

ELECTRONIC AIDS TO CONTROL AND MEASUREMENT

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Many problems in the laboratory involve the measurement of extremely small magnitudes and consequently require delicate and often expensive instruments. Further difficulty is introduced by the fact that such magnitudes often vary rapidly with time, and measuring devices should be capable of following those variations accurately. For many of these measurements, however, it is possible to employ some form of auxiliary equipment which will allow the use of rugged and inexpensive indicating or recording instruments. This paper is a compilation of several such devices, selected for their simplicity, low cost, and utilitarian value.

For the measurement of physical magnitudes other than electrical it is desirable to employ some form of transducing element to convert the magnitude into a proportional electrical signal; this, when amplified and recorded, becomes a record of the physical magnitude. The literature contains much material on simple transducers, therefore only a few general types are listed by broad classes in Table 1.

It should be noted that although electron tubes are used in these circuits, they are used only where they provide the simplest and most satisfactory method. Care has been taken to employ no circuit components which cannot be obtained from any radio parts supplier. Most of the following circuits are operated from

TABLE 1.—SIMPLE TRANSDUCERS

1. Temperature to electrical signal:
 Thermocouple.
 Resistance thermometer.
2. Illumination to electrical signal:
 Photoelectric cell.
3. Movement or dimension to electrical signal:
 Variable resistance device.
 Variable inductance device.
 Variable capacitance device.
 Variable illumination device.

the a-c. line; thus there is no cost for special power supplies. No special tricks in construction are required, although ordinary good practice should be observed. The information given here is adequate for duplicating the circuits. Data in the curves are representative of what may be expected, although some variation will naturally be found from one circuit to another. The circuits are recommended not for their novelty but for their utility; and to this end the designs have been simplified to use the minimum number of circuit elements consistent with good performance.

The first circuit to be described is drawn as figure 1. Here one winding of a transformer is placed in series with a load (or an output device or an instrument) and an alternating current source; its ability to pass alternating current is controlled by the potential of the grid of an electron tube across its other winding. Thus a current of several amperes may be controlled by a small applied potential. With the direct-coupled preamplifier

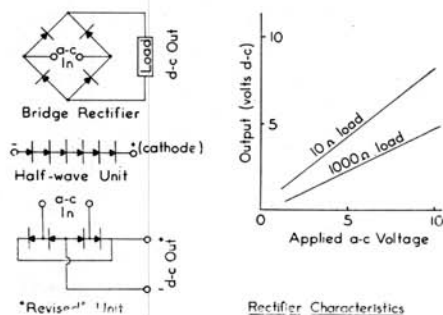


FIG. 4.—Bucking-out Circuits

following inputs varying at a few cycles per second. In addition, the two circuits shown in figure 3 and the one of figure 5 may be given much more rapid response by increasing the frequency of the carrier voltage. For variations in the measured potential up to about 10 cycles per second the 60-cycle line current may be used; for measuring rapid fluctuations in temperature with a thermocouple, 1,000 cycle carrier supply was used with the circuit of figure 3.

With many of these devices, if the amplifier output is simply rectified for d-c. output, it is often not convenient to adjust the circuit so that the output current becomes zero for a particular input potential. To use the indicating instrument in the most efficient manner it will be desirable to inject a bucking-out current into the output circuit. One convenient method for doing this is shown at the left in figure 4. Here a dry-disc rectifier is supplied with alternating current from an independent source and connected so that its output opposes that from the amplifying device. Adjustment of the bucking-out current is simple, and it is used to establish the zero of

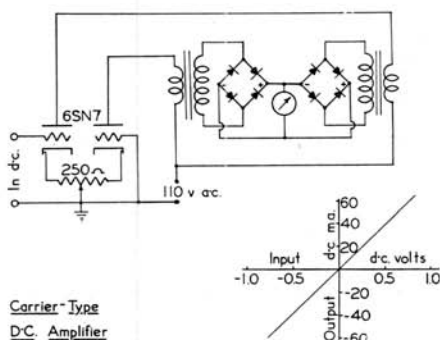


FIG. 5.—Carrier Type Amplifier

the indicating instrument as may be desired. This is often an advantage, particularly with the circuit of figure 1. The circuit at the left is good for large output currents at low voltages; the circuit at the right is better suited to the opposite case.

A circuit basically similar to those of figure 3 but capable of handling more power is presented in figure 5. If the control grids of both triodes are at the same potential, the two plate currents will be equal, and the output of the differencing circuit containing the dry-disc rectifiers will be zero. As the input potential varies, the difference output will vary in proportion. This circuit has sufficient output to actuate an ordinary industrial recording instrument. It is convenient to provide a variable control in the cathode circuit so that individual differences in tubes and rectifiers can be compensated.

It may be helpful to insert at this point a note about the rectifiers used in these circuits. The copper-oxide units used in the modulating circuits are simply small meter rectifiers of the lowest current capacity conveniently obtainable. The rectifiers

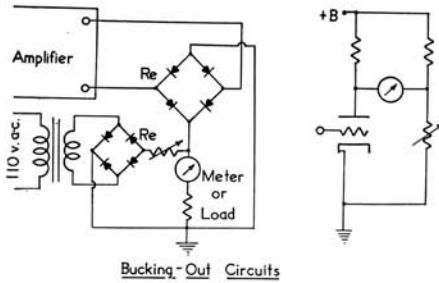


Fig. 6.—Rectifier Characteristics

used in the output circuits, however, must be capable of handling higher currents and also of withstanding greater back voltages. The small selenium rectifier units now popular for use in household radio repair work have been found suitable for this application. As made, they have either five or six plates connected in series, and they are used as simple half-wave rectifiers; they may easily be disassembled, however, and reassembled to form bridge rectifiers as indicated in the diagrams. The performance curve of figure 6 shows what may be expected of such a "revised" rectifier unit. Ordinary filament transformers (117 volts to 6.3 volts, at 1.5 amp.) have been found completely satisfactory for use as output transformers with these rectifiers; they have been used in these circuits. This is another part of the attempt to simplify the problems of procurement and construction.

The circuit in figure 7 has been termed a "current multiplier" by Frank Shepard, who first disclosed it, and the name describes it perfectly. The feeble input current may be a small fraction of a micro-ampere, from a source of a small fraction of a volt, while the output current is enough to actuate a husky

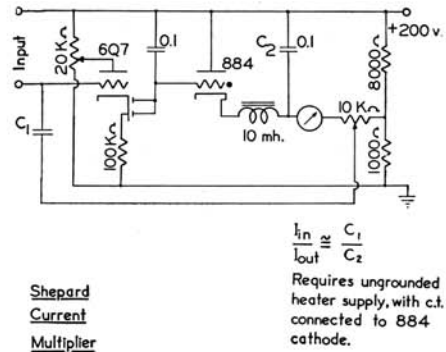


Fig. 7.—Shepard Current Multiplier

milliammeter. The multiplication is controlled by the ratio of capacitors C_1 and C_2 . Changes in other components, fluctuations in supply voltages or variations in tube characteristics due to ageing will have negligible effect on the performance of the circuit. In operation, the 6Q7 plate supply is first adjusted by the voltage divider to a value for which the thyratron, 884, just fails to conduct. If input current is then allowed to flow into capacitor C_1 the circuit will begin a regular series of relaxation oscillations in which the miniature thyratron repeatedly discharges C_2 through the indicating instrument while continually recharging both capacitors from the common power supply.

The last of these circuits, shown in figure 8, is designed to indicate or to measure time intervals. The three neon glow-lamps, *Ne*, are connected in relaxation oscillator circuits containing circuit components so selected that one bulb produces pulses at one-tenth second intervals, one at one-half second, and the third at one-second intervals. Placed side by side and so mounted that their light impinges upon a moving photo-

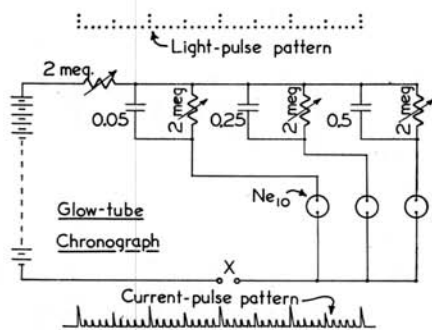


FIG. 8.—Glow-tube Chronograph

graphic film or paper, the device places a time scale on the photographic record like the pattern at the top of figure 8. The current output, taken off at *X*, may be recorded if desired with some current-sensitive device; its wave-form is like the pattern across the lower part of the figure. Other time scales may be afforded by suitable choice of circuit constants; for the lowest rates it is convenient to employ a small clock-type synchronous motor and a suitable commutator. For those laboratories equipped with seconds clocks a pendulum contact is a simple way of making available timing marks at second intervals only.

The device is capable of quite high accuracy if care is taken in design and in adjustment of the circuits. Because of individual variations in neon bulbs, each circuit must be separately adjusted. Operating current is small and is conveniently supplied by a radio B-battery of about 135 volts. Adjustment for variation in battery voltage is made with the two-megohm rheostat in series with the battery. This also serves to synchronize the pulses at the half-second and full-second in-

tervals. One of the best types of neon bulbs for this use is the one-twenty-fifth watt Type Ne-10 baseless bulb.

With the possible exception of the current multiplier, each of the circuits, when incorporated in a measuring system, must be calibrated by comparison to an instrument whose accuracy is known to be at least that with which the final measurement of the unknown magnitude is to be made. Calibration checks under various conditions will help to detect any lack of stability of circuit components. Line voltage variations must be taken into account or eliminated. Since the performance of the current multiplier depends almost exclusively upon the ratio of magnitude of two circuit elements, knowledge of the value of each will allow the performance to be calculated. A calibration of the device is of value, however, in helping to eliminate whatever error has been incurred in measuring the two capacitors. It must be recognized at the outset that the accuracy of a measurement with one of these devices can never be much better than the accuracy of the indicating instrument used in the output, despite calibration, however often.

In order to secure dependability of measuring systems based on these circuits, every non-essential part has been eliminated and the resulting circuit critically re-examined for possible further simplification to secure maximum reliability. We feel that simplification is to be sought after, for it confers ease of construction and reliability, as well as lower cost.