SLAC-TN-70-6
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May 1970

INSTRUCTION MANUAL
END STATION A TOROID CHARGE MONITOR

I. INTRODUCTION

The End Station A Charge Monitor is a toroidal monitor used for measuring the primary beam charge during an experimental run. There are two completely independent systems in End Station A. Each system can select two different toroids for viewing. In addition, each system can drive one or more remote accumulator-display systems, so that a parasite user can have independent control of starting and stopping his measurement. At present, one Remote Accumulator is installed in End Station A. Additional Remote Accumulators are planned.

The two complete systems are arbitrarily labelled "Toroid 0" and "Toroid 1." Toroid 0 is also connected to a Remote Accumulator. All digital outputs (charge per pulse, total charge, and total pulse count) are brought to the SDS 9300 computer. The systems can be placed under the remote control of the Experimenter Control Panel.

The Toroid 0 system serves two toroids: I-16, ahead of the upstream photon target in the Beam Switchyard, and I-405 (labelled I-30 on the Control Panel) located on the removable 42-foot section upstream of the spectrometer target pedestal.

The Toroid 1 system toroid selector switch positions are arbitrarily labelled I-1 and I-2. Toroid I-1 is located just inside the alcove where the main beam line enters End Station A. The I-2 input is not used at present.

Since each toroid system is completely independent, the two systems can be run simultaneously where a redundant measurement is desired for critical applications. At high beam currents, the toroids should track to an accuracy of ±0.1%. In actual application, it is difficult to assure that precisely the same beam charge is passing through both toroids (to much better than 0.1%) especially if the toroids are separated by some distance. Over a large distance, positional effects could affect the accuracy. At low beam currents, the accuracy becomes noise limited. Because of the bidirectional sampling and accumulator system used, noise over a given run is averaged roughly according to the $\sqrt{N}$, where N is the number of measurements at the 360 pps accumulation rate. At the highest gain settings, averaged noise becomes reduced by a factor of about 50, beyond which unidirectional drifts limit the system accuracy.

The following is a brief description of the theory and operating procedure for the system. Additional details will be found in the references cited in Section VIII.

II. SYSTEM DESCRIPTION

Figure 1 is a simplified block diagram of the charge monitor system. The theory of operation is as follows:

Upon passage of a beam pulse, the toroid generates an instantaneous current proportional to $i_b(t)$, where i_b is the beam current. The toroid, transmission line and terminating capacitor form a tank circuit which then resonates at a frequency of about 5.5 KHz. The resultant damped resonant waveform has a peak voltage proportional to charge, $\int_0^T i_b(t)\,dt$, where T is the maximum width of the pulse.

The low-level signal is amplified through a X100 preamplifier, followed by 4 switched-gain stages, and emerges with a peak value between 1 and 9 volts. The second peak of the resonant waveform is sampled to produce a stretched signal, the amplitude of which represents the total charge in the given pulse.

The sampled signal is fed to a bipolar analog-to-digital converter which has an accuracy of ±1 mV for a ±10V full scale range. To assure a conversion accuracy of ±0.1%, the signal level should always be greater than ±1 volt.

The ADC operates at the maximum beam rate of the accelerator, 360 pps, and converts each integrated beam pulse plus system noise, or just the system noise if a beam pulse is not present. The ADC digital output is summed in a 12-digit bidirectional accumulator. For random noise, the longterm average will be zero, so that an average beam current can be read accurately even in the presence of large amounts of random noise, providing a long enough averaging period is used.

The ADC and accumulator outputs are displayed on Nixie readouts on the local control panel (Fig. 2) and are also made available to an external computer. A 7-decade pulse counter keeps count of the number of actual beam pulses, i.e., the gated trigger pulses; this output is also sent to the computer. The ADC display is updated at the gated trigger rate, rather than the ADC convert rate of 360 pps, so that charge per pulse is displayed, with a minimum of flicker due to noise.

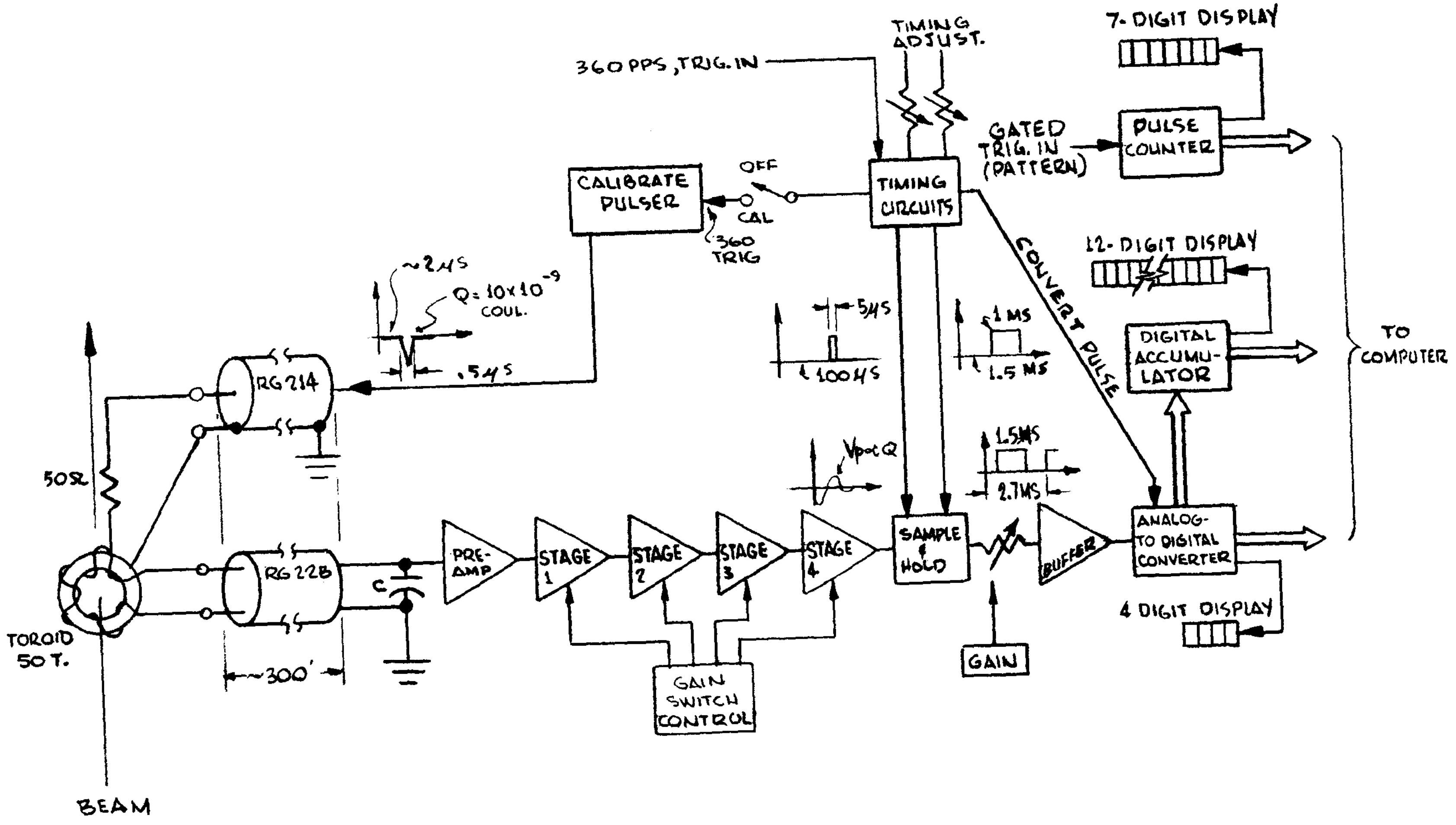

FIG. 1. CHARGE MONITOR - SIMPLIFIED BLOCK DIAGRAM

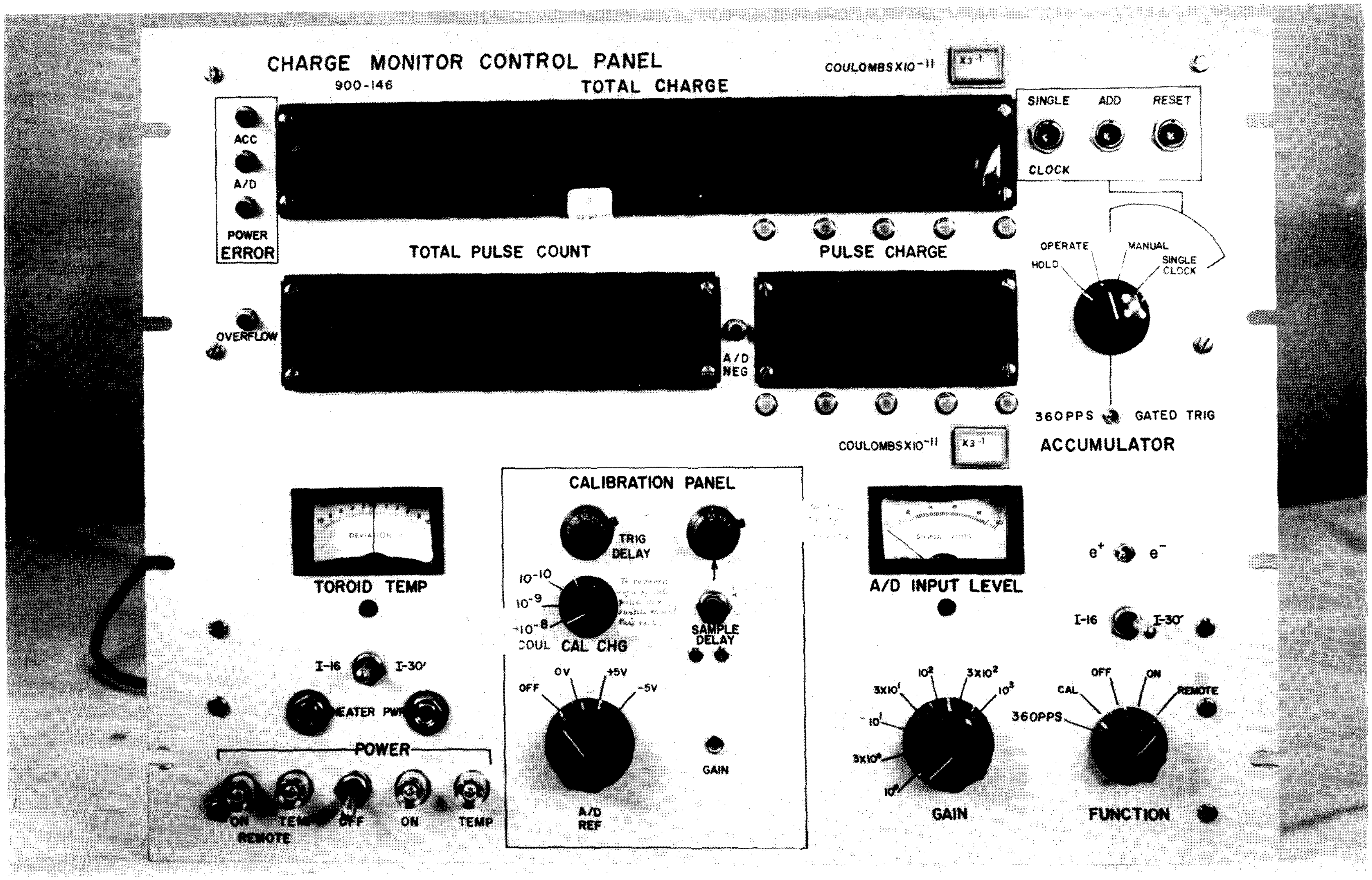

FIG. 2--Charge monitor control panel (photo).

The unit has a built-in 360 pps pulsed calibration source, which acts by discharging a capacitor charged to a known voltage into a 1-turn calibrate winding on the toroid. The calibrate charge is stable to 10.00 ± .01 nanocoulombs. The calibrator is actuated by turning the FUNCTION switch to CAL. (A switch on the timing chassis also allows selection of a calibrate charge of 50.00 ± .05 nanocoulombs.) The calibrate pulser is triggered at a time when the beam pulse would normally enter the toroid, and therefore cannot be used with a beam present. The system is calibrated using front panel timing and gain adjustments.

Some additional features of the system are: Temperature control of the integrator toroids, with a front panel meter to monitor the error voltage; peak sampling meter to monitor the ADC input; a dc calibrate check for the buffer-ADC combination, and adjustable trigger and sample point delays.

III. CONTROLS AND DISPLAYS

The following is a brief summary of the functions of the major front panel controls and displays (see Fig. 2):

A. Function - rotary switch with 5 positions:

- (1) CAL - actuates a 360 pps pulser which sends a 10^{-8} coulomb calibrate pulse through the toroid. The pulse may be attenuated to 10^{-9} and 10^{-10} coulombs by the CAL CHARGE Selector.
- (2) OFF
- (3) ON

$\left.\begin{matrix}\text{(2) OFF}\\ \text{(3) ON}\end{matrix}\right\}$ controls operation of the accumulator, ADC display and pulse counter

- (4) REMOTE - on-off control of accumulator, ADC display and pulse counter is accomplished by applying +8 or 0 volts to a rear BNC connector
- (5) 360 PPS - system runs continuously at 360 pps regardless of pattern rate. This position used for drift measurements.

B. I-1 -- I-2 Selector - left switch under meter monitors toroid temperature proportional control offset; right switch selects which toroid is applied to the preamp input.

C. $e^+ - e^-$ - changes polarity of preamp output to produce a positive output with positrons or electrons, respectively. Polarity of the calibration pulse is likewise changed.

D. Gain - rotary switch changes amplifier gain in steps of 1-3-10, etc., up to maximum of 10^3.

E. Accumulator - 4-position rotary plus toggle:

- (1) HOLD - total charge and pulse count display contents are held
- (2) OPERATE - contents of the ADC are added to the accumulator, at a 360 pps rate. The counter records pattern triggers in the TOTAL PULSE COUNT display
- (3) MANUAL - normal addition of ADC into accumulator inhibited; pushing the ADD button will cause single addition of ADC contents, and add one to the pulse counter. For test purposes only.
- (4) SINGLE CLOCK - for maintenance routine on accumulator only
- (5) 360 PPS - GATED TRIG - toggle selects accumulation rate. 360 pps is normally used. At extremely low beam rates, GATED TRIG position may accumulate less noise.

F. Pushbuttons - SINGLE CLOCK - as in E(4)
ADD - as in E(3)
RESET - when in MANUAL, serves to clear accumulator, pulse counter register, overflow, and error indicators.

G. Error Lights-ACC, A/D - records occurrence of an unallowed BCD code. Register contents invalid.
POWER - indicates power outage has occurred in digital logic; register contents invalid.

H. Displays

- (1) TOTAL CHARGE - 12 decade accumulator display. Decimal point and $x3^{-1}$ light give correct scale factor. Negative charge displayed in 10's complement.
- (2) TOTAL PULSE COUNT - 7 decade pulse counter for beam pulses. OVERFLOW-lamp indicates that overflow of this counter has occurred.
- (3) PULSE CHARGE - displays contents of ADC; updating for each beam pulse. A/D NEG lamp indicates that number is a 10's complement. Scale as in H(1)
- (4) A/D INPUT LEVEL - shows voltage going into ± 10V input of ADC. Meter peak-detects positive sample-and-hold outputs only.

(5) TOROID TEMP - shows deviation of toroid temperature from a preset value. Check for toroid temperature stability.

I. Heater Power - monitoring jacks for toroid proportional controller power

J. Power Switch & Lights

(1) OFF-ON - toggle, controls power supplies for analog equipment
(2) ON - light for power on
(3) TEMP - light for power supply thermal cutout
(4) REMOTE ON - light for power to Amp and Timing chassis

K. Calibration Controls

(1) TRIGGER DELAY - adjusts delay of a one-shot to match the trigger-to-beam pulse delay. Adjusted using oscilloscope and locked in position. Do NOT adjust.
(2) SAMPLE DELAY - used in calibration for setting correct sampling point. (TEST pushbutton is not used)
(3) A/D REF - selects 0V, +5V and -5V standard dc voltage to check final buffer plus ADC. For normal operation, set in OFF position.
(4) GAIN - fine control for adjusting system gain during calibration.

L. Digital Power Supply - supplies accumulator and control logic. Main breaker is located on front panel of supply.

IV. PRELIMINARY CHECKS

A sketch showing the typical installation of the various sections of the system in the ESA Counting Room is given in Fig. 3. The preamplifier is located at the toroid in End Station A. The steps to place the unit into operation are as follows:

1. Turn on power switches on the control panel and on the digital power supply. The preamplifier(s) must be switched on in the End Station. From a cold start, allow at least one hour to assure proper settling of the ADC and the preamplifier circuit ovens. The POWER ERROR light will initially be on; press the ACCUMULATOR RESET to turn it off. (Accumulator mode switch must be in MANUAL).

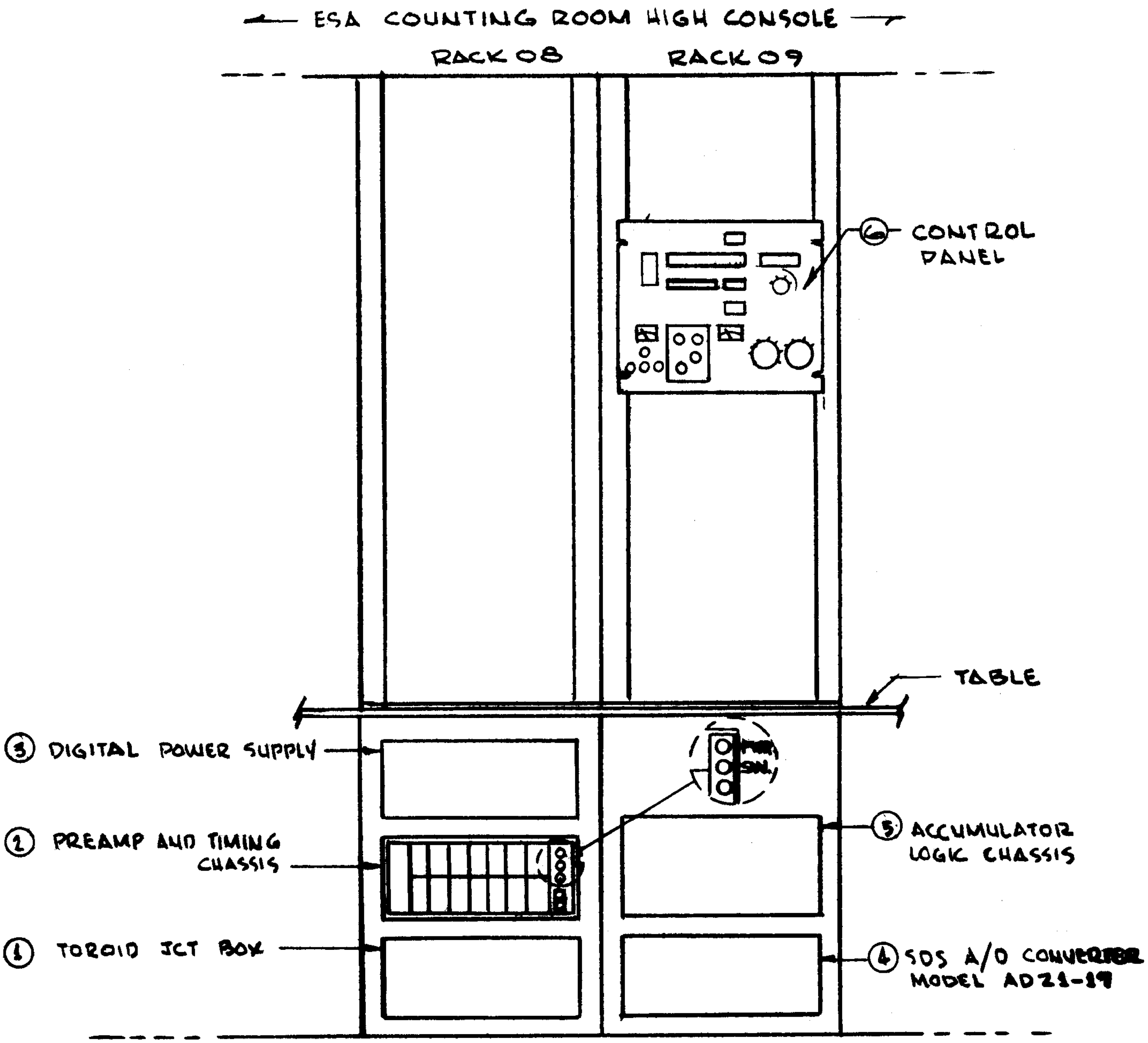

FIG. 3 - CHARGE MONITOR INSTALLATION

2. To check the buffer-ADC calibration, set the controls as follows:

FUNCTION switch on 360 PPS
TOROID SELECTOR at I-1 or I-2 as desired
GAIN at minimum (10^0)
ACCUMULATOR at MANUAL

Successively switch the A/D REF control to 0V, +5V and -5V. The outputs on the A/D display, PULSE CHARGE, should be 0000, +5000 and -5000, ±0001, respectively. To check stability on the minimum gain setting of 10^0, switch the A/D REF to OFF, the accumulator control to OPERATE, and accumulate about 10,000 pulses. By observing the accumulated drift and dividing by the accumulation time, an equivalent drift current can be determined. (See Section V)

To clear the registers, place the accumulator switch in MANUAL and push the RESET.

3. The full-scale sensitivities corresponding to the different gain settings are as follows:

GAIN	COUL. F.S.	ELECTRONS F.S.
10^0	1×10^{-7}	6.25×10^{11}
3×10^0	$3^{-1} \times 10^{-7}$	2.08×10^{11}
10^1	1×10^{-8}	6.25×10^{10}
3×10^1	$3^{-1} \times 10^{-8}$	2.08×10^{10}
10^2	1×10^{-9}	6.25×10^9
3×10^2	$3^{-1} \times 10^{-9}$	2.08×10^9
10^3	1×10^{-10}	6.25×10^8

The meter or A/D gives a reading of charge per pulse. Hence, to calculate current, multiply coulombs per pulse-by-pulses/sec for amperes; or electrons/pulse-by-pulses/sec for electrons/sec.

V. DRIFT ADJUSTMENT

1. The unit is equipped with a hidden adjustment in the Amplifier and Timing chassis which compensates for drift over a limited range. This adjustment was designed to compensate for dc drifts in the final amplifiers and sample-and-hold circuit. It is normally set during routine calibration between operating cycles, and should not be touched during a run. It was <u>not</u> designed to compensate for drifts caused by differences in noise averaging on different gain scales, and is rather ineffective for this purpose.

2. The adjustment is made with the GAIN on 10^0, and FUNCTION on 360 pps, with no beam present. The accumulator is allowed to run, and the adjustment tuned to minimize the tendency to accumulate in either direction. An adjustment of the drift to ~ ±1000 for 10,000 pulse counts is about the best that can be expected.

3. The foregoing adjustment is always carried out prior to recalibrating the system.

VI. CALIBRATION

1. With the controls initially as in paragraph IV (2), place the FUNCTION switch in the CAL position, and GAIN to 3×10^0. This actuates the calibrate pulser, which sends a simulated beam pulse through the one-turn winding around the toroid. The charge in the simulated pulse is calculated at 10^{-8} coulombs, with an absolute accuracy of $< \pm 0.5\%$, and a stability of ±0.1%.

2. Adjust the sample delay potentiometer to give a maximum reading in the PULSE CHARGE display. Carefully lock the pot and note its setting for future reference as a stability check.

(NOTE: The TEST button is not used.)

3. With a miniature screwdriver, adjust the calibration GAIN potentiometer to give a reading of 3000 in the PULSE CHARGE display. The last figure will be undiscernible due to system noise. Run 10,000 pulses into the accumulator and calculate the average charge per pulse. Readjust GAIN if necessary.

4. Change the GAIN switch position to 10^0, and again run 10,000 pulses. The readings should correlate within 0.1% or ±1 digit.

NOTE: The TRIGGER DELAY potentiometer has been adjusted to compensate for the delay between the main trigger and the leading edge of the beam pulse. This control is locked and should not be touched. (The adjustment is best made by running an actual beam, with the system just calibrated, and adjusting TRIGGER DELAY to maximize the charge per pulse. Alternatively, one can observe the video signal and set the delay with an oscilloscope.)

5. A hidden switch on the Amplifier and Timing chassis allows selection of a "X5" calibrate charge - i.e., 50.00 instead of 10.00 nanocoulombs. The purpose of the larger test charge is to assist in observing nonlinearities in the amplifier system at high pulse currents. For example, a small difference of about 0.2% is noticeable at the 1 volt level (10^0 gain) if the accumulation is made first on e^+, then on e^-. At the 5 volt level, 10^0 gain, the asymmetry is slightly worse. The

X5 switch is not normally used, but may be useful in making corrections at high peak currents. The 50 nCoul charge produced should be accurate to ±0.1% relative to the 10 nCoul charge.

6. The system is now ready for operation. With a beam present, select a gain setting which gives a peak signal indication of at least 1 volt on the front panel meter. The accumulator can be actuated either manually or remotely. For manual operation, the FUNCTION switch is ON, and the accumulator and pulse counter are actuated by turning the accumulator switch from MANUAL to OPERATE. The run can be stopped at any point. For remote operation, turn the FUNCTION switch to REMOTE to place the unit under control of the rear panel inputs. The unit can then be controlled by a 0 or +8 volt signal applied to the REMOTE input.

The pulse counter and accumulator can be remotely reset to zero by the application of a +8 volt pulse applied to the RESET input (rear panel BNC).

VII. OPERATION

1. Before making an actual run, inhibit the beam and check the accumulated drift for at least 10,000 pulses on the gain scale previously selected. The drift should be small; however, if it is significant, then several drift runs should be made before and during the course of the beam run, in order to provide a drift correction factor.

In general, a different drift correction factor must be determined for each different gain scale.

2. Since the accumulator normally runs at 360 pps, the drift is essentially independent of beam rate. Thus an equivalent drift current can be measured. At the high gain settings, a number of readings must be taken in order to determine a statistical mean and variance. Once this is determined, it may be used to predict the noise-limited measurement accuracy for a given average beam current.

3. Note that a high repetition rate, low peak beam will give a better S/N than a low repetition rate, high peak beam having the same average current.

4. The non noise-limited accuracy of measurement of the system is ±0.1%. The noise averaging obtained in the bidirectional digital accumulator reduces the peak noise at high gains by a factor of about 50. Therefore noise becomes a limitation when the averaged noise, or equivalent drift current, is of the order of 0.1% of the average beam current.

5. As an example of the performance, on the highest gain scale, 10^3, the equivalent noise current (for Toroid #0) was measured to be 72.0 ± 13.4 pA.[1] Thus, without drift correction, the accuracy is limited by a unidirectional drift of 72 ± 13.4 pA; and with correction, by the random component of ±13.4 pA. In the latter case, a ~13 nA average beam can be measured to ~±0.1%.

6. Further description of the system can be found in the references cited.

REFERENCES

1. R. Larsen and D. Horelick, Report No. SLAC-PUB-398, Stanford Linear Accelerator Center, Stanford, California, published in the Proceedings of the Symposium on Beam Intensity Measurement, Daresbury, 22-26 April 1968.
2. D. Horelick and R. Larsen, Report No. SLAC-100, Stanford Linear Accelerator Center, Stanford, California, March 1969.
3. ESA System Drawings

Drawing Title	SLAC Drawing Numbers
ESA Charge Monitor Control Panel	900-146
Accumulator	135-019
SDS AD21-17 Converter	135-018
Amplifier and Timing Chassis	900-145A
Digital Power Supply	900-144
Junction Box	900-195
Preamp and Cal Attenuator	900-179
Toroid	135-002
Remote Accumulator Control Panel	900-186
Remote SDS Supply PX10	135-022
Remote Accumulator Junction Box	135-023