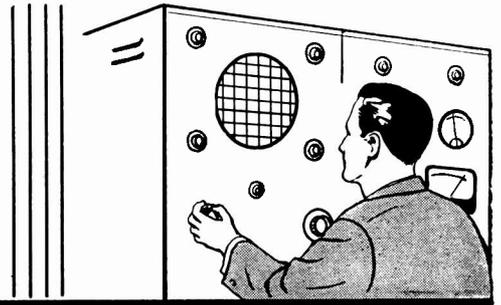


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## Fixed Capacitors in Transistor Circuits

By the Engineering Department, Aerovox Corporation

Transistorized equipment creates a large new application area for low-voltage capacitors. Since much of this equipment is miniaturized, it demands small-sized capacitors. The low impedances of the transistor necessitate much higher coupling and bypass capacitances, in many instances, than are employed in comparable tube circuits. In order to obtain these high capacitances in small packages, electrolytic capacitors therefore are employed in transistor circuits in positions where they seldom are found in tube circuits. This is particularly true of audio-frequency circuits. In transistorized r-f amplifiers and oscillators, and in flip-flops, multivibrators, and other switching circuits, many of the capacitances are very nearly the same as those found in similar tube circuits.

### Typical Applications

Figure 1 shows single-stage, RC-coupled, common-emitter a-f amplifiers circuits. This type of circuit is widely used in sound systems, instruments, and control devices. Figure

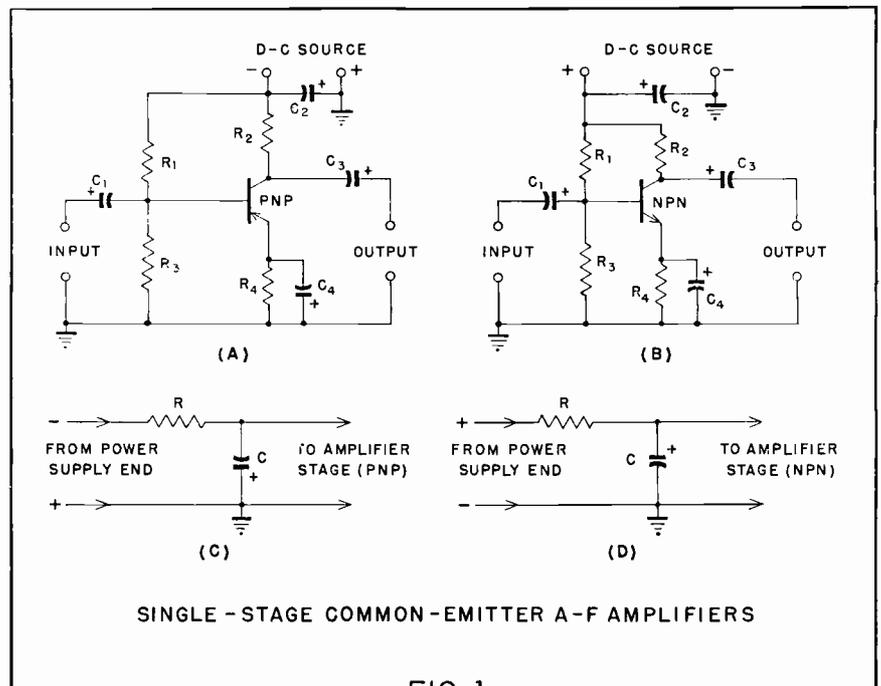


FIG. 1

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1(A) employs a PNP transistor, and Figure 1(B) an NPN transistor. Figures 1(C) and 1(D) show a simple decoupling filter which would be required in a multistage amplifier consisting of several cascaded RC-coupled stages. Figure 1(C) is used with the PNP circuit, and 1(D) with the NPN circuit.

All capacitors are electrolytic. Note that the polarity of all capacitors must be reversed when the transistor is changed from PNP to NPN. In Figures 1(A) and 1(B),  $C_1$  and  $C_3$  are coupling capacitors, whereas  $C_2$  and  $C_4$  are bypasses. D-C base bias stabilization is supplied by the voltage divider  $R_1$ - $R_3$ , and current limiting by the emitter series resistor,  $R_4$ . The voltage division results in the application of a d-c voltage somewhat lower than the supply voltage to the base of the transistor and to the inner terminal of  $C_1$ . This voltage is negative in the PNP circuit and positive in the NPN. Unless degeneration is desired,  $R_4$  must be bypassed heavily by means of  $C_2$ . In a preamplifier employing a conventional a-f transistor and a 6-12-volt supply, typical circuit constants are:  $C_1$  and  $C_3$ , 1 to 10  $\mu$ fd (depending upon desired low-frequency response),  $C_2$ , 100-200  $\mu$ fd,  $C_4$ , 50  $\mu$ fd,  $R_1$ , 100K,  $R_2$ , 4.7K,  $R_3$ , 10K, and  $R_4$ , 1K. In the decoupling filters (Figures 1C and 1D), typical values are  $C$  50  $\mu$ fd and  $R$  220-330 ohms in a 3-stage voltage amplifier.

Capacitor  $C_1$  looks into a relatively low resistance comprised by the internal base-emitter resistance of the transistor in parallel with bias resistor  $R_3$ . This total resistance may be of the order of 1000 ohms. Hence, a high capacitance (1 to 10  $\mu$ fd) is required in  $C_1$  to obtain the same low-frequency response and negligible phase shift afforded by a 0.1  $\mu$ fd looking into a  $\frac{1}{2}$  megohm grid resistor in a comparable tube circuit. When RC-coupled stages are cascaded, each output capacitor ( $C_3$ ) looks into the low base-emitter input resistance of the following stage. In a tube amplifier in which the coupling capacitance  $C = 0.1 \mu$ fd and the grid resistance  $R = \frac{1}{2}$  megohm, the time constant  $t = 50$  milliseconds. To obtain this same value with the 1000-ohm input resistance of the transistor,  $C = t/R = 50 \mu$ fd.

Even when the resistance of the a-f signal source is low (as in the case of a reluctance pickup or dynamic microphone), Capacitor  $C_1$  is required to withstand only the steady d-c voltage developed at the junction of  $R_1$  and  $R_3$ . Since this potential is much lower than the supply voltage, a capacitor rated at a continuous d-c working voltage equal to the sup-

ply voltage will provide more than adequate safety factor. Actually, a much lower dcwv rating may be tolerated here when miniaturization demands a smaller-sized (lower-voltage) capacitor, since in the circuits shown in Figures 1(A) and 1(B), the transistor base voltage is about one-tenth of the supply voltage.

The output coupling capacitor,  $C_3$ , being connected directly to the collector of the transistor, must be rated to withstand continuously the d-c supply voltage (less the drop across  $R_2$ ) plus the peak value of the collector signal voltage. The d-c voltage drop  $e$  developed across the emitter resistor,  $R_4$ , is equal to  $i_e R_4$ , where  $i_e$  is the d-c emitter current. Bypass capacitor  $C_4$  accordingly must be rated to withstand continuous voltage  $e$  plus the peak value of the a-f signal voltage developed across  $R_4$ . The dcwv requirement of  $C_4$  generally will be less than one-half that of  $C_3$ . For simplicity, however, capacitors of the same voltage rating often are used in both positions.

In a multistage circuit, the situation is slightly different. The interstage coupling capacitor ( $C_3$  in Figure 2) has the negative collector voltage of Transistor  $Q_1$  applied to its negative terminal, and the lower negative bias voltage at the base of Transistor  $Q_2$  applied to its positive terminal. (If NPN transistors are used, all voltage and capacitor polarities are reversed.) Capacitor  $C_3$  accordingly must be rated to withstand continuously the d-c supply voltage

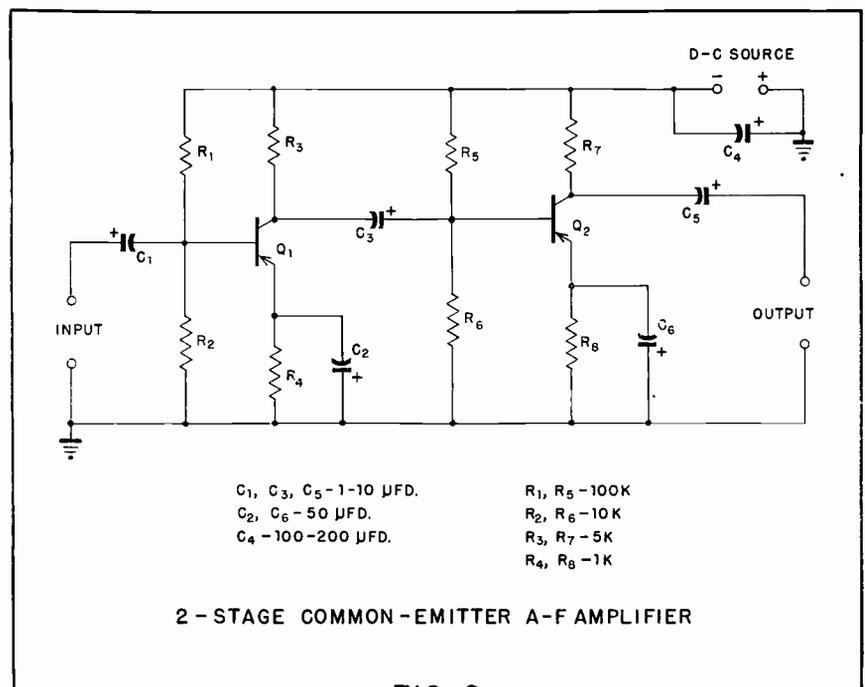
(less the drop across  $R_2$ ) plus the peak value of the  $Q_1$  collector signal voltage. Capacitor  $C_5$  must be similarly rated with respect to the d-c and a-f collector voltages of Transistor  $Q_2$ . The dcwv ratings of bypass capacitors  $C_2$  and  $C_6$ , like  $C_4$  in the single-stage amplifier, are less than one-half those of  $C_3$  and  $C_5$ ; but for simplicity, capacitors of the same rating often are used.

To prevent damage to coupling capacitors in circuits handling high signal-voltage levels, capacitors having sufficiently high dcwv ratings to insure a good safety factor must be employed. Since the total voltage applied to the capacitor is the sum of d-c and signal voltages, the d-c rating of the capacitor can be exceeded during the high signal-voltage peaks if the capacitor is selected only on the basis of the d-c voltage expected in the circuit.

For good safety factor, the supply bypass capacitor ( $C_2$  in Figure 1 and  $C_4$  in Figure 2) should have a dcwv rating equal to twice the supply voltage. The filter capacitor in the decoupling network ( $C$  in Figures 1C and 1D) should be similarly rated.

### Importance of Low Leakage

The necessity that leakage currents be low in miniature electrolytic coupling capacitors in transistor circuits is apparent from an inspection of Figure 2. The voltage divider networks ( $R_1$ - $R_2$  and  $R_5$ - $R_6$ ) stabilize the d-c base bias of the transistors. This



- |                                   |                   |
|-----------------------------------|-------------------|
| $C_1, C_3, C_5$ - 1-10 $\mu$ F.D. | $R_1, R_5$ - 100K |
| $C_2, C_6$ - 50 $\mu$ F.D.        | $R_2, R_6$ - 10K  |
| $C_4$ - 100-200 $\mu$ F.D.        | $R_3, R_7$ - 5K   |
|                                   | $R_4, R_8$ - 1K   |

FIG. 2

stabilization provides some temperature compensation, as well as minimizing changes in operation when transistors are interchanged or replaced. Very importantly, the d-c bias also sets the operating point of the transistor along its characteristic curve, so that Class-A operation, for example, is secured. If the leakage of Capacitor  $C_3$  is high, the voltage at the junction of  $R_5$  and  $R_6$  will be raised to some value approaching the collector potential of Transistor  $Q_1$ . This change in voltage will shift the operating point of Transistor  $Q_2$ , resulting in distortion, and will alter the stabilization provided by the voltage divider. Additionally, the lowered impedance of  $C_3$  will alter the gain and phase shift characteristics of the amplifier. High leakage in  $C_3$  will also reduce the d-c collector voltage of  $Q_1$ .

High leakage in  $C_5$  will cause a d-c component to be applied to the load device (or following amplifier stage) connected to the OUTPUT terminals. In short, d-c leakage must be low enough that a coupling capacitor does not transmit a significant d-c component and that a bypass capacitor does not materially reduce the d-c resistance of the path in which it is included.

### Additional A-F Circuits

The RC-coupled common-emitter circuit presently is the most widely used in transistorized a-c signal circuits. Its general appeal is due to its high power gain, fair-to-good frequency response, and moderate input impedance. Figure 3 shows additional circuit arrangements in which the correct polarity of electrolytic capacitors is indicated. PNP transistors are shown. If NPN transistors are used, reverse all capacitor and voltage polarities.

Figure 3(A) shows a common-base stage. The input resistance of the transistor is very low (50 ohms with some transistors). The input coupling capacitor,  $C_1$ , therefore must be quite high in order to obtain the same frequency response, phase shift, and gain supplied by comparable common-emitter and tube circuits. Whereas an input coupling capacitance of 1 to 10  $\mu\text{fd}$  (Figures 1 and 2) is suitable for the common-emitter circuit,  $C_1$  will be 10 to 50  $\mu\text{fd}$  in the common-base circuit, depending upon type of transistor and desired low-frequency response. The capacitance of  $C_3$  will not be so high (generally 1 to 10  $\mu\text{fd}$ ) unless the load device has low resistance.

Figure 3(B) shows an emitter follower stage. This configuration provides high input impedance, low out-

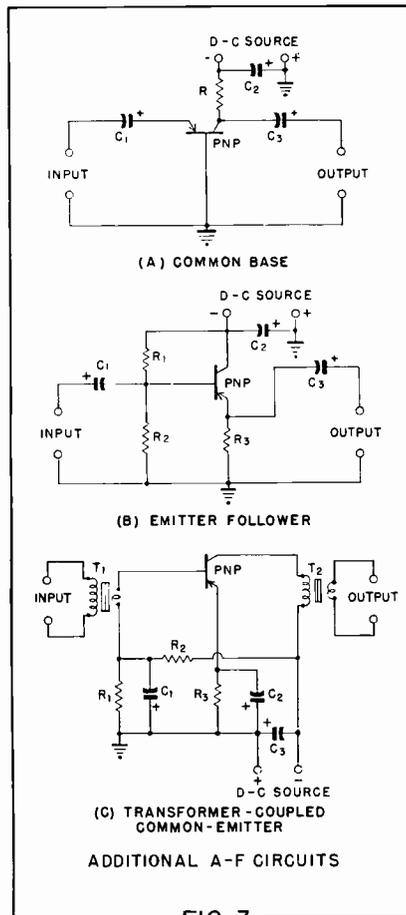


FIG. 3

put impedance, wide frequency range, and no phase shift; and in these respects is similar to the cathode follower tube. Here, Capacitors  $C_1$  and  $C_2$  have the same values specified earlier for the common-emitter circuit. Output coupling capacitor  $C_3$  is effectively in series with the low emitter resistance ( $R_5$ ) and the low resistance external load device. This capacitance accordingly must be high and usually is of the order of 50 to 1000  $\mu\text{fd}$ , depending upon the values of  $R_3$  and  $R_1$  (external load), and the desired low-frequency response.

Figure 3(C) shows a transformer-coupled common-emitter stage in which the d-c bias, developed by the  $R_1$ - $R_3$  voltage divider, is applied to the base of the transistor through the secondary winding of input transformer  $T_1$ . This arrangement often is used in power transistor stages, the bias network being placed in this position instead of across the input terminals (as in Figures 1 and 2) because the lower resistor would absorb some of the input signal. Here, it is necessary to bypass heavily to prevent loss of signal voltage across the lower network resistor,  $R_1$ . The

bypass capacitance,  $C_1$  must be high, since  $R_1$  usually is low (commonly 100 to 1000 ohms).  $C_1$  will have a value between 50 and 500  $\mu\text{fd}$ , depending upon the transistor type and  $R_1$  resistance. Bypass Capacitance  $C_2$  likewise must be high, since  $R_3$  (especially in power transistor stages) may be only a few ohms. This capacitance will be 100 to 1000  $\mu\text{fd}$ , depending upon transistor type and  $R_3$  resistance.

### Capacitors in R-F and Switching Circuits

The majority of capacitances employed in r-f amplifier, oscillator, and oscillator circuits, including intermediate-frequency devices, extend from 5  $\mu\text{fd}$  to 0.1  $\mu\text{fd}$ . This is true also of switching circuits, including flip-flops, multivibrators, Schmitt triggers, pulse amplifiers and inverters, single-shots, etc. These capacitances are obtainable in miniature nonelectrolytic capacitors, such as mica, ceramic, and (in the higher capacitances) metallized paper types. Therefore, there is no polarity problem. These capacitors normally are rated to withstand much higher d-c voltages than ordinarily are encountered in transistor circuits consequently, voltage rating is no problem either.

An occasional high capacitance, such as 10  $\mu\text{fd}$ , is required for a-c filtration or for d-c supply bypassing, and a miniature electrolytic is employed in such instances. Here, the rules discussed earlier apply to this capacitor. That is, the dcwv rating of the capacitor must exceed the sum of the supply voltage and signal-voltage peak, and the polarity is determined by whether the transistor is NPN or PNP.

A wide selection of miniature mica and ceramic capacitors is available for use in r-f and switching circuits. The choice of a particular type will depend upon space requirements and, to some extent, upon whether conventional or printed-circuit construction is employed.

Because of their very high insulation resistance, nonelectrolytic capacitors in transistor circuits present no leakage problems unless the capacitors are damaged. The designer of new equipment in which capacitors are employed in frequency-determining circuits must pay particular attention to the magnitude and direction of the temperature-capacitance coefficient of ceramic capacitors to prevent undesired frequency shift from this source. And the technician who replaces these capacitors in maintaining transistorized equipment must take special pains to use exact replacements.



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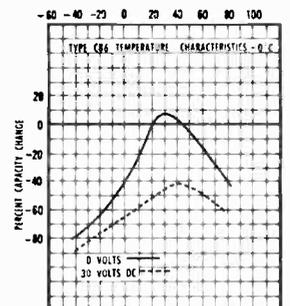
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