1956-11-14

Emitter Bypassing in Transistor Circuits

Murray, Raymond Patrick

Naval Postgraduate School, Monterey California

EMITTER BYPASSING IN TRANSISTOR CIRCUITS

By

RAY P. MURRAY

ACADEMIC DEPARTMENT
GENERAL LINE SCHOOL

NOVEMBER 14, 1956

U.S. NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

EMITTER BYPASSING

IN

TRANSISTOR CIRCUITS

by

RAY P. MURRAY

ASSOCIATE PROFESSOR OF ELECTRICAL ENGINEERING

November 14, 1956

U.S. NAVAL POSTGRADUATE SCHOOL

Monterey, California

EMITTER BYPASSING IN TRANSISTOR CIRCUITS

The use of a resistance in the emitter lead of low-level audio amplifiers is quite common practice. This resistance may have one or more of the following purposes: (1) provide negative feedback at the signal frequency, (2) provide d-c negative feedback to stabilize the operating point, (3) increase the input impedance. If the resistance is unbypassed, it may provide all three of the above functions; however in many cases, the only desired purpose is to provide operating point stabilization, and in order to prevent loss of gain, a bypass capacitor is employed as shown in Fig. 1.

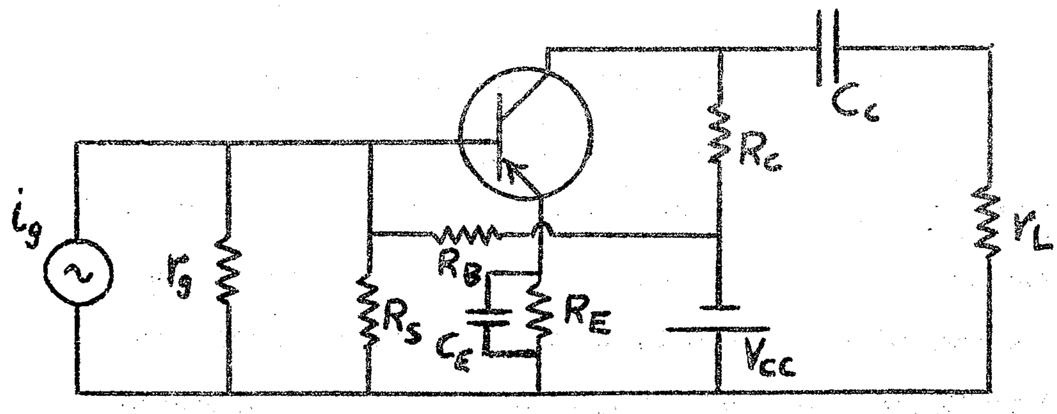


Fig. 1--Stabilized common-emitter amplifier. The signal source is considered to be another transistor amplifier and is simulated in this circuit by a constant current generator.

The proper size of C_E may depend on R_E, R_S, R_B, r_g, the frequency of operation, and the transistor parameters. In the following we will show the effect of R_E on the current gain of the circuit and will derive a formula for the computation of the reactance of C_E.

Equivalent Circuit Representation

r_g of Fig. 1 would normally be the collector coupling resistance of the preceding amplifier as the output resistance of the transistor is very high. In the equivalent circuit of Fig. 2, r_g, R_S, and R_B have been replaced by their parallel equivalent R_g, and r_L and R_e have been replaced by their parallel equivalent R_L. In addition, C_E has been omitted for the present in order to determine the effect of R_E on the current gain. The three terminals in Fig. 2 represent the terminals of the transistor.

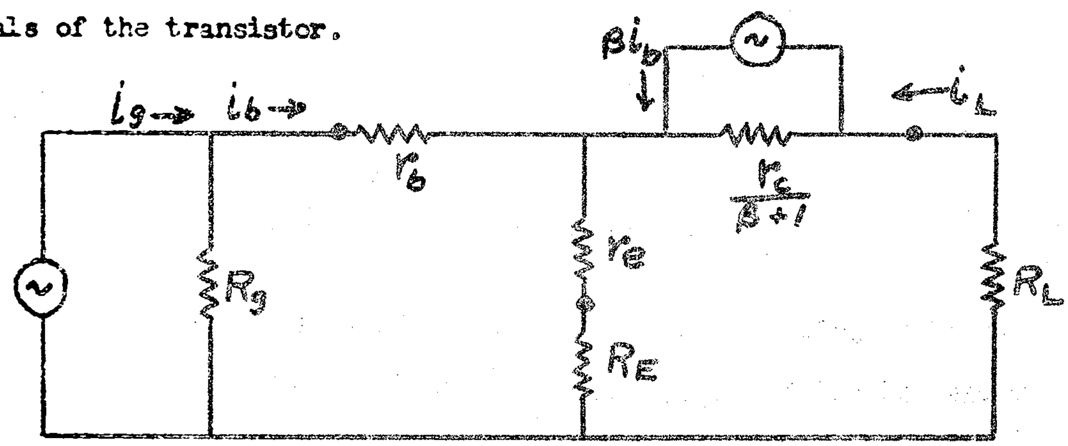


Fig. 2—Equivalent circuit of amplifier in Fig. 1 with C_E omitted.

Ordinarily the sum of r_e and R_E is very small compared to the sum of the other resistances in the collector circuit and we may consider the impedance effects of r_e and R_E to be negligible in the collector circuit. This leads to the simplified equivalent circuit of Fig. 3 in which the effect of the collector current upon the input circuit is taken into account by the modified values of r_e and R_E.

Effect of Emitter Resistor on Current Gain

In order to determine the effect of R_E on the current gain let us define P as the ratio of the current gain with R_E present to the gain with R_E equal to zero. Then, since the output current, i_L, is directly proportional to i_b we may determine P by

$$P = \frac{i_b \text{ with } R_E \text{ present}}{i_b \text{ with } R_E = 0} \tag{1}$$

From Fig. 4, the values of i_b with and without R_E are

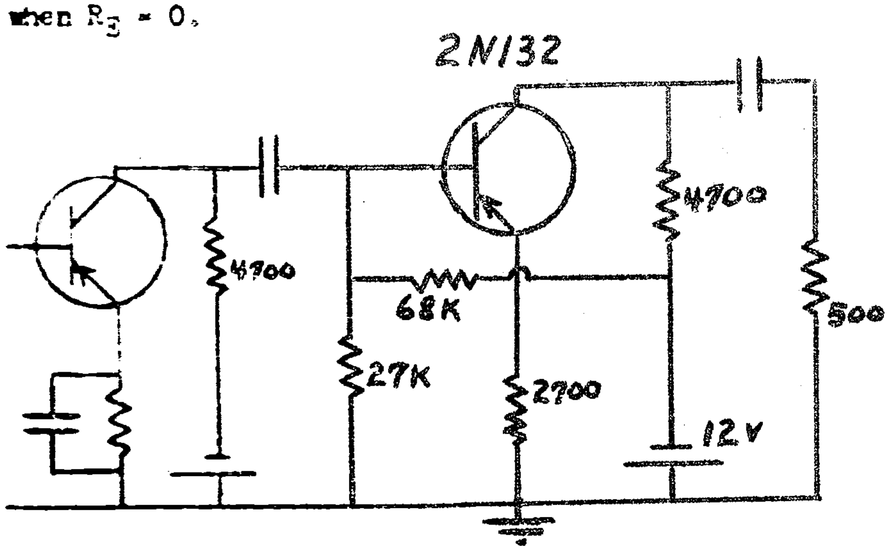
$$i_b = \frac{i_g R_g}{R_g + r_b + (r_e + R_E)(\beta+1)} \tag{2}$$

$$i_b\Big|_{R_E=0} = \frac{i_g R_g}{R_g + r_b + r_e(\beta+1)} \tag{3}$$

Thus, the ratio of the current gains is

$$P = \frac{R_g + r_b + r_e(\beta+1)}{R_g + r_b + (r_e + R_E)(\beta+1)} \tag{4}$$

As an example, let us consider the amplifier of Fig. 5. Substitution of the parameter values in Eq. 4 gives a value of P = 0.0298. Thus the effect of R_E is to reduce the current gain to only 2.98% of its value when $R_E = 0$.



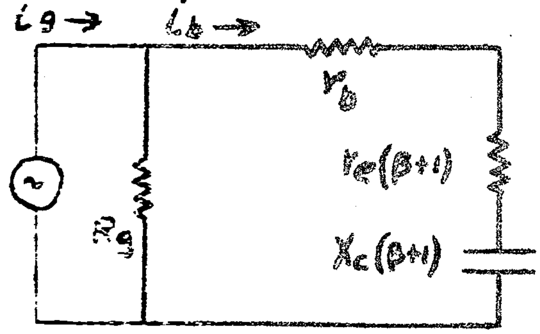
Transistor Parameters

r_e = 25 ohms
r_b = 1500 ohms
r_c = 2 megohms
β = 90

Fig. 5—Amplifier with unbypassed emitter resistor.

Emitter Bypass Capacitor

To prevent the large loss in current gain, R_E may be bypassed with capacitor C_E. In most cases the required reactance of C_E will be much lower than the resistance of R_E, and the approximate equivalent input circuit will be as shown in Fig. 6.



$r_c \gg |r_e - jX_c|$

$r_c \gg (\beta+1)R_L$

$X_c < R_E$

Fig. 6—Approximate equivalent input circuit with C_E present.

From the circuit of Fig. 6, the absolute value of i_b is

$$|i_b| = \frac{i_g R_g}{\sqrt{\left[R_g + r_b + r_e(\beta+1)\right]^2 + (\beta+1)^2 X_c^2}} \qquad (5)$$

and the ratio of the current gains from Eqs. 3 and 5 is

$$P = \frac{R_g + r_b + r_e(\beta+1)}{\sqrt{\left[R_g + r_b + r_e(\beta+1)\right]^2 + (\beta+1)^2 X_c^2}} \qquad (6)$$

Solving for X_c

$$\boxed{X_c = \left(r_e + \frac{R_g + r_b}{\beta+1}\right)\sqrt{\frac{1}{P^2} - 1}} \qquad (7)$$

Using the same circuit values as in Fig. 5 and specifying that the current gain at 30 cps be down to 90% of its mid-frequency value, Eq. 7 gives a value of X_c = 40.3 ohms and therefore C_E = 131 microfarads.

Parameter Variations

Of the quantities in Eq. 7, r_e, r_b and β may be considerably different from the values listed in the transistor specifications. Normally these parameters are specified by the manufacturer as typical or average values at a given temperature such as 27°C and for a given operating point such as I_c = 1 milliampere and V_c = 6 volts. In some cases the manufacturer's specification sheet includes information concerning the variation in parameters due to production spread, temperature, and operating point.* For a conservative choice of C_E, the values employed in Eq. 7 should be based on the minimum values for r_b and r_e and the maximum value of β. However in some cases it will be found that the variations in r_b and r_e tend to offset the variation in β.

-0-

* A listing of many transistor specifications and information on parameter variation will be found in R.F. Shea, "Transistor Audio Amplifiers", John Wiley & Sons, Inc., New York 1955, Chap. 2.