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November 1964
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1.0 INTRODUCTION

The purpose of this report is to describe the design goals, and present status of the beam intensity and position monitoring in the BSY. Although the detail hardware design is in various stages of completion, the general system design, such as types of displays, monitor location, etc., is considered complete and represents the final design goals. Various parts of this system are discussed in other SLAC Reports and are footnoted where applicable. Two reports which are particularly useful are references (1) and (2). These are "Beam Monitoring System" which describes the CCR monitoring scheme and "Proposal For Beam Monitoring In The BSY."

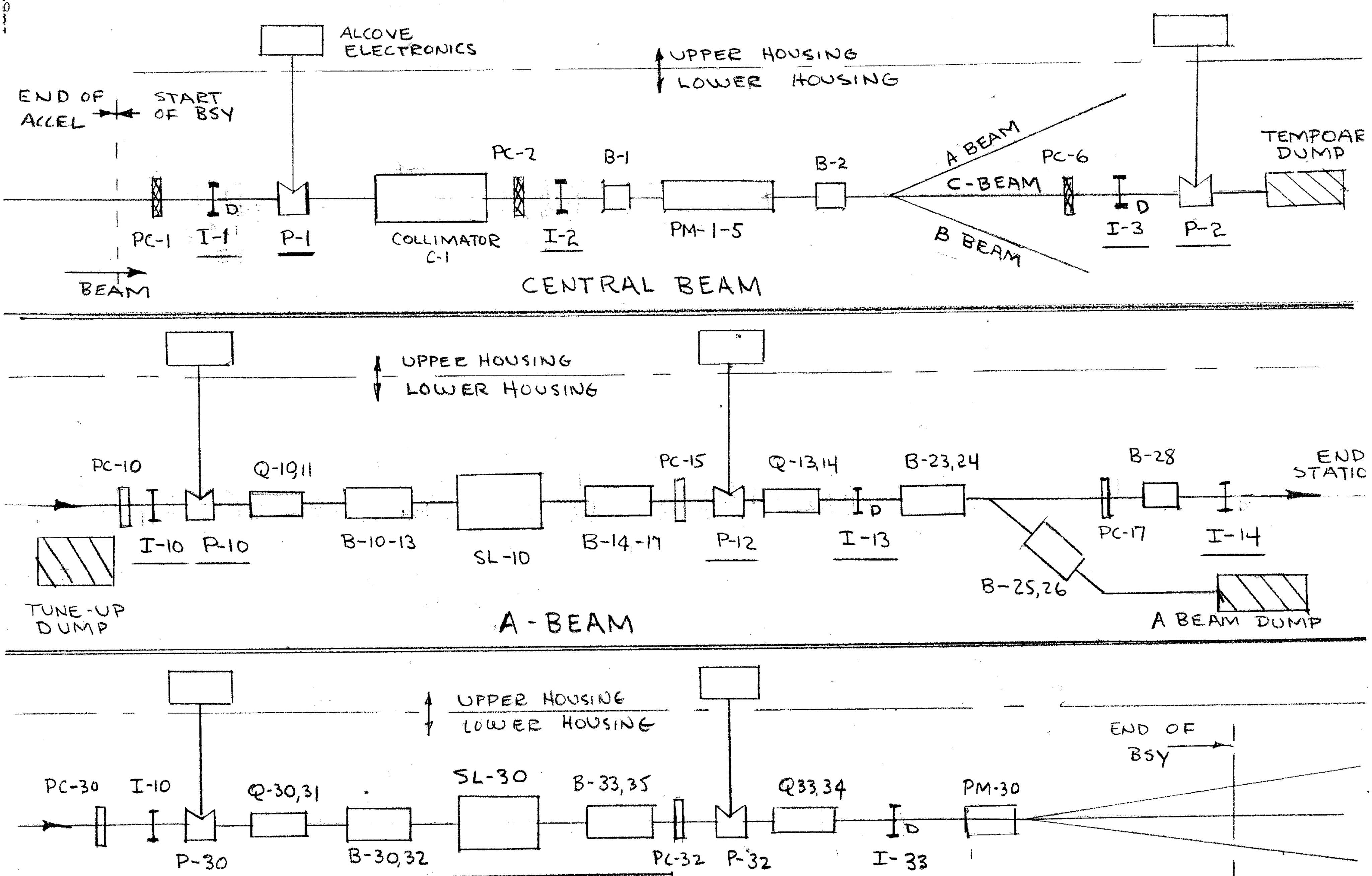
2.0 SYSTEM DESCRIPTION

2.1 Monitors

The locations of the monitors considered in this report are shown in Fig. 1. These monitors are located before and after the collimator and before and after the magnet analyzing system in beams A and B. This allows monitoring the beam current and beam position at these critical locations.

The position monitors are microwave cavities similar to those used on the accelerator, but with 2.0" openings. This is to accommodate the larger beam size, and beam position uncertainty in the BSY. As presently planned, all monitors will be identical except for small variations in mounting. Each monitor will furnish both horizontal and vertical displacement information, the zero reference being the beam axis.

The intensity monitors are toroidal current transformers. All of these transformers will be identical except that I-1, I-3, I-13, I-14 and I-33 will consist of two independent toroids within the same vacuum case. One of these will serve as an average current monitor and will furnish a signal that follows the instantaneous beam current. The second or ' (prime)



I - INTENSITY MONITOR	PC - PROTECTION COLL.
P - POSITION MONITOR	Q - QUADRAPOLES
B - D.C BENDING MAGNET	SL - ENERGY DEFINING SLIT
PM - PULSE MAGNET	

FIG 1 MONITOR LOCATIONS

monitors will be used for either the interlock circuits or for the precise current display. The output of these monitors will not preserve the beam shape.

2.2 Display Requirements

Figure 2 is a functional diagram of the beam position and beam intensity displays and the associated electronics located in the DAB.

2.2.1 Intensity Displays

Three types of beam intensity displays are planned:

a) A scope display of the video pulse directly from the toroid
b) An analog meter display of the integrated current at each toroid
c) A precise digital display of integrated current from toroids I-13 and I-33.

The dynamic pulse display (2) will be a fast (10 mc) dual trace, or dual beam oscilloscope. Manual switches will be provided so that the outputs of any two toroids along a beam may be observed simultaneously. A comparator, providing a precision d.c. voltage, will be used in conjunction with the scope to provide a precise measurement of the beam pulse amplitude. The principal use of this display is expected to be in the beam setup procedure.

Once the beam is established, the average current meters (b) will give a synopsis display of the beam intensity at the various toroid locations. As shown in the diagram there will be two sets of meters, one for the A beam, and one for the B beam. As the C beam is not planned for the initial installation, provisions will be made to display the C beam on either the A or B displays. For beam A, the toroids monitored will be I-1, I-2, I-10, I-13 and I-14; for beam B, I-1, I-2, I-30, I-33. To display the C beam it would only be necessary to add or relabel a meter to either display. The nominal accuracy of the meter display system is 1% to 3%.

The digital readout of monitors I-13 and I-33 will be provided by precise integrators with an accuracy on the order of 0.1%. There will be, as shown, two integrators and readouts; one for the A beam and one for the

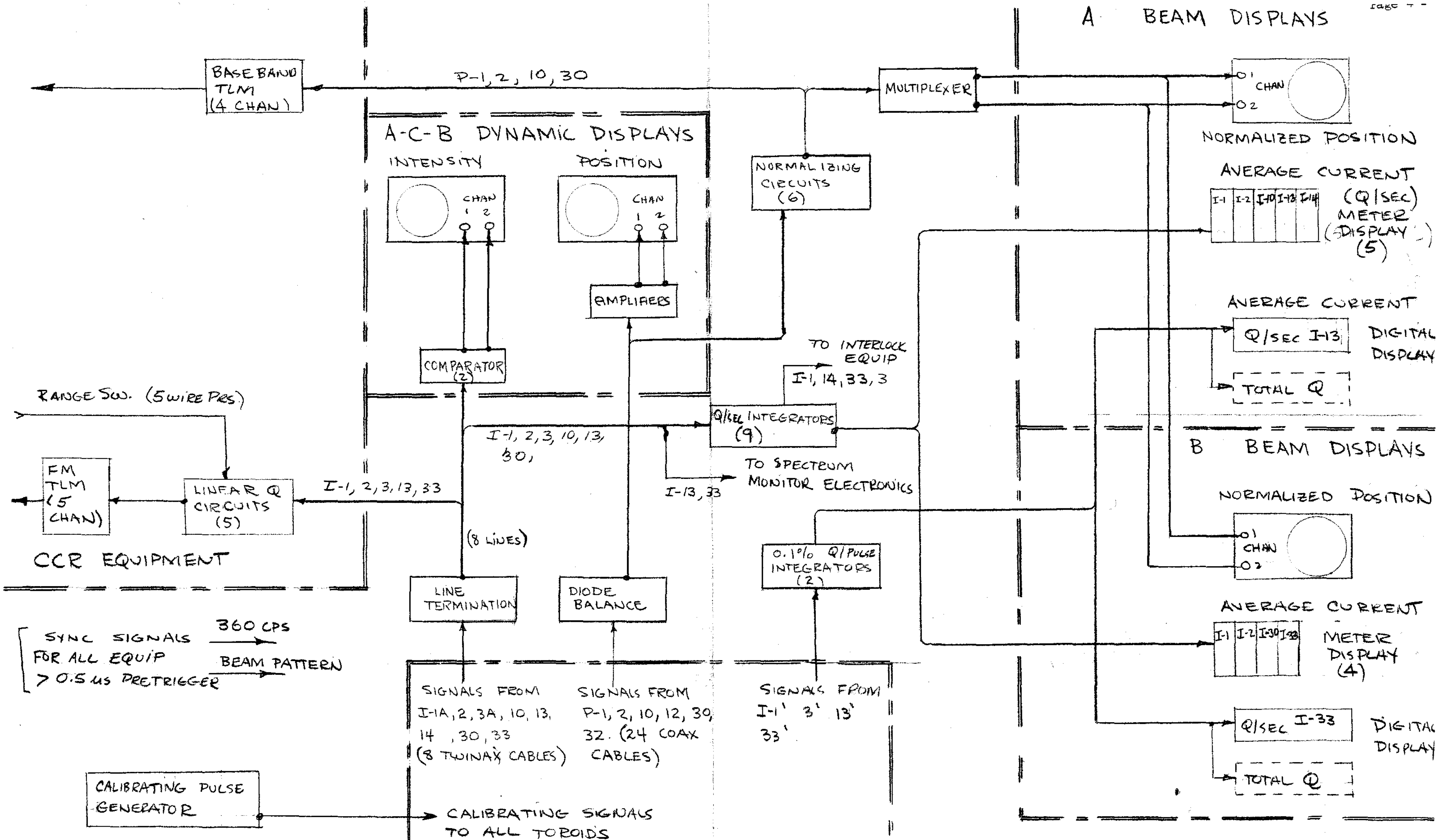


FIG 2 FUNCTIONAL DIAGRAM OF DAB ELECTRONICS & DISPLAYS

B beam. The use of this display is to provide the BSY (and CCR) operator directly with the precise current being delivered to the end stations. This means, for instance, that the beam current to end station A can be established while the beam is directed into the dump.

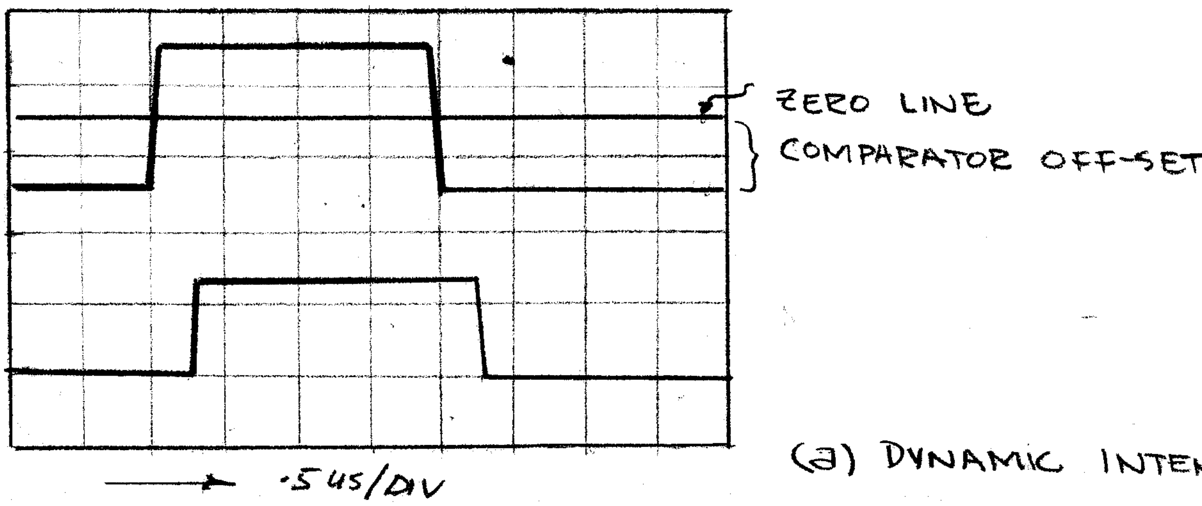
2.2.2 Position Monitor Displays

The position monitor displays planned are (a) dynamic scope display of the monitor video output and (b) normalized position display.

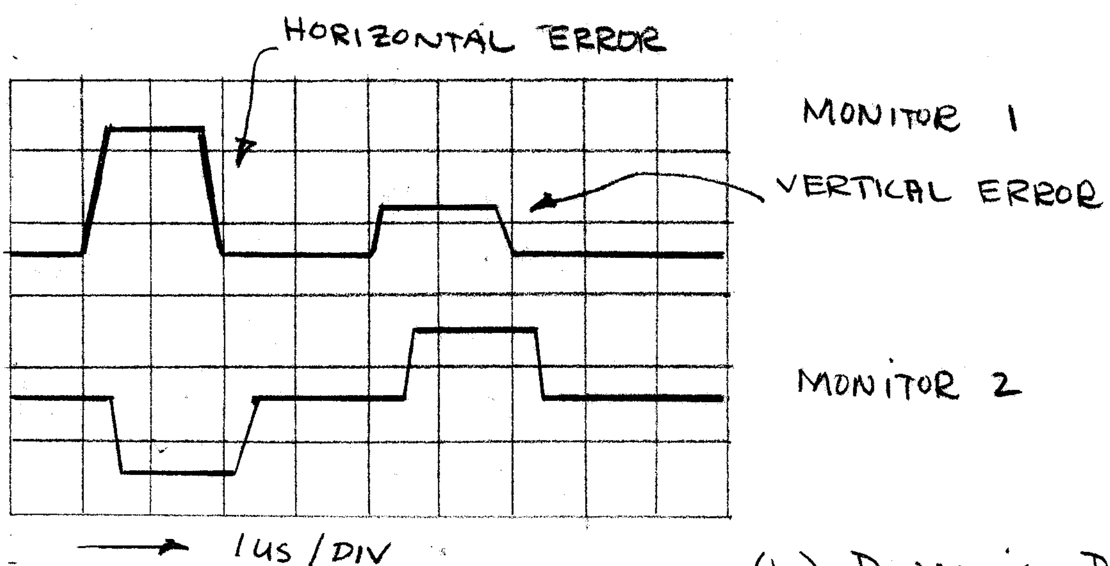
The dynamic or pulse display will be a single dual trace scope and will be used primarily during the time a beam is being setup. As with the intensity display, this will allow simultaneous viewing of the horizontal and vertical output of any two monitors. The principal use of this display is for centering, or null information. Thus the operator would adjust the relevant parameters until the pulse on the oscilloscope vanishes. As the pulse is to be nulled, the fact that the trace amplitude is proportional to the (beam current) X (beam displacement) should not be too disturbing. The dynamic pulse display provides the simplest and most sensitive way of displaying the monitor outputs and will show many conditions such as beam position as a function of time that would not be noticed on a normalized display.

The normalized position will be displayed on a CRT and will present a synopsis for each beam. Trace one would display the horizontal position at each monitor along a beam and trace two the vertical. As with the Q/sec monitors there will be two CRT displays, one for beam A and one for B. If it is ever necessary to deliberately offset the beam, a normalized display is essential. Also, if beam begins to drift, this display will give the operator a clear idea of where the trouble is, and what is necessary to correct it.

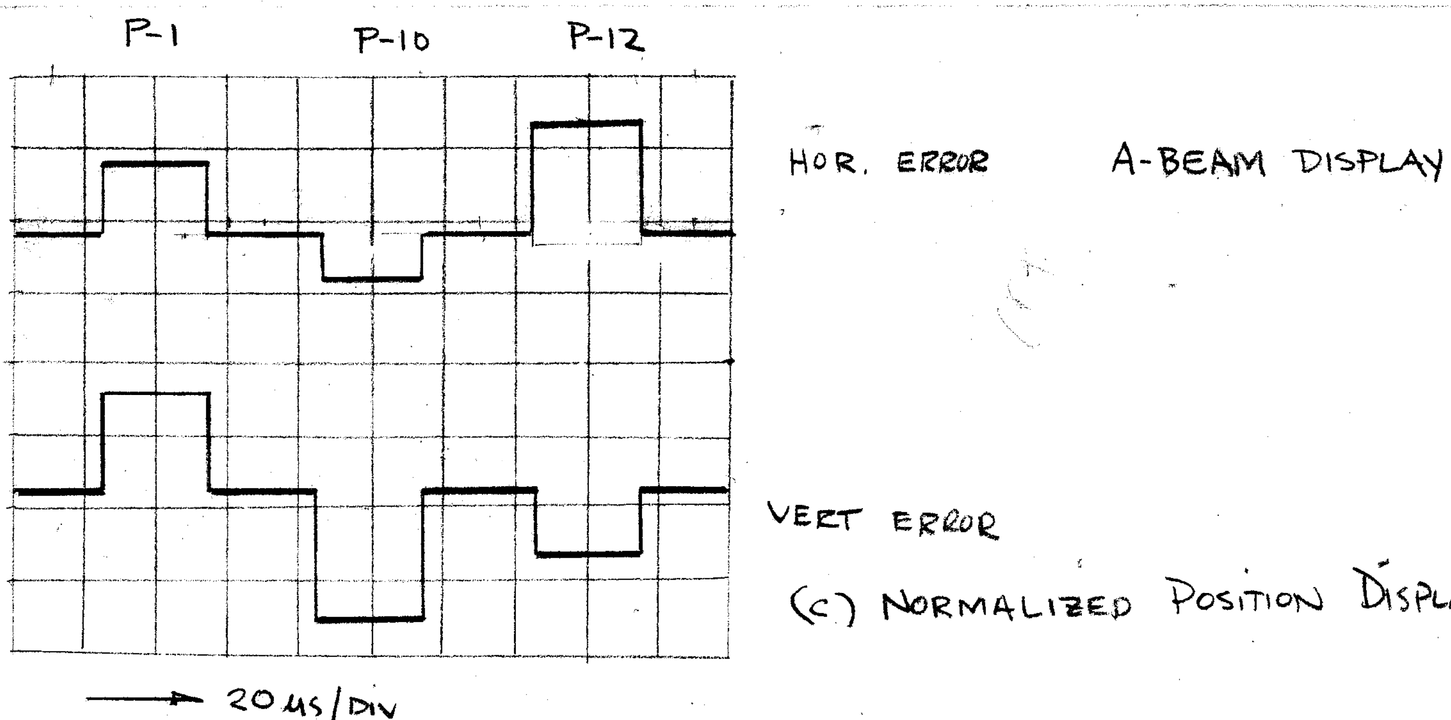
Figure 3 shows the proposed intensity and position oscilloscope displays. The dynamic displays will be presented on a general purpose oscilloscope which may be used for other purposes.



(a) DYNAMIC INTENSITY DISPLAY



(b) DYNAMIC POSITION DISPLAY



(c) NORMALIZED POSITION DISPLAY

FIG 3. DISPLAY FORMAT

2.3 Signals to CCR

Appendix I contains a complete listing of position, intensity and associated signals that are requested for display in the CCR.

2.4 Extension of Displays

The displays and their electronics will be designed to allow for nominal future expansion. This will be a particular problem in the B and C beams where several additional position and intensity monitors may be added.

3.0 HARDWARE DESIGN

3.1 Position Monitor Characteristics (3)

The position monitors, developed by the Microwave Group, will be the cavity type, operating in the TE_{012} mode. Tests have been made on cavities with openings of 1.6", 1.8" and 2.0" with the object of determining sensitivity versus hole size. The test cavities were crudely assembled, but it appears as though the 1.6" cavity is approximately two times more sensitive than the 1.8" or 2.0" models which were of similar sensitivity. As 2.0" units are required for P-10, P-30, P-12 and P-32 this increase in sensitivity does not seem to warrant building special 1.6" monitors for the straight ahead beam (P-1, P-2).

Figure 4 is a diagram of a typical position monitor and its associated alcove electronics. The coax relay allows the same rf voltage (proportional to beam current I_o) to be applied to both diodes regardless of the beam position. This means the diodes can be balanced by means of a potentiometer in the DAB. The phase adjustment is made once, and should not be required again under normal conditions.

A prototype monitor and detector has not as yet been constructed; however, Table I lists the characteristics expected of the final 2.0" design.

The power coupled from the monitors

$$P_o \propto I_o^2 \qquad \text{reference cavity}$$

$$P_o \propto I_o^2 \sin^2 kx \qquad \text{position cavity}$$

(I_o = beam current)

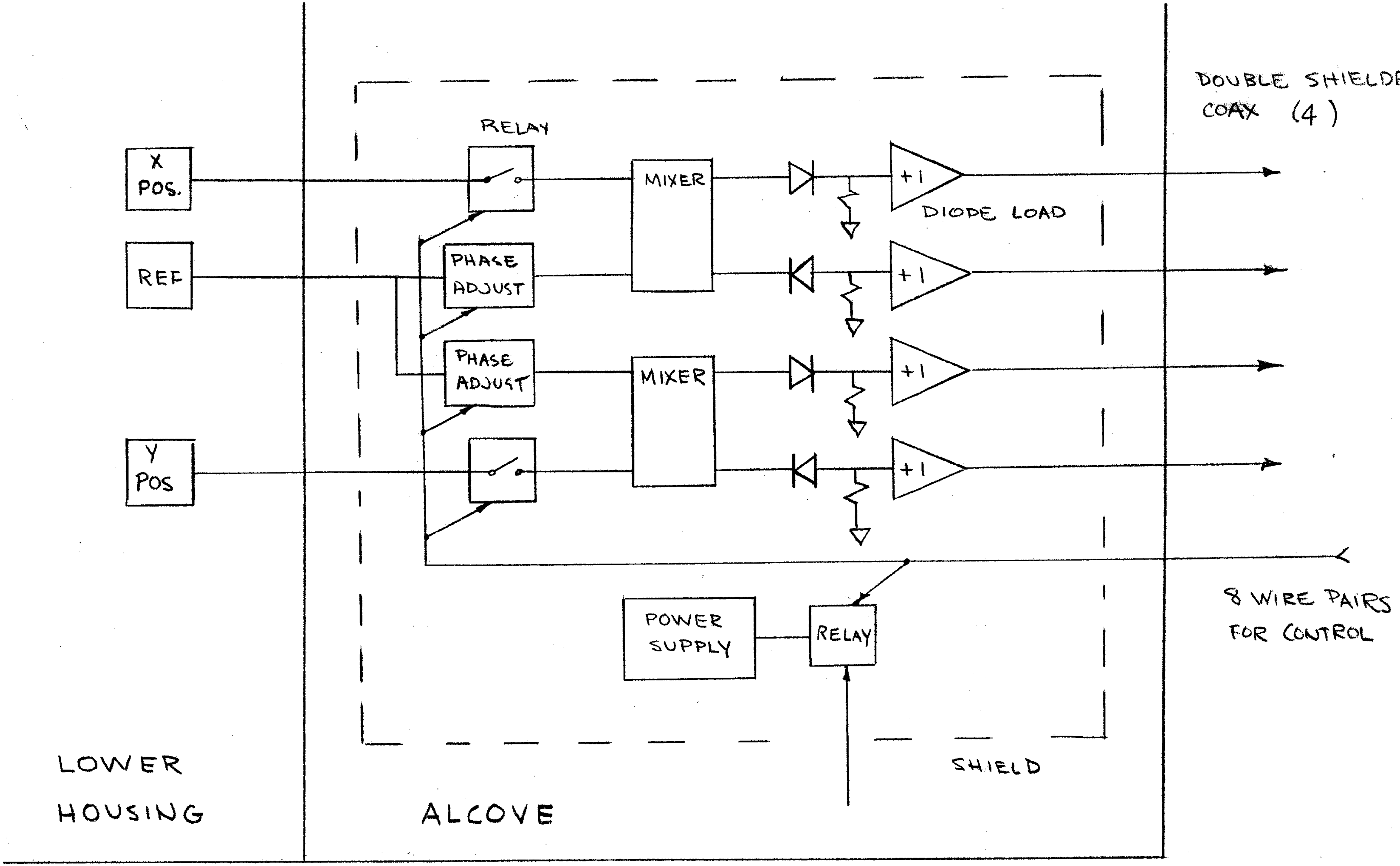


FIG 4.

POSITION MONITOR ALCOVE ELECTRONICS

Thus when the diodes are operating in the linear region ($P_o \geq 10$ mw for thermionic diodes), $V_{diode} \; \alpha \; \sqrt{P_o}$. As cooling water is not available, the temperature variation listed in Table I must be tolerated or the cavities must be made of a material with a temperature coefficient less than that of copper.

The temperature dependence of the monitor will affect only the accuracy of the displacement (normalized) display but will not affect null reading. The null point, however, will be affected by how well the detector diodes are matched over the range of signals, temperature levels, and the mechanical misalignment.

TABLE I

Monitor and Detector Characteristics

Sensitivity	
Position Cavity	0.20 $mw/ma^2 \cdot mm$
Reference Cavity	10 mw/ma^2
Cavity Q	
Position Cavity	800
Reference Cavity	2000
$\frac{\Delta \text{ Powerout}}{\text{Powerout}} / \Delta T$	
Position Cavity	0.8%/°C
Reference Cavity	2.0%/°C
Diode output $V_D \; \alpha \; I_o \cdot X$	60 mv/ma . mm $I_o \geq 3$ ma
(thermionic diodes)	25 mv/ma^2 . mm $I_o \leq 3$ ma
$\frac{\Delta V \text{ Diode}}{V \text{ Diode}} / \Delta T$	1.0%/°C for $V_D \; \alpha \; I_o$
	.4%/°C for $V_D \; \alpha \; I_{ox}$
Mechanical Alignment Error	± 0.5 mm
Diode Null Error (2% unbalance)	± 0.5 mm

At low levels the output of the diodes decreases as I_o^2. To make the monitors useful for low current levels, special attention is being given to shielding and grounding problems.

3.2 Intensity Monitor Characteristics

The beam intensity monitors are toroidal current transformers with an output given by

$$V_o = \sim \frac{Z_\ell}{N} I_o \,. \qquad (N = \text{No. of turns})$$

Table II is a summary of the toroid that will be used in the BSY for the normal monitors (I-1 , I-2, etc.) .

TABLE II

Sensitivity	2 volts/amp
Core Size	6.000" o.d., 3.675" i.d., 2.000" depth
Core Material	Ceramag 24
Pulse Permeability	~ 3000
Number Turns	48
Droop/2μs Pulse	< 1%

The CT(s) for I-1' etc. will be identical except for the number of turns. This in turn will depend on whether the toroid is used for the precise integrator or for interlock purposes.

At present, no plans are being made for amplifiers near the CT(s). This is mainly because of radiation, and maintenance problems. Also, recent tests by L. Johnston[4], and H. Woods have indicated that careful shielding techniques can reduce noise to the order of 5 - 10 μv rms in a noisy environment.

Each CT will have a single turn calibration winding.

3.3 Beam Position Displays

Figure 5 is a diagram of the position display electronics, showing the signal path for a typical monitor and the general timing sequence. The balance pots are used to match the detector diode outputs. They also may be used to correct for monitor alignment errors. The range of the signals $\alpha I_o \cdot X$ will be ~ 1 mv to 30 v . The polarity reversing switch is required so that direction sense will not be reversed for a positron

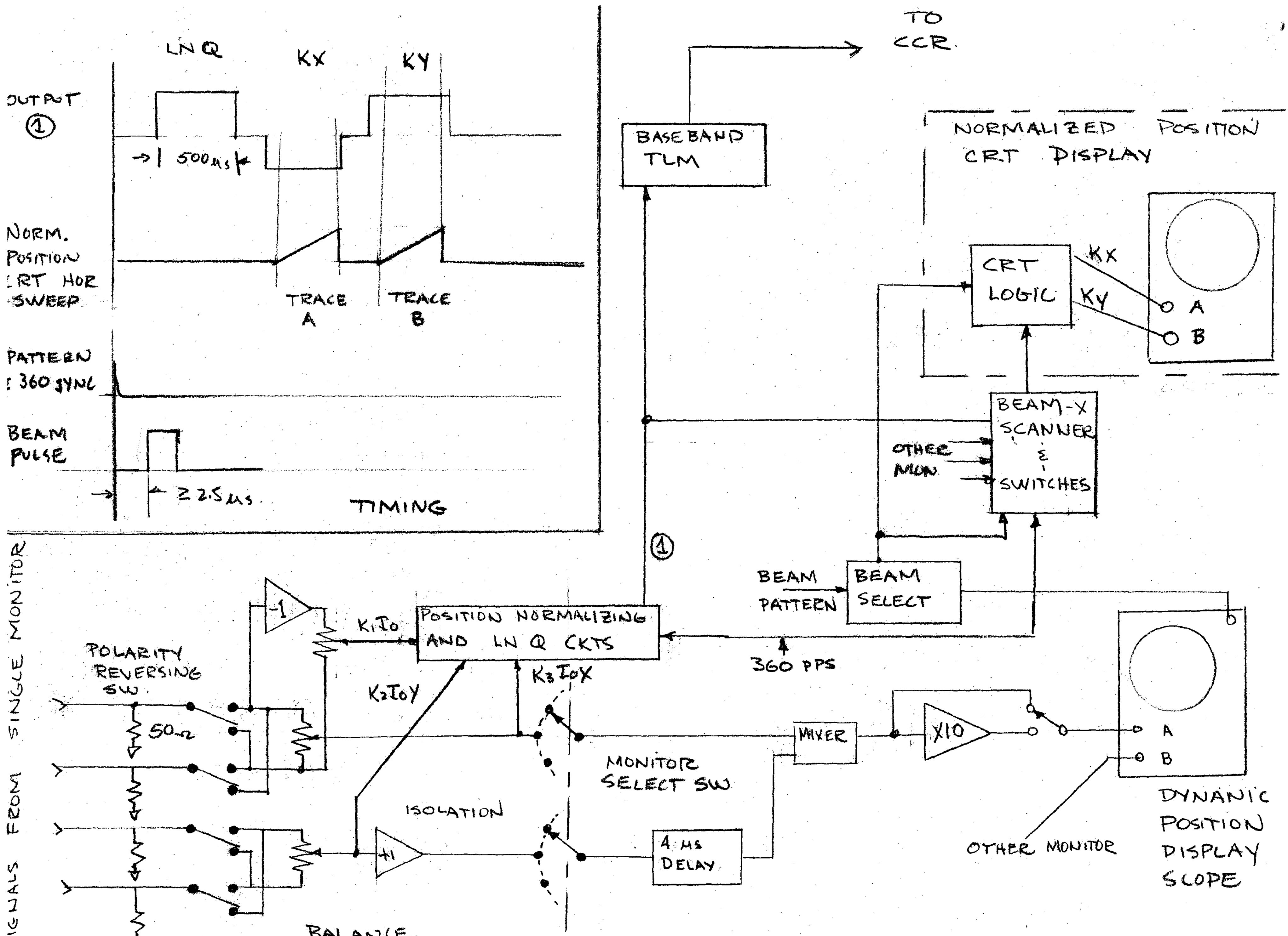


FIG 5 BEAM POSITION DISPLAY ELECTRONICS

beam. The dynamic display scope poses the problem that it must be able to display 1 μs/cm sweeps at repetition rates as low as 1 - 10 per second. The most suitable solution seems merely to use a scope that uses a high accelerating potential for the CRT.

The position normalizing circuits will be as similar as possible to those used in the accelerator.[5] The output of these circuits shown in Fig. 5-b is a sequence of 3 pulses, each lasting ~ 500 μs giving ln Q, X, Y. Even though it is available, it does not seem useful to display the ln Q signal in the BSY.

The CRT display for the X and Y signals (Fig. 3-c) will be identical to the one being developed for CCR. It will have a 1 mc bandpass and will have the logic circuits for displaying several independent beams. A single 10-channel multiplexer will be sufficient for both normalized position displays.

The normalized signals from P-1, P-2, P-10, P-30 will be sent to CCR via the base band telemetry system. The requirement for P-10 and P-30 is currently under discussion.

Nominal specifications for the beam position display electronics are shown in Table III.

TABLE III

Multiplexer	
Linearity	± .5%
Temperature stability 10° - 50°C	± .5%
Calibration and long-term stability	±1.0%
Amplifiers	
Linearity	±1.0%
Temperature stability 10° - 50°C	±1.0%
Calibration and long-term stability	±2.0%
Full scale output	5 v

Normalizing Circuits (see ref (1) p 10)	±10%
Oscilloscope	
Rise time	< 30 ns
Sensitivity	10 mv/cm
Sync. Requirements	360 pps and beam pattern sync. at least 2.5 μs prior to beam

Some simplification of the standard accelerator normalizing circuits and the linear Q circuits is possible as only one timing circuit will be required for the signal conditioning circuits for all channels in the BSY.

3.4 Beam Intensity Displays

Figure 6 is a diagram of the intensity display electronics showing the signal path for a typical monitor, and the general timing sequence.

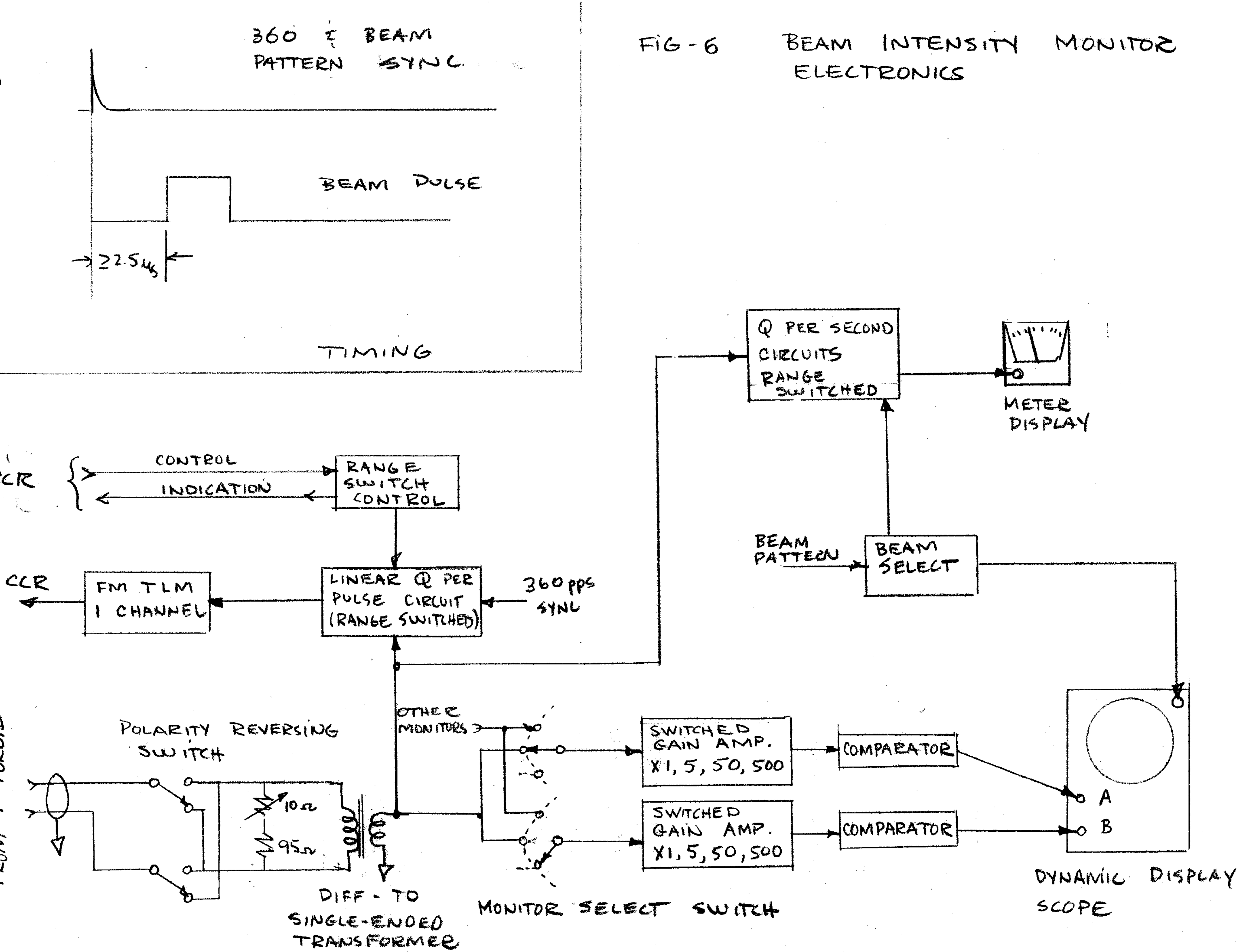
The polarity reversing switch is used so that positron and electron beams will produce the same polarity signal for the display equipment. The transformer is a differential to single-ended type and is used for common mode noise suppression.

The dynamic intensity display consists of a gain switched amplifier, a comparator and an oscilloscope. The amplifiers will give the intensity monitor an effective gain of 0.01 v/ma, 0.1 v/ma and 1 v/ma, to the oscilloscope. Direct viewing of the toroid output will also be provided.

The comparators will furnish a d.c. off-set to the pulse signal. A ten turn potentiometer would be adjusted until the top of the pulse is at ground potential; the pulse amplitude may then be read on the potentiometer. The comparator will also produce a chopped signal such that a ground reference and the pulse may be displayed on the same trace (Fig. 3-c). This will simplify measurements at high repetition rates.

The oscilloscope display requirements for the dynamic display are identical to those of the position display.

FIG-6 BEAM INTENSITY MONITOR ELECTRONICS



Each CT will have an average current display for each beam passing that point. At first, it was hoped that the accelerator linear-Q circuits could furnish the integrated charge (Q/pulse) for both these displays, and where applicable, to the CCR. This, however, means rather involved range-switching circuits, and the inconvenience of dual control (BSY and CCR) of the same instrument. Also, the better than 1% accuracy of the linear-Q circuits is not required in the BSY. Nominal accuracy of a few percent will be acceptable. Another benefit of separating these two functions is that the beam interlock signals could be derived from the BSY integrators. The meters for this display will be direct reading, and will not be used as slide-back meters.

Table IV lists the intensity display specifications.

TABLE IV

Gain Switched Amplifier	
Rise time	< 30 ns
Temperature stability $10^{\circ}C$ - $40^{\circ}C$	.3%
Calibration and long-term stability	.3%
Full scale output	5 v
Integrator	
Range (full scale)	100 μa to 100 na
Nominal accuracy including meter	$\pm$ 3%
Comparator	
Calibration and long-term stability	0.5%
Temperature stability $10^{\circ}C$ - $40^{\circ}C$	0.1%

3.5 Calibration

Calibration for the intensity toroids is done by sending a known current through the calibration winding of the toroid. Nominal specifications for the pulse generator are:

TABLE V

Output	5 volts into 50 Ω
Repetition rate	single pulse or 180 pps
Rise time	< 30 ns
Ripple and overshop	< 2%

The only direct calibration available on the position monitors or their rf chassis electronics, is to balance the detector diode outputs. Exactly how well the diodes will remain balanced over their operating range and with time and temperature is not known at this time. Some experiments will be made with detectors and with the prototype monitors before final installation; but because of the great many unknowns the useful accuracy of the position monitors, and consequently the displays, will probably not be determined until some operational experience is gained.

3.6 Precision Intensity Display

Specifications for the precision intensity display are shown in Table VI.

TABLE VI

Linearity	0.1%
Long-term stability	± 0.05% full scale
Temperature stability $10^{\circ}C$ - $40^{\circ}C$	0.05% full scale
Calibration accuracy	±1.0% absolute
Maximum full scale sensitivity per pulse	25 μa at 2.0 μs
Readout	Digital Q/sec and total Q over arbitrary period
Sync. requirements	360 pps and beam pattern sync at least 2.5 μs prior to beam

As more detail design has been performed on this circuit, and because of the technical problems involved, there will be a more complete explanation of this part of the system.

Two basic approaches have been tried and these are shown in Figs. 7-a and 7-b. Both of these methods are identical except for the manner in which the per-pulse integral (Q per-pulse) is obtained. In both, each pulse is integrated and the level held while the A-D converter changes the input amplitude to a proportional number of counting pulses. These pulses are then summed in a counter for a fixed time, normally 1 sec., for the average current display or summed for a longer period (hours, minutes, etc.) for total Q during that period. By performing the analog integration on a per-pulse basis, and storing the result in digital form, repetition rate does not affect accuracy (other than for noise considerations).

Method 7-a was the original approach and is the one that will be used if a separate toroid is not available for the precision integrator. Integration is accomplished, in the standard manner, by capacitor feed back around an operational amplifier. The integrator output is:

$$V_o = \frac{V_p t_p}{RC}(1 + E)$$

V_p = pulse amplitude

t_p = pulse width

E = general error term

An integrator was built using a Philbrick pp-45 amplifier (100 mc gain bandwidth product) with R = 1000 Ω C = 0.002μf . The integrator capacitor is cleared just previous to the integration. The pulse input rise time had to be limited to 100 ns or greater but this is no problem as a pulse may be rolled-off without altering its area. The test setup had a linearity of better than 0.2% and a noise of $<$ 0.05% of full scale. The stability is dependent entirely on the stability of the capacitor and

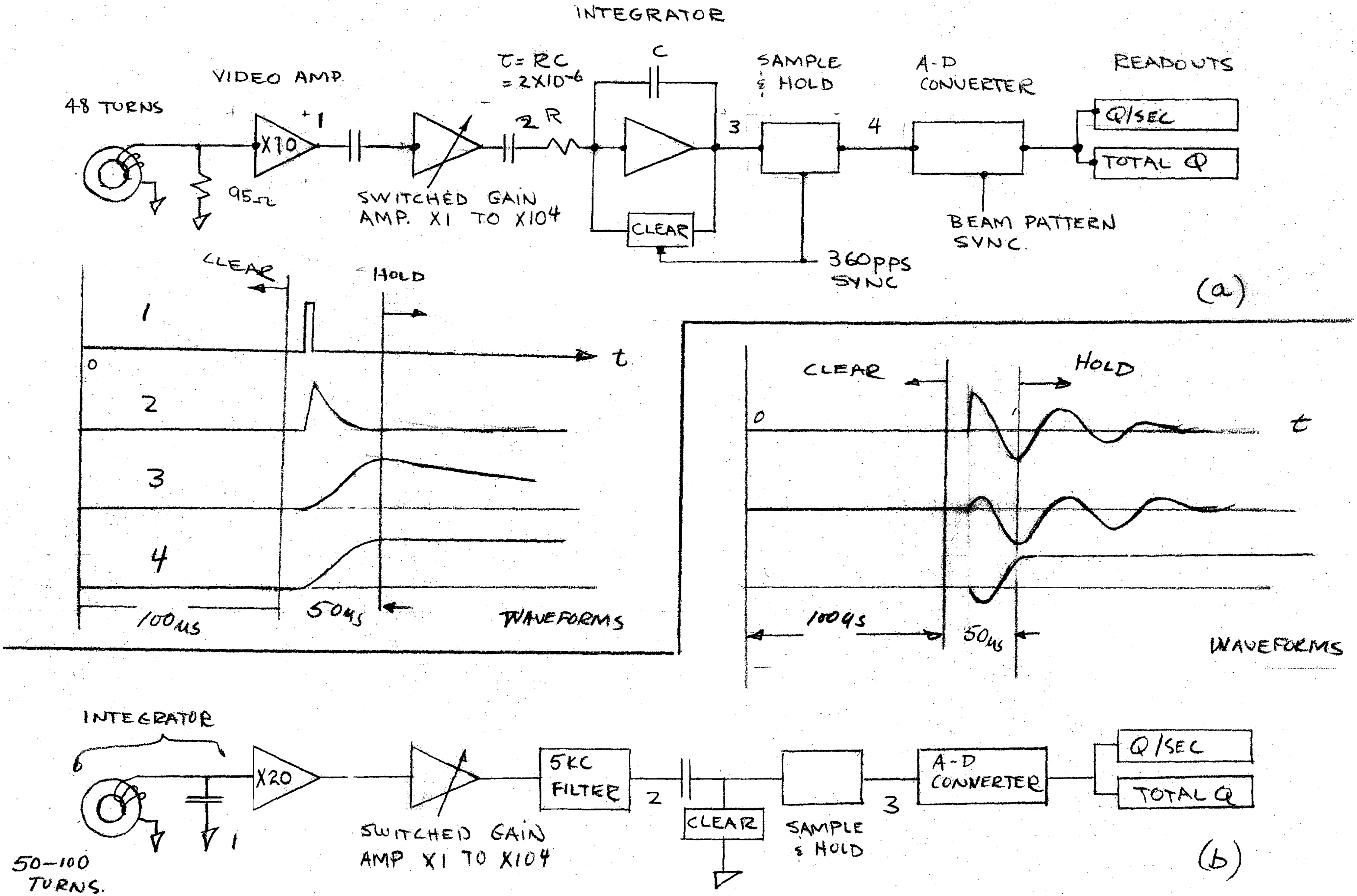


FIG. 7 PRECISE INTEGRATOR

is about 50 ppm/$^{\circ}$C . The switched gain amplifiers also used Philbrick pp-45's as the basic amplifier. The maximum gain of this section is 10^4 and the minimum is 1 . The gain accuracy and stability on all except the 10^4 position is < .05% for temperatures between + 10°C and + 60°C . The bandwidth of the gain switch amplifiers was about 1 kc to 30 kc .

The main problems with this approach are:

a) Noise: for 1 kc - 30 kc bandwidth integrator has approximately 15 times more gain for noise than for the signal

b) Pulse droop: due to the finite inductance of toroids this would amount to ~ .5% non-linearity for pulse width between 2.0 μs and 0.1 μs .

An example of the noise is as follows: For a full scale signal of 5 volts representing a 1 ma 2.0 μs signal and an amplifier 1 kc - 30 kc input noise of 2.0 μv peak-peak, the calculated output noise is ~ 60 mv. This is very close to a measured figure of 100 mv. This is the per-pulse peak to peak noise and will be improved by averaging the output over many cycles such as happens for the Q/sec or the total Q measurement. If a simple sine wave rms value is taken for the peak noise, then

$$V_n \simeq \frac{22}{\sqrt{N}} \text{ mv} \qquad (N = \text{number samples})$$

The second scheme shown in Fig. 7-b is the one that will be used if toroids I-1', I-13', I-33' and I-3' are available for the precision monitor. It is the so-called resonant or ballistic integration. Here the integration is performed at the output of the CT by loading it with a capacitor. The output voltage is (for second peak detection)

$$1_o = \frac{I_o t}{NC} \left(1 - \frac{t^2}{24LC} \right)$$

Thus the only restriction for 0.1% integration for a 2 μs pulse is that $LC \geq 1.6 \times 10^{-10}$. This and the problem of detecting the peak for different pulse widths, sets the maximum frequency to about 5 kc or $LC \geq 10^{-9}$, with this restriction, the output from the CT capacitor combination should be on the order of 1v/A for a 2 μs pulse. Thus, for a 1 ma 2 μs pulse, the amplifier gain would be (for 5 v fs) $\sim 5 \times 10^3$ which for noise figure represents an improvement of ~ 6 over scheme of Fig. 7-a. Also, since this is a resonant system, bandwidths of 1 kc are practical, giving a noise improvement of ~ 30 or about 5. This means a total improvement in the output noise by a factor of about 30, or conservatively at least an order of magnitude improvement in the signal-to-noise ratio. Experiments performed to date have substantiated this: also, the problem of pulse droop is eliminated.

The remainder of the integrator is:

1) Adage sample and hold
2) Systron-Donner A-D converter modified for rep. rate up to 360 pps.

As currently planned, the only readout of the integrator will be a digital Q/sec. Total or accumulated charge can be added later by merely adding a counter. It is hoped that the precise integrator electronics will be useful for end station measurements.

Fig. 7-b is the preferred scheme. It has the disadvantage, however, that a separate toroid is required. As mentioned previously these toroids are available, but were initially planned for the interlock circuits. Thus, either 7-a must be used, or the interlock signals must be derived from the toroids providing the dynamic pulses. This question is not yet resolved.

APPENDIX I

BSY Beam Position and Intensity Signals To And From The DAB

Signals From DAB To CCR

Monitor	Signal Description	Transmission Mode	Cable Required	Comments
P - 1 P - 2	ln Q, X Y	Baseband TLM	8 Wire Pairs Total	
P - 10 P - 30	↓	↓	↓	This requirement not firm
I - 1 I - 2 I - 3 I - 13 I - 33	Linear Q/pulse	FM TLM 1 channel/ monitor	1 coax cable 10 wire pair total	
I - 13 I - 33	Dynamic pulse	To be multiplexed with spectrum analyzer signals		

Signals From Monitors To DAB

Monitor	Signal Description	Cable Required	Comments
P - 1 P - 2 P - 10 P - 12 P - 30 P - 32	Video pulse 1 mv - 30 v	24 coax cables 48 wire pairs total	
I - 2 I - 10 I - 14 I - 30	Video pulse Ω 100 μv - 500 mv	4 twinax cable (RG 22B) 4 coax cables total	
I - 1 I - 3 I - 13 I - 33	Video pulse 100 mv - 500 mv < 50 kc sine wave amplitude uncertain	8 twinax cable (RG 22B) 8 coax cables total	These are dual toroid. Cable requirements for ' (prime) toroids not established

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3. "Microwave Beam Position Monitors" - TN-64-45 - P. Brunet, et al

4. 9/64 Personal conversation

5. "Beam Position and Intensity Monitoring Circuitry" - TN-63-58 - R. Larsen

6. "Errors In Proposed Beam Guidance Monitoring Circuits" - TN-63-59 - R. Larsen

7. "Results of Mark IV Test Of Position Monitor Sector Electronics" - TN-64-55 - R. Larsen