Haw

MASTER

SCR-128

Sandia Corporation

REPRINT

A TRANSISTORIZED SIX-CHANNEL AIRBORNE STRAIN GAGE CALIBRATOR AND EXCITATION UNIT

by

R H Gablehouse

and

C E Erickson

NOVEMBER 1959

Presented at: NATIONAL TELEMETERING CONFERENCE
Baltimore, Maryland, June 1958

LEGAL NOTICE

Printed in USA. Price $0.75. Available from the Office of
Technical Services, Department of Commerce
Washington 25, D. C.

SCR-128
TID-4500 (15th Ed.)
INSTRUMENTS

SANDIA CORPORATION REPRINT

A TRANSISTORIZED SIX-CHANNEL AIRBORNE STRAIN GAGE CALIBRATOR AND EXCITATION UNIT

by

R. H. Gablehouse

and

C. E. Erickson

November 1959

ACKNOWLEDGMENT

Acknowledgment is hereby made for the contribution of Mr. Glen W. Holmes to the design and testing of this unit and for the packaging of the unit by the Product Engineering Section of Division 5224.

A TRANSISTORIZED SIX-CHANNEL AIRBORNE STRAIN GAGE CALIBRATOR AND EXCITATION UNIT

Introduction

This device consists of two subassemblies; namely, the Excitation Unit and the Calibrator Unit. The Excitation Unit provides six independent sources of regulated DC power from a single source of 28 volts DC. The capacity of each source is nominally 1 watt providing either 10.5 or 20.5 volts excitation for bonded or unbonded strain gages. The Excitation Unit, described in Part I of this paper, comprises a transistor series voltage regulator which controls the input to a transistor magnetic flip-flop power supply.

The Calibrator Unit, described in Part II, is actuated upon command. It consists of a Ledex switch which connects strain-simulating resistors across the appropriate arms of the strain gage bridge. The values of these resistors are calculated to simulate precise values of strain or acceleration and provide an accurate scale factor on the final telemetered record.

The Ledex rotary switch has three double decks for calibrating six channels of strain and one deck for voltage increments from zero to plus three volts for calibration of voltage controlled subcarrier oscillators. The block diagram of Figure 1 indicates the two subassemblies to be discussed.

Part I - Excitation Unit

Introduction

The requirement that the strain gage bridge excitation sources be independent of one another, i.e., have no coupling, necessitated the use of a transformer with multiple secondaries, and the development of the transistor current controlled strain-gage oscillator[1] dictated a DC supply for the bridges. Both of these requirements were satisfied by using the well-known transistor switched, saturable-core flip-flop, employing rectification on each output winding. Figure 2 shows the circuit used. The number of independent DC sources per unit was chosen to be six. A power capability of one watt was necessary from each output, or a total of six watts if all outputs were used at maximum power. The use of bridges of different resistances requiring different excitation voltages is provided for by two taps on each of the secondaries at nominally 10 and 20 volts. Fixed series dropping resistors may then be used to obtain the precise maximum voltage for the particular gage to be used.

Each output is supplied through a 100-ma fuse to prevent overloading the power supply should a short occur.

Power Supply

The magnetic flip-flop uses Minneapolis-Honeywell H6 power transistors and a Deltamax No. 4168-D2 core. Frequency of operation is related to input voltage and primary turns according to the equation:

$$E_{in} = 4\, f\, N_p\, B_s\, A \times 10^{-8} \qquad (1)$$

where:

f = Frequency of switching, cps
N_p = Number of primary turns
B_s = Saturation flux density, gauss/cm^2
A = Cross-sectional area of the core, cm^2

To make the filter for each output as compact as possible, the frequency should be high, but to prevent the transistors from overheating because of their finite switching time the frequency should be relatively low. A frequency of 4000 cps was chosen since it meets both requirements.

To calculate the number of turns required on the primary of the Deltamax core to obtain this frequency proceed as follows:

Select the applied voltage, which is the output of the regulator, to ensure that the rated collector voltage of the transistors is not exceeded during switching. The transistor must withstand twice the supply voltage during this interval. For H6 transistors a safe voltage is 18 volts.

The saturation flux density B_s for the Deltamax No. 4168-D2 core is 15,000 gauss per sq cm. The cross-sectional area is 0.086 sq cm. Substituting into Equation 1:

$$N_p = \frac{E_{in}}{4\, f\, B_s\, A} \times 10^{+8} = 87 \text{ turns}$$

To sustain oscillation, the feedback winding comprises 56 turns, center tapped, to supply through a 220 ohm resistor approximately 10 ma of base drive for the conducting transistor. A condenser of .07 microfarad is in shunt with this resistor to decrease the switching time. The resistor connecting the negative side of the voltage source to the base circuit provides a base bias to ensure starting at temperatures to -30°F.

Since all six outputs must be well regulated and independent of one another, the logical location for the regulating circuit is on the primary side of the transformer. One problem then encountered is the transformer leakage inductance which tends to degrade regulation for load changes. By distributing the primary winding, the regulator feedback winding, and each output winding around the full periphery of the core, and winding as tightly as possible, the effect of leakage inductance is reduced considerably. Special multifilar winding techniques could probably reduce its effect further, but this has not been done here.

Regulator

The voltage regulator is a series "loss" type employing three stages of amplification of feedback error signals which are derived from two distinct controlling sources. These amplified signals control the effective resistance of the series transistor. One controlling signal is derived from an auxiliary power supply output winding as seen in Figure 2. The other is derived from a divider network across the unregulated input, Figure 4. Considering the two sources individually, the auxiliary winding source may be represented by the basic circuit as shown in Figure 3, where diode D provides the emitter reference voltage.

The loop equations for this circuit are extremely unwieldy, yielding only approximate results for nonuniform devices and no attempt at solution is presented here. The operation of the circuit can be visualized, however, by tracing the effect of a slight increase in input voltage through the circuit of Figure 3. The change increases the feedback voltage, which increases the collector current of Q_1 and allows the base of Q_2 to become less negative, thereby decreasing the emitter current of Q_2. Since this current is also the base current of Q_3, the emitter current of Q_3 decreases also, causing the base voltage of Q_4 to rise toward its emitter voltage, decreasing the base current. This base current change increases the effective series resistance of Q_4 and the original increase in input voltage appears across the series transistor, returning the regulator output voltage very nearly to its original value.

The effect of temperature on the regulator can be minimized by shunting a thermistor network across the base bias divider of Q_1 as indicated within the broken line rectangle of Figure 3. Without this compensation, the effect of a temperature rise is to increase I_{co} of Q_1, which raises the base voltage of Q_2 and decreases its base current. This decrease is amplified by Q_3 resulting in a decrease of base current to Q_4, which increases its effective resistance and lowers the voltage available to the load. By shunting a thermistor network across the Q_1 base bias divider, this effect can be counteracted.

With the thermistor network connected, consider the circuit action as temperature rises, neglecting for the moment the I_{co} increase of the transistor. As a result of the decreasing resistance of the thermistors, the effective feedback voltage applied to the base of Q_1 decreases, decreasing collector current of Q_1 and increasing base current of Q_2. Emitter current of Q_2 thereby increases, increasing emitter current of Q_3 and decreasing the base current of Q_4. Since this is a change opposite to that caused by the effect of temperature on I_{co} of the transistors, a proper selection of the thermistor network can largely compensate for over-all temperature effects.

Because the primary source voltage supplies other equipment, a further step was taken to regulate the excitation outputs against input changes. A second feedback voltage is derived from a resistive divider across the unregulated input and is applied to the base of Q_1 providing an additional signal in parallel with the auxiliary winding voltage for control of the series transistor. R_f is the control for the additional feedback signal, Figure 4. Emitter reference voltage for Q_1 is obtained from a Zener diode whose current is supplied from the regulator output voltage. Figure 4 shows a 10-ohm input resistor added to the circuit to lower the voltage across Q_4, and decrease its dissipation. A 15-mf capacitor has also been added in the input circuit of Q_2 to suppress any tendency to oscillate.

Typical regulation and temperature characteristics of the Excitation Unit are shown in Figures 5 and 6.

Regulation for input voltage changes is less than 1 per cent. For load changes from 6 watts to 1 watt, it is a maximum of 1 per cent. Over the temperature range of 30° to 145°F, for constant load and input voltage the change in output voltage is less than 3 per cent.

The construction of the Excitation Unit is shown in Figure 7. The transformer is encapsulated in epoxy, and the entire excitation section is a subunit of the complete Strain Gage Calibrator and Excitation Unit.

Part II - Calibrator

Theory

For general telemetry purposes, there are few transducers which lend themselves to calibration as conveniently as do resistive bridge transducers. Used for strain or acceleration measurements, it is possible to simulate the magnitude of the applied stimulus by shunting predetermined resistors across the arms of the bridge. Simulating the actual stimulus is the ideal way to calibrate a telemetry system. Therefore, if the calibration can take place during or just prior to the inflight condition the scale factor, stimulus/unit deflection, introduced upon the telemetered record provides the ultimate in accuracy.

For full bridge transducers a simple calculation will determine the value of the shunting resistor for a given strain.

The incremental change in resistance of one bridge element which determines the bridge unbalance and output is related to the strain by the gage factor, G_f.

$$G_f = \frac{\Delta R}{R} \Big/ \frac{\Delta L}{L} \quad \text{or} \quad \Delta R = R\, G_f \frac{\Delta L}{L} \tag{2}$$

To arrive at a value for the shunting calibrate resistor in terms of ΔR, consider one element of a bridge with initial resistance R paralleled with a calibrate resistor R_c. The incremental change in resistance is:

$$\Delta R = R - \frac{R\, R_c}{R + R_c}. \tag{3}$$

which, when expanded and simplified, is:

$$\Delta R = \frac{R^2}{R_c + R}. \tag{4}$$

Substituting:

$$\frac{R^2}{R_c + R} = R\, G_f \frac{\Delta L}{L}. \tag{5}$$

Then:

$$R_c = \frac{R}{G_f} \frac{1}{\frac{\Delta L}{L}} - 1, \tag{6}$$

for one active arm of a full bridge; and:

$$R_c = \frac{R}{G_f} \frac{1}{\frac{\Delta L}{L}} \frac{1}{n}, \tag{7}$$

for n active arms.

Where:

R_c = The calibrate resistor desired, ohms

R = Gage resistance, ohms

G_f = Gage factor

$\Delta L/L$ = Strain to be simulated - microinches per inch

n = Number of active arms

The minus one may be neglected.

The formula for the calculation of calibrate resistors for accelcrometers of the Statham variety is supplied with the instrument calibration certificate.

Operation

The calibrator consists of three rotary switch wafers driven by a Ledex solenoid. Each wafer is double sided and has provisions for shunting three calibrate resistors, first across one arm of the bridge for one polarity of stimulus and then across another arm providing for the opposite polarity. There are six calibration steps for each revolution of the switch.

The accuracy of these scale factors with respect to authentic representation of the strain is not automatic and consideration must be given to the accuracy of the calculation itself and to the change in line resistance.[2] In addition, the sensitivity of the gage itself may be a function of temperature, any change in which would cause an error in the representation of the strain.

The calibration is a relative indication in that it takes place in conjunction with any residual stimulus which is applied during the calibration. The magnitude of the information for data reduction purposes is considered with respect to the sensitivity and zero immediately after calibration. The accuracy of the measurement is then strictly a function of the authenticity of the strain simulating resistors. Of course, the record reading resolution will be determined by the quality of the transmission, reception and recording.

Figure 8 is a diagram indicating the calibrate switching action and the resulting discriminated record. The calibrate resistors are installed on printed circuit cards in preparation for a test and if possible, actual stress is applied to the transducers to authenticate their representative values.

Figure 9 is the actuating circuitry for the Ledex switch. The stepping speed, which is set for approximately 50 rpm in the Mod 3A6, may be varied by changing the value of capacitor C_3. Temperature has a very moderate effect on switching speed, and a life test indicated that 20 hours continuous run is a conservative rating.

Figure 10 is a photograph of the calibrator without the Excitation Power Supply. Figure 11 is a photograph of the assembled unit, and Figure 12 is a photograph of the assembled unit with the associated six-channel strain gage subcarrier oscillator package.

Environmental Test Results

At this writing two units selected from the pilot production run have been subjected to the below listed environmental tests with the indicated results. The vibration testing will be completed by conference time and the results will be presented then.

1. Temperature

   For the Regulation and Output characteristics of the Excitation Unit, see Figures 5 and 6.

   The rotational speed of the Ledex switch does not change by more than 25 per cent from -20^{o} to $+145^{o}$F.

2. Shock

   The Excitation Unit is uneffected by 200 g, 3 millisecond duration shocks applied in both directions of the three major axes.

   The Calibrator Unit is uneffected by 200-g shocks applied in both directions of two major axes. In the axis parallel to the major axis of the Ledex, the Calibrator is prematurely actuated for one calibrate sequence by shocks greater than 50 g and 7 milliseconds duration in one direction.

3. Acceleration

   The Excitation Unit is uneffected by 100-g acceleration of 20 seconds duration applied in both directions of the three major axes.

   The Calibrator is uneffected by 100-g acceleration applied in both directions of two major axes. In the axis parallel to the major axis of the Ledex, the stepping action of the Ledex becomes erratic when acceleration greater than 30 g is applied in either direction.

4. Humidity

   The entire unit is uneffected by temperature-humidity variations which produce moderate condensation.

5. Altitude

   No effect to 200,000 feet.

6. Vibration

   (No data to date.)

   Target specifications are 15 g from 60 to 2000 cps.

REFERENCES

1. Cecil E. Land, "Transistor Current-Controlled Oscillator for DC Excited Strain Gage Applications," National Telemetering Conference Record, 1958

2. G. William Harrison, "Calibration of Wire Strain Transducer Systems," Alleghany Instrument Company, Inc., Cumberland, Maryland.

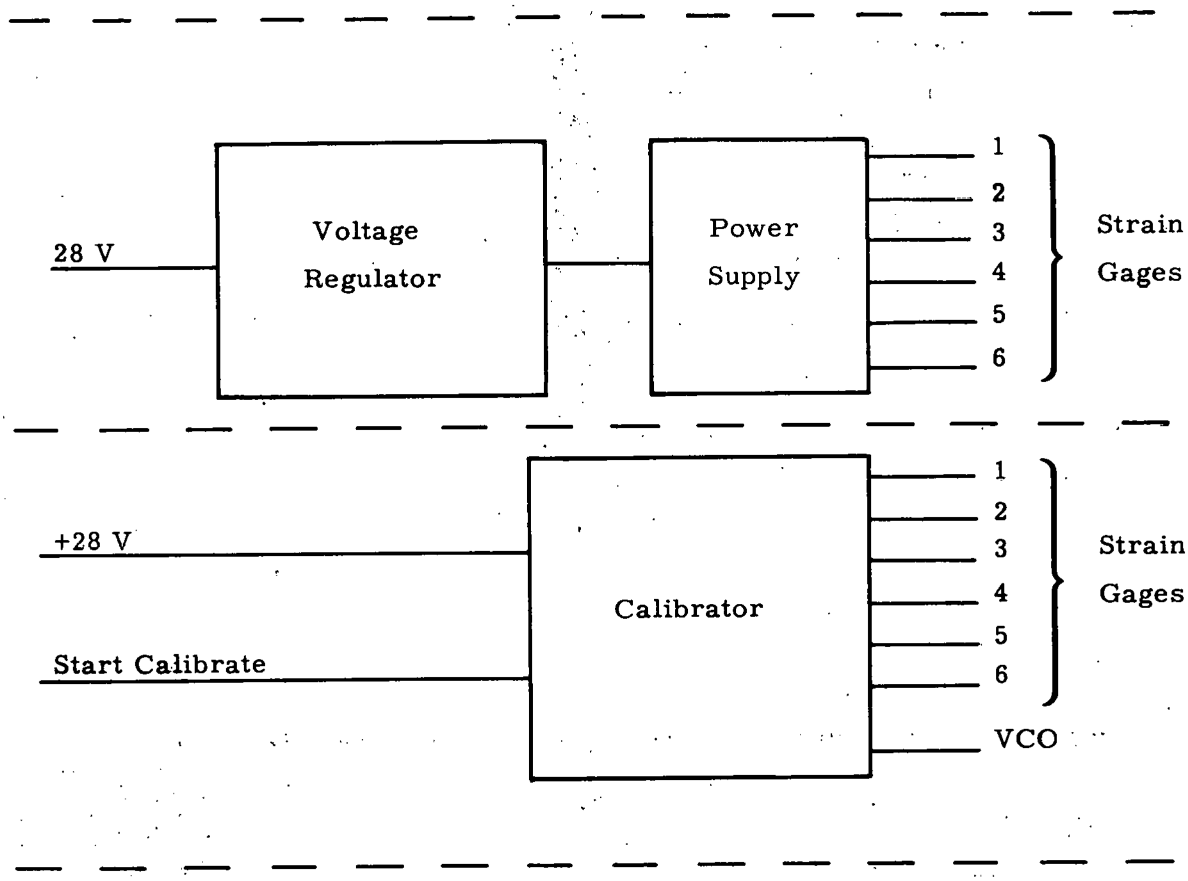

28 V
Voltage Regulator
Power Supply
1
2
3
4
5
6
Strain Gages
+28 V
Start Calibrate
Calibrator
1
2
3
4
5
6
Strain Gages
VCO

Figure 1

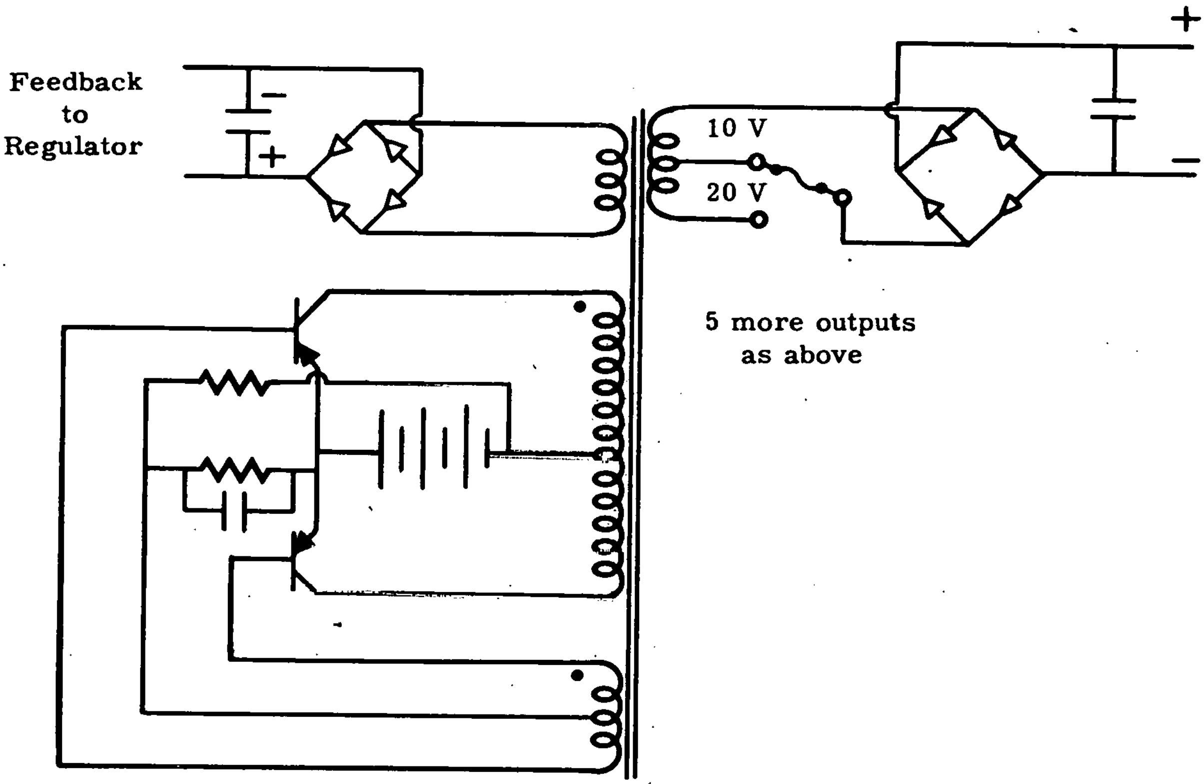


Figure 2

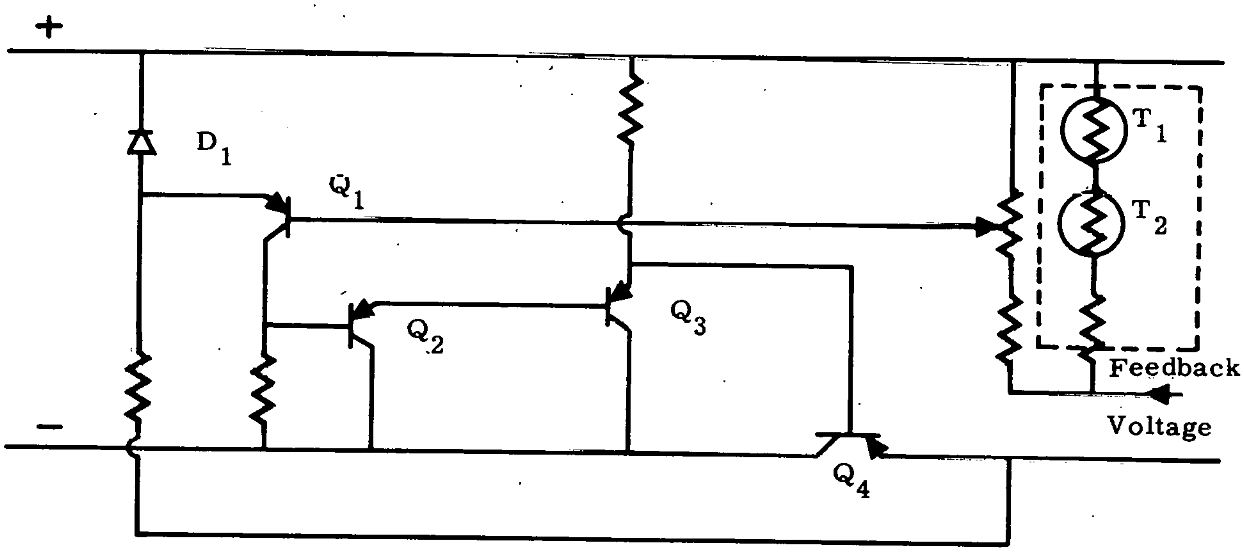


Figure 3

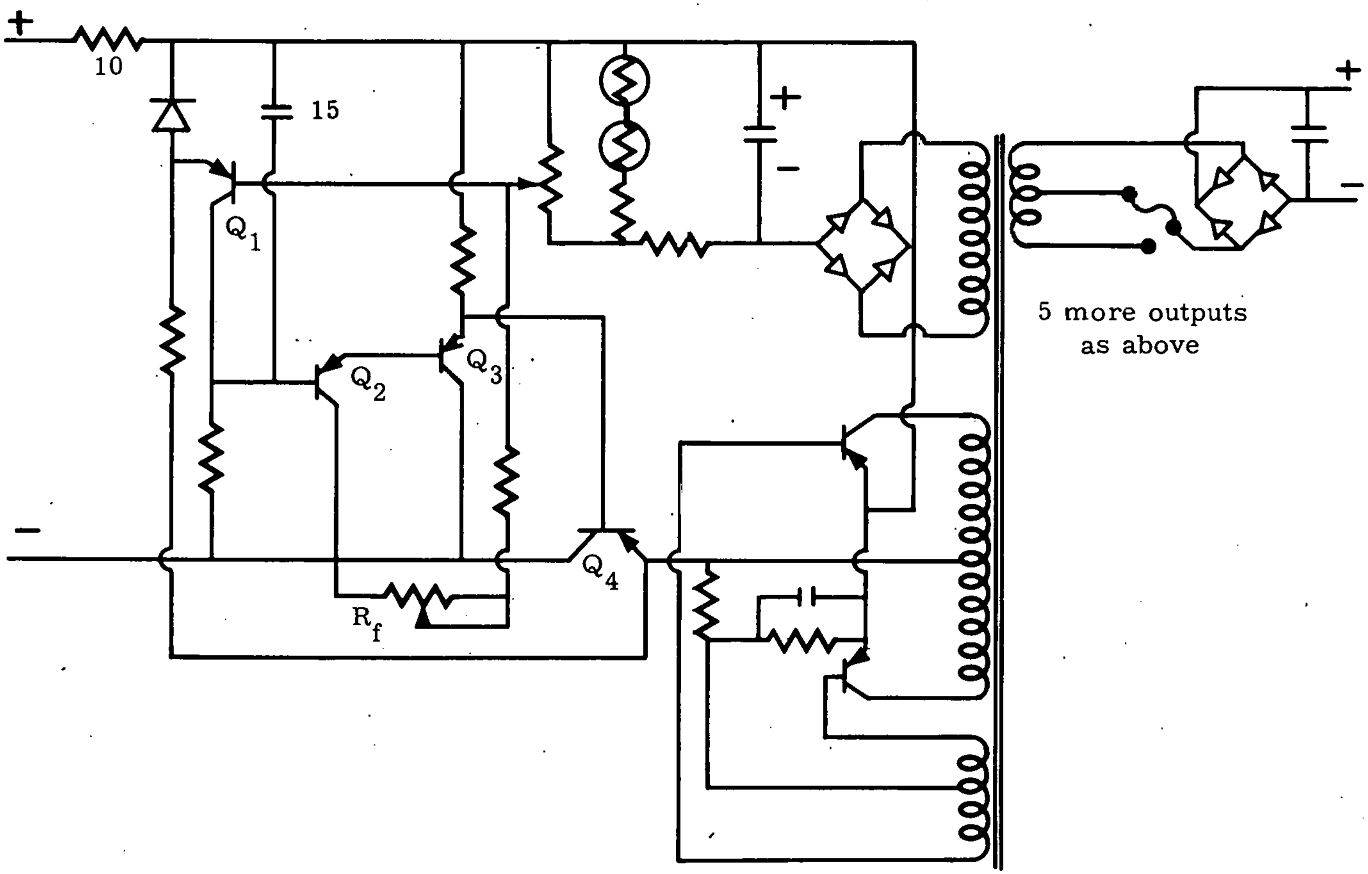


Figure 4

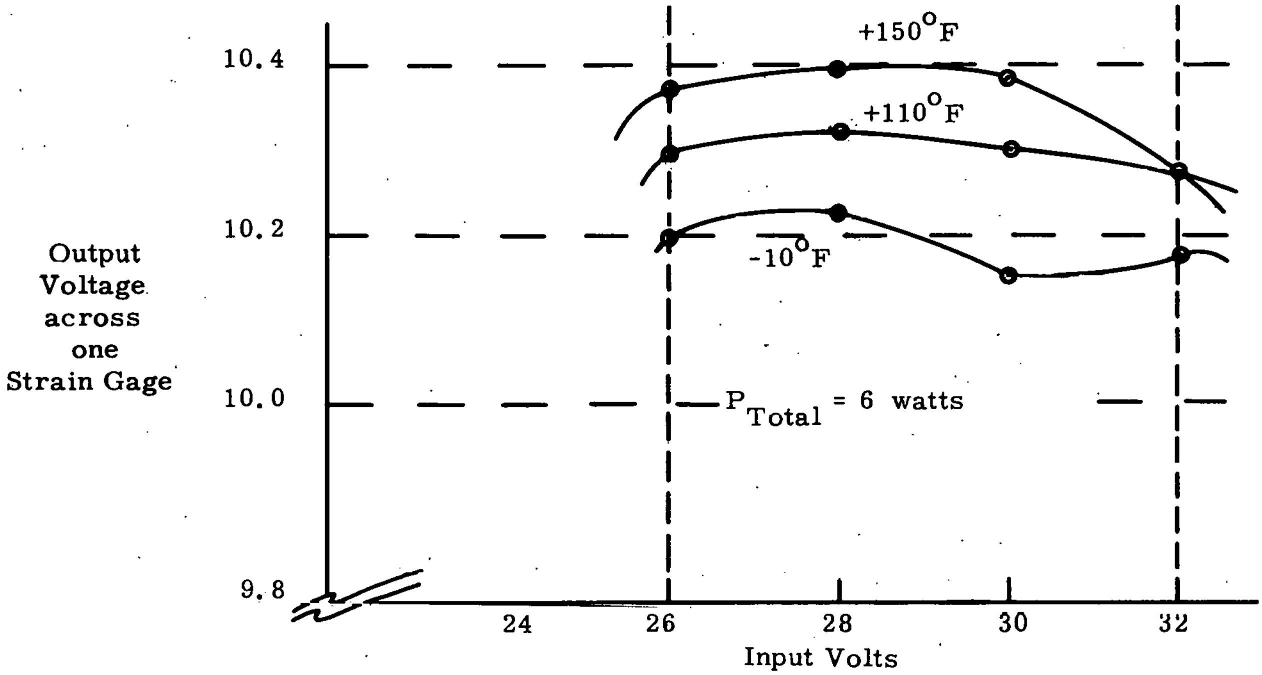


Figure 5

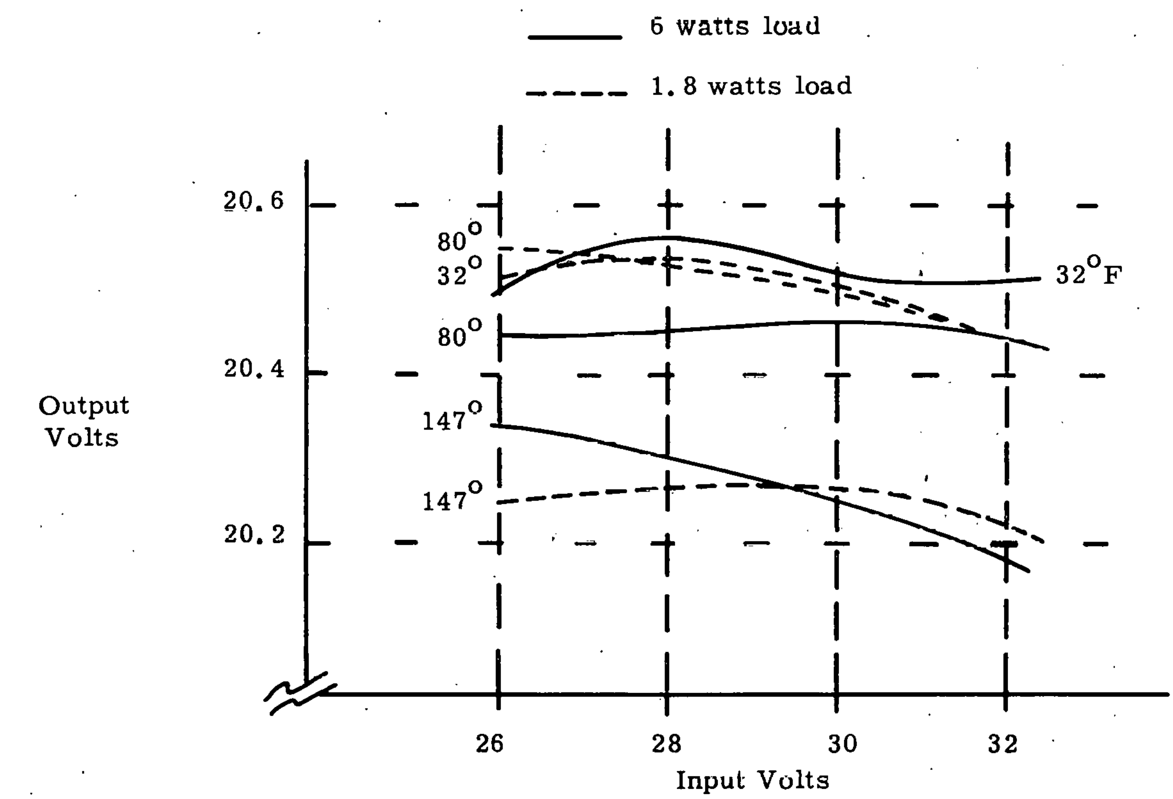


Figure 6

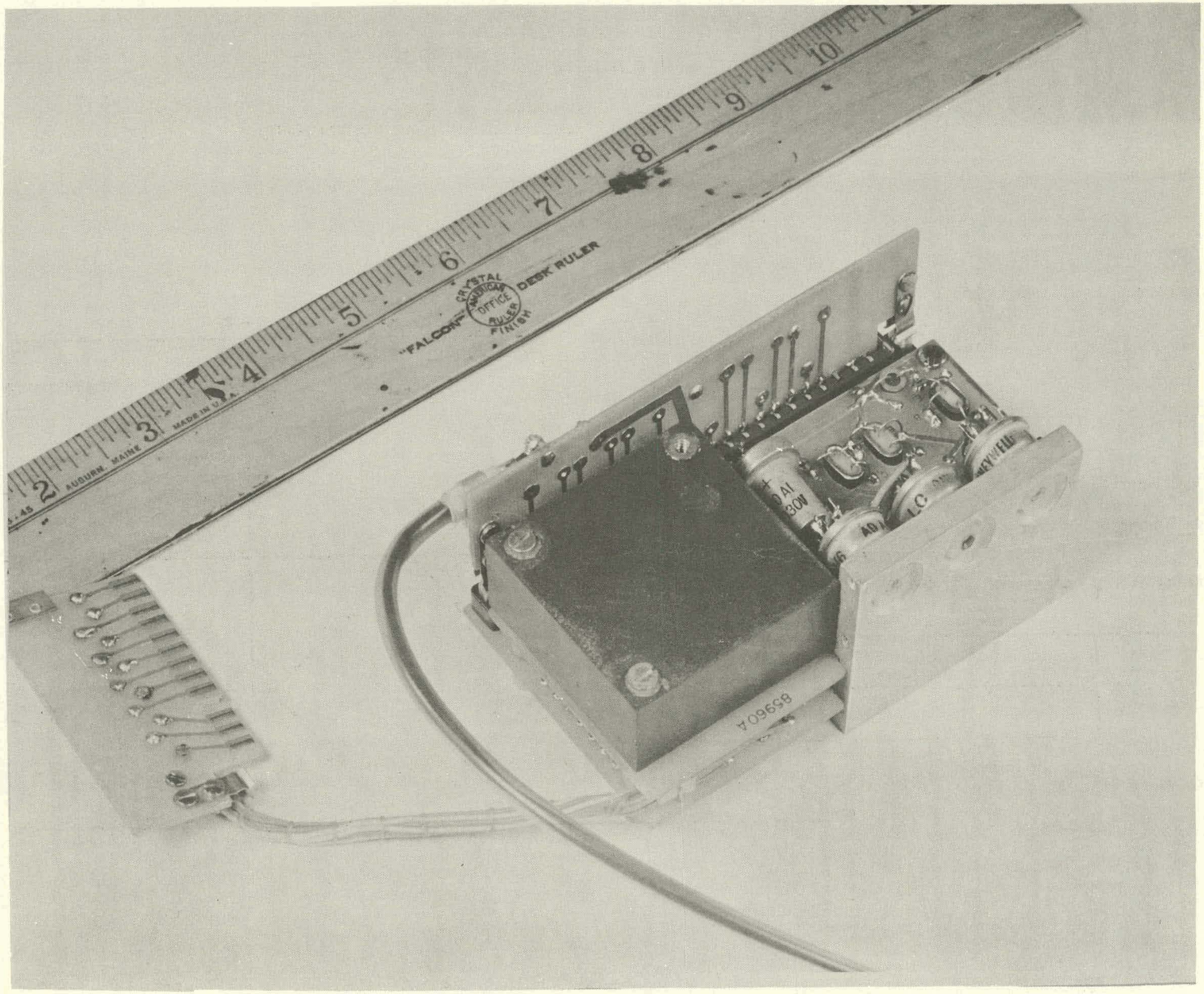
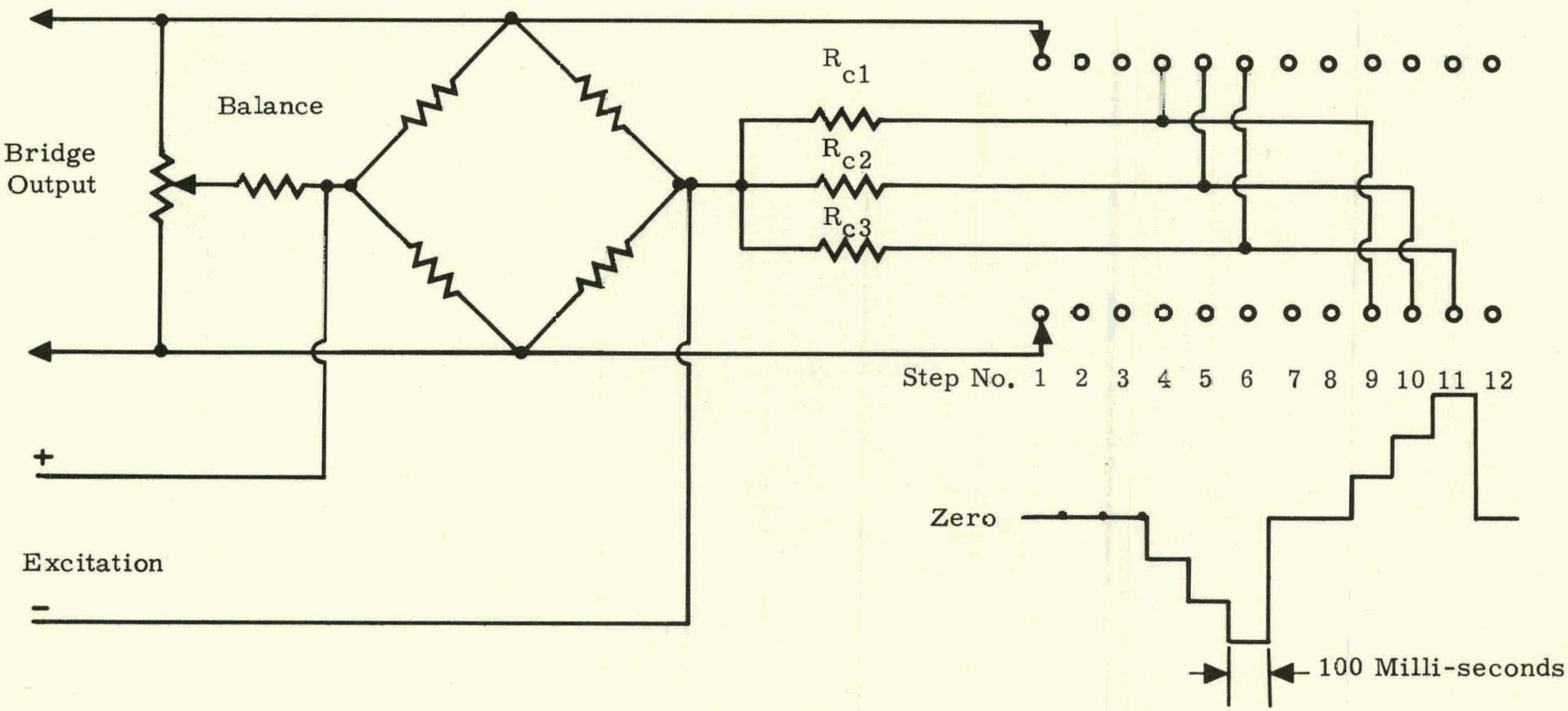
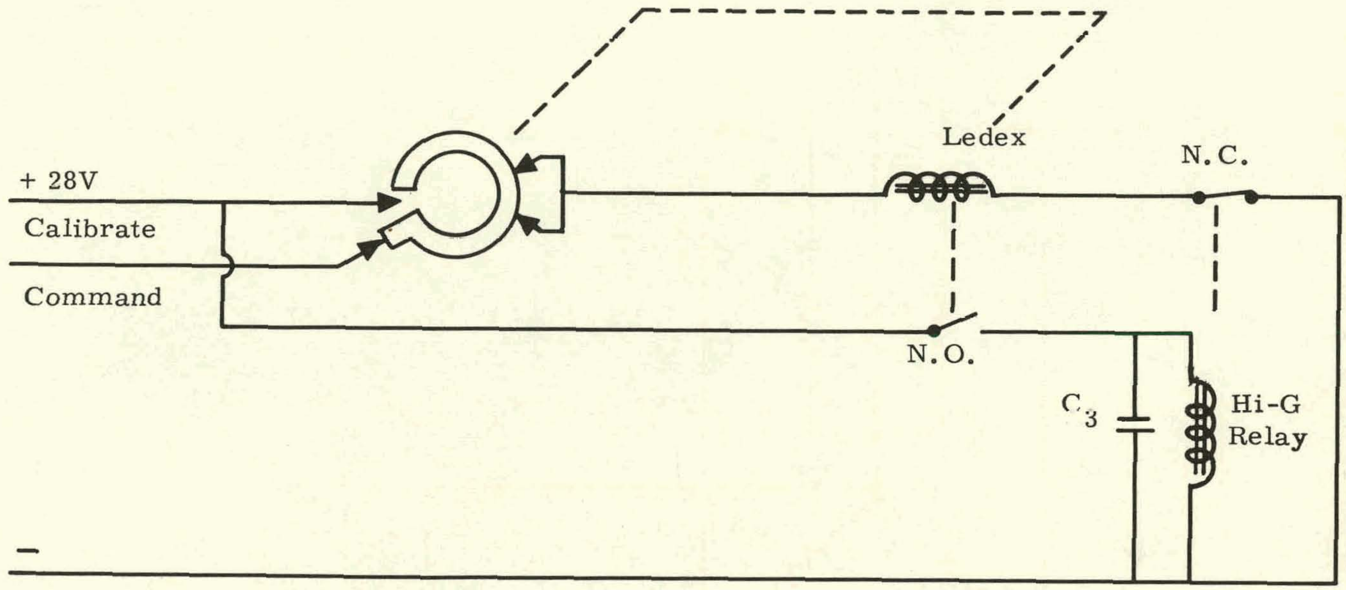


Figure 7



Calibration Switching Action and Resulting Scale Factors

Figure 8



Ledex Stepping Circuitry

Figure 9

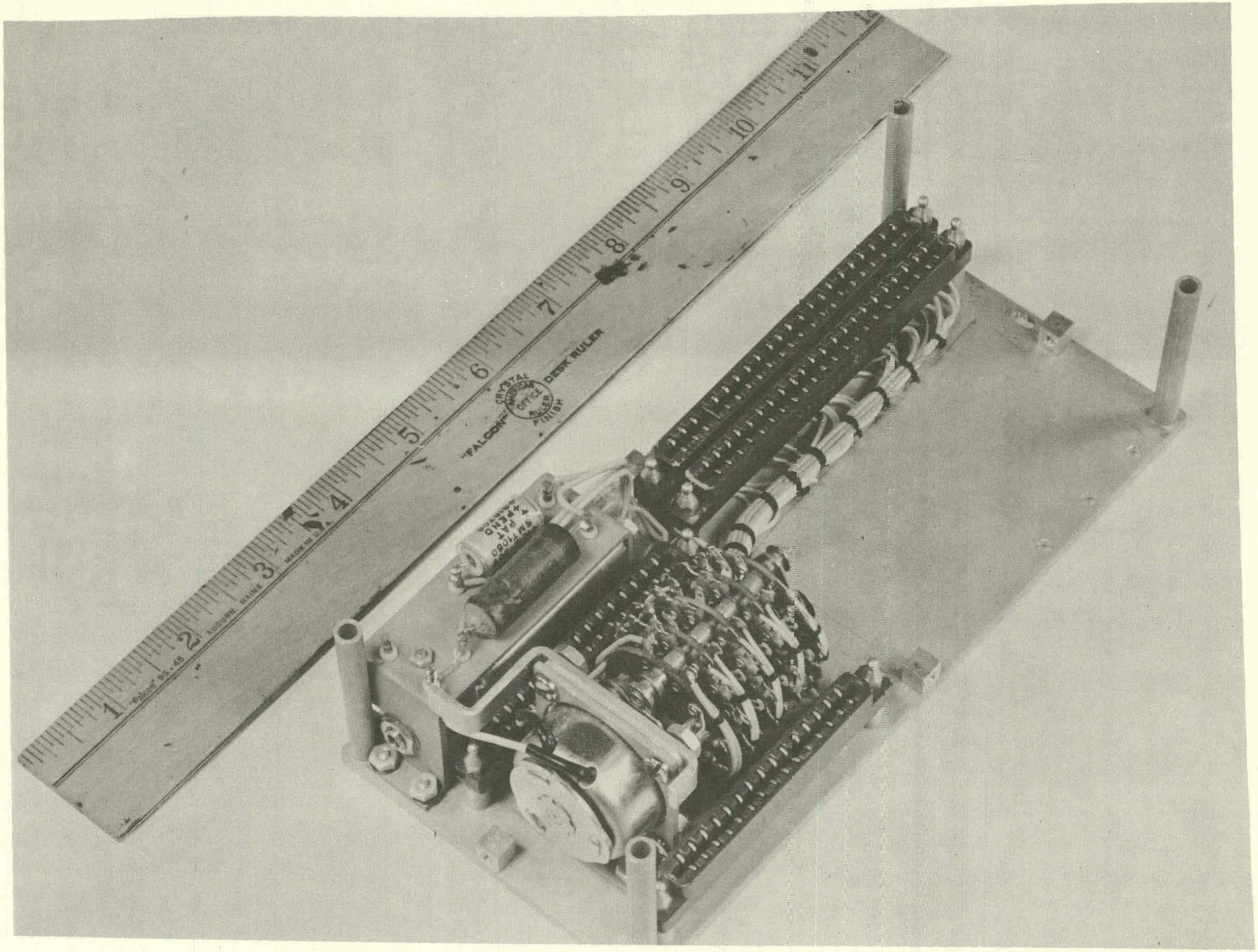


Figure 10

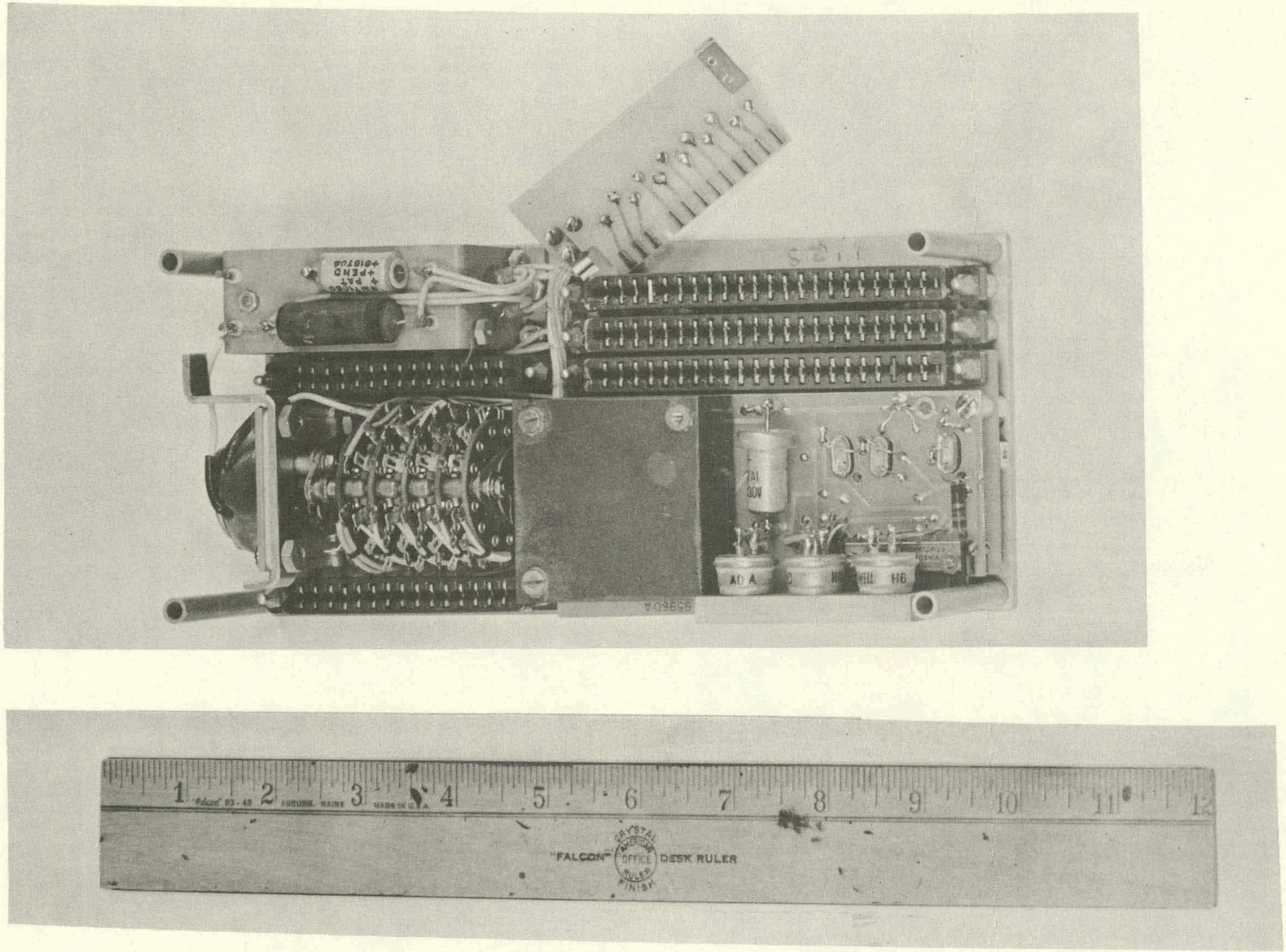


Figure 11

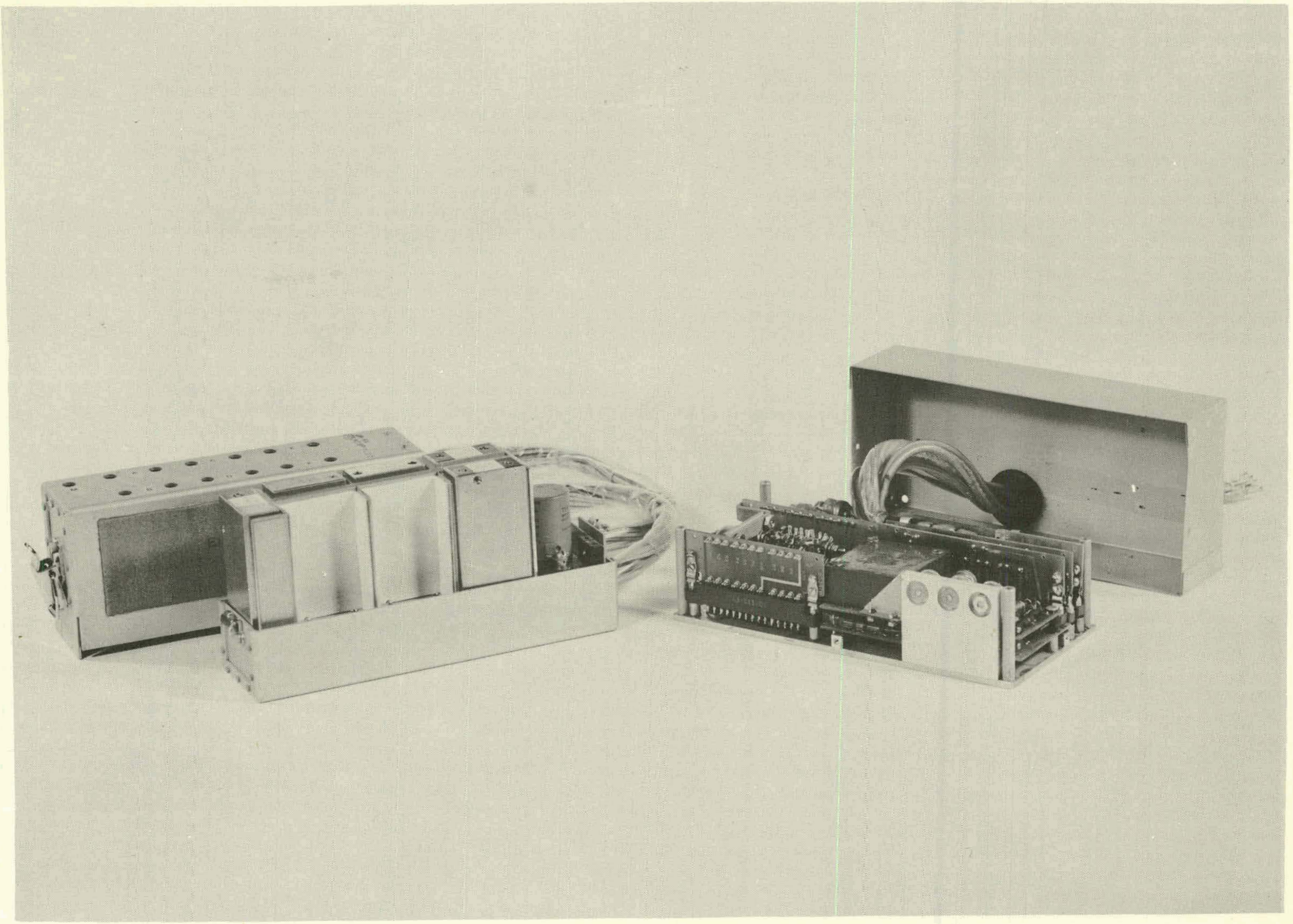


Figure 12