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TESTING POWER TRANSISTORS

The basic electrical difference between a power transistor and the conventional junction transistor is the higher current-handling capacity of the power unit. In most instances, the d-c operating voltages are the same for both types. It follows that the power dissipation and heating are higher in the power type. Because the junctions in the power transistor are larger, internal capacitances are higher, maximum operating frequency is lower, and input and output impedances are lower than in conventional transistors.

Power transistor tests, while embodying the same essential philosophy as those for conventional transistors, must take into consideration these differences in electrical characteristics. For example, the d-c power source for testing a small transistor suitable for use in a hearing aid or radio receiver, low-level stages need supply only a few milliamperes, while 1 or more amperes will be required for the power transistor. The d-c milliammeters and microammeters employed in the testing of general-purpose transistors accordingly must be replaced with ammeters. Similarly, an a-c signal source for the dynamic checking of small transistors furnishes only a few milliwatts at the most, while a comparable source for testing power transistors often must supply 1 watt or more.

Many of the early transistor testing instruments, factory-built or constructed by the user, are unsuitable for power transistors because of a-c and d-c power deficiencies. Suitable new instruments are not appearing on the market in any great number. Expensive, laboratory-grade instruments presently are ahead of service-type testers. Power transistors from many manufacturers now are readily available and are finding application in car radios, audio amplifiers, regulated power supplies, inverters, servo systems, solenoid operation, and motor control. On the heels of this comes the need to test power transistors, either to determine their condition or to verify their characteristics against manufacturer's data.

This article describes several test setups for checking the important characteristics. Polarities shown in the circuits are for PNP transistors. When NPN transistors are to be tested, reverse all power supply, meter, and electrolytic capacitor connections.

Test Precautions

Employ every safeguard to prevent exceeding maximum ratings of the transistor under test. In most instances, maximum permissible current and voltage may not be applied simultaneously without exceeding the maximum power dissipation rating.

Except in temperature studies, tests are made at room temperature (25°C, 87°F, unless specified otherwise). Check the actual ambient temperature and when it exceeds 25°C, apply any derating factor recommended by the transistor manufacturer. Most data tables give power and dissipation ratings both for free air and with heat sink. Dissipation and operating power are higher for the heat-sink condition. When operating at these maximum levels, provide the transistor with the heat sink specified by the manufacturer, used forced-air ventilation, or both.

When checking power gain and power output under a-c signal conditions, the test circuit must not be operated without a suitable load device rated to handle safely twice the maximum output power expected.

Because of the high direct current levels involved, especially in checking collector and emitter currents, the ammeters or milliammeters employed must have the lowest obtainable internal d-c resistance to minimize voltage drop across the instrument. A conventional ammeter will be used in most instances and no problem will be introduced, since the instrument resistance will be less than 0.1 ohm. However, some improvised current meters (e.g., a v-t voltmeter adapted for current measurement) have an internal (shunt) resistance of 1 ohm or higher. Such an instrument would introduce a voltage drop of 1 volt per ampere.

Full protection of the test circuit suggests the adequate fusing of supply leads against current overload. However, the resistance of the fuse must be accounted for if it is significant.

All coupling transformers or chokes must be capable of handling the high direct currents without core saturation or damage to the windings.

Static Leakage Current

Static leakage current (also called cutoff current) may be measured with the circuits shown in Figure 1. The common-base leakage current, i_{co}, is measured with the setup shown in Figure 1(A), and the common-emitter leakage current, i_{cbo}, with Figure 1(B).

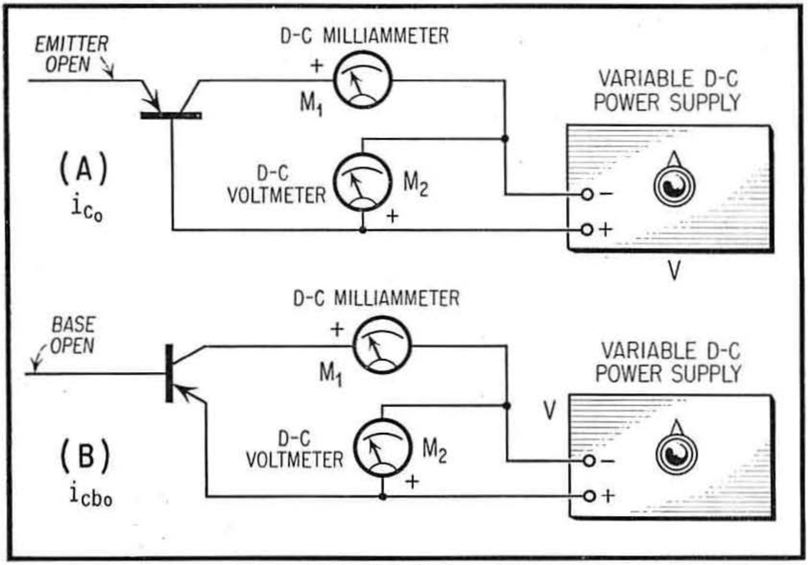

Fig. 1. Static D-C Leakage Current.

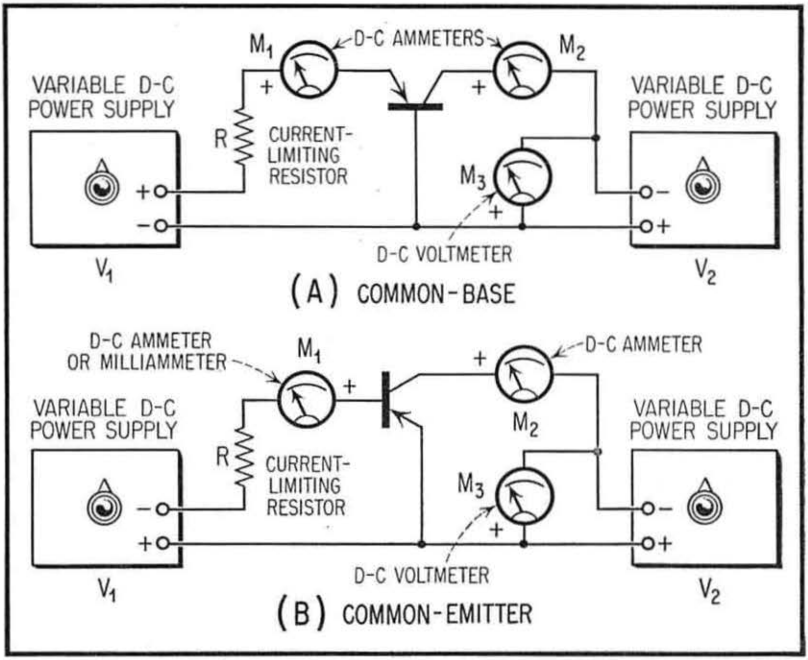

Fig. 2. Input and Output D-C Characteristics.

In each case, the input electrode is left floating.

The d-c power supply voltage, as indicated by M_2, is adjusted to the level at which the transistor is to be operated in its own circuit. The static current is indicated by a d-c milliammeter, M_1.

These tests should be made as rapidly as practicable, since an upward drift of the static current can lead to collector-current runaway which will destroy the transistor. If the ambient temperature is constant and there is no excessive internal heating of the transistor, i_{co} and i_{cbo} should be constant. Drifting or jumping of the current when temperature is constant reveals a faulty transistor. Both i_{co} and i_{cbo} have low values with respect to the normal operating collector current. I_{co} will have a value of several tens to several hundreds of microamperes, depending upon make and power rating of the transistor. I_{cbo} will be from 10 to 50 times higher than i_{co}. The measured values of i_{co} and i_{cbo} should be referred to the transistor manufacturer's specifications. I_{co} will double approximately for each 10 degrees increase of junction temperature.

Input and Output D-C Characteristics

Figure 2(A) shows a setup for checking the input and output d-c characteristics of a power transistor in the common-base connection. Here, a constant d-c voltage, indicated by

M_3, is applied between collector and base. The emitter current, indicated by M_1, then is varied between zero and a selected maximum, and the corresponding collector current values (indicated by M_2) noted. The procedure is repeated at a number of collector voltage steps to obtain data for a family of curves showing i_c vs. i_e for constant v_c. Emitter-current variation is achieved by varying the voltage output of supply V_1. A high limiting resistance, R, permits V_1 to simulate a constant - current supply. Both V_1 and V_2 must be capable of supplying the high direct currents demanded by the power transistor.

Figure 2(B) shows a setup for similarly checking a power transistor in the common - emitter connection. Here, a constant d-c voltage, indicated by M_3, is applied between collector and emitter. The base current, indicated by M_1, is varied between zero and a selected maximum, and the corresponding variation of collector current, indicated by M_2, noted. The procedure is repeated at a number of collector voltage steps to obtain data for a family of curves showing i_c vs. i_b for constant v_c. Because of the inherently high base-to-collector current amplification in the common-emittter circuit, the base current is much lower than the collector current.

Both circuits yield collector voltage-vs.-collector current figures which may be compared with the transistor manufacturer's specifications to evaluate the transistor. If curves are plotted, as suggested above, they may be compared with the manufacturer's curves.

At no time during the test should the maximum permissible values of either collector voltage, collector current, emitter current, or base current be exceeded. Neither should the product $v_c i_c$ exceed the maximum permissible power dissipation of the transistor.

Current Amplification

The setup shown in Figure 2(A) may be employed to measure the emitter-to-collector current amplification factor, alpha; the setup shown in Figure 2(B) for the base-to-collector current amplification factor, beta.

To check alpha (Figure 2A): With power supply V_1 set to zero output, set the collector voltage (indicated by M_3) to the desired operating level for the transistor under test. Next, increase the output of V_1 until the deflection of meter M_2 shows the correct collector current for the selected collector voltage. (This value may be obtained from the manufacturer's data.) Now, increase V_1 to shift the collector current slightly higher than this value, and record this new collector current value as i_{c1}. Record the emitter current (meter M_1) as i_{e1}. Finally, reduce V_1 until the collector current shifts the same amount below the original deflection, and record this value as i_{c2}. Record the corresponding emitter current as i_{e2}. Calculate alpha $= (i_{c1}-i_{c2})/(i_{e1}-i_{e2})$. All current values must be expressed in the same units. Alpha will have a value between 0.95 and 0.98 for most power transistors.

To check beta (Figure 2B): With power supply V_1 set to zero output, set the collector voltage (indicated by M_3) to the desired operating voltage for the transistor under test. Next, increase V_1 until the deflection of meter M_2 shows the correct collector current for the selected collector voltage. Next, increase V_1 to shift the

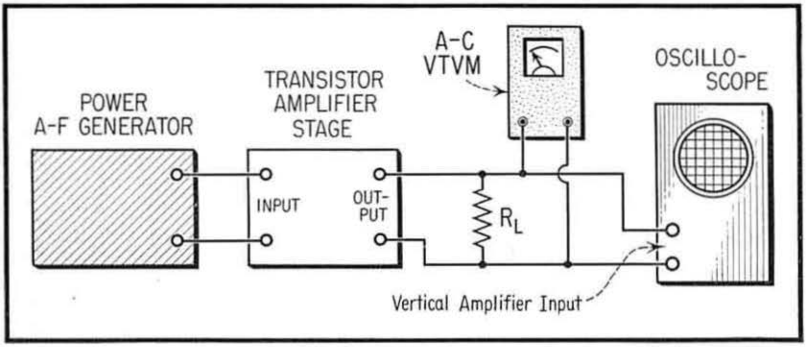

Fig. 3. Power Output.

collector current slightly higher than this value, and record this new collector current value as i_{c1}. Record the corresponding base current (meter M_1) as i_{b1}. Now reduce V_1 until the collector current shifts by the same amount below the original deflection, and record this value as i_{c2}. Record the corresponding base current as i_{b2}. Calculate beta $= (i_{c1}-i_{c2})/(i_{b1}-i_{b2})$. All current values must be expressed in the same units. Beta will have a value between 25 and 50 for most power transistors.

Both alpha and beta may be measured at various collector voltage or collector current levels. All measured values of alpha or beta should be compared with the transistor manufacturer's specifications. Beta decays very rapidly in some defective power transistors.

Collector Dissipation

Collector power dissipation is equal to collector d-c input power minus signal output power. In power output tests, the signal output power is measured in a matched load impedance, and the collector input power is calculated as the product $v_c i_c$. The transistor is delivering power actively to the load. In static tests, however, the collector is called upon to dissipate the entire input power.

In all static tests, the operator must be careful that the product $v_c i_c$, as determined from the deflections of the collector voltmeter and ammeter, at no time exceeds the maximum dissipation rating of the transistor, for the temperature at which the test is made. Excessive power dissipation gives rise to internal heating which, in a circuit such as Figure 1(B), causes the collector current in turn to rise and exceed the dissipation rating still further. The effect is cumulative, is known as **runaway**, and ends in destruction of the transistor.

Power Output

Power output should be checked with the transistor operating in its actual amplifier stage and with its normal signal driving voltage and d-c bias voltages applied. Check the output of power transistors at 1 kc and at as many additional frequencies as are of interest in the proposed application. The amplifier stage should be terminated with a load resistor, the

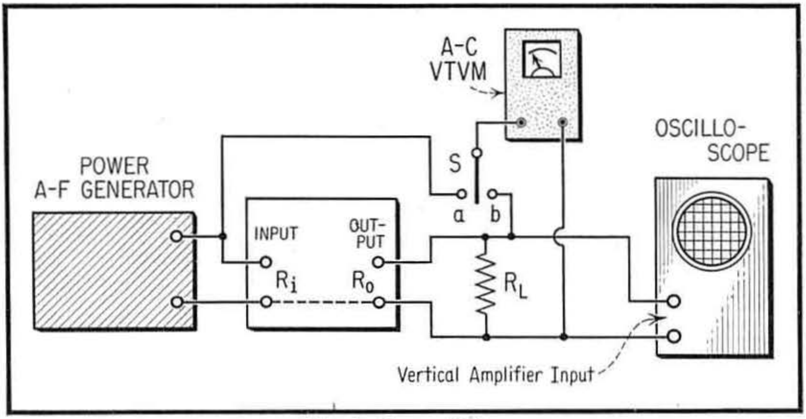

Fig. 4. Power Gain.

resistance of which is equal to the normal output impedance of the stage.

Figure 3 shows the setup for power output measurement. The a-f signal source must be capable of supplying with good regulation the driving power required by the amplifier stage. The oscilloscope permits continuous monitoring of the output-voltage waveform so that distortion may be reduced to a minimum. In this connection, the input-signal amplitude must be held to a level low enough that clipping of the output wave is prevented.

The test procedure is to adjust the input-signal level for maximum output-signal amplitude with lowest distortion, as indicated by the oscilloscope and v-t voltmeter. At this point, the output voltage (E) is read with the vtvm. The output power $P = E^2/R$.

Instead of the v-t voltmeter, an electronic output power meter may be used to obtain direct readings in watts.

Power Gain

Figure 4 shows a setup for checking power gain. This arrangement is similar to the one shown in Figure 3, except that both input and output power are measured and the power gain determined from the ratio of these two values. The power transistor is operated in its own amplifier stage.

The input impedance or resistance (R_i) and output impedance (R_o) of the transistor amplifier stage must be known. The stage is terminated in its characteristic impedance by R_L which is equal to R_o. With the a-f test-signal amplitude adjusted for maximum undistorted output of the amplifier stage, the a-c vtvm is switched first to the input (Switch S in Position a) and its deflection recorded as E_1. Then with Switch S in Position b, the vtvm deflection corresponding to the output voltage is recorded as E_2. Power input $P_i = E_1^2/R_i$, and power output $P_o = E_2^2/R_o = E_2^2/R_L$. Power gain $(PG) = P_o/P_i$. To express the power gain in db, $PG = 10 \log_{10}(P_o/P_i)$.

In both power-test setups (Figures 3 and 4), any transformers in the amplifier circuit must be capable of handling safely the high direct currents of the power transistor. In a Class-A amplifier stage the steady d-c collector current flowing through the primary winding of the output transformer will be between 150 ma and several amperes, depending upon transistor type. The secondary winding of the input transformer must handle between 5 and several hundred milliamperes.

Transistor Resistances

Power transistor resistance parameters may be checked with the setups given in Figures 2 and 5.

Input Resistance, Common-Base. See Figure 5(A). Input resistance (R_{11}) is the slope of the curve showing emitter voltage (read with M_2) vs. emitter current (read with M_1) for constant collector current (read with M_3). To obtain the points for the curve, set the emitter current, by adjustment of supply V_1, successively to a series of test points. At each point, set the collector current to the same constant value by adjustment of supply V_2, and read the corresponding emitter voltage. For a family of curves, repeat at selected values of constant collector current.

Input Resistance, Common-Emitter. See Figure 5(B). Input resistance (R_{11}) is the slope of the curve showing base voltage (read with M_2) vs. base current (read with M_1) for constant collector current (read with M_3). To obtain the points for the curve, set the base current, by adjusting supply V_1, successively to a series of test points. At each point, set the collector current to the same constant value

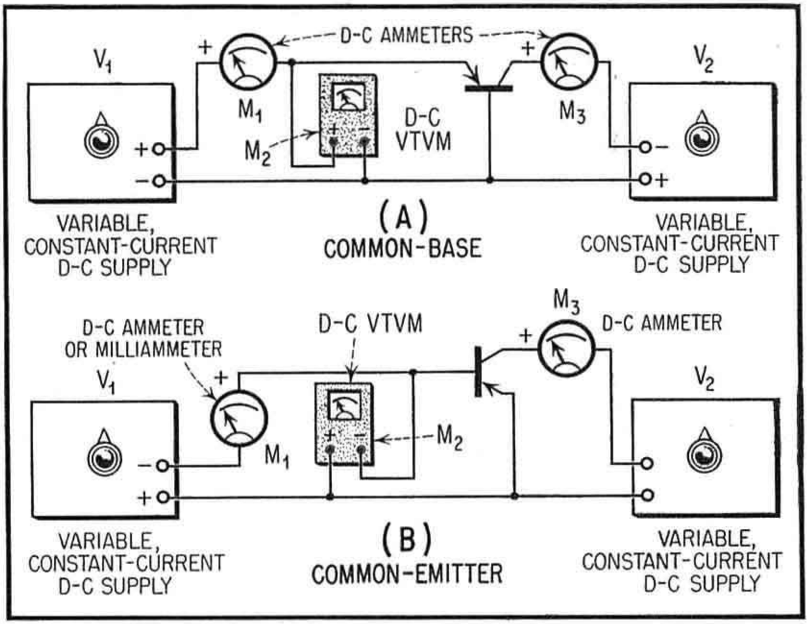

Fig. 5. Input Resistance.

by adjusting supply V_2, and read the corresponding base voltage. For a family of curves, repeat at selected values of constant collector current.

Output Resistance, Common-Base. See Figure 2(A). Output resistance (R_{22}) is the slope of the curve showing collector voltage (read with M_3) vs. collector current (read with M_2) for constant emitter current (read with M_1). To obtain the points for the curve, set the collector current, by adjustment of supply V_2, successively to a series of test points. At each point, set the emitter current to the same constant value by adjustment of supply V_1, and read the corresponding collector voltage. For a family of curves, repeat at selected values of emitter current.

Output Resistance, Common - Emitter. See Figure 2(B). Output resistance (R_{22}) is the slope of the curve showing collector voltage (read with M_3) vs. collector current (read with M_2) for constant base current (read with M_1). To obtain the points for the curve, set the collector current, by adjustment of supply V_2, successively to a series of test points. At each point, set the base current to the same constant value by adjustment of supply V_1, and read the corresponding collector voltage. For a family of curves, repeat at selected values of base current.

Temperature Coefficient

Each of the transistor parameters exhibits some sensitivity to temperature. In applications in which transistorized equipment must operate at elevated or reduced temperatures, it is necessary to determine the extent to which these parameters vary.

To study the effect of temperature on a particular electrical characteristic, use the applicable test setup from Figures 1 to 5. Mount the transistor solidly inside an adjustable temperature chamber, bringing the leads out from the base, collector, and emitter terminals to the external test circuit.

In tests involving a series of temperature levels over a given temperature range, measurements should be made at all points descending, as well as ascending the temperature scale. Any variations in figures obtained at the same temperatures indicate hysteresis effects. A plot of the data will have the characteristic two-route shape of the hysteresis loop.

Operating Temperature

Unlike their low-powered counterparts, power transistors generate appreciable amounts of heat during normal operation. If the operating temperature becomes excessive, the d-c input must be reduced. Transistor manufacturer's data specify maximum temperatures.

The operating temperature of a power transistor should be checked with thermocouples attached to the metal envelope of the unit. The thermocouple must be measured with an accurate millivolt potentiometer.

Matching

For maximum power output and minimum distortion, power transistors which are to be used in pushpull stages should be matched. The main characteristics to be matched are static leakage current, current amplification, collector current, input and output resistance, and power gain. When only the minimum of matching operations can be permitted, static leakage, current amplification, and collector current are suggested.