Vol. 24 MARCH - APRIL, 1959 No. 2

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MODERN SUBSTITUTION BOXES

The substitution box has a long history of usefulness in electronics. The resistor box came first and was followed quickly by the capacitor box. They took their cue from the resistance and capacitance decade boxes of the laboratory. Approximately one generation of technicians has used those two units. From time to time, substitution boxes of other types were devised by experimenters for their own purposes and were publicized but not commercialized.

There are two ways of using a substitution box: In troubleshooting, it can be substituted for a damaged or missing component (and this is how it got its name); or in circuit development work, it can be used to determine the best value for a component. In the first instance, use of the substitution box allows the equipment under test to be restored immediately to operation so that tests may be made. In the second instance, use of the box obviates many calculations or the soldering and unsoldering of many separate trial components.

The utility of the substitution box is due to its adjustable nature. Usually it provides various values of a component in steps obtainable either through a selector switch or a series of terminals. In some instances, however, such as potentiometer or variable capacitor boxes, continuous variation, as well as step-type selection, is provided. One type of substitution box provides separate types of components. Examples of this kind are diode and transistor boxes.

The progress of modern electronic bench work is speeded by substitution boxes of many sorts, some of which are not yet familiar to all technicians. Components of virtually every kind, and networks as well, are switched in these modern boxes. It is interesting to note that transistor substitution boxes have provided the first example of active-component switching. (Vacuum tubes seem to have been neglected in this technique, perhaps for the reason that the tube is an easily-substituted plug-in component itself.) Not all of the modern substitution boxes have been exploited commercially.

Substitution-Box Philosophy

In order successfully and economically to apply the principle of component substitution, the basic philosophy of the substiution box must be considered. The box principles remain substantially the same regardless of the type of component that is switched.

In any substitution box, the components are accessible electrically through either separate terminals (such as binding posts or panel jacks) or through a rotary selector switch. The advantage of a switch is that its use obviates shifting leads externally. However, separate panel terminals for the components are desirable when current levels are too high for a small switch, or when the stray capacitance of a switch would be troublesome.

The mathematical theory of switching might be invoked to analyze the substitution box and to determine its optimum arrangement. However, this approach is beyond the scope of this article, since most of our readers lack the necessary mathematical background. Instead, the principal configurations of substitution boxes will be shown. These illustrations will serve to answer the question as to how many ways are available for connecting the components inside a substitution box and which is the best way. The principal configurations are shown in Figures 1, 2, and 3 and are discussed in the following paragraphs. In each example, components are represented by

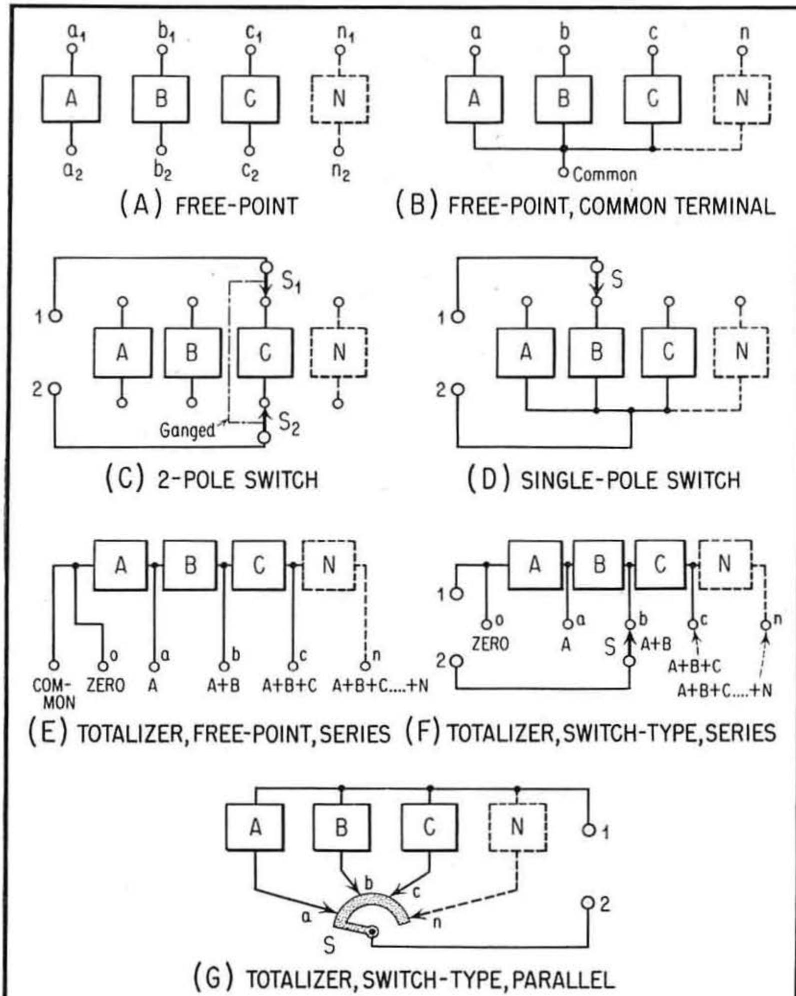

Fig. 1. 2-Terminal Configurations.

blocks, each having the proper number of terminals. The number of components may be extended up to any desired practical limit. The block labelled N represents the nth component in such a series.

2-Terminal Configurations. Examples of 2-terminal units are capacitors, resistors, inductors, diodes, rectifiers, varistors, thermistors, rheostats, varactors, and choke coils. In addition to these single components, two or more such components may be connected in series or parallel to form a network and each such assembly would have two terminals. Figure 1 shows the methods of connecting 2-terminal components.

When both terminals of a component must be separately available, 1(A) or 1(C) may be used. In Figure 1(A), the components are connected between two rows of panel terminals, a_1 to n_1, and a_2 to n_2. External connections are made directly to these terminals. In Figure 1(C), a 2-pole switch (S_1-S_2) is provided for selecting the pairs of component terminals. External connections are made to a single pair of panel terminals (1 and 2).

In many instances, both terminals of each component need not be available separately. Here, one lead of each component may be connected to a single COMMON terminal on the panel, and the opposite leads to separate terminals, as shown in Figure 1(B). The saving in panel terminals afforded by this arrangement is equal to n-1, where n is the number of 2-terminal components. The number of terminals required is n+1. (Compare this with 2n for Figure 1A.)

When one lead of each component may be connected to a single COMMON terminal on the panel, simplicity is obtained also in the switching circuit. Thus, in figure 1(D) the selector switch has only a single pole, resulting in simplified wiring and often in smaller size and lower cost.

When it is desired to add the values of the components in the substitution box, the arrangements shown in Figures 1(E), 1(F), and 1(G) are available. Figures 1(E) and 1(F) show the schemes commonly employed in resistance decade boxes (resistors are added in series), while 1(G) shows the scheme for a capacitance decade box (capacitors are added in parallel). The free-point method of connecting the series components to panel terminals is shown in Figure 1(E), while a switch-type circuit for the series components is shown in Figure 1(F). A short-circuiting switch (S) is required for the parallel-type of totalizer (Figure 1G). The switch is shown in the position in which its shorting sector is connecting together all of the components. The total $(A+B+C\ldots+N)$ therefore is available at Terminals 1 and 2.

3-Terminal Configurations. Examples of 3-terminal units are transistors, resistor T-networks, capacitor T-networks, potentiometers, voltage dividers, and attenuators. Additionally, there are many simple component combinations having an input, output, and common terminal which may be incorporated into substitution boxes. These include filters, special-purpose RC and RL combinations, pi networks, resonant circuits, signal peakers, and notch circuits.

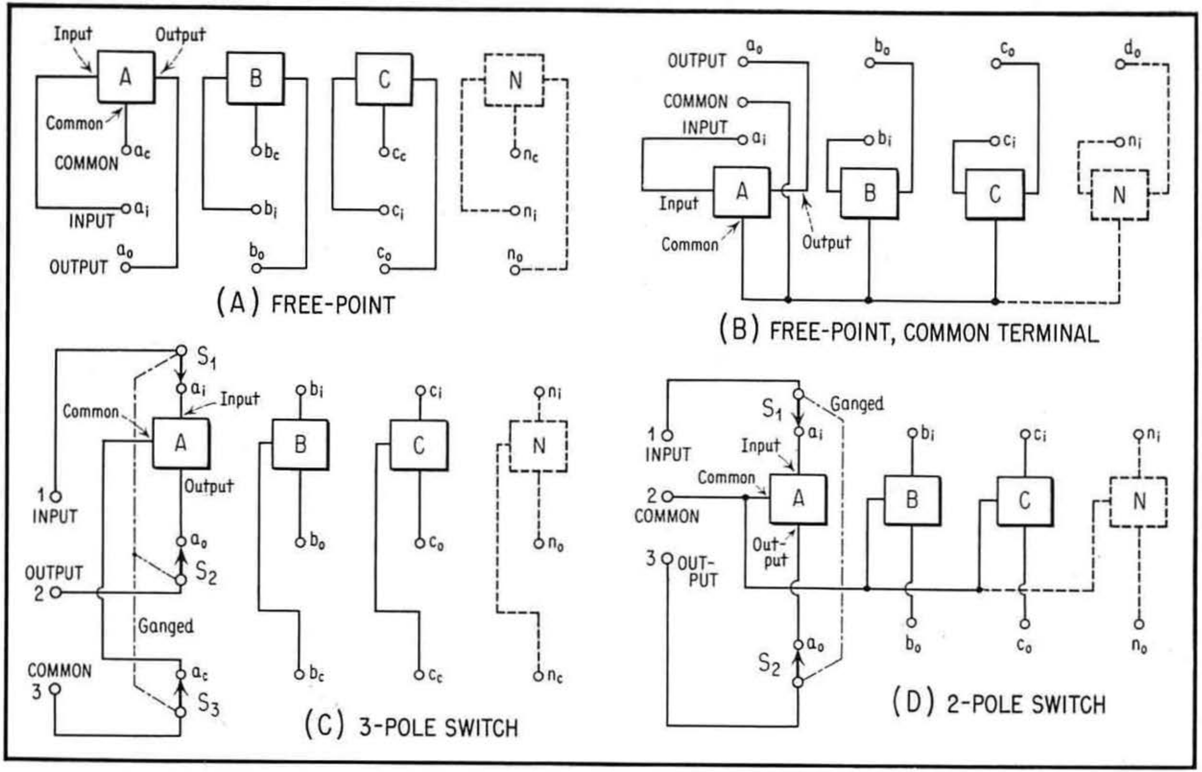

Fig. 2. 3-Terminal Configurations.

Figure 2 shows the principal methods of connecting 3-terminal units in a substitution box. When all three terminals must be accessible externally, 2(A) or 2(C) is available. The free-point scheme (Figure 2A) requires 3n panel binding posts or jacks, where n is the number of components. These terminals are arranged in three rows: a_i to n_i for the input, a_o to n_o for the output, and a_c to n_c for the COMMON terminal of each component. When internal switching is permissible and all three terminals must be accessible externally, a 3-pole switch (S_1-S_2-S_3) is required, as shown in Figure 2(C).

When the common terminals of the 3-terminal units may be connected together, the simplified schemes shown in Figures 2(B) and 2(D) are available. In the free-point arrangement (Figure 2B), the number of panel terminals required is equal to 1+2n, where n is the number of 3-terminal units. This is a saving of n-1 over the number of terminals required by the full free-point arrangment (Figure 2A). The panel terminals are arranged in two rows (a_i to n_i for the input, and a_o to n_o for the output). A single COMMON terminal on the panel is connected to the common terminal of each component. In the switch arrangement (Figure 2D), a 2-pole switch (S_1-S_2) takes the place

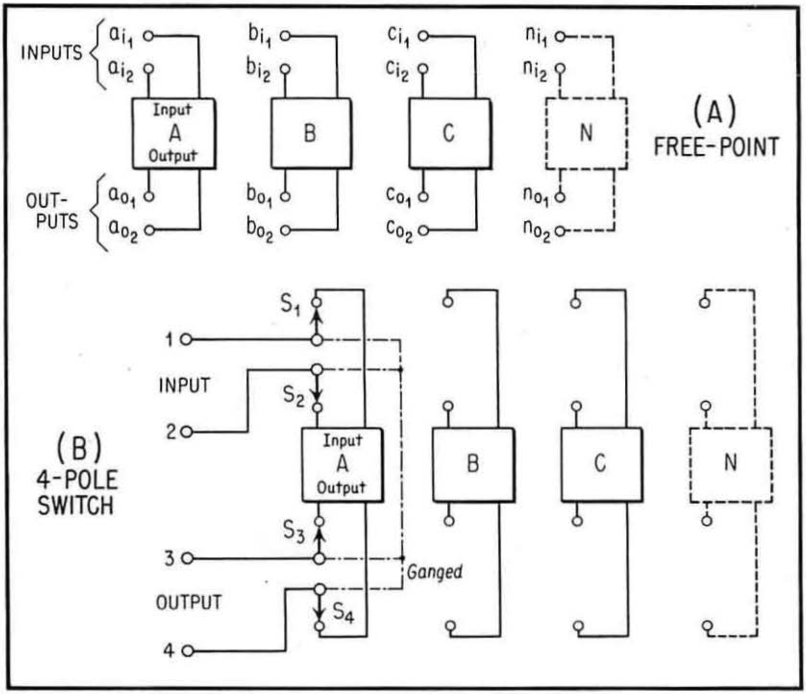

Fig. 3. 4-Terminal Configurations.

of the 3-pole switch required in Figure 2(C).

4-Terminal Configurations. Examples of 4-terminal units are transformers, saturable reactors, H and O attenuators, and bridge circuits. In most 4-terminal circuits, the input and output sections must be separated. This leaves no choice except to provide external access to both input and both output terminals.

Figure 3 shows the principal methods of connecting 4-terminal units in a substitution box. When the input and output terminals must be accessible separately, the free-point circuit of Figure 3(A) is available. The 16 required terminals are arranged in two rows on the panel. (Terminals a_{i1} and a_{i2} to n_{i1} and n_{i2} for the inputs, and a_{o1} and a_{o2} to n_{o1} and n_{o2} for the outputs). When internal switching is permissible, the circuit of Figure 3(B) is available. Here, the 4-terminal units (A, B,-C . . . N) are selected with a 4-pole switch (S_1-S_2-S_3-S_4). Only four panel terminals (1 and 2 for the input; 3 and 4 for the output) are needed.

Sometimes, one input terminal (or one output terminal) of each component can be grounded. This is not true often enough, however, to justify running a common line inside the substitution box and elminating one row of terminals in Figure 3(A) or one switch pole in Figure 3(B). Similarly, it is possible in some applications to ground one input terminal and one output terminal of a 4-terminal device such as a transformer. But it is not advisable to make permanent common connections inside a substitution box containing 4-terminal components, since this will greatly limit the flexibility of the unit. The arrangements shown in Figure 3 therefore are the simplest for this type of box.

Practical Applications

This section describes the circuit details of several substitution boxes other than the familiar capacitor and resistor types. The usefulness of these boxes in circuit development and troubleshooting will be apparent to the engineer and technician. These boxes and others may be used in combination for special applications.

The values given for components are those which have been found most useful by the Editors. Other values may be substituted for greater utility in boxes built for individual applications.

Diode Box. See Figure 4. This substitution box has been designed to supply a choice between five of the

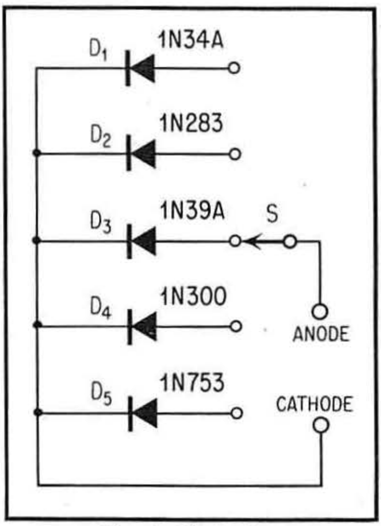

Fig. 4. Diode Box.

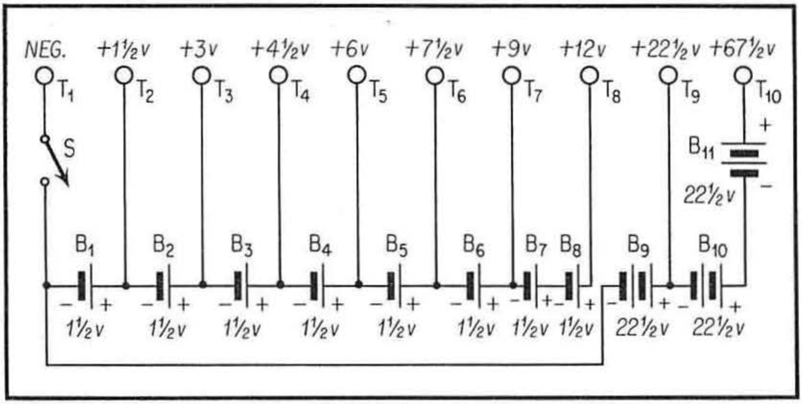

Fig. 5. Battery Box.

principal types of crystal diodes: general - purpose (D_1), high - conductance (D_2), high-back-voltage (D_3), silicon (D_4), and zener (D_5).

Diode D_1 (1N34A) is a standard, general-purpose unit. The important characteristic of D_2 (1N283) is its forward current of 200 ma at 1 volt. The reverse operating voltage of D_3 (1N39A) is 200 v. The silicon unit, D_4 (1N300) passes a reverse current of only 0.001 microampere at −10 v. Diode D_5 (1N753) is a zener reference unit for 6.2-volt operation.

For specific applications, diodes of other types may be used in place of those specified in Figure 4. Also, a greater number of diodes may be employed.

Battery Box. This unit, shown in Figure 5, is a d-c power supply as well as a voltage substitution box. Because two or more voltages often are required separately at the same time, the free-point type of circuit (with Output Terminals T_1 to T_{10}) is employed instead of a switching scheme. Nine voltages between 1½ v and 67½ v are supplied. Various other voltage values may be obtained between the positive terminals. For example, 45 v may be obtained between T_9 and T_{10}.

The batteries are small in size and the unit accordingly may be built in a medium-sized chassis box. B_1 and B_8 are 1½-volt, Size-D flashlight cells. B_9, B_{10}, and B_{11} are 22½-volt B-batteries (such as Burgess Type K-15).

Switch S opens or closes the circuit for any voltage taken between the NEGATIVE terminal and any other terminal.

The voltages specified in Figure 5 will satisfy most demands for bias and reference voltage substitution and for d-c supply for tube and transistor circuits.

Thermistor Box. See Figure 6. Six representative thermistors are arranged for selection by the single-pole rotary switch, S. These thermistors have the following nominal resistance values within ± 10%: R_1 38Ω, R_2 100Ω, R_3

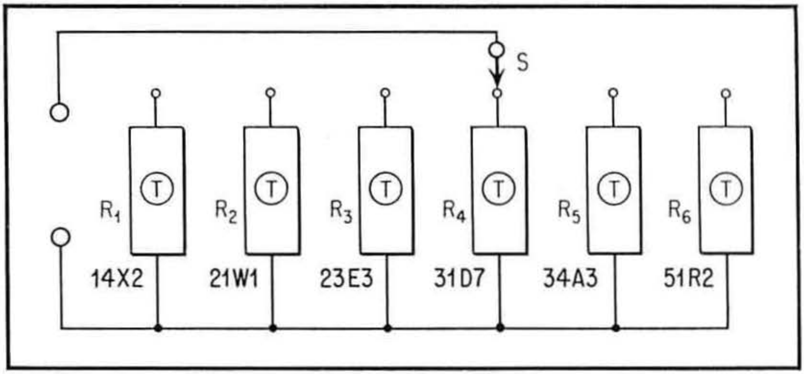

Fig. 6. Thermistor Box.

310Ω, R_4 1200Ω, R_5 3500Ω, and R_6 100,000Ω. All are Veco units; the manufacturer's type numbers appear in Figure 6.

The selected thermistors provide a wide range of uses in control circuits and stabilization networks. However, types having other resistances and temperature characteristics may be substituted for the ones shown. Also, more than six may be employed if a wider selection is desired.

Potentiometer Box. See Figure 7. This box has been found useful both in potentiometer and rheostat substitution and in the bench assembly of special circuits such as bridges. Five potentiometers are shown, since this number usually is the maximum which may be mounted in a small box with direct-reading resistance dials. The potentiometers are selected by means of a 3-pole rotary switch, S_1-S_2-S_3.

The potentiometers in a low-range box should have the following resis-

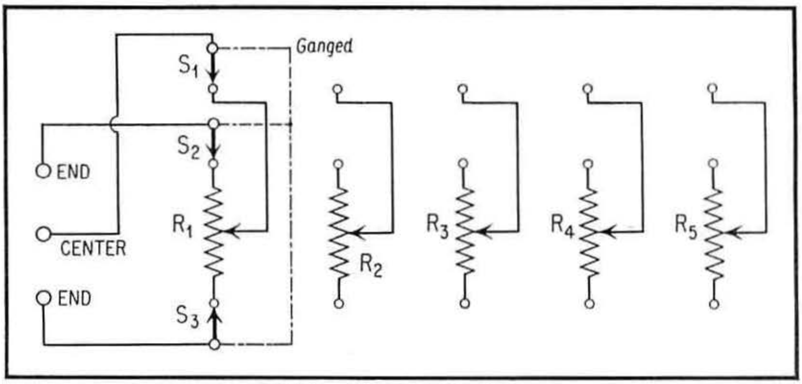

Fig. 7. Potentiometer Box.

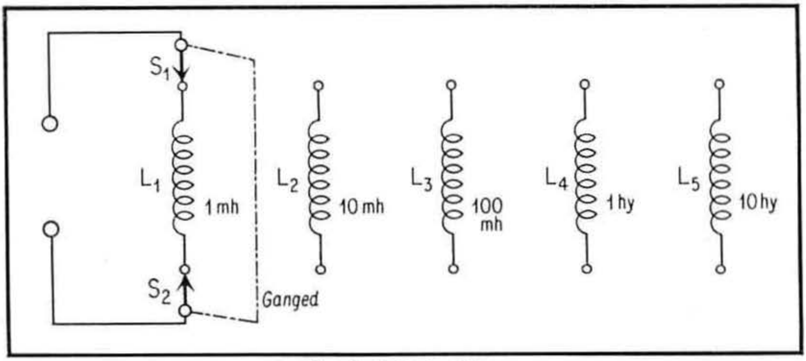

Fig. 8. Inductor Box.

tance values: R_1 50, R_2 100, R_3 200, R_4 500, and R_5 1000 ohms. Those in a medium-range box should be: R_1 5K, R_2 10K, R_3 20K, R_4 50K, and R_5 100K. Those in a high-range box should be: R_1 250K, R_2 500K, R_3 1 meg, R_4 5 meg, and R_5 10 meg.

Inductor Box. See Figure 8. A choice of five inductors (L_1 to L_5) is given, but more inductors might be added. For high Q and minimum interaction between coils, toroids are employed, except for L_1 which is a 1-mh pi-wound r-f choke (National R-300). The U. T. C. toroids are: L_2, 10 mh, Type MQB-1; L_3, 100 mh, Type MQE-7; L_4, 1 hy, Type MQA-12; and L_5, 10 hy, Type MQA-17.

In order to disconnect both ends of unused coils from the circuit, a 2-pole rotary switch, S_1-S_2, is employed.

Variable Capacitor Box. See Figure 9. This box permits a tuning range between approximately 5 uufd and 920 uufd. The 2-pole, 4-position,

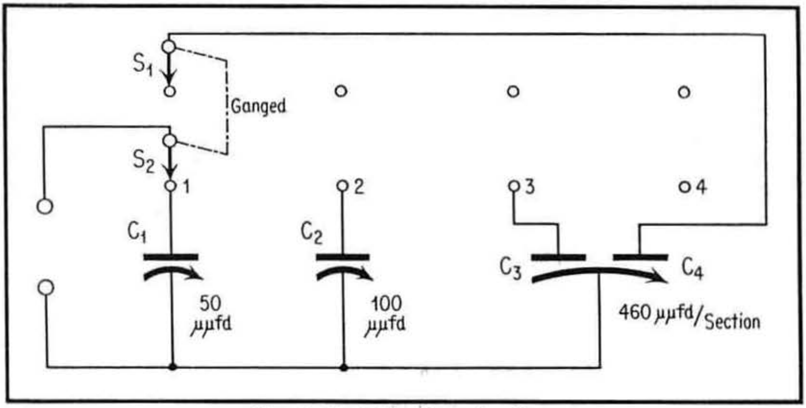

Fig. 9. Variable Capacitor Box.

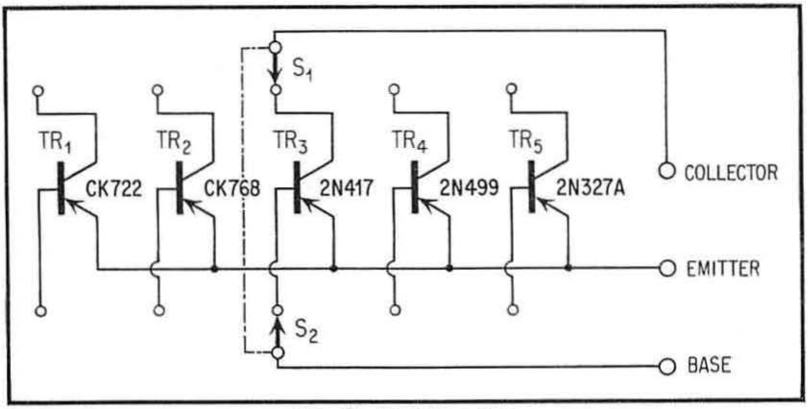

Fig. 10. Transistor Box.

rotary selector switch (S_1-S_2) in Position 1 selects the 50-uufd unit, C_1. In Position 2, the 100-uufd unit, C_2, is selected. In Position 3, one 460-uufd section of the dual capacitor, C_3-C_4, is selected. In Position 4, the two sections of C_3-C_4 are connected in parallel to give 920 uufd.

The capacitor dials may be made direct-reading in micro-microfarads. All wiring inside the box must be rigid and as short as possible.

Transistor Box. See Figure 10. Here, for the first time is a substitution box containing active elements. Five transistors are provided for a selection of useful characteristics from low-frequency audio performance to high radio-frequency operation.

While transistor types may be chosen according to particular demands of the user, the assortment shown in Figure 5 will cover most practical applications. TR_1 is a Ray-

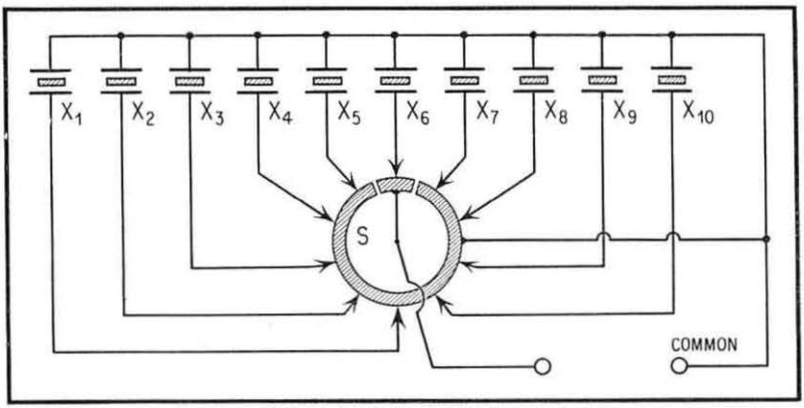

Fig. 11. Quartz Crystal Box.

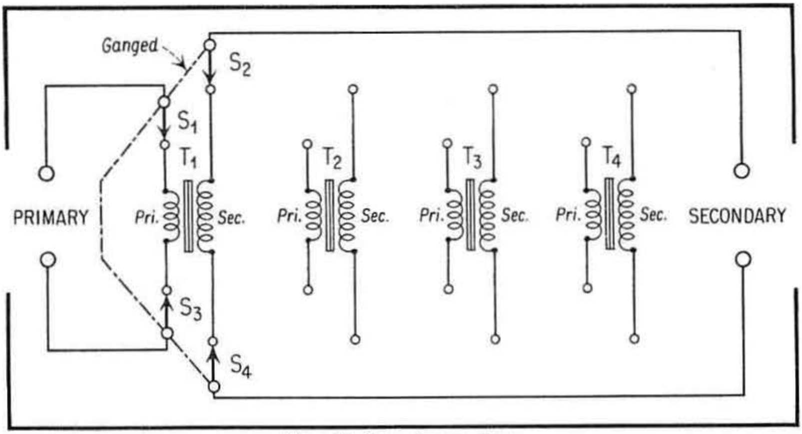

Fig. 12. Transformer Box.

theon CK722 general-purpose audio unit, TR_2 Raytheon CK768 af-if, TR_3 Raytheon 2N417 20-Mc cutoff, TR_4 Philco 2N499 250-Mc cutoff, and TR_5 Raytheon 2N327A silicon general-purpose.

All wiring inside the transistor box must be kept rigid and as short as possible. The emitters are connected together and to the EMITTER terminal post. The collectors are selected by Section S_1, and the bases by Section S_2 of the 2-pole, 5-position, rotary switch, S_1-S_2. If a power transistor is included, the switch must have contacts heavy enough to carry the high direct current, and a heat sink must be provided for the power transistor.

Quartz Crystal Box. See Figure 11. This box is invaluable as the frequency-shifting element of an experimental crystal oscillator. It also will provide a selected crystal for selective filter development.

Ten crystals (X_1 to X_{10}) are indicated and may be chosen in frequency to suit the requirements of the user. At least four should be low-frequency crystals (e.g., 50, 100, 455, and 500 kc) for standardization and i-f filter work.

A short-circuiting type, single-pole, ceramic selector switch (S) is employed. This switch short-circuits and connects to the COMMON terminal all crystals except the one in use. A suitable switch of this type is Centralab Type 2000.

All wiring inside the crystal box must be short and rigid.

Transformer Box. See Figure 12. In this box, both the primaries and secondaries of the transformers are switched simultaneously by the 4-pole rotary selector switch, S_1-S_2-S_3-S_4.

The transformer types may be chosen to satisfy the user's requirements which, of course, vary considerably among technicians. In order to minimize interaction between the units, only well-shielded transformers should be used in a substitution box. Unshielded units may be employed, with somewhat less success, if they are mounted as far apart as possible and with their cores at right angles.

In order to minimize contact sparking, which eventually will ruin the selector switch, the power should be shut off in circuits before switching transformers in the substitution box.

RC-Network Box. Entire special-purpose networks may be switched in substitution boxes with the ease of switching single components. This is particularly true of resistance-capacitance networks, since they suffer very little from interaction and accordingly may be mounted close together in a box.

Figure 13 shows an example. Here, parallel-T null networks are switched. Each network may be set to a desired frequency notch by adjusting its R and C components. (R_1, R_2, R_3, C_1, C_2, C_3).

The common (ground-return) terminals of the networks are connected together and to the low OUTPUT terminal post. The input terminals are selected by Section S_1, and the output terminals by Section S_2 of the 2-pole rotary switch, S_1-S_2.

Additional Uses

Many other possible substitution boxes will sugggest themselves to the alert technician. Some examples are L-pad, T-pad, simple T-networks, bridged-T networks, semiconductor rectifiers, and Thyrite varistors.

Combinations of substitution boxes can save the busy experimenter a great deal of time ordinarily spent in soldering and unsoldering trial components. When considering a new substitution box, however, study the basic configurations given in Figures 1, 2, and 3 and discussed in the early part of this article, in order to determine the optimum arrangement for the box.

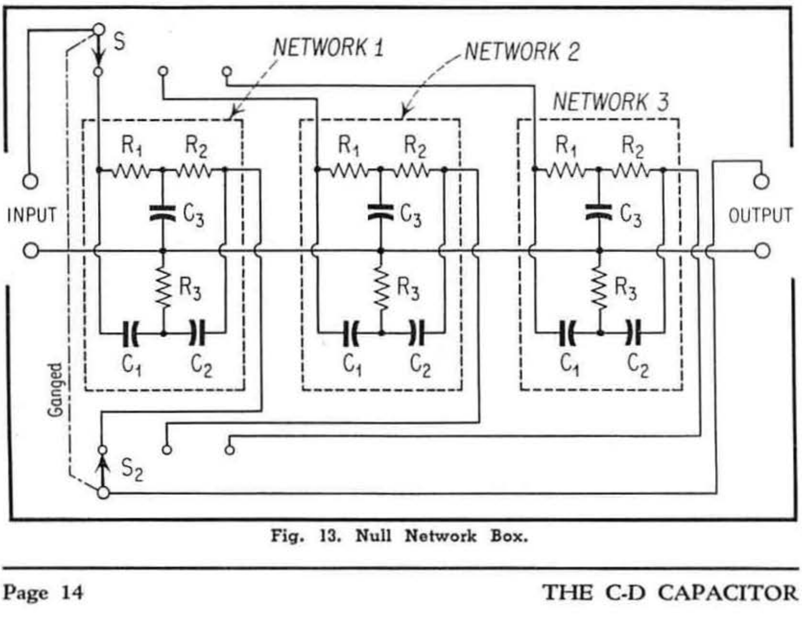

Fig. 13. Null Network Box.