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A Differential Counting Rate Meter for Low Counting Rates

James J. Schmidt
University of Nebraska-Lincoln

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A DIFFERENTIAL COUNTING RATE METER
FOR LOW COUNTING RATES

by

James J. Schmidt

Presented to the Faculty of
The Graduate College in the University of
Nebraska

In Partial Fulfilment of Requirements
For the Degree of Master of Science
Department of Physics.

Under the Supervision of Dr. Robert L. Chasson

Lincoln, Nebraska
June 18, 1957
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I. COUNTING RATE METERS

A. INTRODUCTION

In connection with the International Geophysical Year cosmic ray studies, the need arose for a counting-rate meter to be used as a solar-flare alarm and to provide a continuous written record of the local neutron production in a Chicago-type neutron monitor pile. This rate meter had to meet certain specific requirements:

1. It must be dependable, since it is to run continuously for several months.
2. It must be able to provide an accurate recording of the neutron production rate.
3. It must have a low probable error, which necessitates a long time constant.
4. It must be designed to operate at low counting rates.
5. It must be able to trigger an alarm upon an increase in intensity.

It was decided to investigate the circuit proposed by Harald Trefall¹ and to modify it to match the requirements of the IGY study.

Upon construction and the subsequent testing, the Trefall circuit proved most satisfactory as a monitor for local neutron production. Due to the long time constant, the rate meter failed to meet the requirements of an alarm circuit. It responded too slowly to increases for this use.

B. COUNTING RATE METERS

A counting rate meter is an instrument which provides, as an output, the time average of pulses coming in at a random rate. Since it is to record the time average, the instrument is to be insensitive to pulse height or shape. The output can be in the form of a meter reading or a permanent written record if a pen recorder is used.

In operation, the meter converts input pulses to a uniform size and charges a condenser using these standard pulses. This condenser is being continuously discharged by a resistor. The voltage across this resistor is then proportional to the counting rate. The voltage is measured by a vacuum tube voltmeter which is calibrated to read counting rates directly.

C. THE TREFALL CIRCUIT

Referring to the block diagram in figure 1, the input pulses are fed through a phase inverter T1 (in figure A2) which reverses their polarity and amplifies them. The output of this element triggers a univibrator T2 which
FIGURE 1. BLOCK DIAGRAM WITH WAVEFORMS
provides a uniform output pulse independent of the shape or size of the triggering pulse. The input grid of this section is equipped with a variable bias which serves as a discriminator. The output of the univibrator is coupled to a DC restorer T3 which superimposes the pulses upon a base of -170 volts.

The pulses are then fed through a clipping circuit T3, which shapes them further, and are then applied to the grid of the pentode T4 in the integrating section. This pentode is normally cut off, supplying charge to the integrator only when a pulse is on the grid. A pentode was chosen for this tube so that the charge fed into the condenser with each pulse is independent of the charge already stored there. A sharp cutoff pentode 6SH7 was used because an undesirable continuous current of as small as 3 microamperes would be noticeable on the output.

The charge which is supplied to the condenser depends upon the pulse duration, pulse amplitude, and the cathode resistor of this pentode. The only one of these variables which can be changed with any accuracy is the cathode resistor. By switching in various values, the different maximum counting rates are made possible.

The pulses are supplied through this pentode to a Miller Intermittent T5. A long time constant is needed; hence the Miller effect is used to provide a high capacitance with a low dielectric leakage. A 6SL7 was chosen
for the integrator because of its low grid current. The potential difference across the grid resistor of the integrator tube (also referred to as the integrator resistor) is a measure of the counting rate.

This voltage is measured with a differential amplifier (vacuum tube voltmeter) T6, T7, and T8. The meter is calibrated to read the counting rate directly and has provisions to read the absolute rate or fluctuations about a mean rate. An Esterline-Angus recording milliammeter may be driven by this circuit to provide a continuous permanent record of the rate.

\[2\text{Vacuum Tube Amplifiers, M. I. T. Radiation Laboratory Series, pp. } 418-20.\]
II. THEORY

A. INTRODUCTION

The circuitry preceding the integrator supplies it with uniform pulses. The vacuum tube voltmeter serves only to read the output of this integrator. The waveform of the output depends then, upon its response to these standard pulses.

There are two time constants associated with an integrator:

(1). The charging time constant depends upon the plate resistance of the tube supplying the charge to the condenser, the discharging resistor across the integrator capacitance, and the value of this integrator capacitance. The integrator capacitance is equal to the effective capacitance of the Miller integrator.

(2). The discharging time constant depends only upon the value of the integrator capacitance and the resistor which discharges it. While discharging, the input tube is cut off and offers an infinite resistance to the flow of current; the charge is drained only through the integrator resistor.

B. CHARGING TIME CONSTANT

Consider first the integrating section of the rate meter. The circuit diagram and the equivalent circuit are shown in figure 2. Corresponding points are labeled.
MILLER INTEGRATOR

FIGURE 2. EQUIVALENT CIRCUIT

FIGURE 4. DISCHARGE CIRCUIT
$R_p$ represents the plate resistance of the 6SH7 input tube; $C_1$, the capacitor across the integrating resistor $R$; $C$, the integrating capacitor, and $A$, the gain of the 6SL7.

Considering the currents in the circuit:

$$i_1 = i_2 + i_3$$  \hspace{1cm} (1)

or

$$\frac{V_1 - V_2}{R_p} = \frac{V_2}{C_1} + \frac{V_2}{R} + \frac{V_2 - V_3}{SC}$$  \hspace{1cm} (2)

by the use of Laplace transforms. $V_1$ represents the transform of the voltages $V_1$ of the circuit, and $S$ is the algebraic parameter arising out of the Laplace transformation.

From the voltages in the circuit:

$$V_3 = -AV_2$$  \hspace{1cm} (3)

Combining (2) and (3) and solving for $V_2$:

$$V_2 = V_1 \left[ \frac{1}{(1 + \frac{R_p}{R}) + \frac{R_p}{C_1(A+1)C}} \right]$$  \hspace{1cm} (4)

Now in the circuit $(A+1)C \gg C_1$

Let $(1 + \frac{R_p}{R}) = B$ \hspace{1cm} $R_p(A+1)C = G$  \hspace{1cm} (5)

These simplify (4) to give

$$V_2 = V_1 \cdot \frac{1}{B + GS}$$  \hspace{1cm} (6)
To determine the wave form, the response of this circuit to a series of pulses must be calculated. Consider the pulse train of figure 3. \( x \) represents the pulse length, \( T \) the period of repetition, and \( E \) the pulse height. The equation of this train is then:

\[
V_1 = E \left\{ U(t) - U(t-x) + U(t-T) - U(t-T-x) + U(t-2T) - U(t-2T-x) + \cdots \right\} \tag{7}
\]

where \( U(t) \) represents a unit step pulse.\(^3\) The Laplace transform of \( 7 \) is:

\[
\bar{V}_1 = E \left[ \frac{1}{s} - \frac{e^{-xs}}{s} + \frac{e^{-Ts}}{s} - \frac{e^{-(T+x)s}}{s} + \frac{e^{-2Ts}}{s} - \cdots \right] \tag{8}
\]

The output of the integrator is obtained by substituting (7) into (5).

\[
\bar{V}_2 = \frac{E}{G(s+\alpha)} \left[ 1 - e^{-xs} + e^{-Ts} - e^{-(T+x)s} + e^{-2Ts} - \cdots \right] \tag{9}
\]

where \( \alpha = \frac{B}{G} \) \tag{10}

The inverse transform of (8) is

\[
V_2 = -\frac{E}{B} \left( e^x \right) \left\{ 1 + e^x + e^{2x} + \cdots + e^{\alpha x} \right\} - e^x \left[ 1 + e^x + e^{2x} + \cdots + e^{\alpha x} \right] \tag{11}
\]

\( \text{\textsuperscript{3}} \text{S. Goldman, Transformation Calculus and Electrical Transients, (New York, 1949), p.67.} \)
This is a finite series and becomes for m pulses:

\[-V_z = \frac{E_0 \cdot e^{-\frac{t}{T}} \{1 - e^{-\frac{T}{\alpha}}\} \{1 - e^{-\frac{(m+1)T}{T}}\}}{\{1 - e^{-\frac{t}{\alpha}}\}} \tag{12}\]

If the number of pulses into the integrator has been large enough so that \(|mT - t| \ll t\), this reduces further to

\[V_z = \{1 - e^{-\frac{t}{\alpha}}\} \left[ \frac{E_0 (1 - e^{-\frac{T}{\alpha}})}{B (1 - e^{-\frac{T}{\alpha}})} \right] \tag{13}\]

The terms in the brackets are constants, and the wave form is given by

\[V_z = \text{const.} \{1 - e^{-\frac{t}{a}}\} \tag{14}\]

This is similar to the charging curve of a condenser with the \(a\) replacing the usual RC time constant.

Thus \(a\) is the time constant of the instrument.

The numerical value can readily be calculated.

Combining (5) and (10):

\[a = \frac{R \cdot R_p \cdot (1 + A) \cdot C}{R + R_p} \tag{15}\]

The values of the variables from the instrument are:

\[R = 2.4100 \text{ megohms.} \]
\[R_p = 4.9 \pm 1.3 \text{ megohms.} \]
\[A = 55 \pm 5. \]
\[C = 32 \pm 2 \text{ microfarads.} \]
R and C are the rated values from the components. The values of $R_p$ and $A$ are obtained from the tube curves.\(^4\)

Substituting these values into (15), the theoretical time constant of $2900\pm1500$ seconds was obtained. This agrees quite closely with the value $2760\pm300$ seconds, resulting from measurements on the traces of the output of the instrument.

C. **DISCHARGING TIME CONSTANT.**

The discharging time constant is that of the integrator capacitance discharging through the integrator resistor. The waveform for discharging is given by

$$V(t) = \text{const} \left[ e^{-\frac{t}{RC(A+1)}} \right]$$

The time constant is then

$$\tau_{\text{DIS}} = RC(A+1)$$

Substituting the values given earlier, the discharging time constant is calculated to be $4320\pm650$ seconds. From measurements on the output, a value of $4680\pm120$ seconds was observed.

---

\(^4\)Since the pentode is operated in a region not covered in published characteristics, curves had to be plotted to obtain the plate resistance. These curves are given in figure A4.
D. PROBABLE ERROR

Consider the simplified equivalent circuit of figure 4. 
C' represents the effective capacitance, \((1+A)C\), of the integrator, and R is again the integrator resistor. When the meter has run for a sufficient time for equilibrium to be attained, the average voltage across R is

\[
V = IR = nqR
\]  

where \(q\) is the charge supplied by each pulse and \(n\) is the number of pulses per second.

To calculate the probable error, Campbell's theorem will be used. In one form this states that: If the voltage \(v(t)\) is induced in a circuit by each event of many which occur randomly at the average rate \(n\), the mean square fluctuation voltage existing in the circuit is given by

\[
\Delta V^2 = (\overline{v(t)} - V)^2 = n \int_{-\infty}^{+\infty} v^2(t) \, dt
\]  

A pulse produced at time \(t=0\), produces the voltage pulse in the circuit

\[
v(t) = \frac{q}{C} e^{-\frac{t}{RC}}
\]

---

Therefore:  \[ \Delta v^2 = n \int_0^{\infty} \frac{8}{(C)^n} e^{-\frac{3t}{RC^n}} dt \]  (21)

The limits are now taken from 0 to +\( \infty \) since there are no pulses in the circuit for \( t < 0 \).

Integrating this and taking the square root:

\[ |\Delta v| = \sqrt{\frac{h_0^2 R}{2C^n}} \]  (22)

The RMS error is then

\[ \frac{\Delta v}{v} = \frac{1}{\sqrt{2RC^n}} \]  (23)

and the probable error is

\[ \xi = 0.67 \frac{\Delta v}{v} = \frac{0.67}{\sqrt{2RC^n}} \]  (24)

It should be noted that the probable error depends upon the rate being counted.

Substituting the values from the instrument into (24), the probable error for different settings of the instrument are:

<table>
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<th>Rate</th>
<th>100cpm</th>
<th>200cpm</th>
<th>300cpm</th>
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<td>Low Probable Error</td>
<td>0.6%</td>
<td>0.4%</td>
<td>0.3%</td>
</tr>
<tr>
<td>High Probable Error</td>
<td>1.2%</td>
<td>0.8%</td>
<td>0.6%</td>
</tr>
</tbody>
</table>

The accuracy of reading the output is limited more by the width of the trace than by the probable error of the instrument.
III. CONSTRUCTION

A. POWER SUPPLY

An Elmore and Sands Model 50 power supply was chosen as best fulfilling the requirements of the Trefall circuit. However, due to the several bias voltages required, some modification of the power supply circuit was necessary.

A negative supply, regulated only by voltages regulator tubes was added. The critical bias voltages are regulated by 5651 glow tubes. Due to the small range of current (0.5-3.5 MA) in which these tubes operate, it was found necessary to precede them with a stage of VR105 regulating tubes.

To supply the necessary plate voltage to the rectifier of the negative supply, it was essential to replace the transformer of the Elmore circuit with a 1200 volt center-tap power transformer. This higher plate supply necessitated replacing the rectifier tube with a 5R4GY and using a choke input. The rest of the circuit is identical with the Model 50.

After construction, the power supply was tested and found to have a stabilization factor\(^7\) of 1500 and an output impedance of 1 ohm. The ripple is 0.01% when supplying a current of 120 milliamperes.

---

\(^7\)From Elmore and Sands, the stabilization factor \(S\) is defined as

\[
S = \frac{E_o \Delta E_t}{E_t \Delta E_o}
\]

Where: \(E_o\) = output voltage, and \(E_t\) = line voltage.
Included on the chassis of the power supply is a meter which enables voltages throughout the circuit to be measured simply by proper switching. On rotating the control, the meter is automatically calibrated and proper polarity selected. The meter reads percent normal voltage so the correct values need not be known by the operator. Provision is also made to check the balance of the cathodes of the differential amplifier by the use of this meter.

B. RATE METER

The rate meter was constructed on a chassis separate from the power supply.

In order to prevent any stray currents to ground, the integrating portion, including tubes T3, T4, and T5, with the associated parts, were mounted on a polystyrene sheet which was placed over a cutout in the metal chassis.

Most of the resistors are wire wound to give greatest stability. All critical condensers are mica or oil filled. The components of the integrator were chosen most carefully. The integrator resistor is a vacuum, wire wound, precision resistor. The integrating condensers, made by Western Electric, contain a pyranol dielectric. These were chosen because of their low dielectric leakage. These condensers are switched to series or parallel connection to provide a dual-range probable error.
In the differential amplifier, adjustments were incorporated to balance the cathodes of the two stages to compensate for variations in tube characteristics. To improve linearity in this section, an RCA Red Base 5692 was chosen as the input tube. 6AG7 pentodes, balanced on a transconductance tube tester, were chosen for the second stage. The output meters are connected between the plates of these pentodes.

By varying the series resistance of the meters, they can be calibrated to give full scale reading of 100%, 50% or 30% of the maximum counting rate. (This maximum counting rate is that determined by the cathode resistor of the 6SH7 tube). A set of switched reference voltages is included in the plate circuit to calibrate the output sensitivity to any of these values. With the use of these potentials, the meters may be calibrated without disturbing the charge on the integrator condenser.

In adjusting the variables of the circuit to the specifications of the proposed application, the differential amplifier was first constructed, and a study made of its linearity. The curve of figure 5 resulted. It can be seen from this that best results could be obtained if the maximum voltage applied to the inputs were limited to 4 volts. To remain within these limits, 3 volts was chosen as the potential which would give full scale de-
FIGURE 5. AMPLIFIER LINEARITY

FIGURE 6. METER SAFETY CIRCUIT
flection of the meters in the least sensitive setting of the series resistance. Known rates, which were to be the maximum for each of the three settings of the Maximum Counting Rate switch, were then applied to the input. The values of the cathode resistors of the 6SH7 which would give 3 volts across the integrator resistor, were then determined experimentally.

A potential divider provides the reference voltages in ten equal increments with 3 volts as the maximum. The bias voltages supplying this potential divider are regulated by glow tubes. In operation these allow a voltage fluctuation of 1%. This would lead to a variation of the maximum reference of less than 0.03 volt. To prevent changes due to aging, the potential divider is comprised of wire wound, precision resistors. These were tested and found to have a temperature coefficient that would vary the reference voltage by 0.06% per degree. This would change the 3 volt maximum by 0.002 volt per centigrade degree.

The entire set of reference voltages can be shifted so their base is from 0 to 0.5 volts above ground while the increments remain constant. This is necessary because it was found that a potential of 0.04 volts appeared across the integrator resistor when the instrument was allowed to operate with no pulses feeding into it. The internal resistance of the condensers (3x10^9 ohms) in series with the integrator resistor form a potential
divider from the plate of the 6SL7 (+120 volts) to ground, giving this result. The variable base is necessary to provide bias to eliminate this effect.

The integrator circuit provides a DC voltage as its output. The value of this voltage is proportional to the counting rate. The reference voltages provide potentials of the same magnitude. By switching to these known voltages, which simulate known rates, the meter circuit is calibrated.

To study fluctuations about a mean rate, a zero-center meter is used. The mean rate can be calculated and simulated by the appropriate voltage applied to the reference grid of the differential amplifier. This mean rate would then give a null reading on the meter. This reference voltage can be varied continuously by switching to the potentiometer in the reference voltage circuit.

Since the instrument will run unattended, a safety circuit was included to disconnect the meters in the event of an overload. Since this circuit is included between the plates of the difference amplifier, a relay which operates on low currents was necessary. One which would open on a current of 7 milliamperes and close on a current of 5 milliamperes was chosen for this purpose.\(^8\)  

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\(^8\)Sigma Relay, Model number 26f-8000-cds/pal.
2 milliamperes difference between opening and closing currents was not sufficient to prevent chatter of the contacts when the current increase was slow. To eliminate this effect the circuit shown in figure 6 was developed. The values of the resistors $R_m$, $R_r$ and $R_t$ were chosen so that a 10% overload of the meters would give a current of 7 MA through the relay. When this point is reached the contacts open, disconnecting the meters. The shunting resistance, consisting of $R_m$ and the meter coil, is removed. This causes an increase in the current through the coil which prevents chatter of the relay. The values of the resistors were also calculated so that the contacts would again close when the current fell to the value which would give a deflection of 80% of full scale. Upon opening the contacts, the relay turns on a warning light to indicate that the meters are not operating.

Throughout the instrument all rated limits of maximum voltage and power were in excess of the required values. After weeks of operation, no parts were found to be overheated.
IV. THE COMPLETED INSTRUMENT

A. CONTROLS

The front panel controls of the instrument are as follows:

(1) ZERO ADJUST: This varies a potentiometer in the plate circuit of the pentodes in the differential amplifier to achieve balance between them.

(2) MAXIMUM COUNTING RATE: This varies the value of the cathode resistor of the 6SH7 which determines the maximum allowable counting rates for the three positions of 100, 200, or 300 counts per minute.

(3) PROBABLE ERROR switches integrating capacitors from series to parallel connection to provide a variation of probable error. The discharge position shunts resistors across these condensers to discharge them.

(4) SENSITIVITY adjusts the value of the resistors in the meter circuit so that 30, 50, or 100 percent of the maximum counting rate setting (2) will give full scale deflection on the output meters.

(5) CALIBRATE: This is the continuous fine adjustment of the SENSITIVITY (4).

(6) GRID 1, GRID 2: These select the inputs to the grids of the differential amplifier. With these switches, various reference voltages can be sampled for calibrating the meters. With GRID 1 in the OPERATE position, the meter
is comparing the voltage across the integrator resistor with the reference voltage selected by the GRID 2 switch.

(7) CONTINUOUS REFERENCE: Switched into the reference grid of the differential amplifier by the GRID 2 switch, this provides a continuously variable reference voltage.

(8) CHARGE: This connects the integrator capacitor to ground and allows a small condenser to be charged to the equilibrium potential. Upon releasing the switch, the charge is transferred from the small condenser to the large one. Repeating this process, upon first turning the instrument on, will accelerate charging the integrator condenser to equilibrium.

(9) INTERNAL METER, EXTERNAL METER: These switch the panel meter or the Esterline-Angus meter in or out of the circuit.

An input for the instrument and output for the Esterline-Angus recorder are included on both the front and rear of the chassis. Caution: The average potential of the Esterline-Angus jacks is 120 volts above ground. Neither post is near ground potential.

The SAFETY light indicates when the safety circuit has disconnected the output meters.

The controls on the panel of the power supply chassis are:

(10) POWER: This switch controls the power for the entire instrument.
(11) VOLTAGE CHECK: This rotary switch enables voltages to be checked throughout the power supply. It automatically calibrates the meter and connects proper polarity so that each voltage, if of the proper value, will cause the meter to read in the green portion of its scale. Four positions of this switch connect the meter to the cathodes of the differential amplifier to check their balance. There are two positions for each cathode pair. These are identical except for reversal of polarity. Correct balance will result in a null reading on the meter.

B. CALIBRATION

The only equipment necessary in the calibration of the instrument is a source of pulses of known rates. The calibration is accomplished in three steps:

(1) Balance the cathodes of the differential amplifier with the use of the meter on the power supply chassis and the CATHODE 1, CATHODE 2, screwdriver adjustment on the rear of the chassis. Balance the first and second stages in that order.

(2) After the instrument has been allowed to warm up, bias out dielectric leakage using the back chassis BIAS ADJUST to set the rate-indicating meter to zero-center.

(3) Calibrate the integrator by counting known rates for each of the three positions of the MAXIMUM COUNTING RATE control.
21.

Since the differential amplifier is used to adjust the other sections of the instrument, it should be adjusted first. This balancing of the cathodes is necessary to compensate for variations in tube characteristics.

Switch the GRID 1, GRID 2 controls to the same reference voltage. Adjust the output meter to read as near to zero as possible by use of the ZERO ADJUST. Rotate the VOLTAGE CHECK switch to one of the CATHODE 1 positions. If the meter on the power supply has a negative deflection, switch to the other CATHODE 1 position. Turn the CATHODE 1 BALANCE for a zero reading on this meter. In the same manner switch to a CATHODE 2 position and repeat the procedure to balance the cathodes of the pentodes by the use of the other balance adjustment. The balance of the plates of the pentodes is accomplished by the ZERO ADJUST control on the panel and is indicated by a null reading on the rate-indicating meter. Balance these plates, and repeat the above procedure until balance throughout the circuit is achieved.

To bias out the stray current caused by the dielectric leakage, let the instrument remain on for several hours with no pulses being fed into it and with the probable error set as the instrument is to be used. The use of the Esterline-Angus will indicate when equilibrium has been reached.

With the SENSITIVITY set for the most sensitive (30%)
scale, zero the rate-indicating meter after switching both grid switches to 0. Switch GRID 1 to the OPERATE position and set BIAS ADJUST to give a null reading on the output meter. This shifts the base of the reference voltages to the value of the voltage across the integrator resistor caused by the leakage currents.

To calibrate the integrator, a source of known rates is required. This is supplied most readily by an audio oscillator. However, the rates of the instrument are much lower than can be readily obtained from an oscillator. Dividing the audio frequencies with a scaler furnishes the necessary rates.

To calibrate, the GRID 2 switch is turned to the reference voltage which represents the known rate being supplied by the oscillator through the scaler, figure 7. (The use of the pen recorder facilitates the calibration procedures). With the output of the differential amplifier on the most sensitive scale (30%), the CHARGE switch is held open and the appropriate scale adjustment on the chassis top is set to give a zero reading on the rate-indicating meter. Under these conditions, the trace will be several divisions wide since the time constant is lessened by switching the integrator capacitor out of the circuit. The mean must be estimated. After this preliminary adjustment, charge the integrator condenser as fully as possible by rocking the CHARGE switch. Due to its long time constant, the instrument is slow in reaching an equilibrium position for a given rate. This position can be obtained more
FIGURE 7. USE OF SCALER AND OSCILLATOR

FIGURE 8. CALIBRATION TRACES
rapidly in the following manner.

Increase the oscillator frequency from the calibration rate until the deflection on the trace is one or two divisions higher than the expected average. Return the oscillator to the calibration frequency and observe the decay of this reading. (Figure 8). Repeat this procedure, this time by first lowering the frequency, then increasing it. Observe its rise. The equilibrium rate is then represented by the mean of the trailing ends of these two traces.

Hold the CHARGE control and readjust screwdriver setting to change the trace by the proper amount for correct calibration. Repeat the above procedure until the mean of the decay and rise is the calibrating rate on the scale.

This procedure must be followed for each position of the MAXIMUM COUNTING RATE switch and must be repeated if the integrator tubes are replaced. As a final check on the calibration, it is recommended that the meter be allowed to run for approximately three hours with the calibration rate impressed upon it. The trace from this will show the accuracy of the calibration.

There is a chassis adjustment for the bias of the univibrator. This is set and probably will not need readjusting. A discriminator is also included as a screwdriver adjustment on the chassis top. As the calibration
is seriously affected by this control, it is capped to prevent accidental changing. It can be set to respond to a given source of pulses by first connecting this source to the instrument; hold the CHARGE switch and adjust the discriminator until the output responds to the input pulses. It is necessary to recalibrate when the discriminator setting is changed.

This completes the calibration of the rate meter.

The voltage check meter on the power supply chassis is calibrated with the set of five variable resistors on the rear of the front panel. Jacks are provided on the rear of the chassis by which the voltages can be checked with a voltmeter. If they are found to be of the proper values, then each resistor should be adjusted so the meter will read in the center of the green portion of the scale. An exception is the 300 volt position, which should be adjusted to read exactly on the 100 mark.

The value of the B plus is adjusted to 300 volts with the screwdriver control on the rear panel. The remaining control varies the current through the 5651 regulator tubes. It should be set so these tubes just fire when the power is turned on.

C. OPERATION

For operation of the counting rate meter the following procedure is recommended.
(1) After warming up, test the voltages with the VOLTAGE CHECK control.

(2) Set MAXIMUM COUNTING RATE switch to the position which includes the expected rate.

(3) Select the HIGH or LOW PROBABLE ERROR setting.

(4) Turn on the rate-indicating meter.

(5) Select the mean rate and set both GRID switches to the reference voltage representing this rate. The numbers on these switches represent tens of percent of the rate set on the MAXIMUM COUNTING RATE selector.

(6) Zero the output meter with the ZERO ADJUST.

(7) Choose the percent of the MAXIMUM COUNTING RATE setting desired to give full scale deflection. Set this with the SENSITIVITY control.

(8) Select a difference of approximately 0.6 full scale and advance GRID 2 to voltage representing this difference.

(9) Turn CALIBRATE until the rate-indicating meter reads this differential rate (8).

(10) Return GRID 2 to mean rate and turn GRID 1 to operate position.

(11) Charge integrator by rocking CHARGE switch.

The meter is then operating. To shut off, return PROBABLE ERROR to DISCHARGE, turn off meters and shut off power.

After sufficient time has elapsed for the instrument to warm up, it is a good practice to check the voltages
throughout the instrument with the VOLTAGE CHECK switch.

The MAXIMUM COUNTING RATE should be set to include the maximum expected rate. Select the desired PROBABLE ERROR setting from table 1. This control should be set at the DISCHARGE position upon changing the probable error or upon shutting the machine off.

Calibration of the output meter depends upon the mean rate about which the instrument is to operate. The numbers 0 to 10 on the GRID 1, GRID 2 switches refer to tens of percent of maximum counting rate selected by the MAXIMUM COUNTING RATE control; i.e. Number 6 switches to the reference voltage equivalent to 60 percent of the potential representing the maximum counting rate. If the MAXIMUM COUNTING RATE were selected as 200cpm, position 6 would give the same meter reading as would a rate of 120cpm.

The meter should be zeroed at the reference voltage of the mean rate. This is accomplished by setting GRID 1, GRID 2 to the appropriate position for this rate and turning ZERO ADJUST.

After zeroing, select the SENSITIVITY and simulate a known differential rate by the difference in the setting of the GRID switches. Since each position of the GRID switches represent a percentage of the MAXIMUM COUNTING RATE, the difference between any two positions represents a percentage difference of the MAXIMUM COUNTING RATE. The CALIBRATE control is then adjusted to calibrate the meter.
## TABLE 1.

PROBABLE ERROR SETTINGS

<table>
<thead>
<tr>
<th>RATE</th>
<th>100 CPM</th>
<th>200 CPM</th>
<th>300 CPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>0.6 %</td>
<td>0.4 %</td>
<td>0.3 %</td>
</tr>
<tr>
<td>HIGH</td>
<td>1.2 %</td>
<td>0.8 %</td>
<td>0.6 %</td>
</tr>
</tbody>
</table>
This CALIBRATE control gives some leeway in the adjustment of the sensitivity of the rate-indicating meter; especially so when operating in the 30% sensitivity position. With it, the meter can be calibrated to give full scale deflection at 30, 33, or 35 percent of the maximum counting rate. This enables calibration in a manner to facilitate reading the output. As an example, consider operation on the 300cpm scale. Calibrated to 30%, full scale deflection would be 90cpm while there are 100 divisions on the scale. Calibrated to 33% by the CALIBRATE control, there would be 100 counts full scale for 100 divisions.

As an example of the operation of the instrument, consider the case where fluctuations about the mean rate of 120cpm are to be studied. Assume that the fluctuations are not expected to exceed 100 cpm. The MAXIMUM COUNTING RATE selector would be set to 200 cpm. Position 6 of the GRID switches would represent the mean rate; both would be set at 6 and ZERO ADJUST turned to give a null reading on the output. To read fluctuations of 100 cpm, the SENSITIVITY would be positioned at 50% (50% of 200 cpm will give full scale fluctuation of 100 cpm). The meter is then calibrated by leaving GRID 2 at 6 and advancing GRID 1 to position 9. In this manner, a difference of potential is applied to the two inputs of the differential amplifier equivalent to a differential rate of 60 cpm. The CALIBRATE adjustment is varied until
the meter reads 0.6 full scale.

The GRID 1 switch is rotated to the OPERATE position. The meter reading will be the difference between the impressed rate and 120 cpm. The full scale deflection represents a difference of 100 cpm so any rate in the range 20-220 cpm can be read on the meter.

Since the time constant for charging is forty-six minutes, it required practically three hours for the instrument to reach equilibrium. This time can be shortened by the use of the CHARGE switch. Depress this switch and hold it until the meter reaches a maximum and ceases to rise; then release it. Repeat this procedure until the meter reads nearly the same with the switch off as with it depressed. This indicates that the integrator is charged approximately to the equilibrium potential.

The instrument is then operating.

To check the calibration while the instrument is in operation, turn GRID 1 to the proper positions to check the zero and calibration. If the CONTINUOUS REFERENCE is being used, GRID 2 switch must also be changed for these checks. By comparison with GRID 1 settings the simulated rate of the CONTINUOUS REFERENCE control can be determined.

D. INTERPRETATION OF THE OUTPUT

When an increase above the average counting rate is fed into the instrument, the output will rise in a manner
depending upon this increased rate. For an instantaneous increase, independent of the amplitude, the plot of the output will follow the curve characteristic of the charging of a condenser through a resistor, the equivalent time constant being forty-six minutes. For a given increase, the curves appear identical whether it occurs instantaneously or gradually over a period as large as five minutes.

Knowing these facts, a method of reading the output can be devised. The time of the increase can be determined from the time scale of the recording instrument. The output starts rising immediately, enabling the time to be fixed within a few minutes. The trace will rise following an exponential growth curve \((1 - e^{-\frac{t}{\tau}})\) toward a final value corresponding to the increased rate. From the shape of this curve, the value of the increase can be determined even though the output, due to the long time constant, may never record the maximum.

A set of curves of known increases is included in figure 9. These can be matched to the output traces and the value of the increase determined. These curves were all obtained with the control settings: PROBABLE ERROR, low; MAXIMUM COUNTING RATE, 200 cpm; SENSITIVITY, 50% (100 counts full scale); paper rate on the Esterline-Angus, 20 minutes per inch. They are made from a base rate of 140 cpm chosen because it is the mean rate expected for the operation of the instrument for IGY purposes.
A counting rate meter was constructed after a circuit suggested by Harald Trefall, with a power supply after Elmore. The instrument was tested and proved quite stable after operating for several weeks. The response of the instrument was calculated and the experimental results verified the calculations. Methods of calibration and operation of the instrument were developed to obtain the full benefit of its design. A set of calibration curves was obtained from the counting rate meter and a suggestion for their use in interpreting the output was made.

The research resulted in the construction of an instrument with the following specifications:

Maximum Counting Rates: 100, 200, 300 cpm.

Sensitivity of indicating stage: 30, 50, 100% of maximum counting rate for full scale deflection.

Time constants: Charging $2760^{+} 300$ seconds
Discharging $4680^{+} 300$ seconds

Probable Error: 0.3-1.2%, depending upon rate.

Overall Resolving Time: 290 microseconds.

Univibrator Deadtime: 220 microseconds.
FIGURE A3: PLATE VOLTAGE vs. PLATE CURRENT.
6SH7 PENTODE SCREEN=67 VOLS.
EFFECTS OF HEATER VOLTAGE VARIATIONS

In the course of testing the instrument it was found that the output is sensitive to heater voltage fluctuations that are fast compared with the time constant. This was traced to its effect on the 6SL7 integrator stage.

A change in the heater voltage affects the circuit as shown in figure A4. The gain is independent of heater voltage fluctuations in this range, but the plate voltage is seriously affected by such changes.

Since the integrator condenser is connected from the plate to the end of the integrating resistor, quick increases in the plate voltage will increase the voltage across the condenser. This shows up on the rate-indicating meters as an apparent rate increase. If the increased voltage is maintained for a long enough time, the meter would return to its original reading. If the changes are slow, therefore, the instrument adjusts itself and no variation shows on the output.

The grid current also varies as is shown in figure A4 but the effect of this upon the output is negligible when compared with the plate voltage effect.

For these reasons it is recommended that a regulated heater supply be added if the instrument is to be used in any application where a line regulator is not available.
FIGURE A4. EFFECTS OF HEATER VOLTAGE IN CIRCUIT OF 6SL7 INTEGRATOR
FIGURE A6. RATE METER CHASSIS TOP.

6SN7

6SH7

6SL7

6AG7

5692

NOTUBE

NOTUBE

NOTUBE

POLYSTYRENE

BACK

DISCRIMINATOR

UNIVIBRATOR

SCALE ADJUSTMENTS

CONDENSERS

INTEGRATOR
FIGURE A7. REAR CHASSIS PANELS.

POWER SUPPLY

- B+ ADJUST
- +300-105-105
- -8.8V
- VOLTAGE CHECK POINTS

- FILAMENT
- PLATE
- OCTAL

- A.C.
- 6-PRONG

LINE

FUSE

- CANNON

RATE METER

- PLATE
- OCTAL
- EXTERNAL METER
- BALANCE CONTROLS

- FILAMENT
- 6-PRONG

- CANNON

BALANCE
The primary reference for this work is


Information on ratemeters and electronics components

can be found in the following references:

Schiff and Evans, Reviews of Scientific Instruments, 7, (1936).

A. Bousquet, Nucleonics, 4, No. 2, (Febr. 1949).


Vacuum Tube Amplifiers, M. I. T. Radiation Laboratory Series.

Techniques used in the mathematical analysis of

the integrator section can be found in the following

texts:


DIFFERENTIAL COUNTING RATE METER, FIGURE A2.

JAMES J. SCHMIDT, PHYSICS DEPT., UNIVERSITY OF NEBR.

VOLTAGES ARE FOR GRID SWITCHES AT 0.

*SIGMA RELAY 26F - 8000-COS/PAL

HEATER SUPPLY (6 PRONG)