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A PROPORTIONAL CHAMBER FRONT END AMPLIFIER AND PULSE SHAPING CIRCUIT*

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Introduction

A proportional chamber amplifier/discriminator package has been designed to perform well under conditions of high instantaneous data rate and low duty cycle. The electronics system described is one which maximizes the detector area within the confines of a magnetic spectrometer (LASS)[1] at the same time increasing the reliability of the system by removing all electronics from the chambers to a position of easy access. Stability of the system is enhanced by having the electronics properly cooled, preventing large temperature variations from affecting electronic thresholds and delays. We have reduced crosstalk and RF pickup problems by using shielded coaxial cables to transport the signal from the chamber to the amplifier.

Preliminary Comments

Proportional chamber signals are negative going pulses having a rise time of 10 nanoseconds and a fall time determined by the distributed capacitances and resistance of the electronics. Pulse heights vary from 100 microvolts to tens of millivolts. In addition to these signals, there are the capacitively induced positive pulses from neighboring wires.

We have chosen to terminate our chamber wires by connecting them directly to 40 feet of properly terminated, 95Ω miniature coaxial cable, resulting in a signal shape which is somewhat triangular at the input to our amplifier circuit, and whose baseline is on the order of 40 nanoseconds long. Table I lists the characteristics of the actual cable used (Brand Rex cable T5563, which is a composite of 8 T209A cables in one ribbon). Sixty four signals are transmitted to the amplifier by one bundle, as shown in Fig. 1.

Table I (Brand Rex T5563 Cable)

Impedance	95Ω
Capacitance	13.5 pf/ft
Velocity of Propagation	0.8 c
Attenuation at 400 MHz	14 db/100 ft
Dielectric Material	Air
Number of Coaxial Cables/Ribbon	8
Outer Diameter of one Cable	".112"
Drain and Signal Wire Size	29AWG

Cable crosstalk is reduced substantially by the use of an input transformer first reported by Jones and Martin,[2] which has the effect of forcing the signal current to flow through the ground sheath of the cable, which cancels the field radiated by the signal wire. A separate ground sheath is placed around each cable bundle, which reduces RF pickup to negligible levels and provides the necessary ground link to our chamber (see Fig. 2). The transformers are packaged four to a dual inline package and have the properties listed in Table II. To terminate the cable properly requires 400Ω to ground at the transformer secondary, which gives an L/R time constant of ~2.5 microseconds. Since the area of the negative pulse equals that of the positive overshoot,[3] the pulse height of the positive overshoot is down by a factor of ~100 from that of the signal.[4] This is especially important when we consider the effects of positive signals induced from neighboring wires. The induced pulse height has been measured to be between 1/5 and 1/10 of the primary one.[5] Our circuit is immune to the positive pulse but the negative undershoot might be a bother; however, we see that the pulse height of this undershoot is ~1/500 of the main pulse. The average signal is ~2.5 millivolts, hence the negative undershoot on the neighboring wire will be about 5 μvolt, well below our threshold for detection (100-200 μvolts). That this is in fact true can be seen from a cluster size distribution shown in Fig. 3. The absence of 3 wire events (< 2%) illustrates this point. An analysis of cluster size has been done[6] which explains our distribution. Multiple hits at this level can be explained by track inclination, delta rays, and a wide time window of acceptance.

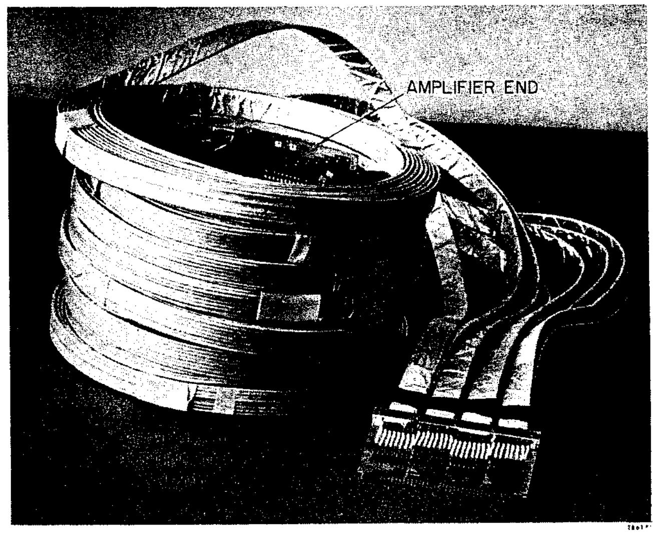

FIG. 1--Photograph of the signal cable: 8 lengths of Brand Rex T5563 terminated at both ends, and shielded with an aluminum mylar laminate, forming a bundle of 64 separate coaxial cables.

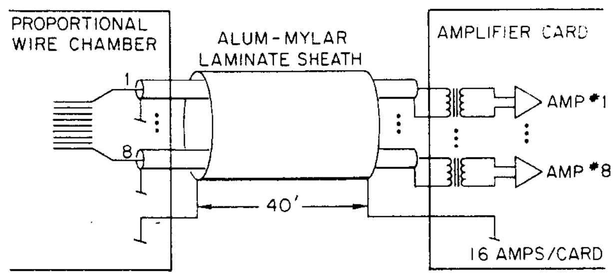

FIG. 2--Details of the grounding scheme necessary to reduce crosstalk and RF pickup.

Table II (Pulse Engineering PE 30056)

Open Circuit Inductance (OCL)	1000 μH
Volt-Microsecond Constant (ET)	10 volt μsec minimum
Winding to Winding Capacitance (CW/W)	20 pf maximum
Leakage inductance (L_L)	1.5 μH maximum
Packaging	4 per dual inline package
Turns Ratio	1:2
Primary dc Resistance	~0.25Ω

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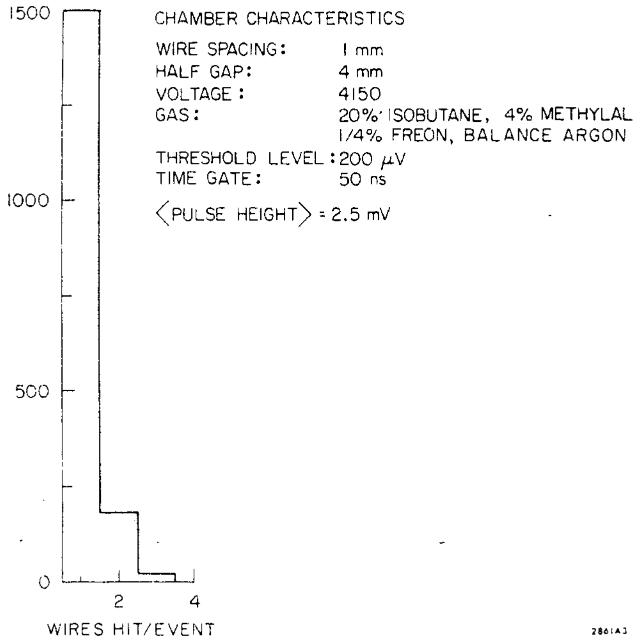

FIG. 3--Typical cluster size distribution.

The Circuit

The heart of our front end circuit (shown in Fig. 4) is a fast inexpensive differential video amplifier (Motorola MC1733CG). This device features a gain of 100 using no external components, high common mode rejection, low noise, wide bandwidth, and good overall gain stability. To retain the common mode rejection and to realize a bit more gain, we have preceded the 733 with the 1:2 step-up 1000 μH pulse transformer already discussed. The 733 is ac coupled to the next stage since it has a variable output offset voltage. It is this coupling capacitor which will limit the duty cycle of the circuit. It is, however, ideal for the SLAC duty cycle of 1.5 μseconds of beam every 5.5 milliseconds. For our discriminator/comparator we have chosen a Fairchild 760HC high speed differential comparator. The trigger threshold of the 760 has been set so that 100 μvolt signals developed across the 100Ω input impedance have been detected and stable operation achieved (in the laboratory). In the field, however, we set the threshold to 200 μvolts.

The output of the 760 is a TTL compatible pulse. Extreme care must be taken in the printed circuit layout to accommodate the expected 5 volt swings of this output lest some fraction of this signal leak back to the 733 input and cause oscillation. To reduce this problem we have run all TTL circuits at Vcc=+4.75 volts, have strengthened the ground paths near the 760 outputs with auxiliary copper straps (Fig. 5b) and have provided a cover for each board to reduce the radiated fields.

The trailing edge of the 760 output pulse is stretched slightly (20 nsec) by the emitter follower as signals at or near the 760 threshold tend to be narrow—too narrow in fact to trigger the next stage—a 74123 retriggerable multivibrator. The multivibrator shapes the pulse to 60 nanoseconds and presents this shaped pulse to the inputs of Intel 3101 Random Access memories.[7] Note that the use of a multivibrator here does not imply the usual deadtime associated with monostable devices as we have no intention of doing coincidence timing with the trailing edge of this pulse. When the pulse arrives, it is loaded into a memory location. If it is broadened by the passage of a second particle additional memory locations are loaded. Thus we can see that our circuit is basically deadtimeless, the slight stretching of the 760 trailing edge and the setup time necessary for retriggering of the 74123 being but minor exceptions.

Pulse Pair Resolution and Deadtime

Figure 6 illustrates the pulse pair resolution measured for our circuit using a signal generator. A pulse separation of ~24 nanosecond is necessary to retrigger and observe a second pulse over a wide range of pulse widths. This of course is not the full story, since we are concerned with pulse pair resolution on a single wire of a proportional chamber. Calculation and measurements have been made[5,8] of the electron collection time in chambers having 7 mm half gaps (~200 nsec). Should a second particle traverse the chamber near this wire it would be difficult to distinguish the collection of new electrons produced by the second particle from those electrons still drifting in from the old track. Our proportional chambers have a 4 mm half gap and hence have an electron collection time of less than 110 nanoseconds. We might, therefore, expect that our amplifiers will not be ready to accept another pulse without a significant shift in threshold for about that length of time. Figure 7 displays the efficiency of a single wire for detecting a second particle as a function of its separation from the first. The timing information for this wire was recorded by a scintillation counter-TDC system and a one to one correspondence then

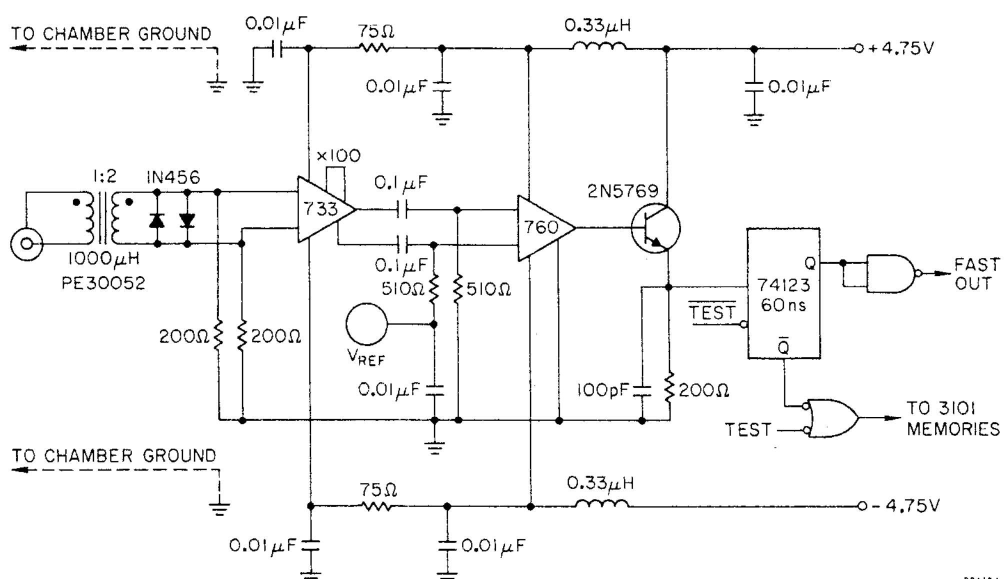

FIG. 4--Schematic of the amplifier-discriminator-shaper circuit.

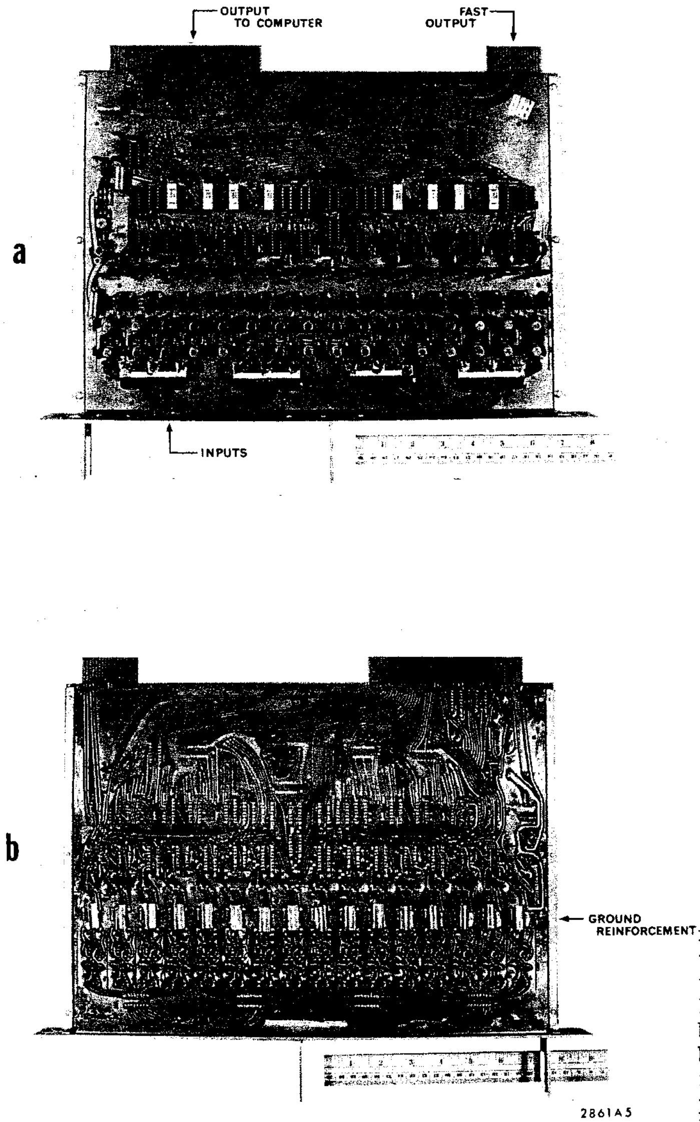

FIG. 5--(a) Component side photograph of the actual amplifier board; (b) trace side photograph showing supplementary ground straps.

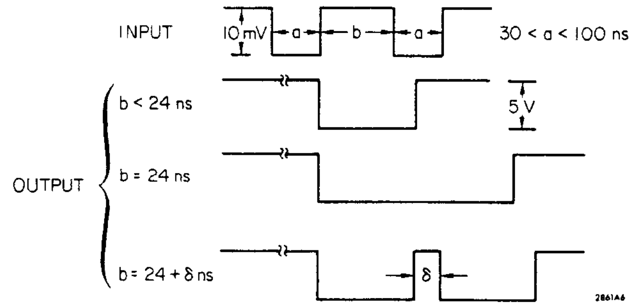

FIG. 6--Pulse pair resolution of the electronics.

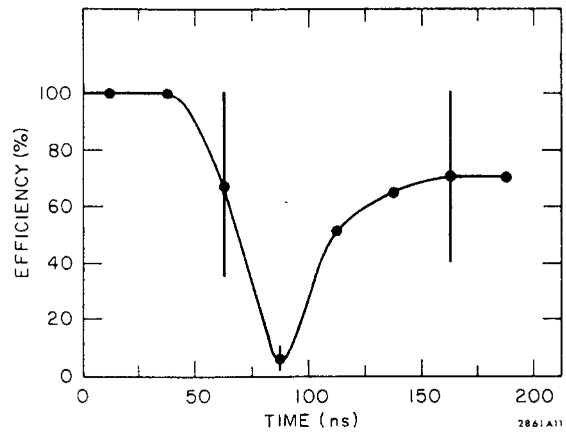

FIG. 7--Single wire efficiency for detecting a second particle. The abscissa represents the time of arrival of the second particle relative to that of the first.

made for the limited number of cases where the second particle hit the same wire as the first.[9] Further evidence for the deadtimeless feature of this system is shown in Fig. 8. Here (Fig. 8b) we display the efficiency of a 1 mm spacing beam chamber as a function of incident rate, along with a beam profile (Fig. 8a). An analysis of these curves (which involves the matched point efficiency of 3 planes) yields a pulse pair resolution of one wire of 125 ± 25 nanoseconds. Further analysis also shows that, at these rates and chamber parameters, we are not yet limited by the space charge effects discussed by Sadoulet and Makowski.[10]

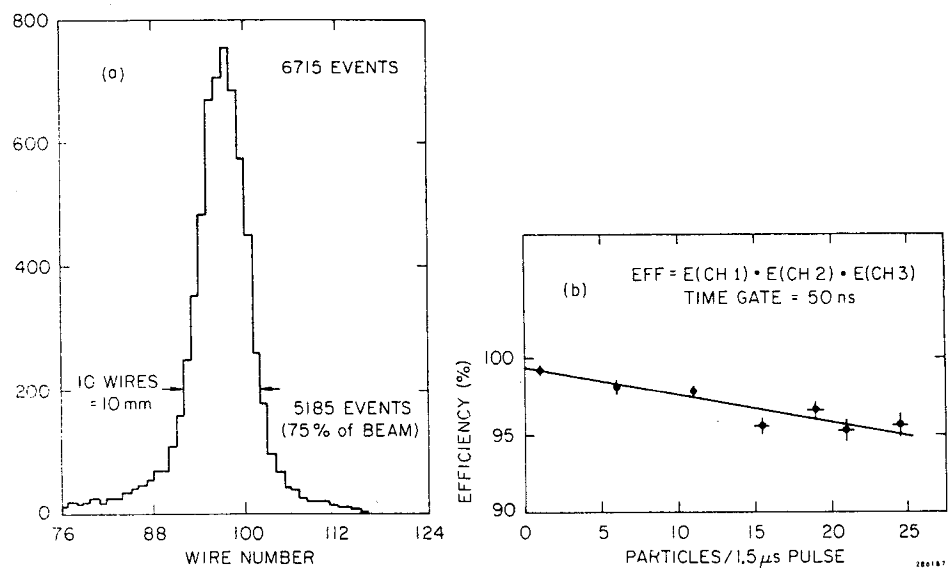

FIG. 8--(a) Histogram showing a typical beam profile as measured by our 1 mm spacing beam chamber; (b) beam chamber matched point efficiency as a function of beam flux.

Circuit Characteristics

The timing characteristics of the circuit are displayed in Fig. 9, the most important features being a delay variation of 12 nanoseconds from twice threshold to 100 times threshold. We see also that the asymptotic delay through the circuit is about 30 nanoseconds.

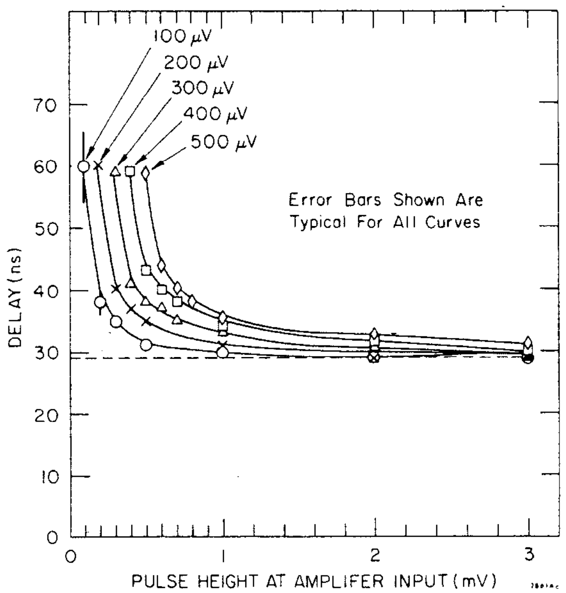

FIG. 9--Time delay vs input amplitude for various threshold settings.

The circuit boasts the following additional features:

(a) A dynamic range of measurable signal voltages in excess of 1000.

(b) A crosstalk rejection ratio of about 330:1 from neighboring channels.

(c) An immunity to positive pulses of about 10:1.

(d) A noise level of about 40 μvolts when 100Ω is placed across the input (to be compared to our input threshold of 100-200 μvolts).

Sixteen channels of amplifier discriminator are packaged per printed circuit board along with the necessary readout electronics described elsewhere.[7] We do not make an attempt to adjust the delay through each circuit as we measure a delay variation of only ±1.5 nanoseconds for 16 channels. However we do adjust thresholds such that the variation for 16 channels is ≤ 3 dB.

Each amplifier requires 2 amps of 5 volt powers as well as minor amounts of -5 volt and reference voltage power. A rack containing 48 boards, therefore, uses about 100 amps or 500 watts of power. To cool these circuits we use rack mounted, 800 cubic foot/min twin squirrel cage blowers.

An additional feature of this circuit is that it performs identically in the detection of positive pulses if the input transformer is replaced with an inverting transformer having the same electrical characteristics[11] (e.g., Pulse Engineering PE 30066).

Cluster Logic

A useful feature included for each channel is the cluster logic circuit shown in Fig. 10. The output of the 74123 feeds a signal to the cluster "chain" whose output gives an analog signal proportional to the number of clusters (groups of consecutive wires) hit within one chamber plane. This output, amplified and fed into a commercial discriminator is useful in multiplicity type fast logic triggers.[12] Figure 11 displays the pulse shape found for 1 to 8 clusters. Additionally the cluster signal can also be used as a fast "OR" of the chamber wires for rough efficiency measurements.

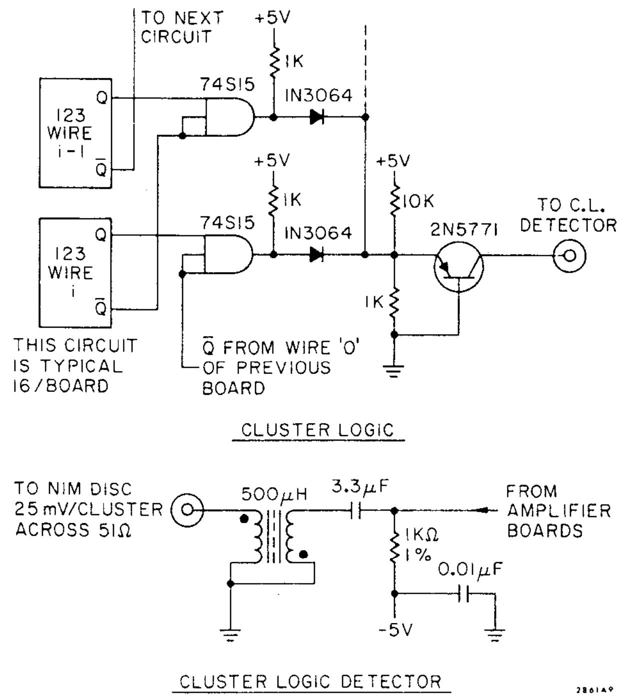

FIG. 10--Schematic of the cluster logic circuits. The upper circuit is resident on each amplifier board while the lower one is present in the crate controller. Connection is made via a rear panel mother board trace.

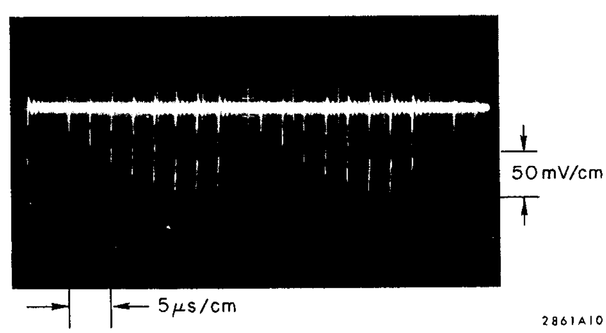

FIG. 11--A photograph of the output of the cluster logic. This picture has been generated by our amplifier board tester which generates sequentially one through eight clusters for each board.

Cost

The components for this front end circuit can be purchased for under $8.00 per channel. However, to this cost must be added the cost of cables, PC board, labor, cooling, power, etc. The total cost figured this way approaches $20.00 per channel including the cost of the full readout electronics.

Acknowledgements

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2. D. F. Jones and E. R. Martin, Nucl. Instr. Methods 98, 535-540 (1972).
3. Jacob Millman and Herbert Taub, Pulse, Digital and Switching Waveforms (McGraw-Hill Book Company, New York, 1965), p. 79.
4. The high frequency behavior of the transformer in our circuit is that of an underdamped oscillator and hence there will be leading and trailing edge oscillations. The effect of this is to worsen the undershoot problem by at most one order of magnitude. Ibid., p. 74.
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7. S. L. Shapiro, M.G.D. Gilchriese and R. Friday, "A Deadtimeless Shift Register Style Readout Scheme for Multiwire Proportional Chambers," Proceedings of the Nuclear Science Symposium, November 1975, IEEE Trans. Nucl. Sci. NS-23, No. 1 (February 1975); to be published. (SLAC-PUB-1714)
8. D. H. Wilkinson, Ionization Chambers and Counters (Cambridge University Press, Cambridge, 1950).
9. The data presented were taken with a 300 nanosecond time window with the bulk of the beam arriving 75-100 nanoseconds after the window began. The second particle therefore is close to the end of the time window and time jitter has caused an inefficiency. Part of the inefficiency is real, however, and due to incident first particles with substantially higher than average pulse heights (and hence pulse widths).
10. B. Sadoulet and B. Makowski, CERN/D.PH. II/Phys 73-3 (27 February 1973).
11. M. Davier, M.G.D. Gilchriese and D.W.G.S. Leith, Stanford Linear Accelerator Center preprint SLAC-PUB-1581 (May 1975).
12. The usefulness of the cluster circuit was first demonstrated to us by E. Platner at Brookhaven National Laboratory where it was used as part of the Mark I Spectrometer Facility of the Lindenbaum-Ozaki Group.