 1 m	10^{-8} to 10^{-9} sec.	10^6 to 10^7/sec.
Spark chambers	1 to 2 mm	10^{-6} sec.	10 to 100/sec.
Bubble chambers	0.2 mm	10^{-3} sec.	1 to 10/sec.
Cherenkov counters	5 mm to 1 m	10^{-8} to 10^{-9} sec.	10^6 to 10^7/sec.

Proportional Wire Chambers

Proportional counters are among the earliest of detectors of ionizing radiation. They were used years ago as single counters typically 1 to 5 cm in diameter. The positive electrode is a fine wire. The smallness of the wire diameter is responsible for the large electric field close to the wire. When the counter contains a gas such as argon in which electrons can move as free electrons (rather than attaching to an atom or molecule) there can be electron multiplication (release of electrons from gas atoms or molecules) in the small region close to the positive wire. This multiplication can give gains in charge available at the output of the counter of the order of 10^5, so that a few electrons released in the gas by ionizing radiation can result in a pulse of the order of 1 millivolt on a wire electrode.

In recent years these counters have been revived and improved, particularly by Charpak, who has placed many positive wires in a single envelope. The basic geometry is sketched in Fig. 1a.

Because of the recent availability of inexpensive amplifiers, it is now feasible to install an amplifier on each wire (or each group of several wires). Typical wire spacings are 1 to 2 mm, giving typical spatial resolutions of 0.5 to 1 mm.

I am told that the electrical signal from the counter is more due to the movement of positive ions away from a fine wire than due to electrons moving toward the wire, though I have never verified this for myself by explicit calculation.

The pulse from a proportional counter rises rapidly at first, then more slowly: see Fig. 1b. A short pulse in time is obtainable from this pulse by rapid "differentiation" with an RC network.

Usually, proportional counters are not filled with pure argon, but with a gas mixture designed to give faster and more stable operation. A typical gas mixture might contain argon as the largest constituent, but large fractions of CO_2, isopentane, or isobutane, and small amounts of methylal and a certain Freon. The mobility of electrons in such a mixture is of the order of 10^3 cm^2-sec^{-1}-$Volt^{-1}$, so fields of the order of 10^3 V/cm lead to drift velocities of the order of 10^6 cm/sec. Typical anode wire diameters are about 25 μm, and typical spacings between anode and cathode are 4 to 8 mm.

The usual circuit used to read out information from one wire (or one group of wires) is given in its elementary form in the diagram of Fig. 1c. The fast signal output can be combined in OR circuits with other similar outputs to give a signal when any wire of a given proportional wire chamber (PWC) gives an output. Such signals can be used with similar signals from other PWC in coincidence circuits which pick out the interesting events. The interesting events lead to outputs from coincidence circuits that can be connected to the "Strobe inputs" of the basic circuits. Providing the time delay is properly adjusted, a signal on the wire in question can lead to the setting of its particular flip-flop, which preserves the information until it can be read into a computer or memory device.

The difficulty with this method of readout is only its high cost. The electronic equipment tends to cost more than 3000 yen for each amplifier channel.

Delay-line Readout

In the interests of lower cost and greater reliability Perez-Mendez and his colleagues[2] have developed a delay-line readout for proportional wire chambers. The delay line is basically of a standard type: a long coil of wire capacitatively coupled to a conductor that acts as a ground plane; see Fig. 1d. In order that the delay line may be capacitatively coupled to the wires of a PWC simply by pressing the delay line, which is insulated, against the wires of the chamber, the long coil is wound on a rectangular coil form. For convenience the ground plane is placed inside the coil. To preserve pulse shapes over long lengths of delay line the line has capacitatively coupled patches in the form of numerous diagonally placed electrodes placed on one flat surface. The assembled delay line is shown in Fig. 2 (Fig. 2 of Reference 2). These delay lines have impedances of approximately 600 ohms. Delays of between 4 and 20 nanoseconds/mm have been achieved. This readout is used to determine the position of a signal in a PWC by observation of the time difference between the signals received at the two ends of the delay line. The authors report that excellent position resolution can be achieved, since the delay line tends to interpolate between wires of the PWC. Costs are reduced since relatively few amplifiers are needed.

Tests of a similar delay-line readout for PWC are reported by Parker and Jones.[3] They have arranged to get a fast signal from the PWC as well as the signal from the delay line. They have also arranged to get 3 delayed signals from the same PWC. For example, a delay line coupled to the anode (central) wires can give the coordinate x. One set of cathode wires, perpendicular to the anode wires, gives the coordinate y. The other set of cathode wires is placed at 45° from each of the previously mentioned sets of wires giving two readouts that provide the coordinate they call u, which is used to remove ambiguity when several signals are present. In fact, the cathodes utilize copper strips attached to a plastic sheet in the case of y and u coordinates, so arranged that the plastic sheets are also gas barriers. Fig. 3 (XBL 725-2999) shows the preliminary plan of a 1 meter × 1 meter chamber in disassembled (exploded) view. Dimensions are shown in inches. Wire diameter is 20 μm, with wire spacing approximately 5 mm. The frames are made of specially ordered G10 fiberglass whose dimensional tolerance on thickness is ±0.05 mm. Fig. 4 (XBL 725-2984) shows the top G10 frame as seen from the bottom. The placing of the O-ring, that makes the final gas seal, can be seen. The anode wires are of number 304 stainless steel.

Fig. 5 (XBL 725-2993) shows details of the delay line. Fig. 6 (XBL 725-2996) shows the connections of the Fairchild A-733 amplifiers that allow a prompt signal, as well as the delayed signals, to be obtained. (The prompt signal is not necessary in all applications, however.) Fig. 7 (XBL 725-2997) shows more detail of the delay-line amplifiers.

In the application as planned by Parker and Jones[3] the use of a gas mixture containing only argon and CO_2 is expected to give chambers of very long life. Fig. 8 (XBL 725-2986) shows the pulse amplitude as a function of chamber high voltage for various fractions of CO_2 in argon, for an arrangement with 8 mm spacing between electrodes. The authors seem to favor the higher concentrations of CO_2. They favor a gap of about 8 mm. Larger spacings than 8 mm result in rather too much spreading in space of the induced signals on the cathode delay lines.

The advantage of this readout system, as mentioned above, is mainly its low cost. The disadvantages are the relatively poor pulse pair resolution (2 pulses must be separated by about 10 mm to be separately observed) and the necessity of keeping down the particle rates to allow time for the signals to propagate along the delay lines. Rates of about 10^4 per second seem barely allowable. In spite of these disadvantages there may be many experiments for which these chambers are superior to other detectors of similar cost, and that is why these chambers are discussed here. Certainly they seem well adapted to the use proposed by Parker and Jones[3], namely as an external muon identifier in connection with neutrino-induced events in the 15-foot bubble chamber at NAL. They expect to separate high-energy pions from high energy muons at the 5% level with PWCs surrounding two absorber sheets of 150 g/cm^2 each. That is, they expect to be able to divide particles leaving the large bubble chamber into two classes, one of which contains 95% of the π and only 5% of the μ while the other class contains 95% of the μ and only 5% of the π.

Next, I wish to discuss some recent developments in high-resolution liquid xenon counters made by Derenzo, Muller, Zaklad, Alvarez, and others.[4] The motivation for studying noble liquid counters is the desire for better spatial resolution than can be obtained with gas counters, where electron diffusion and chamber thickness tend to limit the obtainable spatial resolution. In liquid counters there is the possibility that electron diffusion may be much less. At the same time, more electrons will be obtainable because of the greater density of the liquid. This promises to give a very useful device for experiments at very high energies, where spatial resolution can be very important due to the costs of large-volume magnets.

To a first approximation noble liquids act qualitatively rather like noble gases as far as the motions of electrons and ions are concerned. Because of the higher density of the liquid the mobility of ions is less than in gas, being about 3×10^{-4} cm^2/Volt-sec in the liquid. The limiting drift velocity of electrons in the liquid at high fields is 3×10^5 cm/sec. To show these properties cleanly the liquid must be fantastically pure. Given the required purity of the liquid xenon, a proportional counter can be made in which the operation bears a strong resemblance to a gas proportional counter.

To obtain the very high electric fields necessary to get multiplication in the liquid it is helpful to use very fine wires. Wires of 3.5 μm diameter have been used, at times.

Proportional counters containing liquid xenon utilize electric fields on the order of 10^6 V/cm close to the fine wires. They have gains of the order of 100. The anode wires must be made quite small for satisfactory operation because field emission of electrons from the cathode is one of the important modes of breakdown of these counters. To keep the field much smaller at the cathode than at the anode it is necessary to use very small-diameter anode wires.

Spatial resolution is expected to be as good as ±15 μm r.m.s. in liquid-xenon proportional counters. Various schemes are being studied for the readout of these chambers, in the hope that a low-cost readout can give excellent spatial resolution. Time jitter of ±100 nsec has been observed in large liquid counters, but it is hoped that smaller counters will give much better time resolution.

Multiplication has been obtained in liquid argon, but the results are less reliable than with xenon. There are also unexplained phenomena dependent on the pressure in liquid argon.

Development for particle physics has been delayed in recent months to allow development for a medical application. A liquid xenon counter offers the possibility of giving a superior gamma-ray camera. Compounds are known which concentrate in tumors such as brain tumors. When these compounds are loaded with a positron emitter the annihilation radiation can be used as the basis for a coincidence camera that can accurately determine the spatial distribution of the positron emitter and hence the size and shape of a tumor. Such a coincidence camera is now under development. Within a few months further work toward particle-physics applications should proceed again.

References

1. Robrish, Peter, Backward Neutron Proton Scattering with a Polarized Target, UCRL 20043 (unpublished).
2. Grove, Ko, Leskovar, and Perez-Mendez, Nuclear Instr. and Methods 99, 381(1972).
3. Report LBL 797 of the Lawrence Berkeley Laboratory entitled External Muon Identifier Development: Half Meter Proportional Chamber Test Results.
4. Derenzo, Smith, Smits, Zaklad, Alvarez, and Muller, Lawrence Berkeley Lab. report UCRL-20118, and Zaklad, Derenzo, Muller, Smadja, Smits, and Alvarez, Lawrence Berkeley Lab. report LBL-338. See also Physical Review Letters 27, 532 (1971).

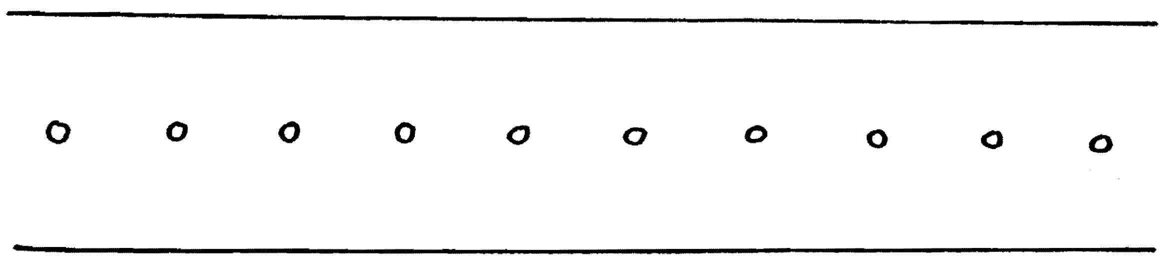


Fig. 1a.

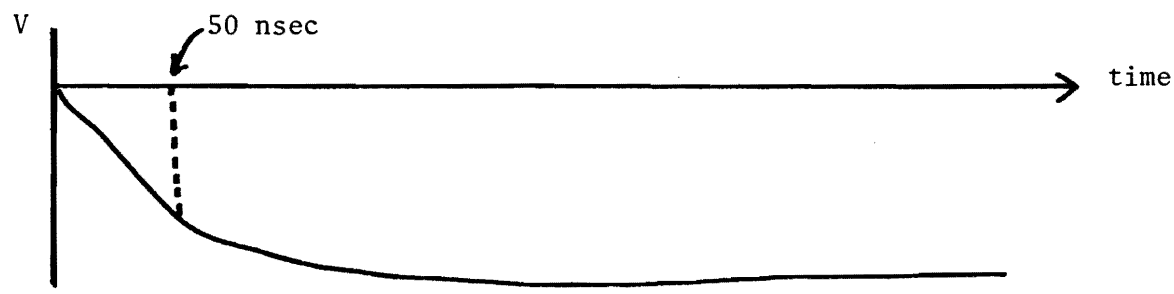


Fig. 1b.

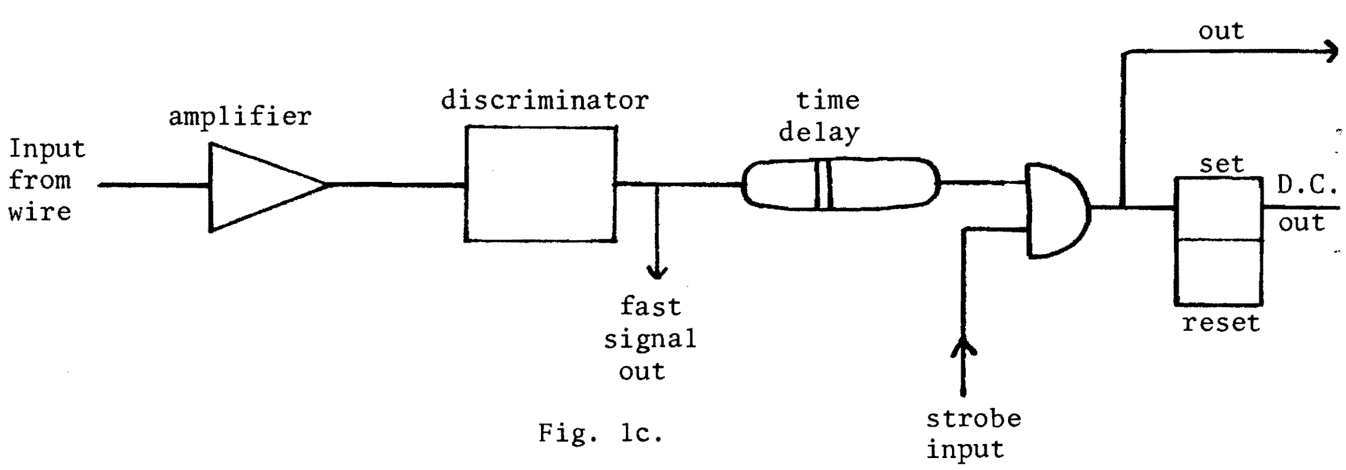


Fig. 1c.

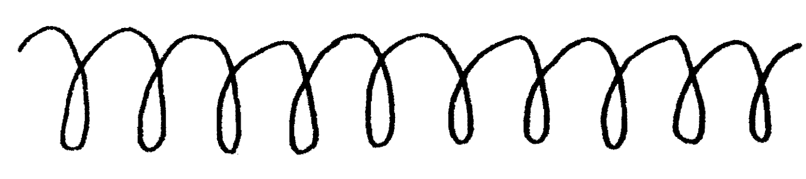
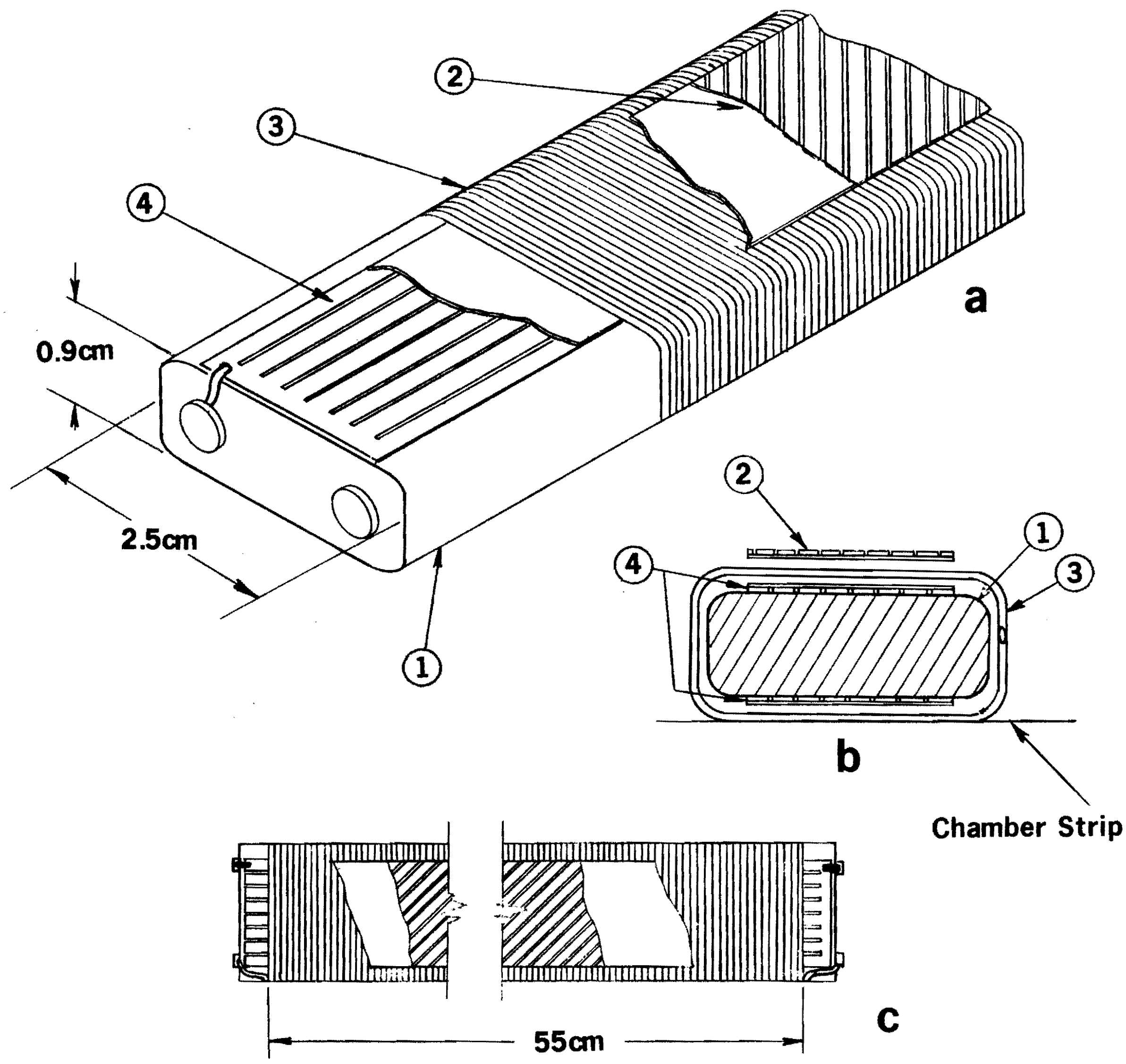


Fig. 1d.



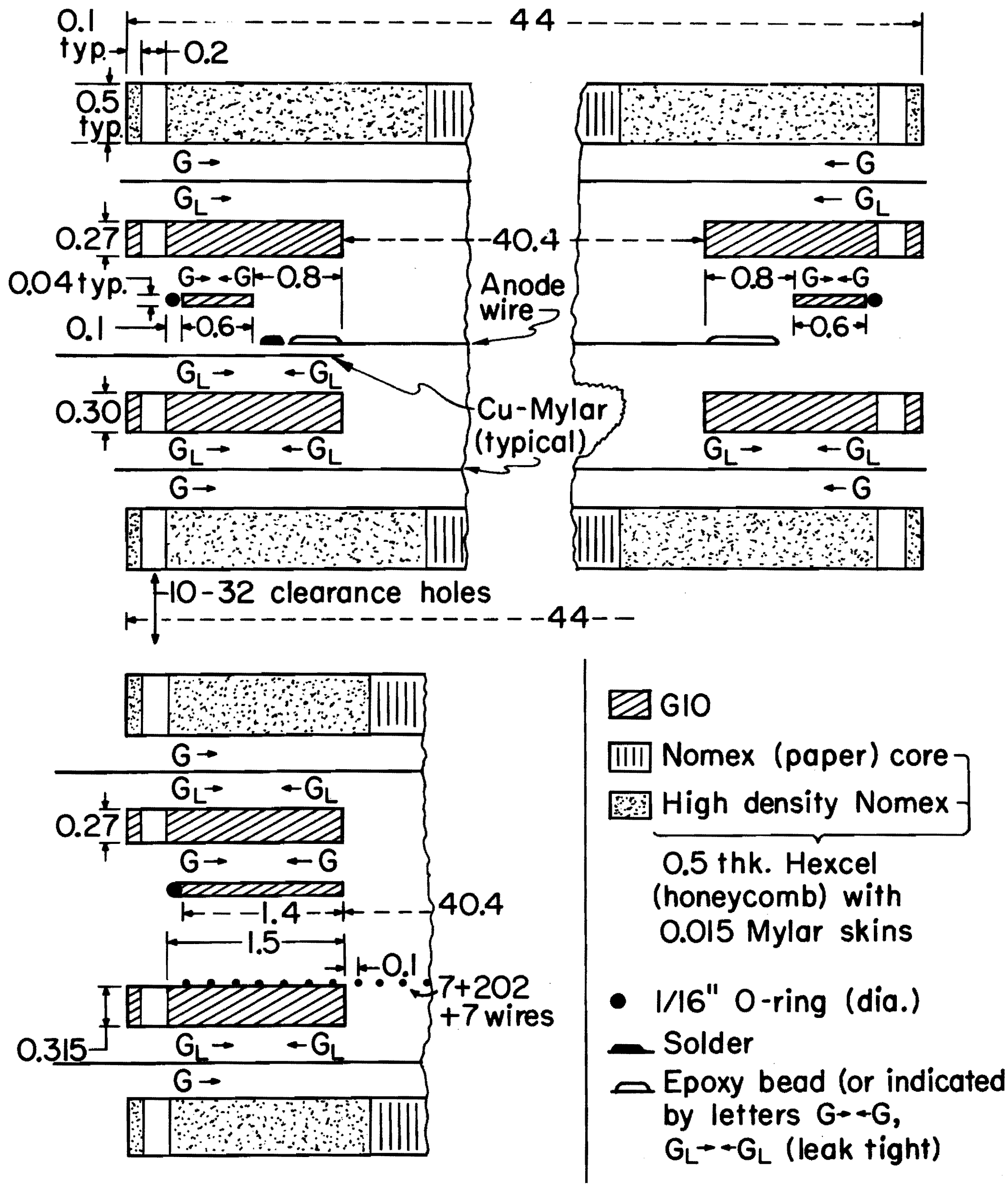
① Plastic Core

② Floating Metal Strips On Mylar Base: Strips = 1.8mm Wide; Gaps = 0.3mm Wide; Mylar = 25 Microns Thick

③ Winding = #30 Formvar Wire

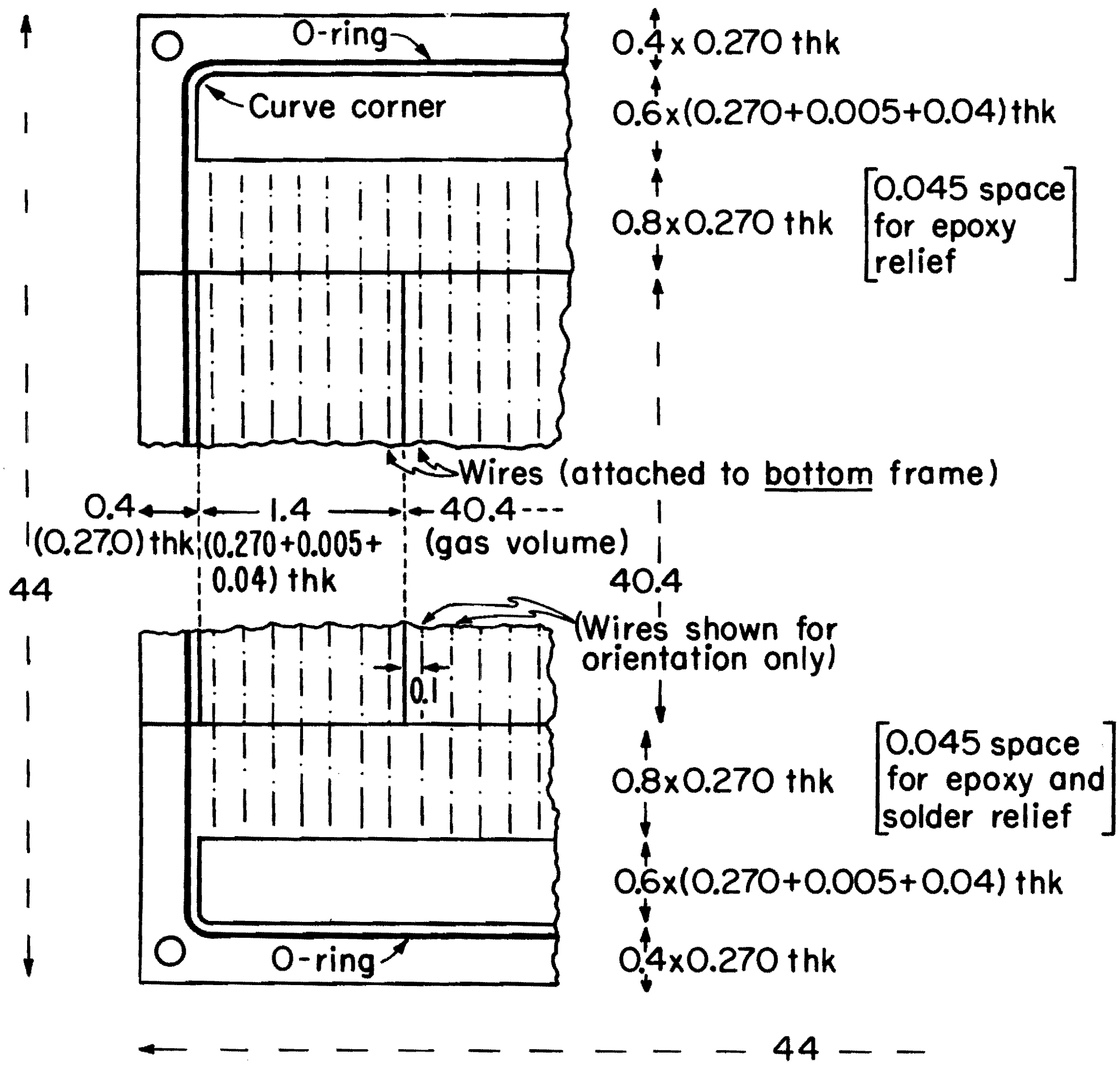
④ 8 Copper Strips On Mylar Base: Strips = 1.8mm Wide; Gaps = 0.3mm Wide; Mylar = 25 Microns Thick

XBL 714-679

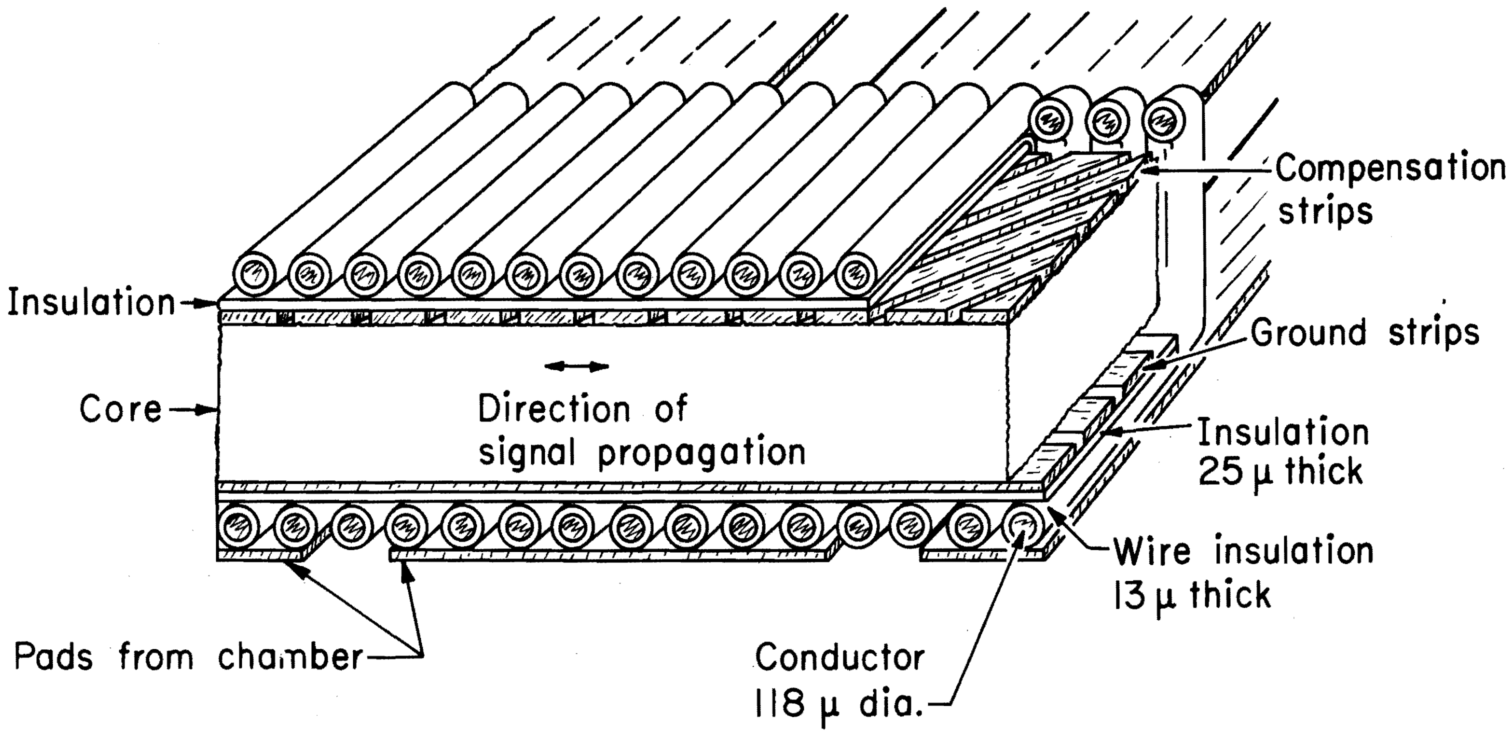


0.1 typ.
0.2
44
0.5 typ.
G→
←G
G_L→
← G_L
0.27
40.4
0.04 typ.
G→ ←G
0.8
0.1
0.6
Anode wire
G_L→ ←G_L
0.30
Cu-Mylar (typical)
10-32 clearance holes
44
0.27
G→ ←G
1.4
40.4
1.5
0.1
7+202 +7 wires
0.315
G10
Nomex (paper) core
High density Nomex
0.5 thk. Hexcel (honeycomb) with 0.015 Mylar skins
1/16" O-ring (dia.)
Solder
Epoxy bead (or indicated by letters G→←G, G_L→←G_L (leak tight)

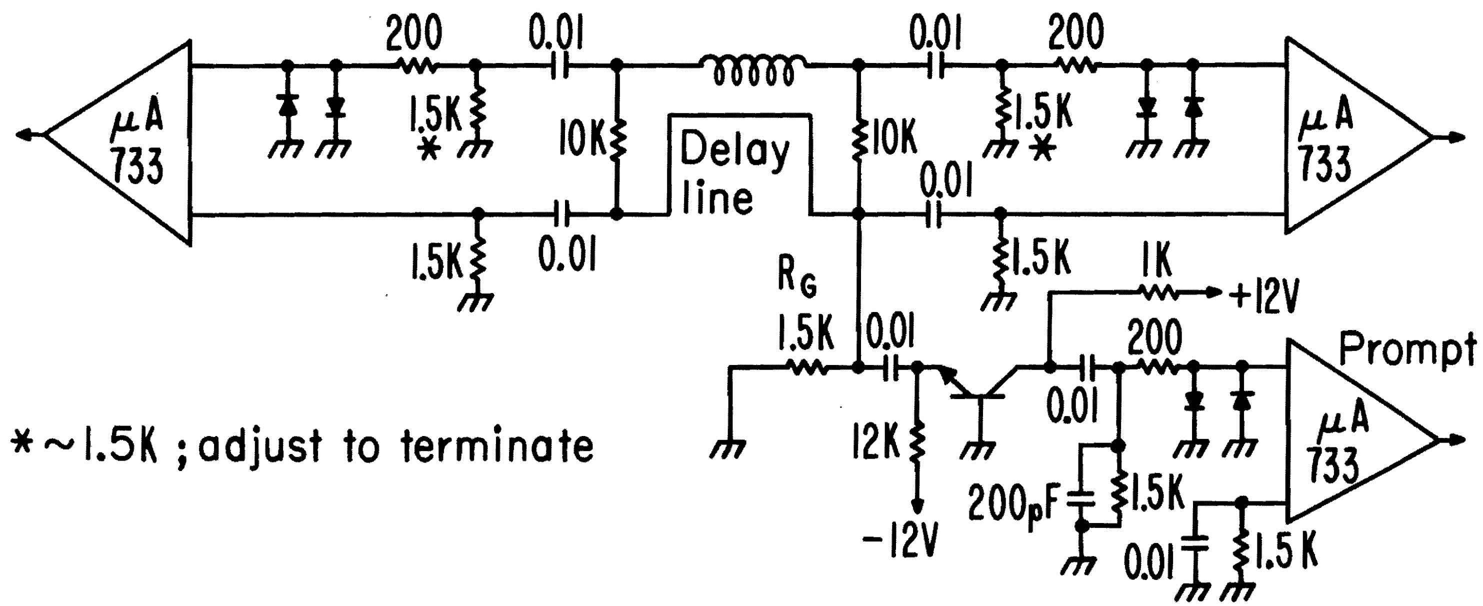
XBL725-2999


O-ring
Curve corner
0.4 x 0.270 thk
0.6x(0.270+0.005+0.04) thk
0.8x0.270 thk
[0.045 space for epoxy relief]
Wires (attached to bottom frame)
0.4
(0.270) thk
1.4
(0.270+0.005+ 0.04) thk
40.4
(gas volume)
44
40.4
(Wires shown for orientation only)
0.1
0.8x0.270 thk
[0.045 space for epoxy and solder relief]
0.6x(0.270+0.005+0.04) thk
0.4x0.270 thk
O-ring
44

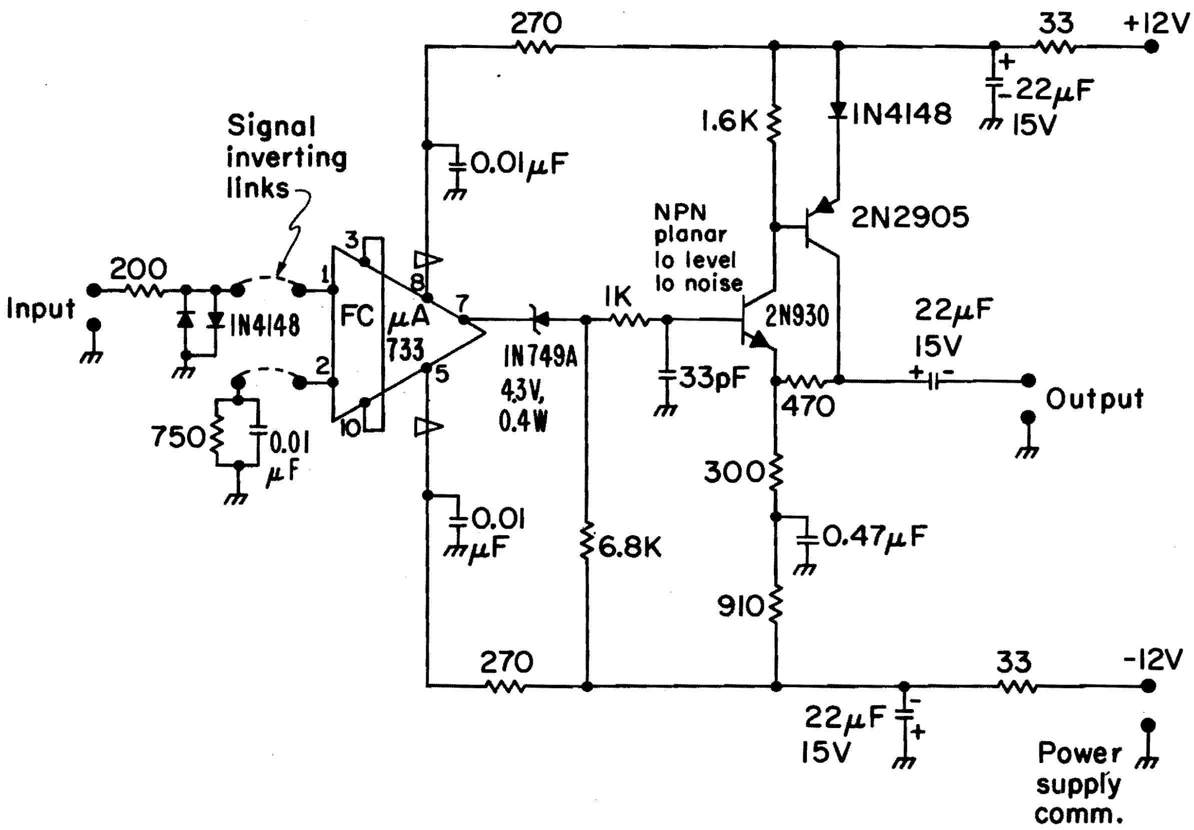
XBL725-2984


Compensation strips
Insulation
Ground strips
Core
Direction of signal propagation
Insulation 25 μ thick
Wire insulation 13 μ thick
Pads from chamber
Conductor 118 μ dia.

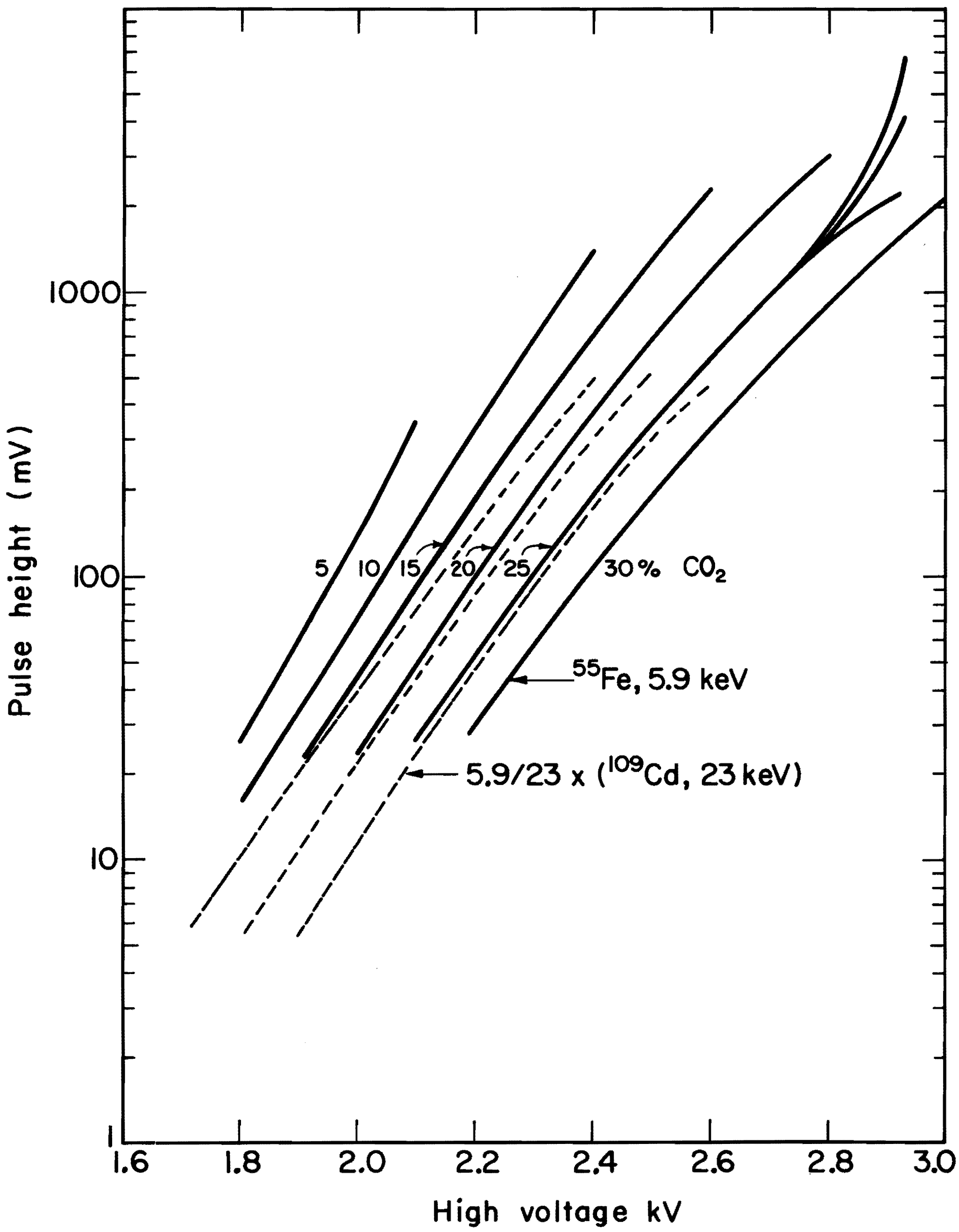
XBL725-2993


µA 733
200
0.01
1.5K
*
10K
Delay line
10K
0.01
200
1.5K
*
µA 733
1.5K
0.01
0.01
1.5K
RG
1.5K
0.01
1K
+12V
200
Prompt
0.01
µA 733
12K
-12V
200pF
1.5K
0.01
1.5K
*~1.5K ; adjust to terminate

XBL725-2996


270
33
+12V
22μF
15V
1.6K
1N4148
Signal
inverting
links
0.01μF
2N2905
NPN
planar
lo level
lo noise
200
Input
1N4148
FC
μA
733
1K
2N930
22μF
15V
1N749A
4.3V,
0.4W
33pF
470
Output
750
0.01
μF
300
0.01
μF
6.8K
0.47μF
910
270
33
-12V
22μF
15V
Power
supply
comm.

XBL 725-2997



1000
100
10
1
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
Pulse height (mV)
High voltage kV
5
10
15
20
25
30% CO_2
^{55}Fe, 5.9 keV
5.9/23 x (^{109}Cd, 23 keV)

XBL725-2986