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SOLID-STATE PLUG-IN CIRCUITS AS INSTRUMENT BUILDING BLOCKS

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Instruments
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SOLID-STATE PLUG-IN CIRCUITS AS INSTRUMENT BUILDING BLOCKS

by

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ABSTRACT

Seven standard solid-state circuits were developed for use in radiation instrumentation. These circuits are a pulse amplifier, a variable discriminator, a pulse-shaping univibrator, a counting tube (dekatron) driver, a count rate meter, and multiple range and time constant circuits to operate with the count rate meter. These circuits may be combined to make instruments for specific needs.

CONTENTS

LIST OF FIGURES

SOLID-STATE PLUG-IN CIRCUITS AS INSTRUMENT BUILDING BLOCKS

SOLID-STATE CIRCUITS

Solid-state components have replaced vacuum tubes in many applications for increased reliability and decreased size. Experience gained at the Savannah River Laboratory in the application of transistors, diodes, and switching devices led to the development of seven standard solid-state circuits that can be used in various combinations to form basic radiation measuring and indicating instruments.

The numbers PC-1 through PC-7 assigned to the circuits are unrelated to their development or use (Fig. 1). Standard components (1/2-watt resistors, etc.) are used wherever possible, but miniature components are used where space is limited.

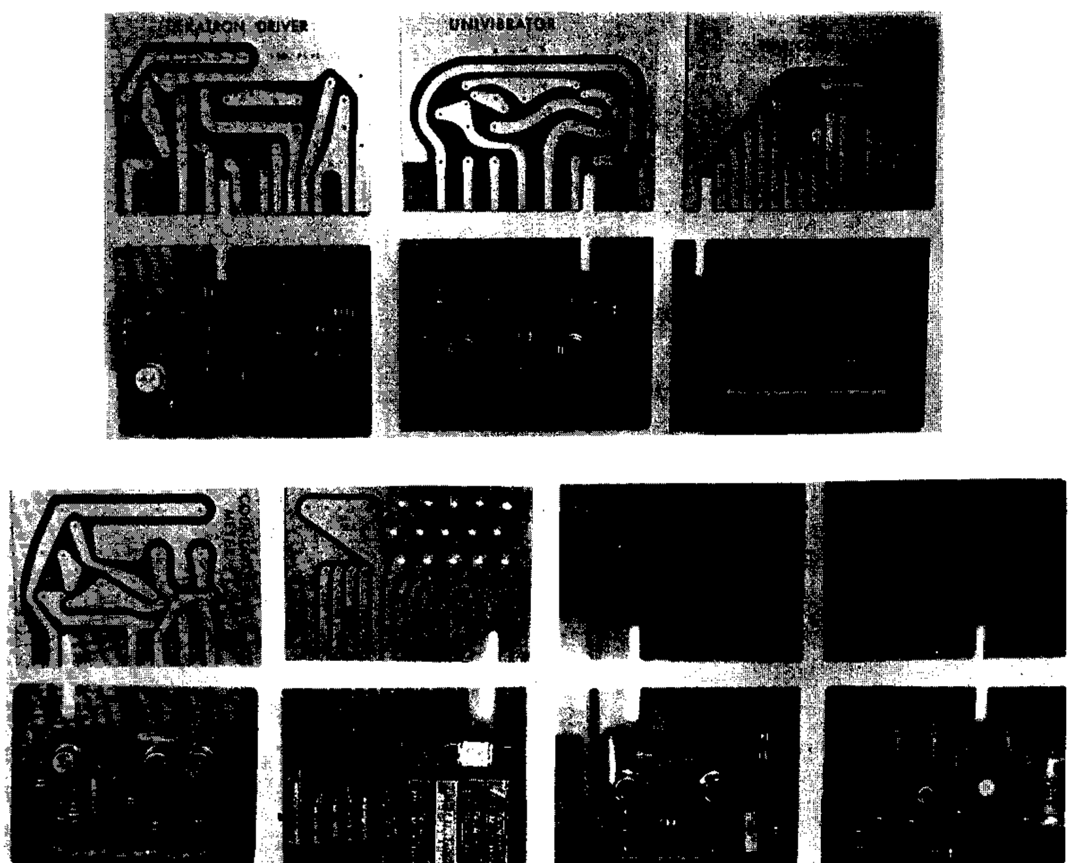


FIG. 1 CIRCUIT BOARDS

The PC-series circuits require a slightly higher power supply voltage than some transistor circuits. This voltage allows outputs of sufficient amplitude to drive vacuum tube devices, and also allows solid-state switching of control relays. A regulated power supply may be constructed easily, using a 39-volt regulator diode.

Various combinations of the PC-series circuits have been used (Fig. 2), and individual circuits have been modified for special applications. Approximately two hundred of these circuits have been used at the Savannah River Laboratory over a two-year period; none have failed, and operation has been entirely satisfactory.

CIRCUIT BOARDS

An etched circuit board 2-1/4 in. x 3 in. x 1/16 in. is used because it is convenient for most of the basic circuits, and it fits a standard connector. These circuit boards can be mass produced since 16 boards can be cut from standard 9 x 12-in. stock with no waste.

The circuit boards are made by drawing the circuit layout four times its actual size, then photographically reducing the drawing to actual size. A 9 x 12-in. composite of 16 negatives is used to expose a sheet of glass-epoxy/copper laminate that is coated with photo resist. After the exposed 9 x 12-in. sheet is developed and etched, the 16 boards are sawed apart. Each circuit is identified by lettering etched into the conductor side.

The completed circuit boards plug into standard bifurcated-contact connectors (Cinch-Jones 251-36A-30) which have been proven reliable and safe. (The terminals on only one side may be wired so that a reversed board makes no electrical connections.) Each board is notched in one of its terminal positions, and the corresponding socket position is filled with a plastic nib supplied by the connector manufacturer. Since even-numbered positions are keyed, the notched boards cannot be inserted into the wrong sockets, even when reversed.

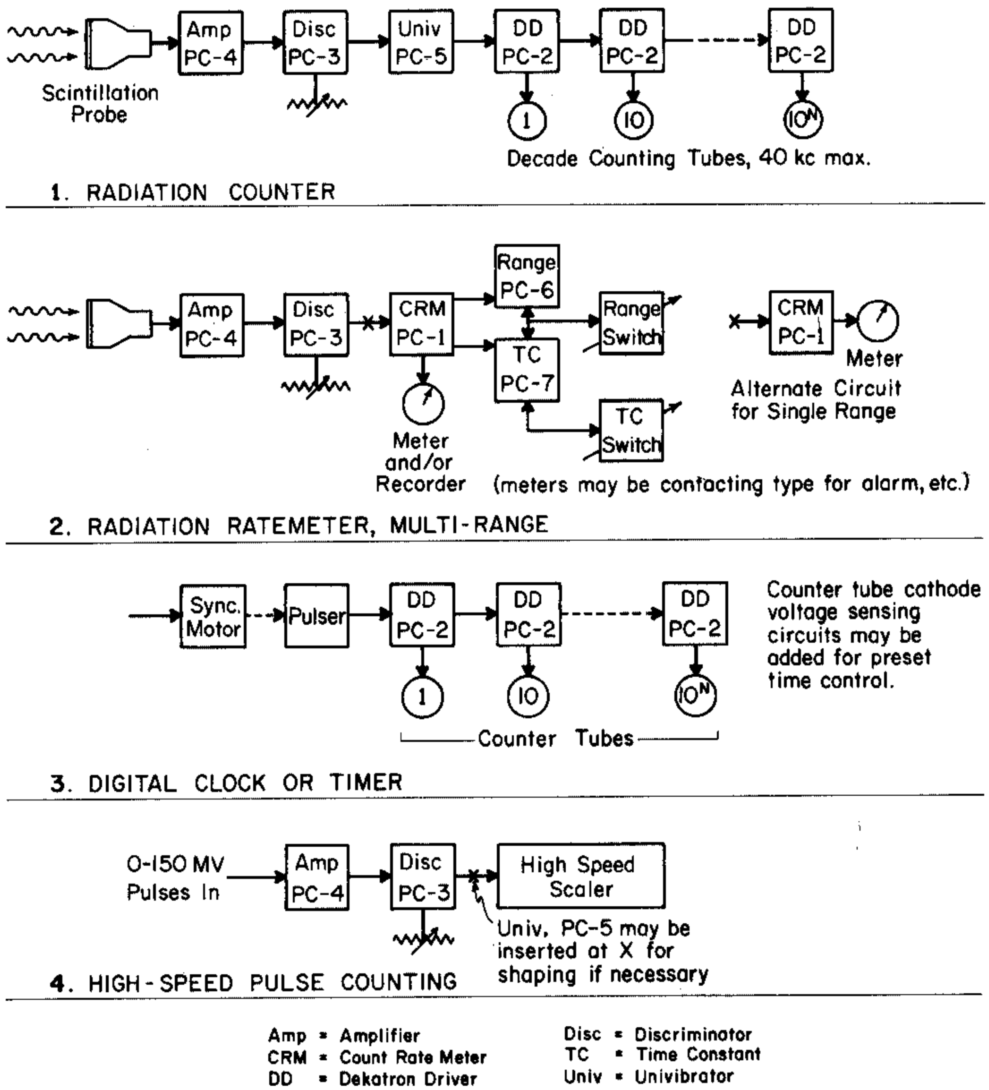


FIG. 2 COMBINATIONS OF PC BOARDS IN INSTRUMENTS

DESCRIPTION OF CIRCUITS

AMPLIFIER

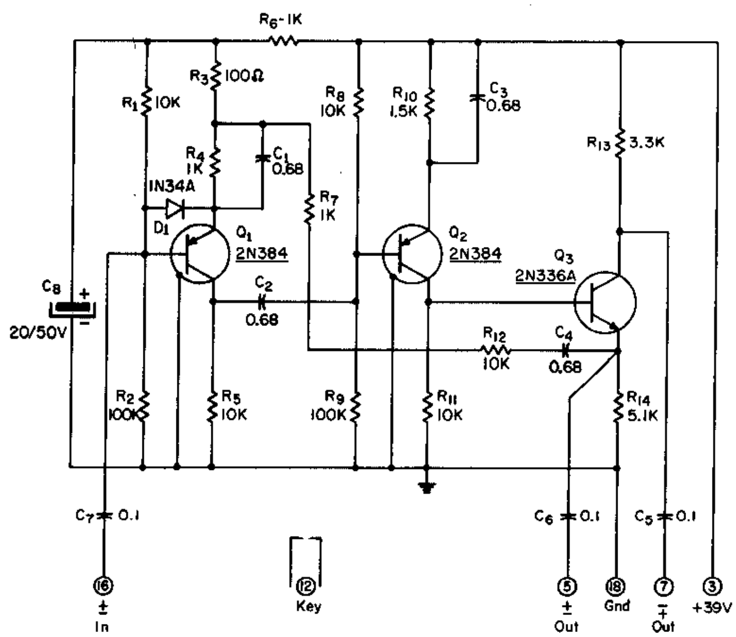


FIG. 3 AMPLIFIER, PC-4

Germanium drift transistors (Q_1 and Q_2) were used for their high frequency response characteristics because the amplifier is to handle fast-rising pulses from scintillation detectors. Since all other circuits in this series require a positive power supply, the PNP amplifier stages are "upside down" (with collectors toward ground) so they can operate from the same supply. Q_1 and Q_2 are cascaded common-emitter stages, with Q_2 directly coupled to a silicon phase splitter, Q_3. Negative feedback, which limits overall amplifier gain to about 100, is applied from Q_3 to Q_1 via C_4, R_{12}, R_7, R_3, and C_1. R_{12}, R_7, and R_3 form a voltage divider, while C_1 bypasses bias resistor R_4. Unbalanced load resistors R_{13} and R_{14} compensate for different impedance levels at the emitter and collector of Q_3, and provide normal or inverted outputs through C_5 or C_6. Diode D_1 prevents base-emitter breakdown in Q_1 from large positive pulses.

High-frequency response is greater than 100 megahertz, but low-frequency response falls off below 1 kilohertz because of the relatively small coupling and bypass capacitors. Gain is stable from under 10°C to over 50°C. Signals below 130 millivolts are amplified without distortion. Signals of several volts do not harm the amplifier, but overload recovery time increases with signal amplitude.

DISCRIMINATOR

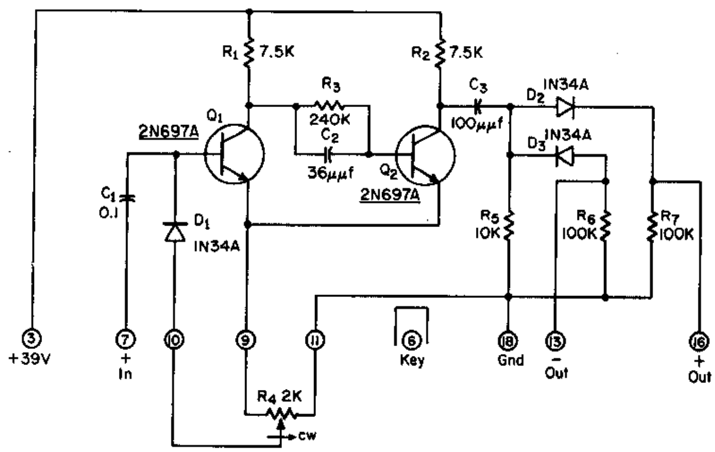
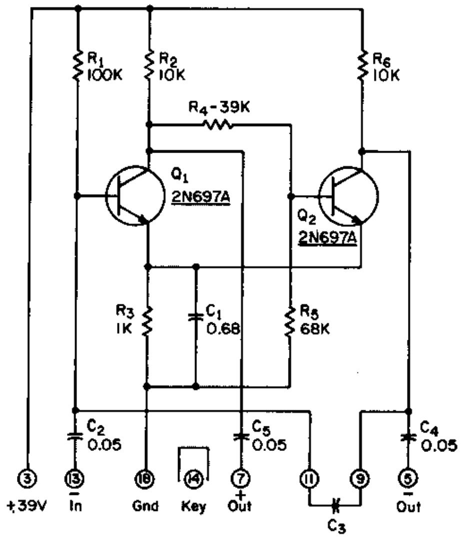


FIG. 4 DISCRIMINATOR, PC-3

A pair of silicon NPN switching transistors is used in a modified Schmitt trigger circuit. Q_2 is biased "on" through R_1 and R_3; Q_1 is biased "off" because the slider voltage of R_4 is more negative than that of the Q_1 emitter. (R_4 is not on the board, but is connected externally through Terminals 9, 10, and 11. For fine discriminator control a 10-turn potentiometer is recommended.) Incoming positive pulses are developed across diode D_1, and those exceeding the base-emitter reverse bias cause Q_1 to conduct. Then the Q_1 collector voltage becomes less positive, and this negative swing is transferred to the Q_2 base through C_2. Regenerative action takes place (as Q_2 conducts less) via emitter coupling, and the state is rapidly reversed with Q_1 turning completely "on" while Q_2 turns completely "off." This state prevails until the Q_1 base voltage falls below the reverse bias point; then the original states of Q_1 and Q_2 are restored by reverse action.

The output at the Q_2 collector is, therefore, a positive square pulse of about 30-volt amplitude with the same width as the input pulse at the discriminator trigger level. This square pulse is differentiated by C_3 and R_5; the positive spikes are developed across R_7 through D_2, and the delayed negative spikes are developed across R_6 through D_3.

UNIVIBRATOR



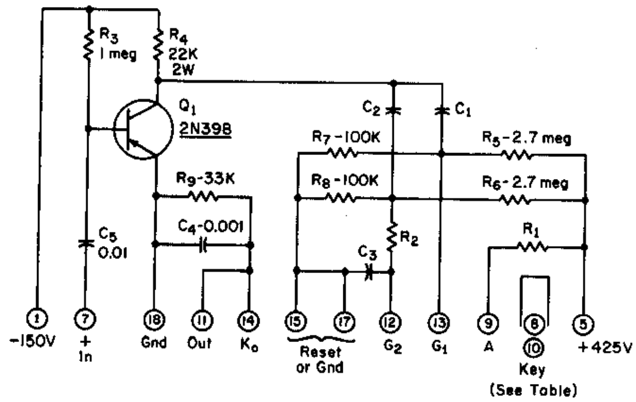
C_3	Approximate Pulse Width
100μμf	4 μsec
510μμf	10 μsec
1000μμf	20 μsec
0.005μf	85 μsec
0.01μf	170 μsec

FIG. 5 UNIVIBRATOR, PC-5

A triggered multivibrator, or "one-shot," is made with a pair of silicon switching transistors. This circuit provides pulses of constant size and shape to reliably drive counting circuits.

In this circuit, Q_1 is biased "on" through R_1. The Q_1 emitter current develops a more positive voltage at the upper end of R_3 than is present at the Q_2 base through voltage divider R_4 and R_5; therefore Q_2 is "off." A short negative input pulse, such as the negative spike from the discriminator output, is applied to the Q_1 base through C_2. This causes Q_1 to conduct less; consequently, the voltage across R_4 and R_5 rises. As Q_2's base voltage increases, Q_2 begins to conduct and its collector voltage decreases. This negative swing of the Q_2 collector is applied as regenerative feedback to the Q_1 base through C_3 (external to the board), causing the change of state to proceed to saturation. (C_1 bypasses R_3 to prevent emitter coupling effects during this action.) At saturation, the input spike has disappeared and C_3 must discharge through R_1 until Q_1 begins to conduct again. R_1 is chosen to provide saturation bias in the rest state; C_3 is chosen for the desired pulse width. Reset to the rest state occurs in the reverse manner after the R_1-C_3 time delay has elapsed, and the resulting pulse output (positive at the collector of Q_1, negative at Q_2) is about 30 volts in amplitude with widths corresponding to the C_3 values shown in the table of Fig. 5.

DEKATRON DRIVER



Maximum Frequency	Tube Types	Key Way	R_1	R_2	C_1	C_2	C_3
4KC	GS-10C 6802 7978	Term (9)	820K	68K	0.004µf	0.01µf	510µµf
40KC	8262 6909	Term (10)	330K	22K	0.001µf	0.004µf	150µµf

FIG. 6 DEKATRON DRIVER, PC-2

A germanium PNP switching transistor is operated in saturation (conducting) from a -150-volt supply. Most of this voltage is dropped across the 2-watt collector resistor R_4, with only about a 2-volt drop from Q_1 collector to emitter. A positive input pulse of 1 volt at the base is capable of turning Q_1 "off," causing its collector potential to move rapidly toward the supply voltage. Loading and collector-base leakage combine to limit the actual pulse amplitude to about -100 volts. These pulses are the same width as the input pulses, and are coupled through C_1 and C_2 to the guide electrodes G_1 and G_2 of a glow-transfer counting tube (dekatron). For G_1, R_5 and R_7 establish bias; and for G_2, R_6 and R_8 establish bias while R_2 and C_3 delay the pulse as shown in Fig. 7. The two overlapping negative pulses cause the glow discharge to transfer rapidly from cathode K_0 to G_1, then to G_2, and as G_2 returns to its positive bias voltage, the glow moves to the next most negative point, cathode K_1. The zero cathode is returned to ground through R_9 so that succeeding stages (decades) may be driven directly from the voltage rise as the glow reaches K_0. Other cathodes and the guide bias networks may be grounded either directly or through a normally closed reset switch. The table in Fig. 6 shows component values for two maximum frequencies and various tubes.

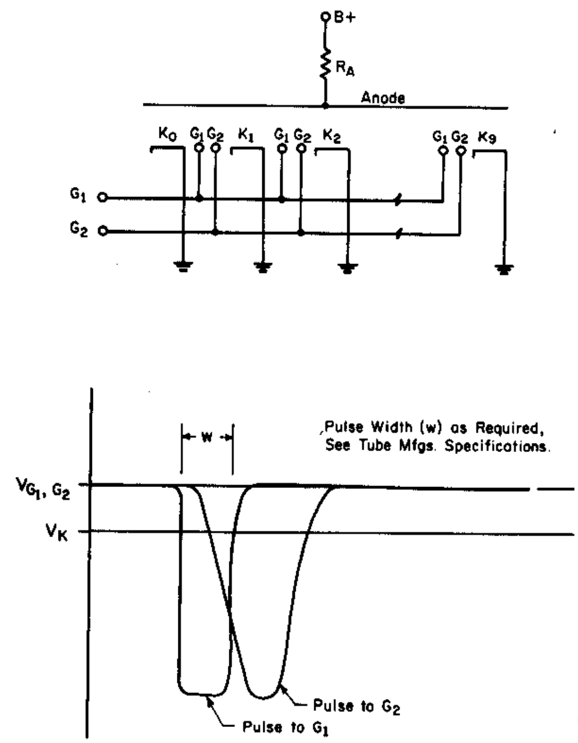


FIG. 7 GLOW-TRANSFER COUNTER TUBE OPERATION

COUNT RATE METER

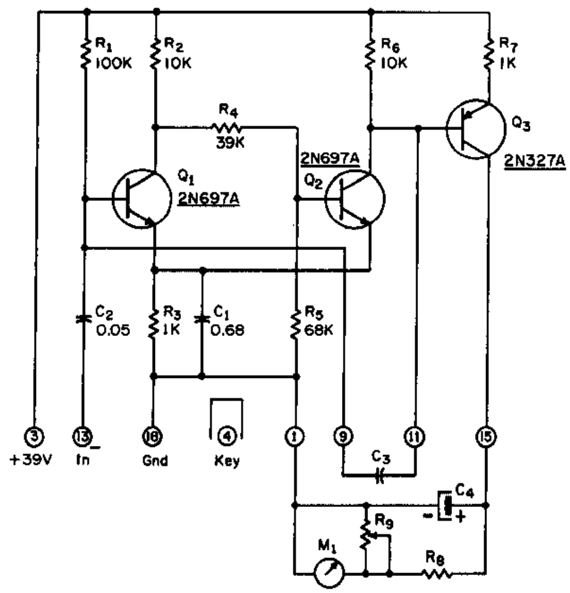


FIG. 8 COUNT RATE METER, PC-1

The count rate meter (CRM) circuit is the univibrator circuit with a meter drive amplifier (Q_3) added. Q_1 and Q_2 form a "one-shot" and operate in the same manner as in PC-5. Q_3 is a silicon PNP transistor, directly coupled to Q_2. The gain of this stage (G) is proportional to the ratio of collector load and emitter resistances:

$$G = k\left(\frac{R_8 + \dfrac{R_m R_9}{R_m + R_9}}{R_7}\right)$$

where R_m is the resistance of meter M_1 and k is a constant. Output pulses to the meter circuit are integrated by its parallel combination with a large capacitor C_4.

Varying R_8 in this circuit will vary the integration time constant, but will not affect the voltage developed across the meter and its shunt. For example, let

$$R_8 = 0 \text{ and } \frac{R_m R_9}{R_m + R_9} = R_7$$

then

$$G = k$$

Now let

$$R_8 = R_7 \text{ and } \frac{R_m R_9}{R_m + R_9} = R_7$$

then

$$G = 2k$$

Although voltage across the collector load is now doubled, the voltage across M_1 is proportional to the ratio

$$\frac{\left(\frac{R_m R_9}{R_m + R_9}\right)}{R_8 + \left(\frac{R_m R_9}{R_m + R_9}\right)} = 1/2 \qquad \text{when} \qquad \frac{R_m R_9}{R_m + R_9} = R_8 = R_7$$

or exactly what it was before R_8 was added. Thus, the meter voltage is always the same regardless of the R_8 value, even though the integration time constant changes.

Integrated pulses of constant amplitude and width are thus converted to an analog representation of frequency. Full-scale frequency range (or count rate) is determined by C_3, which determines pulse width, and by the calibration adjustment R_9. A single-range count rate meter may be made by soldering C_3 and C_4 directly to the PC-1 socket, but multiple ranges having different time constants require switch-selected components that may be mounted on other boards.

Since recovery time of the CRM multivibrator is finite, two pulses occurring within the total pulse and recovery time (dead time) cannot be resolved. Error due to dead time in random pulse counting is shown by

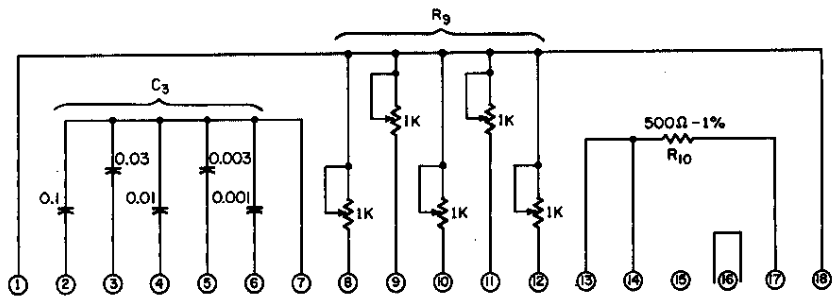
$$N_1 = N(1 - Nt)$$

where an actual counting rate of N yields an observed rate of N_1 when t is dead time and $Nt << 1$. Dead time error for the PC-1 circuit with five ranges is shown in the table of Fig. 9. Actual dead time was determined experimentally by observing the maximum frequency of 1-microsecond pulses that could be resolved at each range setting.

Range, c/m	C_3	Maximum Count Frequency, pulses/sec	Dead Time, $\frac{1}{\text{max count freq}}$	Maximum Error, % full scale
30,000	0.001 μf	30,000	33 μsec	1.7
10,000	0.003 μf	12,000	83 μsec	1.4
3,000	0.01 μf	4,000	250 μsec	1.3
1,000	0.03 μf	600	1.67 msec	2.8
300	0.1 μf	200	5 msec	2.5

FIG. 9 CRM CHARACTERISTIC TABLE

CRM RANGE



C_3 Capacitors = 200 WVDC Metallized Paper, Aerovox P-123ZG Type
R_9 Potentiometers = 1K Trimpots, Bourns No. 273-1-102

FIG. 10 CRM RANGE, PC-6

PC-6 is a convenient mounting board for five values of C_3 and R_9 in the CRM circuit, with terminals for connection to a selector switch. It also provides a mounting location for a precision resistor that may be connected in series with the meter to develop a recorder output voltage. For example, a 500-ohm resistor in a 100-microampere circuit develops 50 millivolts, a standard recorder range. If desired, a recording microammeter may be connected instead of the resistor. Used in conjunction with PC-1, the PC-6 makes a five-range CRM (Fig. 11), and PC-7 provides an individual time constant for each range.

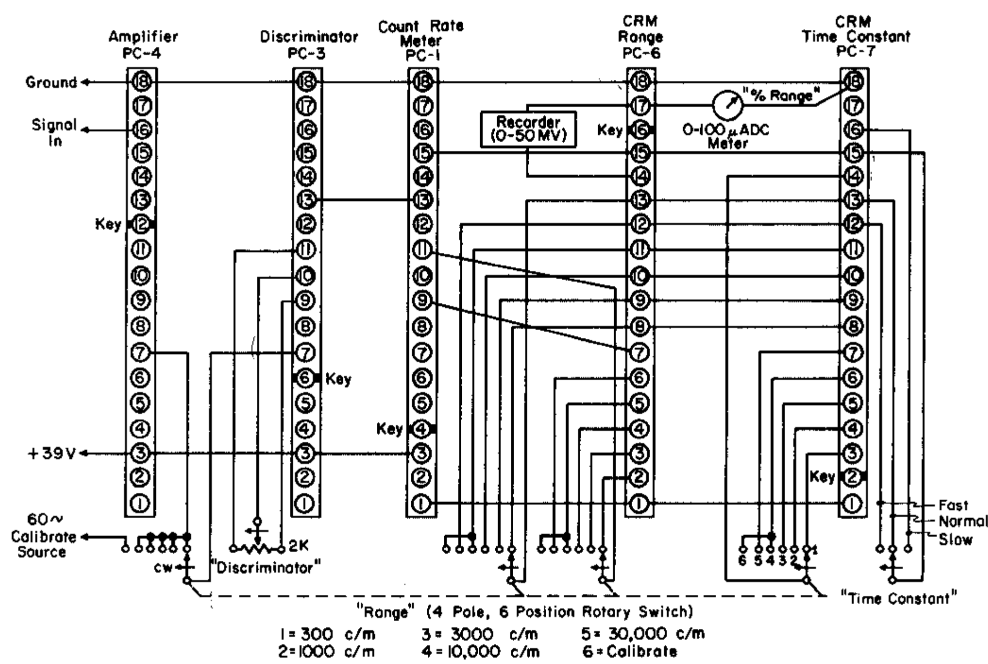


FIG. 11 SOCKET INTERCONNECTIONS FOR FIVE-RANGE CRM

CRM TIME CONSTANT

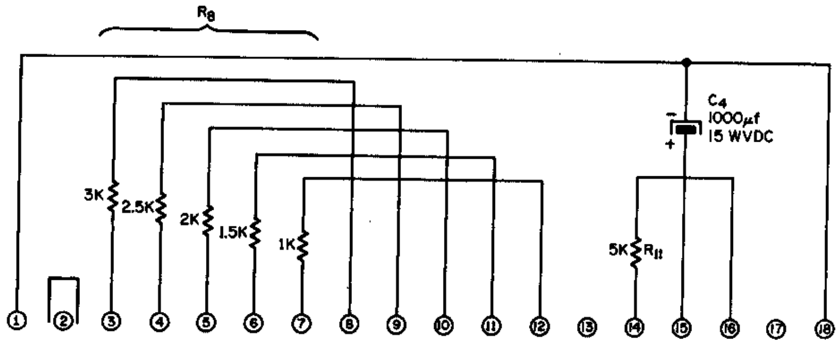


FIG. 12 CRM TIME CONSTANT, PC-7

Normally, to prevent flicker of the meter's pointer, the very low counting rates indicated by a count rate meter require a long integration time constant. The PC-7, which contains the integrating capacitor, permits the selection of any one of five values of R_8 (in the PC-1 circuit). An additional switch may short this section or connect another 5000 ohms in series with it, providing "slow," "normal," and "fast" time constants as desired. Only in the "fast" position does the time constant not change with range. All resistors are 1% precision carbon film types.