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Houston, Texas

on

THE DEVELOPMENT OF A PERSONNEL DOSIMETRY SYSTEM FOR APOLLO

by

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I. INTRODUCTION

During the past quarter, the mechanical design and packaging concept of the miniaturized proton dosimeter was completed. Following consultation with the cognizant personnel of Manned Spacecraft Center, Houston, the following concepts have been incorporated:

1. Overall dimensions have been held to approximately 1 x 2 x 3 inches with no protrusions in order to permit the dosimeter to be carried inside a pocket attached to the outside of the spacesuit.

2. The detector is located within the package even though this entails a dose measurement concept by which dose at some effective tissue depth is measured rather than skin dose.

3. Battery life is sufficient for 300 hours of continuous operation. No on-off switch is provided, operation commencing upon the insertion of the battery cartridge. Batteries are interchangeable in flight without the use of tools though some difficulty may be experienced in changing batteries with a heavily gloved hand. The battery compartment is adaptable to the concept of a pre-packaged, drop-in battery which can be changed with a heavily gloved hand.

4. Readout can be initiated at any time by means of a flush push-button located at the top of the instrument. An automatic mode results in periodic readout in the absence of such manual initiation.

With these concepts in mind, the design has been solidified surrounding the subminiaturized amplifier, the accutron watch readout and the other components developed during previous periods of the contract.

II. DETAILED DESIGN

The basic envelope of the proton dosimeter is shown in Drg. 1554-50-1. All components of the dosimeter, with the exception of the power supply, are located within the main case, also housing the readout initiate button and readout indicator. The power supply module housing the batteries and the bias converter together with necessary filtering and decoupling capacitors, plugs into the hand of the main case. An alignment key is provided to prevent accidental insertion of the power module in the wrong direction and this module is retained by means of two ball-catch latches. In the event that this method of retention proves marginal under the shock and vibration testing, provision has been made for the incorporation of a locking screw which prevents accidental withdrawal of the power supply module.

Drg. 1554-50-2 shows in detail the dimensions and the layout of the major internal components. All of the electronic components of the main body are located on a printed circuit board assembly shown in the upper right hand corner of the referenced drawing. These components include the thin film hybrid amplifier, detector and detector socket and microswitch for manual readout initiation. The power connector for mating with the power module is also mounted on this printed circuit board. In addition, but not shown, are the electronic components for the readout circuitry and accutron tuning fork drive. These mount in the available blank space behind the accutron watch movement. The accutron watch movement itself is mounted flush with the front face of the case by means of four mounting screws in the corner and a shim ring to adjust the normal mounting flange to flush mounting. Threaded spacers between the mounting screws and the printed circuit board assist in stabilizing the structure against distortion under vibration and acceleration. The manual pushbutton is constructed partially of the ultra-miniature microswitch attached to the printed circuit board and the pushbutton itself attached to the outer case. A .030" silicone rubber diaphragm serves to retain the pushbutton and permit the necessary flexibility for actuating the microswitch. The power supply module is machined from a solid block of Zxtel plastic with cavities for holding twelve silver oxide cells and a compartment for the detector high voltage converter assembly. Interconnection is accomplished by means of an Amphenol subminiature strip connector having the female mounted on the power module and the male in the main assembly. Two stainless steel guide pins prevent misalignment of the detectors upon mating. This connector is used for breaking the circuit between the power module and the main equipment during periods when dose integration are not desired. When properly inserted and in operation, a green indicator spot is visible through an opening in the main case. No provision has been allowed for securing the dosimeter in the compartment in the spacesuit. It has been assumed that a "Velcro" strip will be bonded to the back side of the case engaging a similar "Velcro" strip in the spacesuit pocket. No special provisions for temperature control have been incorporated other than the polished aluminum case surface to minimize thermal transfer through radiation. The total power dissipation in the unit is sufficiently small to permit adequate thermal transfer without appreciable junction temperature rise of the critical components.

III. DETAILED CIRCUIT CONSIDERATIONS

For sake of completeness, the full electrical design will be reviewed as this represents the final version of the electronic circuits. Drg. 1554-36 shows the basic interconnection of the major circuit blocks. The battery group in the power supply module is decoupled from the main circuitry by means of a tantalum capacitor bypassed by a high frequency ceramic capacitor to avoid coupling of noise and transients into the sensitive circuits. A series resistor, shunt capacitor decoupling is used on the detector bias power supply to avoid its transients from feeding into the main circuitry. The detector is coupled to the amplifier and is furnished detector bias through its integral bias decoupling network. The amplifier outputs, three in number corresponding to various energy ranges of the input pulses, connect to the threshold integrator which serves to produce a DC current proportional to the dose rate observed by the detector. The threshold integrator deposits charge in the E-cell which serves to provide long-time integration of the dose rate to provide a reading of total dose. The E-cell is periodically readout by the readout control which can be manually cycled from the external pushbutton. The readout control provides a signal to the accutron drive circuit for a duration corresponding to the amount of accumulated charge in the E-cell. The accutron drive circuit consists of the necessary oscillator transistor and switching networks necessary to provide rapid start, stop and proper running for the tuning fork drive system of the accutron watch movement.

The final diagram for the detector bias power supply is shown in Drg. 1554-34. This circuit represents a simplification of the previous double ended circuit reported earlier. Because of the extremely modest power demands of the detector, the single ended circuit is adequate with a consequent saving of components and power consumption. The base return of the transistor is directly to the positive supply through the transformer assuring prompt starting even at reduced temperatures. A simple half wave rectifier is used on the secondary to obtain the required bias voltage of 150 volts without an excessively high turns ratio on the transformer. An additional filter section is provided to remove residual ripple from the detector bias.

Drg. 1554-28 is the final drawing of the thin film hybrid amplifier. The only modification required from the previous design is the use of feedback compensation capacitors in the voltage amplifier stages to provide proper roll-off and stability. The input stage is basically a classical charge sensitive preamplifier using a cascode input stage consisting of two silicon planar transistors operated at approximately 10 microamperes collector current. An emitter follower provides the charge feedback through a 5 picofarad integrating capacitor. A DC feedback network is employed to assure overall DC stability of the charge sensitive preamplifier. The sensitivity of the charge sensitive preamplifier is given by:

$$V_o = \frac{q_d}{C_f}$$

where V_o is the output signal voltage step, q_d is the charge deposited by the detector and C_f, the feedback capacitor. q_d can be computed in terms of the energy necessary to produce one hole electron pair in the silicon. This is computed as follows:

$$q_d = \frac{e \times E}{3.5}$$

where e is the electronic charge in coulombs, E is the energy deposited in the detector in electron volts and 3.5 represents the energy electron volts to release one hole electron pair. To convert this to dose it is necessary to determine the energy deposited in the detector in electron volts/rad. Thus:

$$E = 100 \frac{R\rho V \times 10^{-7}}{e}$$

where R is the dose in rads, ρV the volume and density of the detector and e the electronic charge. Substituting this equation in the previous one:

$$q_d = \frac{R\rho V \times 10^{-5}}{3.5}$$

and substituting in the first equation:

$$V_o = \frac{R\rho V \times 10^{-5}}{3.5\ C_f}$$

In our case, C_f = 5 picofarads, V = 8 x $10^{-3}cm^3$ and ρ = 2.33 grams/cm^2. The net result is V_o = approximately 10^4 volts/rad. While this result has the dimensions of volts, it is actually the product of the average voltage/event by the number of events/rad. To calculate the distribution of pulse heights, it is necessary to consider the stopping power of the detector for protons of various energies.

The largest pulse height which can be produced in the detector is that associated with a proton energy which is just stopped within the volume of the detector. With a detector dimension of 2mm this corresponds to approximately 20 MeV. At the other extreme, a minimum ionizing particle will deposit approximately 0.7 MeV. The dose in the former case is approximately 2 x 10^{-5} rads/event while in the latter case it is approximately 6 x 10^{-7} rads. The pulse height in the former case is 200 millivolts and in the latter case approximately 7 millivolts. In order to minimize the noise associated with these signals, it is necessary to apply near optimum clipping and signal shaping. This is accomplished in a feedback amplifier consisting of a difference amplifier employing two NPN transistors and a PNP output amplifier. Integration is accomplished in the feedback capacitor, differentiation in a differentiating network at the output. An over-all gain of ten is realized from this stage bringing the sensitivity to 100 millivolts/MeV at the output. Since the largest signal expected is 20 MeV, a maximum signal of 2 volts appears at this point. The minimum ionizing signal, a factor of 30 less than this, is approximately 70 millivolts. In order to raise the minimum ionizing signal to a useful level, two additional gain of ten stages are employed. These are identical to the shaping stage with the exception that the feedback capacitor is made only large enough to provide good stability and no additional differentiation is employed. At the output of these two stages, the minimum ionizing signal would be 7.0 volts but is limited at the saturation level of 5.0 volts. The largest signals, of course, will also be saturated. This is a basic reason for the use of the multi-output amplifier. Since the dynamic range is limited by the power supply to approximately five volts and the threshold for integration is of the order of 0.5 volts, the extreme range can only be accommodated by a multi-scale integrator.

Some estimate of the probable counting rates must be made to avoid the possibility of overload of the system from large counting rates. Using differentiating and integrating time constants of the order of 0.5 microseconds, which are typical of those giving minimum noise from the detector, counting rates of up to 10^5/second can be accommodated without excessive gain shifts and pulse pileup phenomenom. 10^5, 20 MeV protons/second would result in a dose rate of 2 rads/second, clearly far beyond anything anticipated. In the case of minimum ionizing particles, this maximum rate would be approximately .07 rads/second or over 200 rads/hr, again far beyond anything to be encountered in actual use.

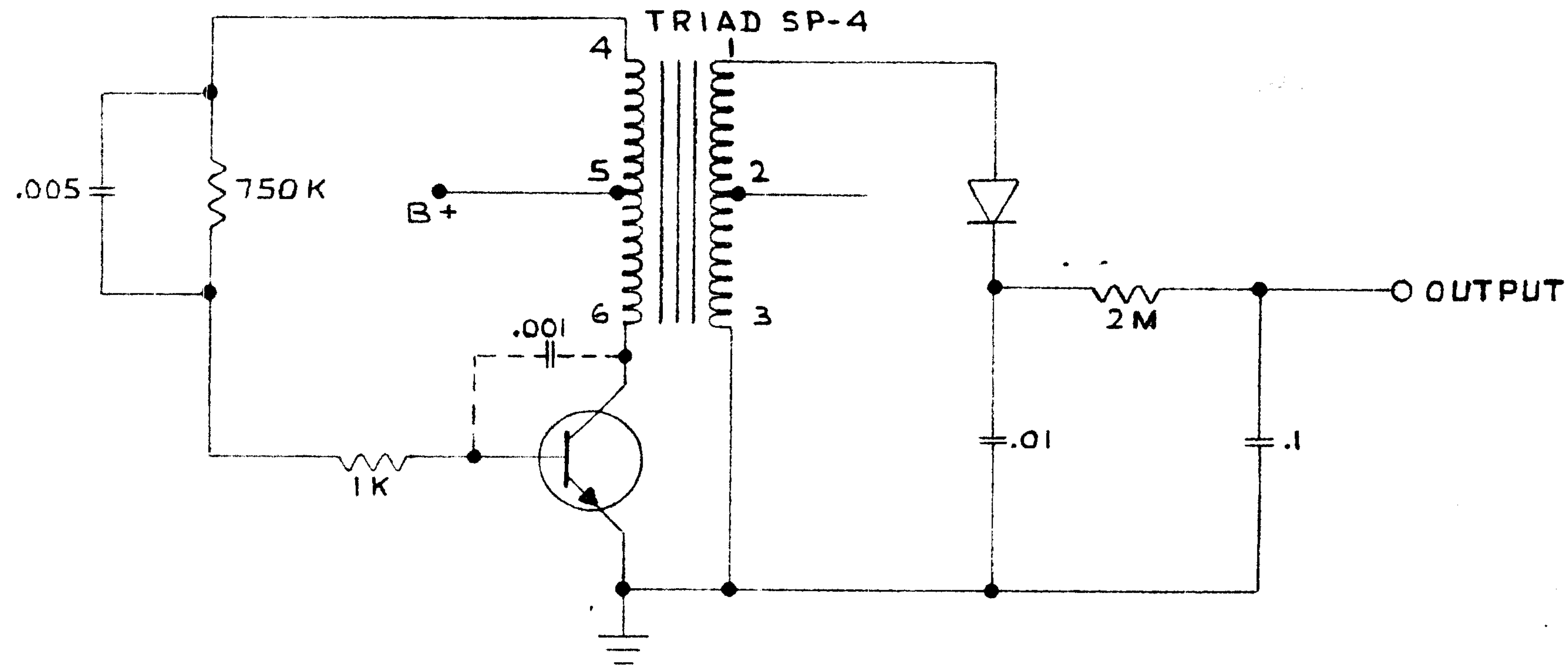
Drg. 1554- 35 shows the combination of the integrator, E-cell circuitry and E-cell readout circuitry. While this circuit has been dealt with in previous reports in great detail, some of the salient points will be reviewed. Three emitter followers, Q_1, Q_2 and Q_3 serve as biased amplifiers to deposit a charge proportional to the pulse height on the three integrating capacitors, C_1, C_2 and C_3. Each emitter follower introduces a bias of approximately .5 volts and the respective capacitors are weighted in accordance with the sensitivity of the amplification up to that point. For example, Q_1 derives its signal from the 100 millivolt/MeV output of the amplifiers such that its 0.5 volt threshold corresponds to 5 MeV. C_1 is then made 0.01 microfarads, the largest of the three integrating capacitors. Similarly, Q_2 derives its input from the 1000 millivolt/MeV output and C_2 is 1000 picofarads. Q_3 derives its input from the 10,000 millivolt/MeV output of the amplifier and C_3 is 100 picofarads. Because of the unique relationship between the bias point and the saturation level, the bias discrepancy in each signal is precisely compensated by the saturated signals in the higher sensitivity channels. That is to say, the charge loss due to the 0.5 volt bias in Q_1 is just compensated by the 5 volt saturated signal in C_2 and a 0.5 volt bias in Q_2 just compensated by the saturation voltage in C_3. The 0.5 volt bias in Q_3 is compensated by the use of a dummy step charge generated in D_1 by Q_4 saturating. Whenever a signal in Q_3 exceeds threshold, this voltage across D_1 being precisely the 0.5 volt bias which was lost. Capacitor C_4 adds this in to provide a linear relationship between integrated charge and input dose. The integrated charges are all summed into the base of the operational integrator Q_5 which is gated by Q_6. The gating signal is most conveniently derived from the collector of Q_4. Normally, Q_6 is held in saturation by the resistive divider between its base and ground. When a signal to be integrated arrives, the collector signal from Q_4 cuts off Q_6 permitting the collector of Q_5 to fall. The collector of Q_5 will fall sufficiently to permit C_7 to discharge through D_2 by an amount corresponding to the total charge delivered into the base line of Q_5. To put another way, the total charge flowing into C_1, C_2, C_3 and C_4 is derived with the exception of a very small base signal for Q_5, from the collector current of Q_5 displacing through C_7 and diode D_2. At the cessation of a pulse, Q_6 once more saturates raising the collector of Q_5 and Q_6 back to the voltage of the positive supply. C_7 then discharges through D_3 into the electrochemical cell and the saturated transistor collector Q_8. As long as there is platable material on the E-cell, the base of Q_7 cannot rise sufficiently to cause Q_7 to conduct, as long of course, as Q_8 is saturated. As soon as the platable material on the E-cell is exhausted, the base of Q_7 begins to rise to a voltage which permits Q_7 to conduct and cut off Q_8. The collector resistor of Q_8 now back plates the E-cell through the base emitter diode of Q_7 resulting in a readout cycle the length of which is determined by the amount of platable material on the E-cell for reverse plating the B+ voltage and the collector resistor of Q_8. At the end of the plating cycle, the collecter voltage of Q_8 begins to rise, this rise being limited by the forward drop of D_4 and D_5. Base current to Q_7 falls to zero and its rising collector voltage saturates Q_8 once more returning the system to the original state. A manual readout cycle is initiated by the pushbutton which momentarily cuts off Q_8 by grounding the collector of Q_7 through a capacitor. This momentary cut off of Q_8 permits reverse plating to commence provided there is platable material on the E-cell for plating in this direction. If no such platable material exists, Q_8 returns to saturation and the system is normal. If reverse platable material is available, the plating cycle goes as before. Thus, the E-cell readout cycle is freed from dependents upon relay contacts or other mechanical switching arrangements with the exception of the manual pushbutton.

The accutron watch movement requires somewhat special treatment in order to produce accurate accumulation of the total readout dose. Simple interruption of the power supply to the internal tuning fork oscillator results in sluggish start up and excessive coasting after power is removed. A starting circuit then must be used which momentarily applies excess drive to the tuning fork oscillator causing it to reach equilibrium amplitude in a very short time. Upon removal of power, the oscillation must be rapidly damped to prevent coasting. Drg. 1554-37 illustrates the means of accomplishing this. The collector of Q_9 supplies the necessary current to operate the accutron movement. As Q_9 is normally cut off, the emitter of Q_{10} is open and hence the oscillator receives no power. The emitter voltage of Q_{11} is at the B+ level and thus the divider in the base circuit of Q_{11} saturates this transistor, damping the main winding. When Q_9 conducts corresponding to a readout cycle, Q_{10} then goes into oscillation. The drop across the emitter resistor of Q_{11} is sufficient to cut off Q_{11} permitting oscillations to take place. The starting transient is supplied by the capacitor in the emitter of Q_{10} which upon conduction of Q_9 dumps an excess charge through the oscillator causing it to start with sufficient amplitude to operate the watch movement.

An examination of the circuits shown, eleven transistors, six diodes and approximately 35 small components are required in addition to the subminiaturized amplifier. As a board area of approximately 2 inches^2 is available for these components, it is clear that rather extreme measures of miniaturization must be employed. This represents some compromise in the selection of components plus the full exploitation of all the possible available volume for circuitry.

IV. CONCLUSIONS

A mechanical design and packaging concept has been completed for the subminiaturized dosimeter. All circuits have been proven in breadboard operation and in no case employ components which cannot be included in the mechanical design. The effort therefore, in circuit design, must be considered complete and the remainder of the effort devoted to completion of the package with performance and environmental testing of the resulting dosimeters.



NOTE

1. ALL RESISTORS IN OHMS
2. ALL CAPACITORS IN MICROFARAD
3. TRANSISTOR IS A FM708

REQD	PART NO	DESCRIPTION	ITEM

LIST OF MATERIALS

SOLID STATE RADIATIONS, INC.
2261 S. CARMELINA AVE., LOS ANGELES, CALIFORNIA

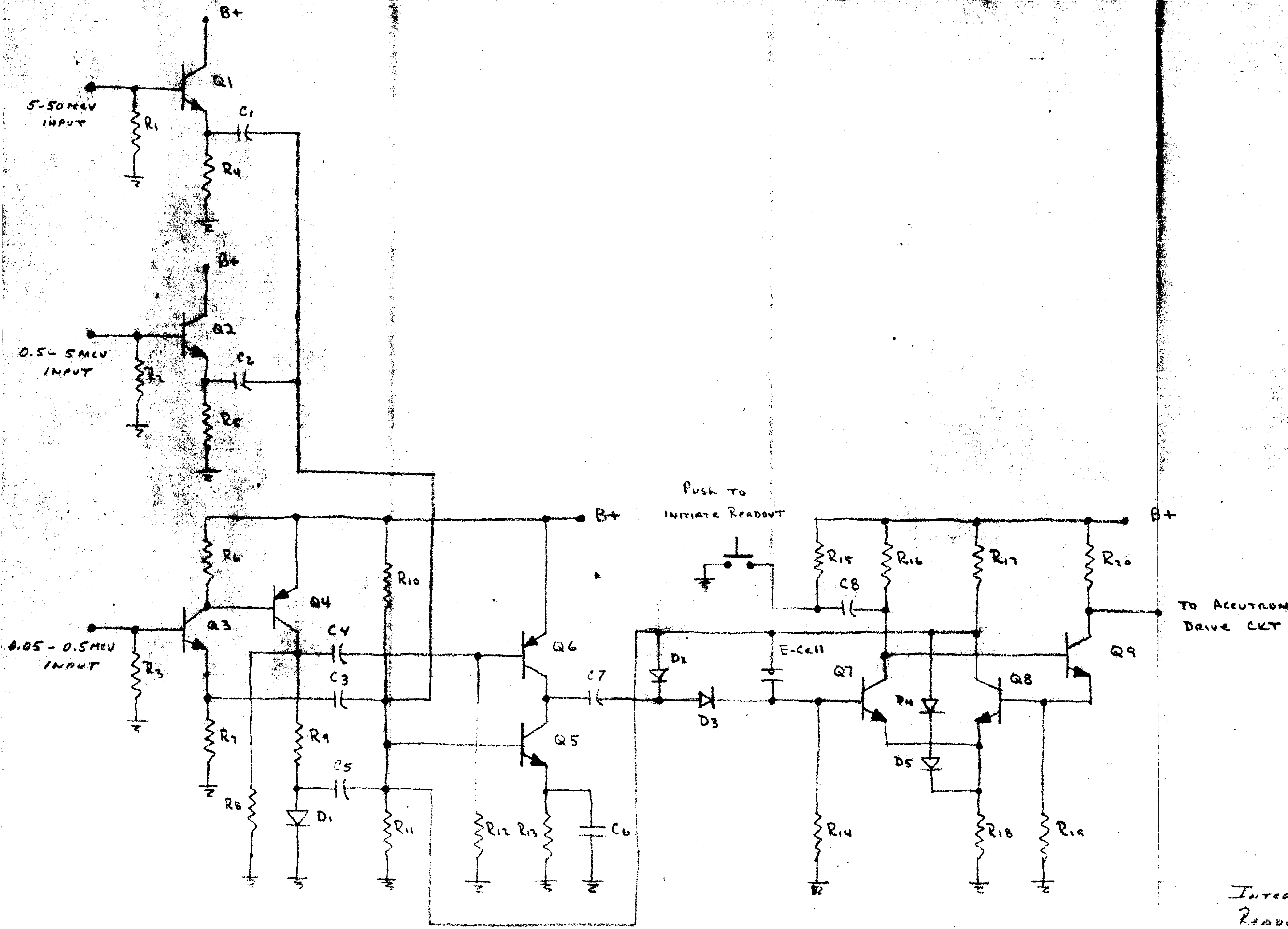
DRAWN V. BER 3.1.65
CHECKED J. M. U. 3.1.65
APPROVED

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
2 PLACE DEC ± 3 PLACE DEC ± ANGLES ±

DC TO DC CONVERTER FOR PROTON DOSIMETER DETECTOR BIAS

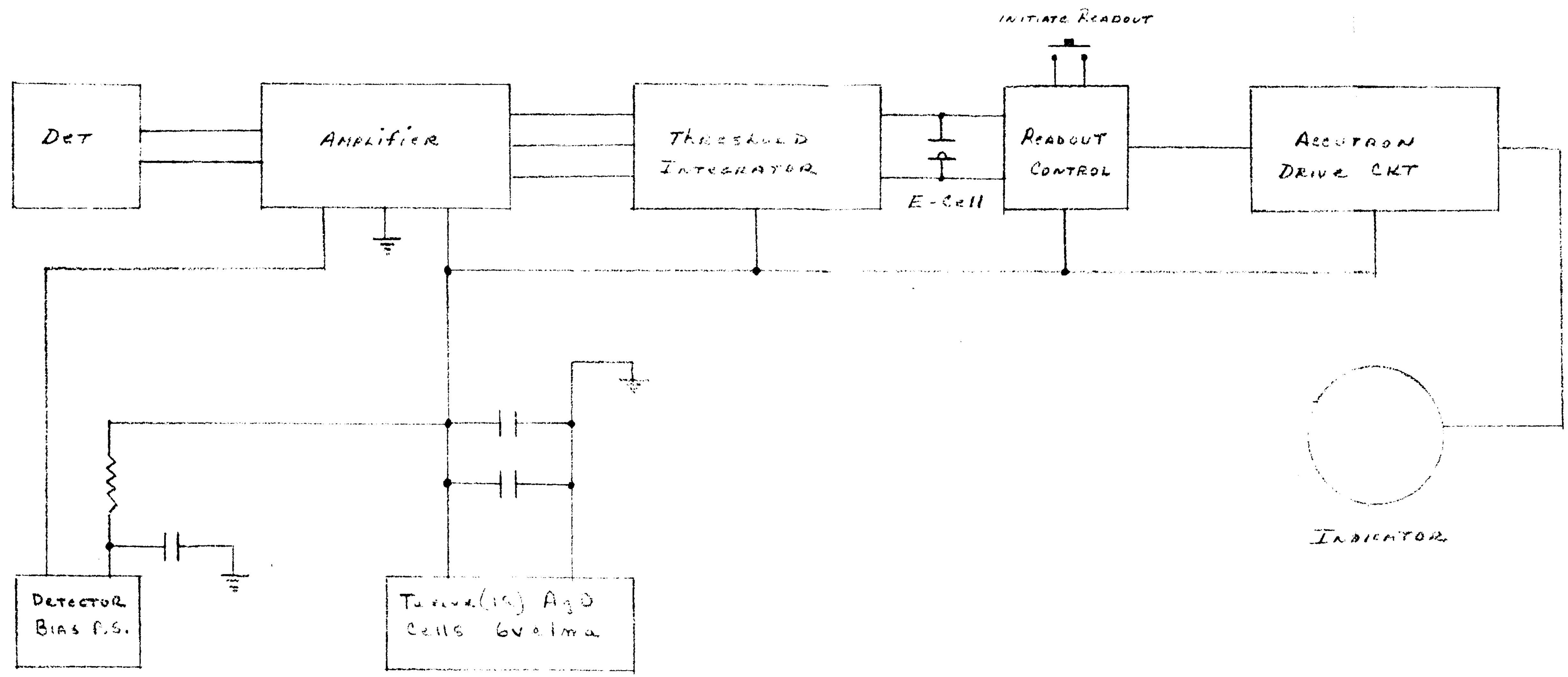
SCALE

1554-34



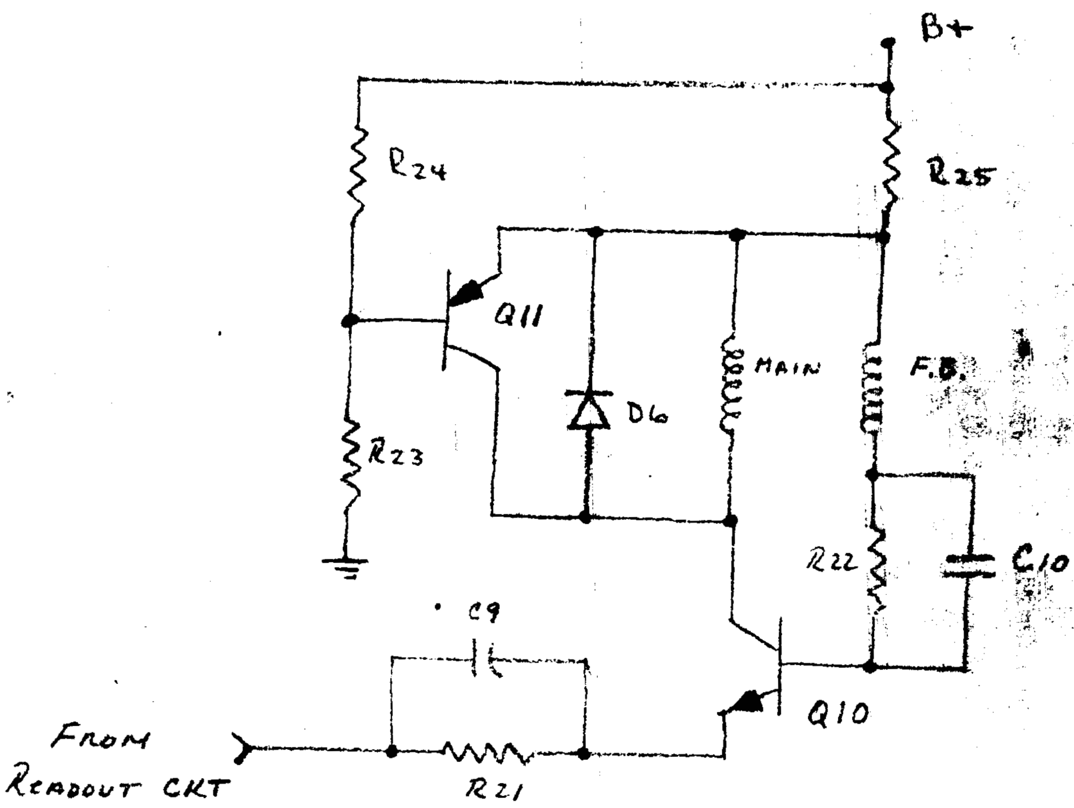
Integrator + Cell Readout

1554 - 35



System Block Diagram

1554-36



ACCUTRON DRIVE CIRCUIT

1554 - 37

JIMU
3/11/65