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Class-B Transistor Amplifier Data

By the Engineering Department, Aerovox Corporation

THE transistor is an efficient device by nature. Even when we fail to take into account the absence of filament power, the transistor is found to offer higher operating efficiency than the vacuum tube. This is especially true of the junction transistors.

In transistor amplifiers, as in tube amplifiers, higher efficiencies are made possible by class-B operation. There are two main reasons for the present growing interest in class-B transistor operation. First, class-B gives maximum output watts per dollar of initial cost — an important consideration when utilizing present, high-priced *power* transistors. Second, the rather low power output of conventional transistors may be boosted several times by utilizing class-B.

Class-B Tube vs Transistor

In a conventional class-B tube amplifier, the control grids are biased for plate current cutoff, or very nearly so, under zero-signal conditions. The plate current then is driven to a certain peak value at maximum signal. Large economies are effected by the low, resting, no-signal d. c. plate power input.

There are two ways of adjusting a transistor amplifier for class-B operation. Under zero-signal conditions, the output electrode (usually the collector) may be operated either at low direct current and high voltage (comparable to static operation of the class-B tube amplifier) or at high direct current and low voltage. In the first instance, the input a. c. signal will drive the output-electrode direct current upward. In the second case, it will drive the current downward.

The family of common-emitter collector curves in Figure 1 will serve to illustrate this point. When the circuit is adjusted for no-signal operation at v_1i_2, the resting point is X. The positive half-cycle of the input signal then will drive the collector current from i_2 down to i_1, and the operating point to Y which corresponds to v_2i_1. When, instead, Y is chosen as the no-signal operating point corresponding to v_2i_1, the *negative* half-cycle of the input signal will drive the collector current up from i_1 to i_2, and the operating point to X which corresponds to v_1i_2.

While both operating points (v_1i_2 and v_2i_1) can represent points of low "resting" collector dissipation, the greater overall operating economy is afforded by the high-voltage, low-current condition (Y, v_2i_1). This is because the establishment of the opposite condition, a low collector voltage at high current from a constant-voltage collector d. c. supply would necessitate use of a dropping resistor with attendant IR loss. Large initial collector current also reduces the transistor current amplification factor, alpha.

As in the class-B tube amplifier, dynamic output-electrode current in the transistor class-B amplifier becomes a series of quasi half-sinusoids. Thus; in the common-emitter circuit with static characteristics such as displayed in Figure 1, the half-sinusoids of collector current would extend from the "zero" value, i_1, to the peak value, i_2, and back.

Figure 2 shows a comparable family of curves for the common-base transistor amplifier configuration. Note the general similarity to the family in Figure 1, but the increased linearity due to the more even spacing of the common-base curves. In the common-base circuit, collector current is driven upward from point Y by positive half-cycles of emitter signal voltage, or downward from point X by negative half-cycles of emitter signal voltage. This is the opposite of conditions with the common-emitter configuration.

Circuit Configurations

Transistors must be used in push-pull pairs in class-B amplifiers, the same as in comparable tube ampli-

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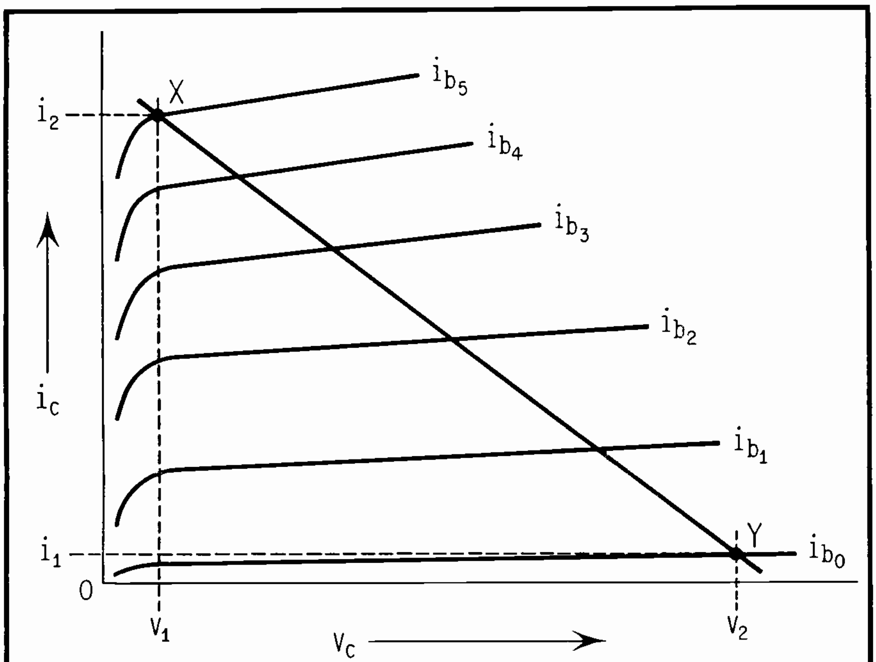


COMMON-EMITTER COLLECTOR CURVES, WITH CLASS-B OPERATING POINTS

FIG.1

fiers. However, the distortion reducing properties of the symmetrical arrangement are somewhat less in the transistor circuit. Either of the three well-known transistor circuit configurations may be employed: common-base, common-emitter, or common-collector.

D. C. output-circuit efficiency runs close to 80 percent for each circuit. Power gain is highest with the common-emitter, less by a factor of 10 with the common-base, and quite low (of the order of 10) with the common-collector. However, the common-base configuration affords the highest power output and overall power gain, for a given distortion level. The output vs distortion ratio is due to its more favorable v_c-i_c characteristic.

Figure 3 shows typical circuit arrangements for the three configurations. While batteries are shown for simplicity, the bias voltages may be obtained likewise from a. c. — operated power supplies.

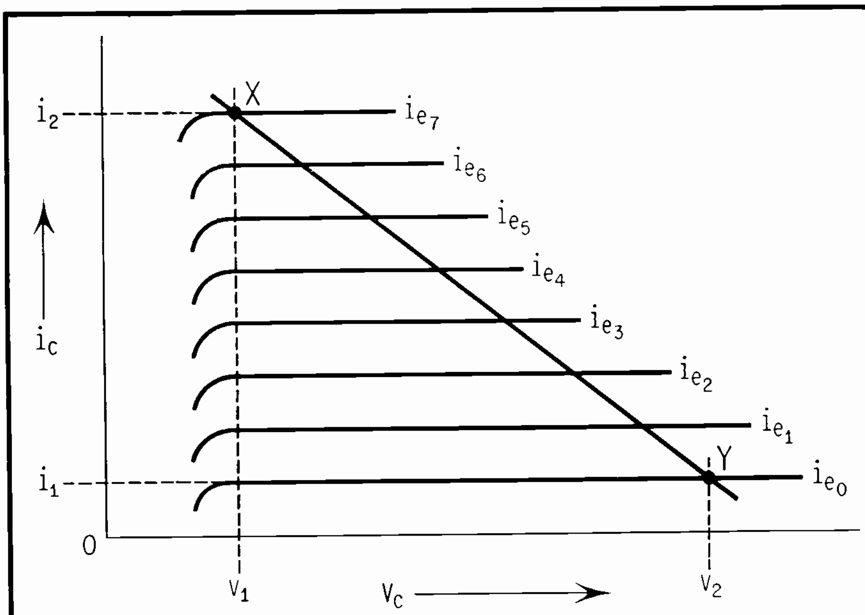
The currents and voltages i_b, i_c, i_e, v_b, v_c, and v_e are d. c. or peak values obtained from the static characteristic curves of the transistor employed. For example; in the common-emitter circuit (Figure 3B), i_c corresponds to collector current i_2 at point X in Figure 1, and i_b to the constant base current i_{b5} in Figure 1. The base voltage (v_b) and emitter voltage (v_e) must be determined experimentally for the particular transistor employed, since most transistor manufacturers do not now supply input characteristic curves. This is done by finding the base voltage in a common-emitter circuit which will produce base current value i_{b5} (Figure 1) or the emitter voltage which will produce emitter current i_{e7} (Figure 2). In each case, it is assumed that collector current is held constant at value i_2 (Figures 1 and 2) during the measurement.

Design and Operating Data

After selecting the type of junction transistor to be used and obtaining a pair matched for v_c-i_c characteristics and alpha, the first requirement is choice of collector supply voltage, v_{cc}. This voltage must not exceed one-half the maximum permissible peak inverse voltage specified by the transistor manufacturer.

In most applications, the common-emitter circuit will be employed, because of its superior power gain. The maximum collector supply voltage then corresponds to v_2 in Figure 1, and this value is to be ½ the maximum peak inverse. The point X must be selected such that the product v_1i_2 does not exceed the maximum permissible collector d. c. power dissipation specified by the transistor manufacturer. The primary winding of the output coupling transformer, T_2, is assumed to have low d. c. resistance, in order to minimize voltage drop between v_{cc} and the collector.

The following approximate common-emitter class-B design equations have been adapted from those given



COMMON-BASE COLLECTOR CURVES, WITH CLASS-B OPERATING POINTS

FIG. 2

by Shea[1]. Currents i_b and i_c (both in amperes) and voltages v_b and v_c (both in volts) are maximum-signal peak values. Values are for two transistors, except where noted otherwise.

(1) D. C. Collector Power Input = $(v_c i_c)/1.57$ watts

(2) Peak A. C. Power Output = $(v_c i_c)/2$ watts

(3) Peak A. C. Driving Power = $v_b i_b$ watts

(4) Load Resistance = $(4v_c)/i_c$ ohms (collector-to-collector)

(5) Input Resistance per transistor = v_b/i_b ohms = $(4v_b)/i_b$ ohms base-to-base

If i_1 (Figure 1) is taken as the peak value of the zero-signal collector current and i_2 as its maximum-signal peak value, the maximum-signal *average* value of the d. c. collector current for each transistor, as read with a d'Arsonval-type d. c. milliammeter in series with the collector is:

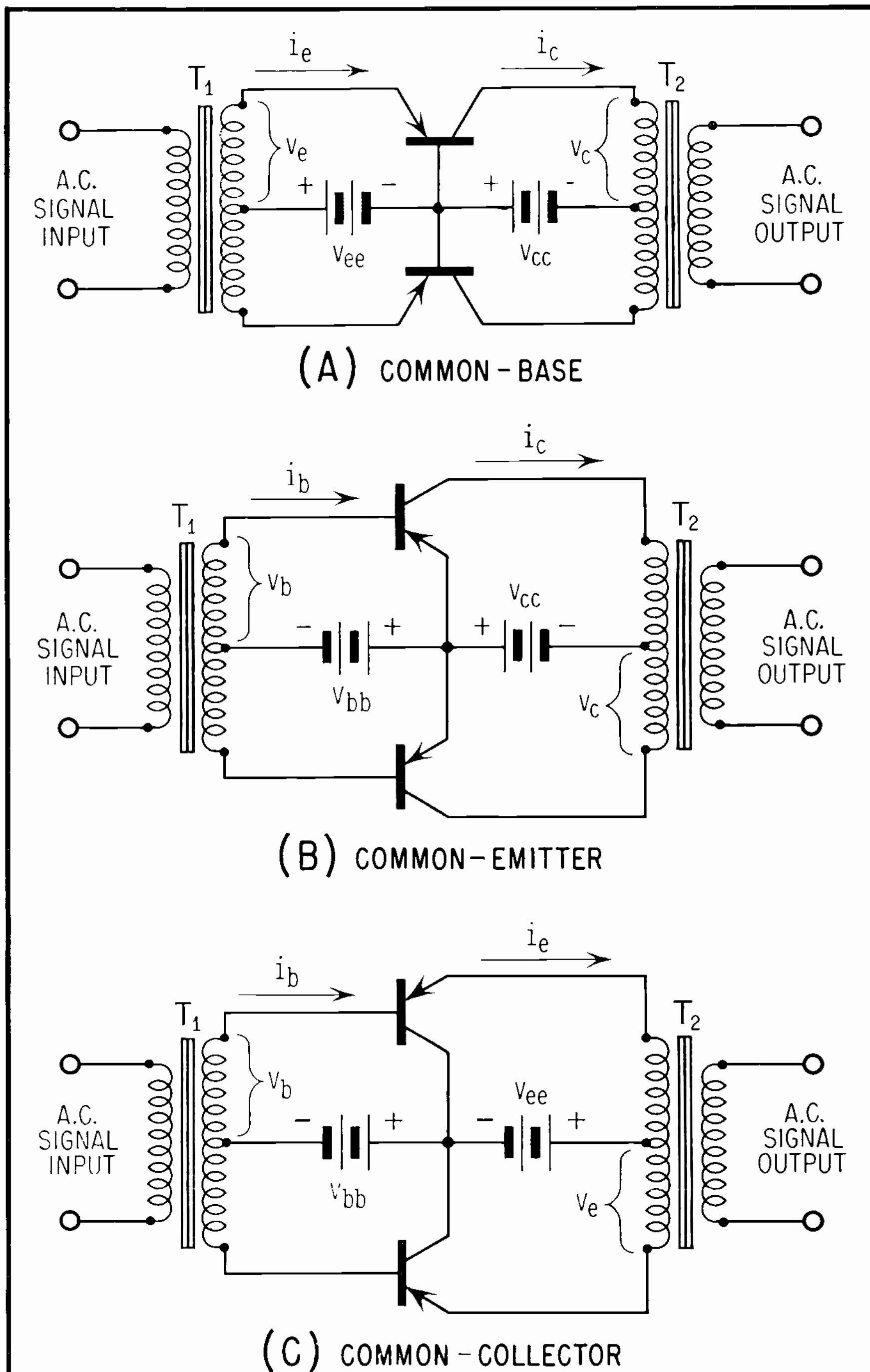
(6) i_c avg. = 0.318 $(i_2 - i_1)$ amperes

Power gain for the common-emitter stage is:

(7) PG = $(Bv_{ce})/v_{be}$, where B is the grounded-emitter current amplification factor (beta) of the transistor used.

Input and output transformers (T_1 and 2_2, respectively are chosen to match the transistor input and output impedances obtained by means of Equations (4) and (5). To minimize d. c. voltage drops, the secondary of 1_1 and the primary of T_2 must have low d. c. resistance.

A satisfactory practical method of checking performance with calculated circuit values utilizes an oscilloscope to measure peak values of input and output signal voltages, and heavily-bypassed d. c. milliammeters to check i_b and i_c values. The sinusoidal input-signal voltage is increased slowly from zero, while monitoring the waveform of both input and output voltages for peak amplitude (not inexcess of transistor dissipation rating) and distortion. A satisfactory frequency for class-B audio tests is 1000 cycles.



SINGLE-STAGE CLASS-B TRANSISTOR AMPLIFIER CIRCUITS

FIG. 3

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