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POSITION AND INTENSITY MONITORING SYSTEM FOR THE SPEAR TRANSPORT SYSTEM AT SLAC*

A. K. Chang, H. K. Kang, and R. S. Larsen
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Abstract

A brief description of the stripline position and intensity monitor for the SPEAR transport system is presented. The basic objective of this system is to visually display on an oscilloscope the current and position information of a 7 ns positron/electron beam of very low duty cycle (10-20 pps). The system incorporates and uses much of the video system at the Main Control Center (MCC) which was designed to display video pulses of 1.6 μs width. In order to maintain compatibility with this system, the detected signals from the stripline monitors, which are 7 ns bipolar signals, are transformed into stretched signals of the order of 1 μs, the amplitude and polarity of which reflect those of the original signals. System functions and the associated electronics are described in detail.

Introduction

The recent addition of the Stanford Positron-Electron Asymmetric Ring (SPEAR) to the Stanford Linear Accelerator Center (SLAC) has presented some new problems in beam monitoring. The original beam monitoring instrumentation in the beam switchyard (BSY) was designed to handle only the regular SLAC beams (e^+ or e^- currents of approximately 1.6 μs duration). SPEAR requires both e^+ and e^- beams consisting of two 7 ns bursts of RF bunches from the accelerator, spaced by the revolution period of the ring of 780 ns (see Fig. 1). Each 7 ns burst consists of 21 bunches of approximately 10 ps duration, spaced by the RF period of the accelerator of approximately 0.35 ns. The conventional beam monitors at SLAC (e.g., toroids) and associated electronics are no longer useful for these special SPEAR beams, necessitating the design of new and different beam position and intensity monitors and associated electronics.

For operational convenience, the decision was made to incorporate the new beam monitoring system into the original video display system at Main Control Center (MCC). The original system, which was designed to display the position and intensity information-carrying pulses of 1.6 μs on various oscilloscopes at different locations in MCC, is bandwidth limited and will not handle the faster SPEAR signals. The SPEAR monitors in response to the 7 ns beam, produce a bipolar pulse of Gaussian shape with about a 7 ns width. The problem then became one of transforming the 7 ns bipolar signals from the new monitors to stretched signals of the order of 1 μs so that they could be accepted by the original video display system.

General System Description

Figure 2 is a simplified diagram of the complete monitoring system. The position and intensity monitor is a stripline detector consisting of two pairs of electrodes (x and y) placed in the horizontal and vertical planes respectively. The signal induced in any one electrode by the passage of the beam is a bipolar pulse, each half of which is a nominal 7 ns FWHM.

Signals from the two pairs of electrodes are fed through summing transformers from which sum and difference signals are obtained. The difference signals represent the horizontal or vertical deflection, x or y, for the beam. The two sum signals are again summed to obtain the intensity signal, i. These signals, representing i, x and y, are then fed through high gain wideband amplifiers followed by a dc-controlled video multiplexer, before being driven along long hauls of high quality coaxial cables to MCC. This multiplexing system is used in order to minimize the number of high cost coaxial cables required.

At MCC the raw signals are fed into stretcher units, along with trigger signals from an 8-channel digital delay unit which are timed to select only one of the two 7 ns beam bursts present. Note that under some conditions, such as tuneup, more than two 7 ns bursts may be present; in any event only one such burst is selected by the timing circuits for viewing in i, x and y. The stretcher outputs, which are pulses of the order of 1 μs width, are now sent through the existing video display system[1] at MCC, where the properly selected i, x and y signals are displayed sequentially with x and y delayed in time with respect to i.

Note that at present there are 4 sets of stretcher electronics in the system. Two sets serve the multiplexer outputs, which select 2 of 4 different monitors for viewing. Two others each serve a single monitor. Only one monitor is normally viewed at the operator's console, although 4 monitors could in principle be viewed simultaneously. Figure 3 shows the location of the 6 monitors presently comprising the total system.

Detailed Circuit Description

The Stripline-Type Monitor

The stripline monitor is based on the principle of the traveling-wave beam electrode.[2, 3, 4, 5] Basically it consists of a section of cylindrical steel pipe with 4 conducting copper strips of length, L (see Fig. 4). The dimensions A, B and C are chosen to give each strip a 50 ohm characteristic impedance. L is chosen such that 2L represents a propagation delay equivalent to the detected pulse width of 7 ns. The rear ports are terminated in 50 ohms and the front ports are used as outputs.

A simplified description of the operation is as follows: As a very narrow beam pulse (see Fig. 5) passes adjacent to the front end of the stripline it induces a signal v which has components that travel in both directions, one towards the output and one towards the 50 ohm load. The components of v traveling towards the load reach the load at approximately the same time as the beam. At this time the beam induces another signal, v' (opposite in polarity to the first one, v) in the stripline. V' also has components that travel in both directions. Re-examining the induced signals v and v' shows the following: The components of v and v' which travel towards the load cancel each other out. Those components of v and v' which travel towards the output port appear at the output port with v leading v' by a time, δt, where δt is the time for a traveling wave to cover a distance of 2L. Thus, for the 7 ns SPEAR beam the output is a bipolar 7 ns pulse, the polarity of which depends upon the sign of the charge. The pulse amplitude is proportional to the beam current and inversely proportional to D, the distance between the beam path and the stripline. Thus, by utilizing sum and difference signals from the pairs of electrodes, beam current and displacement can be measured, as follows:

Beam current ∝ sum of all four outputs
Horizontal displacement ∝ difference between the 2 horizontal strip outputs

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Vertical displacement $\propto$ difference between the 2 vertical strip outputs

Figure 6 is a photograph of the actual monitor. The measured sensitivity of this monitor for the beam described is as follows:

Position sensitivity (difference signals) = 0.25 mV/mA-mm
Intensity sensitivity (sum signal) = 4.33 mV/mA

Figure 7 is a photograph of a typical output signal.

Figure 8 shows the actual amplified position signal as a function of displacement for a 2.9 mA simulated beam. Note that the output is linear over a range of approximately ±2 cm.

The Local Amplifier Chassis

The local amplifier chassis consists of three summing transformers and three amplifiers. A block diagram is shown in Fig. 9. The four outputs from the monitor are connected to the four inputs, TOP, BOTTOM, RIGHT and LEFT. The summing network is designed such that all inputs are equivalent to 50 ohms when the 50 ohm monitor outputs are connected. The analysis is as follows: Consider the resistor network shown in Fig. 10a. $R_{eq} = 2R//2R = R$. Since the R's are equal to each other no current flows through R_j. R_j can therefore be of any value and the result is still true. Let us then choose $R_j = R$. Figure 10b shows the equivalent circuit for the input network excluding the amplifiers. One can see that it consists of three of the basic equivalent networks shown in Fig. 10. Analysis shows that the equivalent input resistance at each input port is R, which is 50 ohms. In the actual circuit, signals are coupled to R_x, R_y and R_i by means of 1:1 broadband isolation transformers; 50 ohm coaxial cables are used as the transformer windings.

The basic amplifier stage is shown in Fig. 11. This stage has a theoretical gain of approximately

$$\frac{R_2}{R_1} = \frac{100}{13} \approx 7.5$$

In practice the gain is 6-7 for either polarity of signal. With the 2N3960 and 2N4261 transistors shown, the bandwidth of the stage is above 200 MHz. The amplifiers are formed by cascading two or three of these basic stages followed by a push-pull emitter follower pair to provide low output impedance. The overall bandwidth in this case is 150 MHz for a 2-stage and 120 MHz for a 3-stage amplifier; the overall amplifier can handle an output voltage swing of ±5 V.

In packaging the circuit particular attention had to be given to grounding and shielding. A photograph of the finished unit is shown in Fig. 12.

The Stretcher Unit

Figure 13 is a simplified schematic of the stretcher unit. A timing diagram is shown in Fig. 14. The 7 ns bipolar signal passes through two parallel limiter channels, where either the positive or the negative half of the input is processed. The series and shunt fast gates select the particular signals to be stretched, and also help reduce low frequency noise. The signal is now converted to a charge which is stored in a capacitor having a decay time constant of approximately 50 μs. Slow 1 μs gates (generated from the fast gate) are used to gate parts of the stored signal on the capacitor to be displayed as an output. The output is now a pulse of approximately 1 μs width which is comparable to the video signals from the conventional BSY beam monitors.

There are two possible display modes. In one mode the separate halves of the stretched pulses are recombined to give a stretched version of the original bipolar pulse. In the other mode only one or the other half of the stretched bipolar pulse is viewed. In either case, a polarity sensing circuit is necessary to invert the order in which the outputs appear when the input signal reverses polarity. This sensing circuit has a threshold of about ±30 mV.

Because of the critical timing of the input signal and the noisy environment, fast gate timing stability is vital to proper performance of the stretcher unit.

Figure 15 shows a typical stretched signal from one of the monitors.

A photograph of the final package is shown in Fig. 16.

The Trigger Circuitry

Since some monitors are more than 2000 feet apart, the signal arrival time between monitors can be as much as 4 μs (the time for the beam to travel from one monitor to another plus the difference in time for monitor signals to reach MCC). Very stable trigger delay circuits are therefore necessary. In order to guarantee a stable trigger relative to the SPEAR beam, a trigger is derived from the SPEAR RF system, sent to the injector from SPEAR, and then sent back along the same drive line to MCC. (Refer to Figs. 2 and 14.) A commercial discriminator, the EG&G TR204, gates and shapes the proper trigger, which is then passed through an accurate 8-channel digital delay unit. A stable external clock, synchronized to the SPEAR trigger, is used as the clock for the digital delay unit. This clock is derived from the 51.2 MHz SPEAR RF frequency. Figure 17 is a simplified schematic diagram of a digital delay channel. Basically, the circuit works as follows: The input trigger starts a counter which was preset to a value by a set of switches. When the counter reaches this pre-set value a trigger is generated. A fine control for a variable delay range of approximately 200 ns is provided; this is more than sufficient to overlap the gap between counts of approximately 80 ns (4 times the time period of the 51.2 MHz clock). An adjustment for output pulse width is also provided. The specifications for this unit are summarized below:

Input	- NIM (-800 mV into 50 Ω), min width = 20 ns
Delay range	- 100 ns to 10 μs
Delay jitter	- Dependent on external clock stability; < 1 ns for a 4 μs delay using the external clock described
Output	- NIM (-800 mV into 50 Ω), width 10 ns to 100 ns

To save component costs, TTL rather than ECL logic units were used wherever possible. Very stable components were selected for the critical timing units. Figure 18 is a photograph of the 8-channel digital delay unit.

Video Multiplexer

Functionally, the video multiplexer[6] is equivalent to a dc-controlled set of coaxial switches. The basic circuit is shown in Fig. 19 and consists of hot-carrier diode gates used as a 1P2T switch. The unit has a bandwidth of approximately 700 MHz for signal levels under ±0.5 V.

Long-Haul Cables

In order to preserve the quality of the fast 7 ns bipolar signals from the local amplifier box to MCC, high quality coaxial cables having an attenuation of less than 2 dB/100 ft at 1000 MHz are required. HELIAX MJ5-50 was selected for this system.

The Real-Time Display

As a backup in case of failure due to the stretching process or due to the regular display system, a real-time display for the intensity signals from the monitors is provided. Each unstretched signal from the intensity channels of the video position monitors can be selected and displayed on a fast oscilloscope, Tektronix Model 7704 or equivalent.

Summary and Conclusion

The following is a summary of the specifications of the overall system:

Monitor sensitivity:
  Intensity - 4.33 mV/mA
  Position - 250 μV/mA-mm

System sensitivity (nonstretched):
  Intensity - 100 to 150 mV/mA (dependent on the distance between the monitors and MCC)
  Position - approximately 50 mV/mA-mm

System sensitivity (stretched pulses):
  Intensity - 100 mV/mA
  Position - 50 mV/mA-mm

Accuracy:
  Linear to nominal ± 10% for beam intensities of 0.5 to 8.0 mA and deflection of ±2 cm for a beam of $\leq$ 3 mA

Various parts of the system have been in operation for over a year; other parts such as the digital delay unit have been implemented only recently.

In general, the various components described have performed according to their design specifications. The monitor meets its design sensitivity and the stretched signals preserve the basic signal-to-noise seen at the output of each monitor.

The most serious system problem is pickup noise in the monitors themselves from various noise sources. One such noise source has been the SPEAR kicker magnets and drivers; another appears to be beam-synchronous ground currents which build up as the stored beam current increases. These affect the two monitors closest to the ring in the e^+ and e^- beam lines. A further problem is that the main trigger is sometimes unstable causing timing shifts which deteriorate performance. Work is continuing to improve system performance and reliability by eliminating these problems.

In general, the system described, with its backup display for the unstretched monitor signals, is becoming a useful and reliable means of detecting the very short duration beams in the SPEAR transport system.

Acknowledgements

It is a pleasure to acknowledge the contribution of J. Harris who initiated this project; of J.-L. Pellegrin who was responsible for the electrical design of the stripline monitor described in this report; and of D. Walz and W. Basinger who where responsible for the mechanical design and fabrication of the monitors. The assistance of T. V. Huang, D. Tsang and R. Miller in implementing and evaluating the system is also gratefully acknowledged.

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2. Q. A. Kerns and D. B. Large, "Analysis of a Traveling-Wave Beam Electrode," Report No. UCRL-11551, University of California, Berkeley (July 1964).
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5. J.-L. Pellegrin, "Beam Feedback Electronics for the SPEAR Storage Ring," Report No. SLAC-PUB-1150, Stanford Linear Accelerator Center (November 1972).
6. A. Chang, Electronic Design 20, 158 (1972).

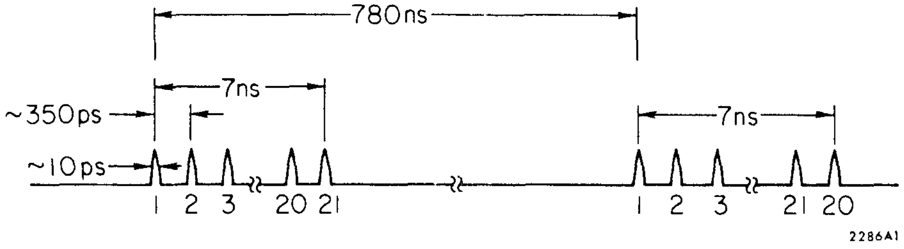


FIG. 1--SPEAR transport beam structure.

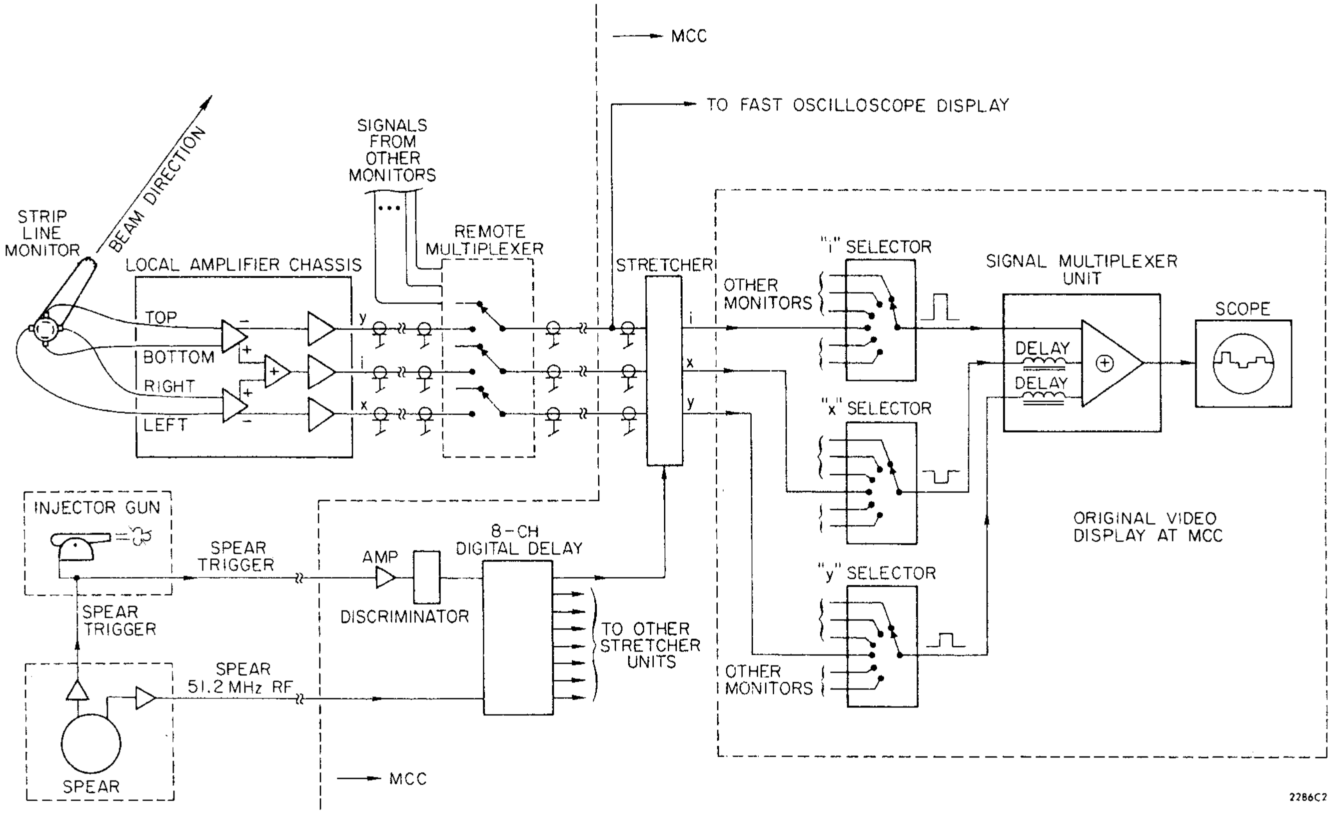
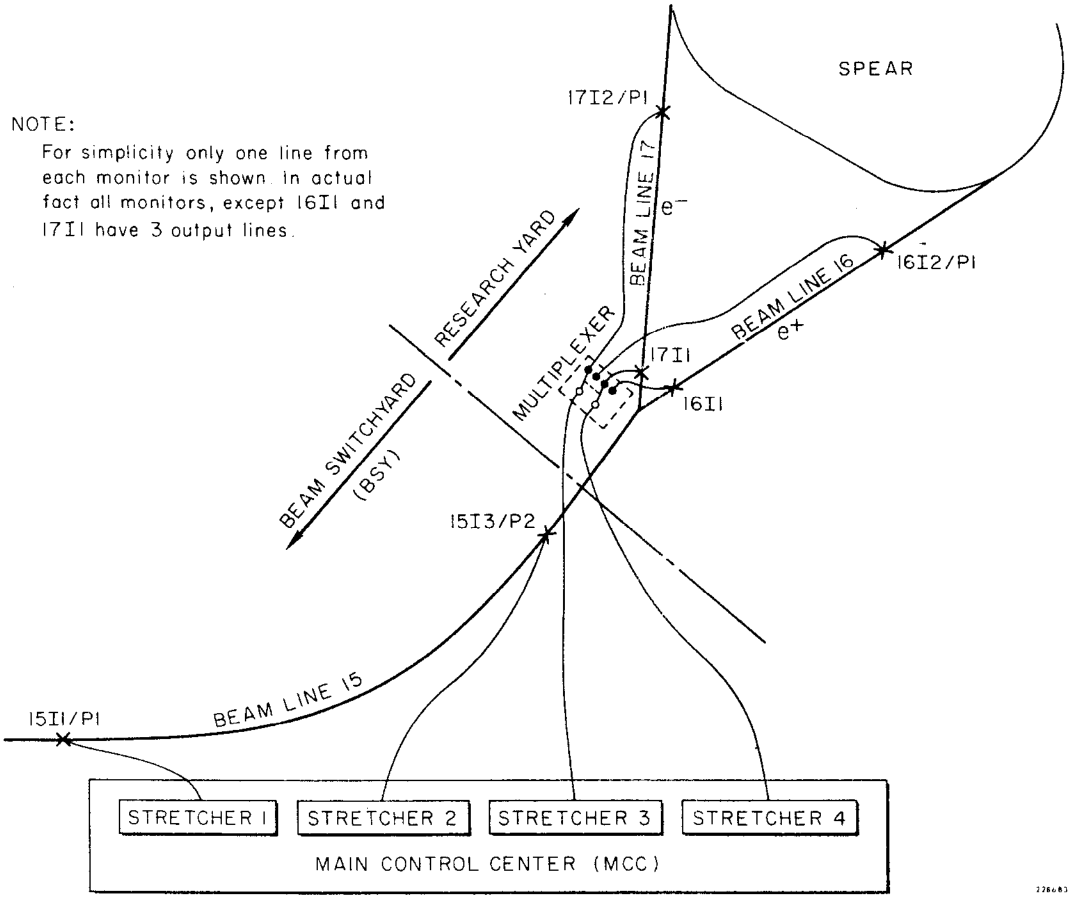
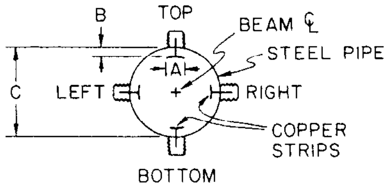


FIG. 2--SPEAR transport position and intensity monitoring system.

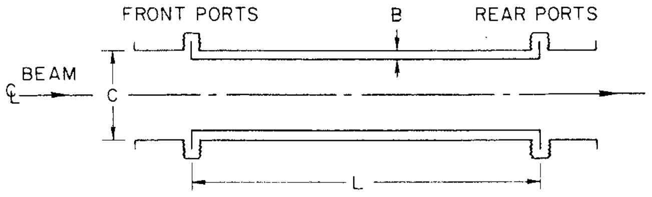


NOTE:
For simplicity only one line from each monitor is shown. In actual fact all monitors, except 16I1 and 17I1 have 3 output lines.

FIG. 3--Locations of monitors in the SPEAR transport system.

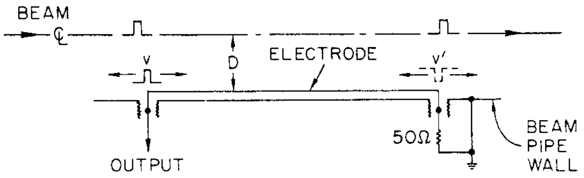


END VIEW

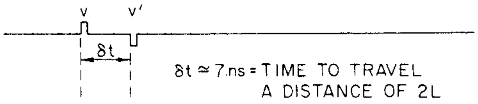


LONGITUDINAL CROSS SECTION

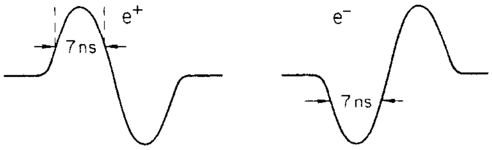
FIG. 4--Simplified diagram of a position and intensity monitor.



(a) LONGITUDINAL CROSS SECTION



(b) SIGNAL AT OUTPUT FOR A VERY NARROW BEAM, e^+



(c) RESPONSE AT OUTPUT FOR A 7ns BEAM

FIG. 5--Schematic diagram and output response for e^+ and e^- beam.

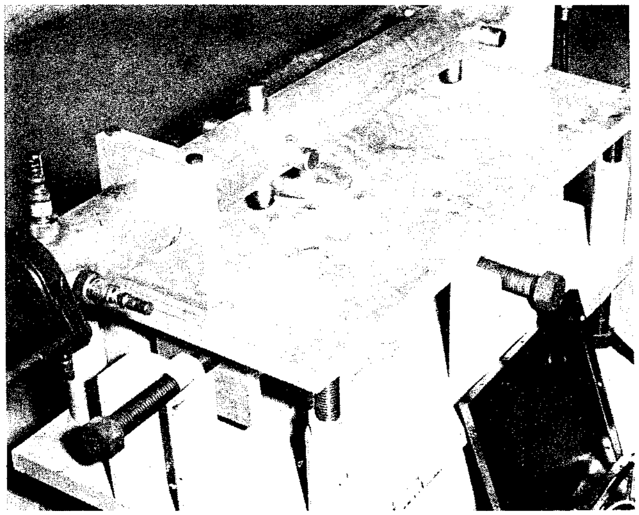
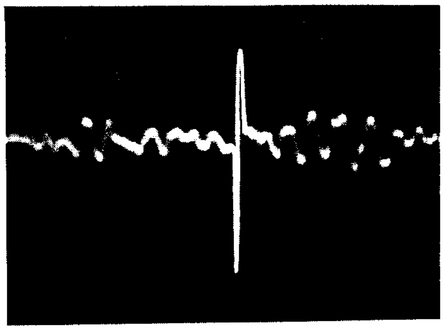


FIG. 6--Position and intensity monitor.



H = 50 ns/cm
V = 100 mV/cm
BEAM (e^-) = 2.5 mA/PEAK
STORED RING BEAM: 8.5 mA e^+
8.5 mA e^-

FIG. 7--Typical monitor output signal.

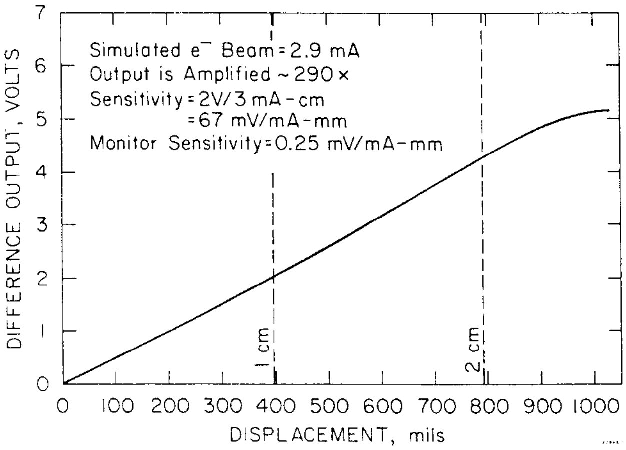


FIG. 8--Position signal output vs displacement.

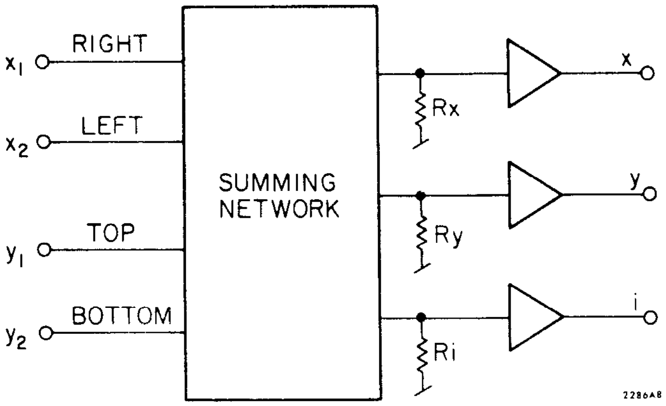


FIG. 9--Local amplifier chassis block diagram.

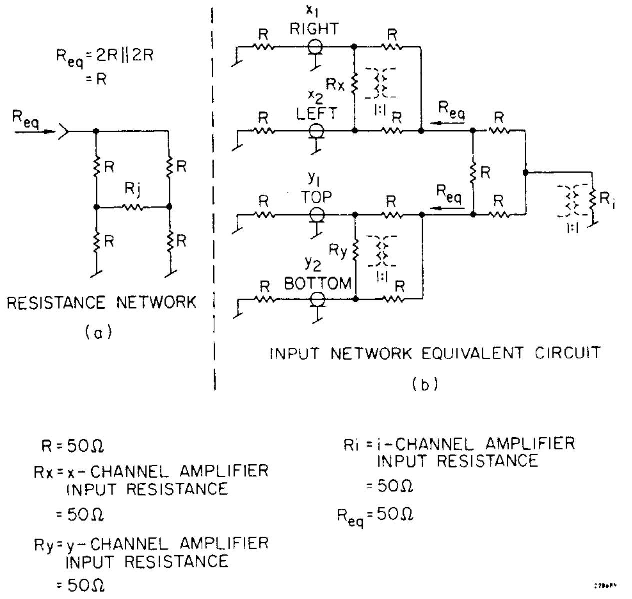


FIG. 10--Equivalent input network for the local amplifier chassis.

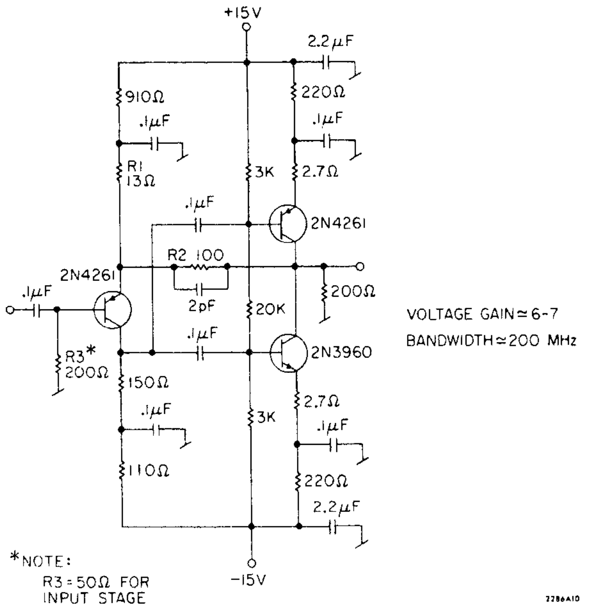


FIG. 11--Basic amplifier stage.

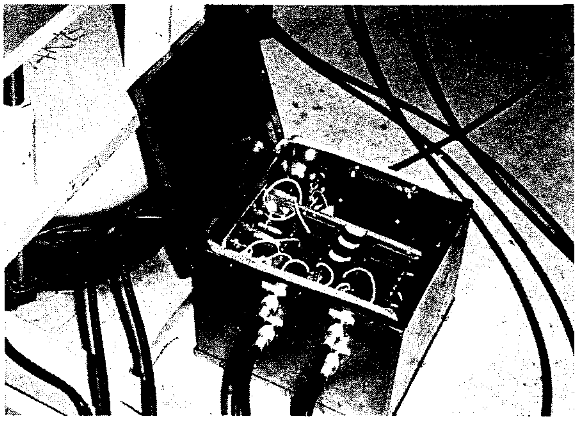


FIG. 12--Local amplifier chassis package.

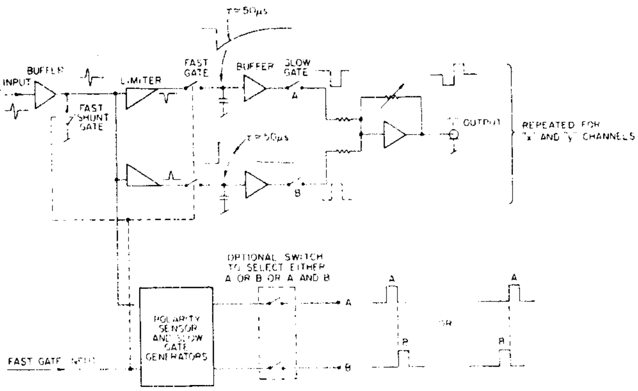


FIG. 13--Simplified schematic for stretcher unit.

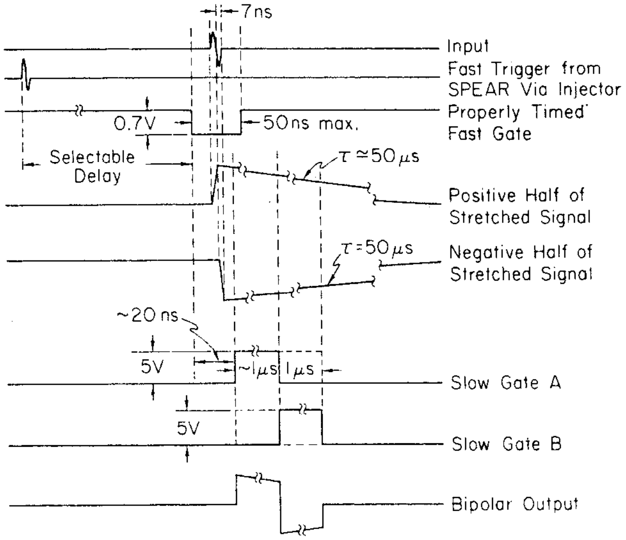
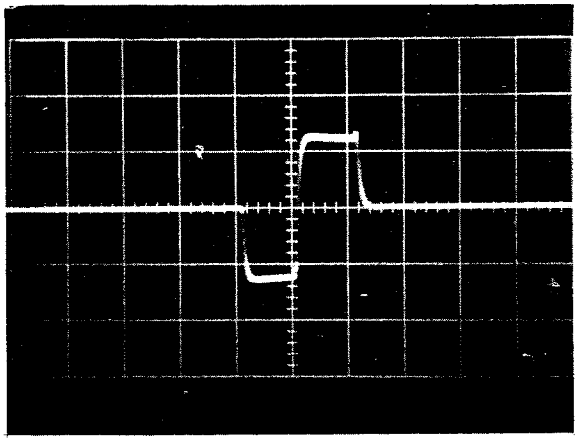


FIG. 14--Timing diagram.



V = 100 mV/DIVISION
H = 0.5 μs/DIVISION
SIMULATED BEAM (e^+) ≈ 5 mA PEAK

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FIG. 15--Typical stretched signal.

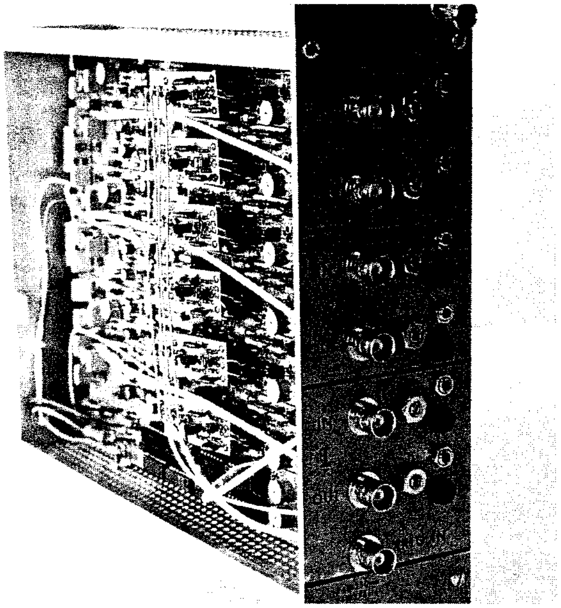

FIG. 16--Stretcher unit package.

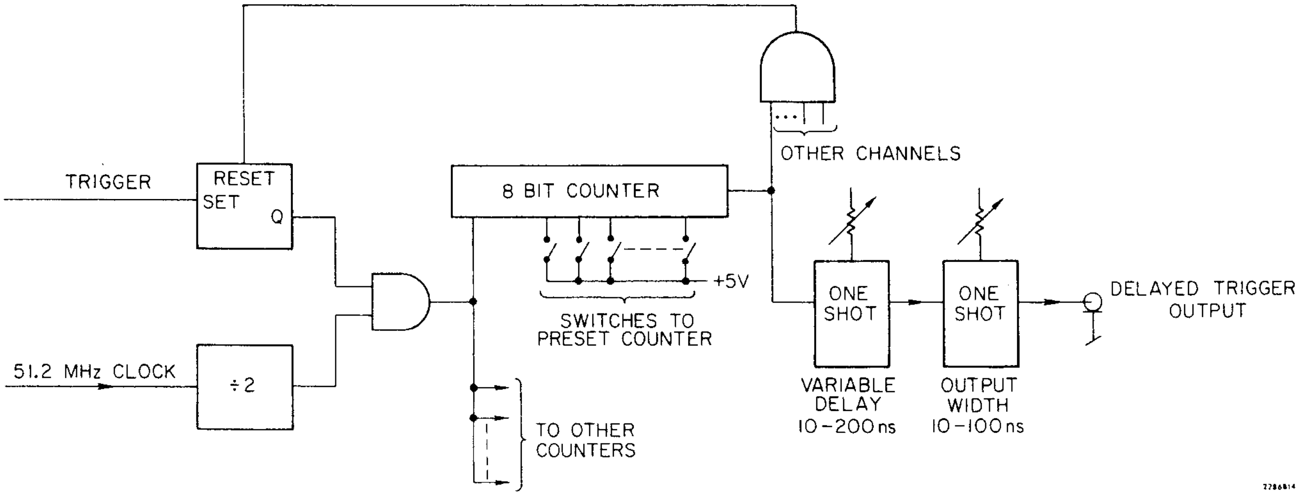

FIG. 17--Simplified schematic for a delay channel.

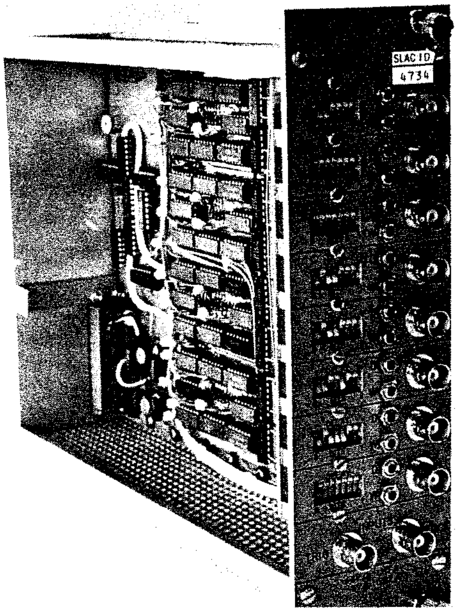

FIG. 18--Eight-channel digital delay.

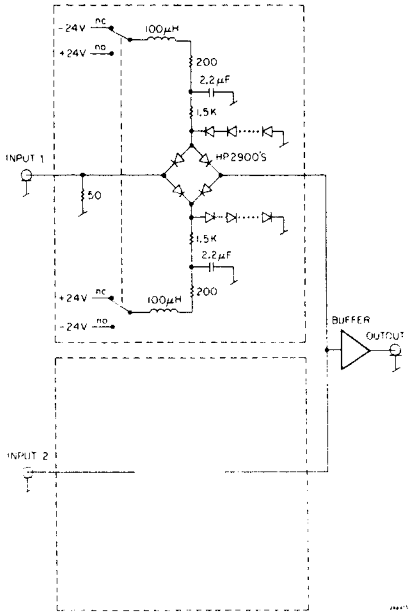

FIG. 19--A 1P2T coaxial switch using diode gates.