How To Use DC Voltmeters

Some useful tricks of the trade for getting the most out of your dc voltmeter

By Robert G. Middleton

A few months back, we discussed troubleshooting of the base-biased and emitter-biased common-emitter circuits (see "Troubleshooting With DC Voltmeters" *Modern Electronics*, October 1988). We are now ready to dig a bit deeper, this time into the basic collector-bias configuration. Our discussion here deals with circuit action and dc-voltage distribution patterns for localizing circuit faults, including collector-junction and coupling-capacitor leakages. As you will soon see, some circuit-action features may be a bit unexpected.

Collector-Bias Circuit Action

Referring to Fig. 1, the elementary collector-bias configuration uses single bias resistor R_{b1}. Bias stability is reasonably good, since an increase in collector voltage is fed back to the base, where it produces an increase in emitter current that tends to reduce the collector voltage. Technically, collector bias circuit action involves voltage feedback, whereas base bias with emitter-bias circuit action involves current feedback. We will find some inconsistency in the literature regarding nomenclature. Therefore, here you will find it helpful to go along with tradition to designate collector-base feedback as voltage feedback and emitter feedback as current feedback.

Observe in Fig. 1 that the base bias voltage can be forced off-value by leakage in either coupling capacitor C_C or by leakage resistance from collector to base in the transistor. The primary symptom of leakage is decreased collector voltage.

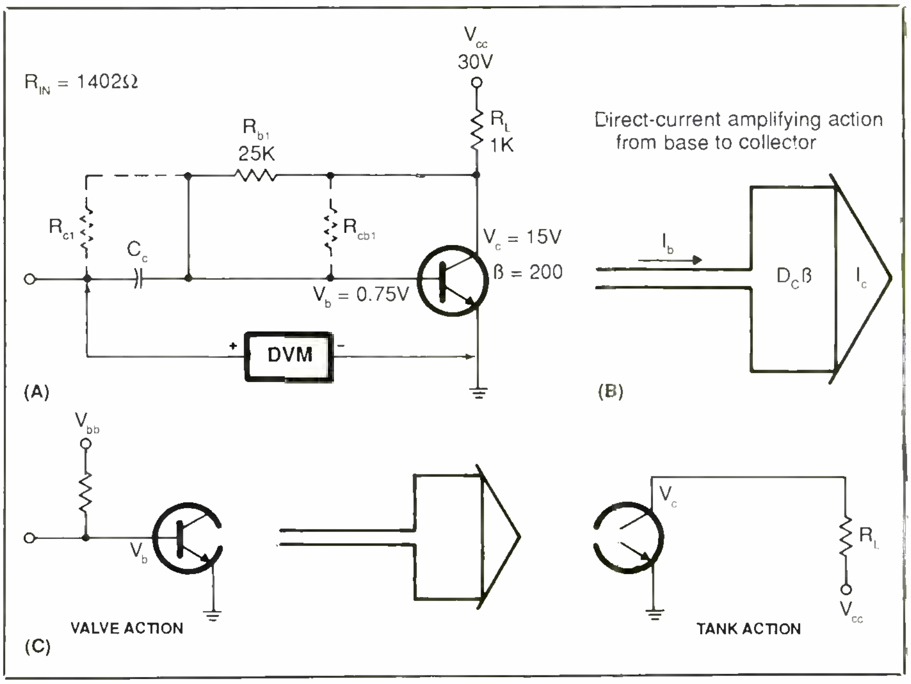

Fig. 1. Basic collector-bias circuit. Circuitry (A) with normal dc voltages; beta circuit action (B); and beta action taking place in collector branch (C).

To check for leakage in C_C, you monitor the base voltage while temporarily short-circuiting the left-hand end of C_C to ground. If the base voltage does not change, you conclude that C_C is not leaky and if base voltage changes, you can conclude that C_C is leaky and must be replaced.

To check for leakage from collector to base in the transistor, this particular circuitry requires a "last-resort" procedure. This is just another way of saying that troubleshooting procedures that do not require unsoldering of connections are required. In this case, you have no choice but to unsolder one end of R_{b1}. In turn, the resistance of R_{b1} can be measured with an ohmmeter.

After one end of R_{b1} has been disconnected from the circuit, you can make a standard turn-off test to check for collector-base leakage. This is accomplished by temporarily short-circuiting the base and emitter terminals of the transistor as you monitor V_C. If V_C jumps up to the V_{CC} value, the collector junction is not leaky. If V_C falls short of the V_{CC} voltage, the transistor is leaky and must be replaced.

DC Voltage Distribution Patterns

It is helpful now to consider the dc voltage distribution patterns for the

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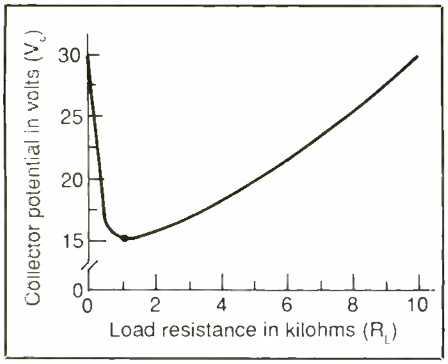

Fig. 2. Plot of variation in collector voltage versus load resistance.

Fig. 1 circuit configuration. You expect the patterns to change when a component drifts off-value. However, voltage-feedback circuitry can be a bit tricky in this regard. In this example, as the resistance of R_L varies from a very low value to a high value, V_c decreases to a minimum of 15 volts when R_L is 1,000 ohms, as illustrated in Fig. 2. Then, as the resistance of R_L increases further from 1,000 to 10,000 ohms, V_c no longer decreases. Instead, it increases steadily up to 30 volts when R_L is approximately 10,000 ohms.

Note that after V_c has increased to 30 volts, the collector cutoff level has been reached and no further increase will occur in V_c, regardless of an increase in the resistance of R_L. This fall-and-rise collector circuit action should be kept in mind when you troubleshoot voltage-feedback circuitry. Otherwise, you could jump to false conclusions by assuming that collector circuit action is a one-way trend when the value of R_L goes high or low. Note that off-values of R_L cannot drive the transistor into saturation. However, leakage resistance can reduce V_c to near-zero potential.

Now consider the voltage-distribution patterns for abnormal and subnormal parameter values, as shown in Table 1. There is one unique pattern in this tabulation: V_c low/V_b high indicates that R_{b1} is low. Note that the combination of V_c high/V_b low can be caused by R_{b1} high or (sometimes) R_L high.

To make a tentative distinction between these possibilities, a trick of the trade will prove helpful. It involves an extension of the data shown in Table 1 and pursues the question of how low V_b has gone in a particular trouble situation. This is just another way of saying that when the value of R_{b1} or R_L is high, V_b goes low—but with a proviso.

Suppose that the normal V_c value is 15 volts and the normal V_b value is 0.75 volt, as in Fig. 1. If R_L is the culprit, V_b will go twice as low as in the case that R_{b1} is causing the problem.

A practical example at this point is illuminating. If you consider the circuit parameters in Fig. 1, V_b is normally 0.75 volt. If the value of R_L increases from 1,000 to 5,000 ohms, V_c will rise to 21.2 volts and V_b will decrease to 0.66 volt (a decrease of 0.09 volt from the normal of 0.75 volt).

If the value of R_{b1} increases from 25,000 to 40,000 ohms, V_c will rise to 21.5 volts and V_b will decrease to 0.71 volt (this time, a decrease of 0.04 volt). Accordingly, with all other things remaining the same, increased values of R_L push V_b down twice as much as do increased values of R_{b1} (in this example).

The essence of this trick of the trade is for you to keep in mind that the foregoing general idea is base-voltage decrements under trouble conditions. A trouble condition is generally "spotted" first as a substantial increase in V_c, such as an increase from 15 volts to 20 volts or more, as in this example.

When this off-value condition is encountered, you ask how V_b is behaving. You know from experience (or the service data) that V_b normally rests at 0.75 volt. Then if you find that V_b has dropped in value by about 0.1 volt, you know that the value of R_L has probably gone high. On the other hand, if you find that V_b has dropped in value by about 0.05 volt, you conclude that the value of R_{b1} has gone high.

Now consider a low-beta fault condition. As detailed in Table 1, when beta goes low, both V_c and V_b go high. In this example, when the value of R_L goes low, both V_c and V_b go high. A similar trick of the trade is very helpful in this situation. As a rough rule of thumb, V_b will go twice as high if beta is the culprit.

As a practical example, if the value of R_L decreases from 1,000 to 150 ohms, V_c will rise to 20.1 volts *and* V_b will rise to 1.11 volts. However, if beta decreases from 200 to 20, V_c will rise to 21.8 volts *and* V_b will rise to 1.22 volts.

The bottom line is that, disregarding the integral part of the measured values, the decimal portion of the measurements went twice as high when beta decreased in value.

As in the above example, it is evident that the essence of this trick of the trade is for you to keep in mind a general idea of base-voltage increments under trouble conditions. The guidelines are the same in either case.

Table 1. Dc Voltage Distribution For Abnormal & Sub-Normal Circuit Parameters

	R_{b1} High	R_{b1} Low	R_L High	R_L Low	Beta Low
V_c	High	Low	High or Low	High	High
V_b	Low	High	Low	High	High

Note: In this example, normal Vc is 12 volts and normal Vb is 0.75 volts; a High Vc is greater than 15 volts; a Low Vc is less than 15 volts; a High Vb is less greater than 0.75 volt; a Low Vb is less than 0.75 volt. Except for normal Vc and Vb voltages, all voltages are measured values.

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You are looking at base-voltage decrements in the first example, whereas you are looking at base voltage increments in the second example.

Boundary-Limit Parameters

Practical troubleshooting situations often involve boundary-limit analysis. Hence, the transistor will be cut off wherein collector voltage will be at the V_{cc} level, or the transistor will be in saturation wherein collector voltage will be almost zero. Although the transistor will be cut off (in this configuration) when any parameter goes sufficiently off-value, saturation cannot even be approached when R_L goes off-value, as we saw in Fig. 2. However, saturation can occur in the case of coupling-capacitor or collector-base junction leakage.

In Fig. 1, if R_{b1} increases in value to 62,650 ohms, V_c will equal V_{cc} and V_b will be 0.65 volt. However, if R_{b1} decreases in value to 1,000 ohms, V_c will fall to 2.2 volts. Perhaps unexpectedly, if R_{b1} decreases in value to less than 1,000 ohms, V_c will not decrease; instead, it will proceed to increase.

When R_{b1} is 1,000 ohms, V_b is 0.73 volt. If R_L goes very low in value or becomes short-circuited, V_c goes to 30 volts and V_b goes to 1.68 volts. This excessive bias voltage is a clue to you that the collector load resistor is the culprit.

There is a joker to contend with here. The excessive bias voltage is a clue to the possible cause of the trouble, but it is not conclusive evidence that it is the culprit. In the event that beta goes extremely low—below unity —V_c goes to the V_{cc} level and V_b goes to 1.68 volts.

If you suspect that V_c has slumped to an extremely low value, you can opt to make an in-circuit resistance measurement of R_L with power to the circuit turned off, using a low-power ohmmeter. A low-power ohmmeter is required to avoid turning on a transistor junction and thereby falsifying the resistance measurement being made.

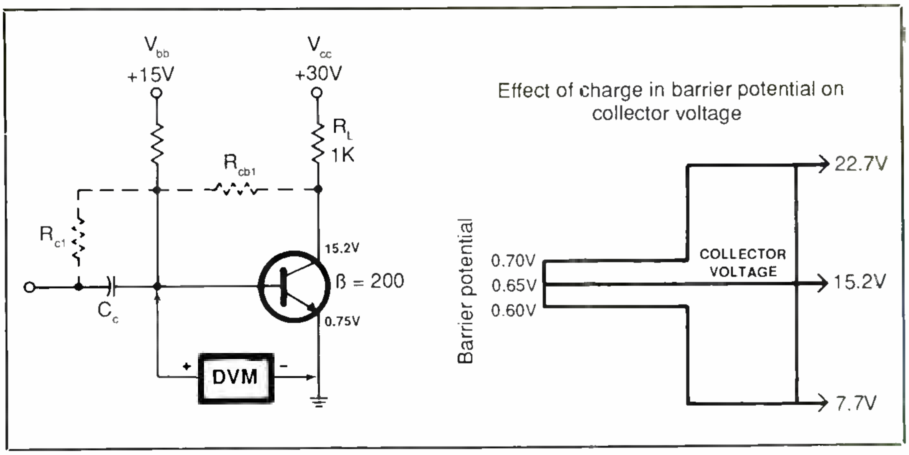

Fig. 3. Basic base-bias circuit without current or voltage feedback.

Base Bias, No Feedback

It is helpful to briefly consider a very simple common-emitter circuit that employs base bias without either current or voltage feedback, as illustrated in Fig. 3. This "skeleton" arrangement illustrates the basic factors that are the foundation of circuit action in comparatively elaborate feedback networks. In practice, this elementary arrangement is rarely encountered, due to its relatively poor bias stability, susceptibility to "thermal runaway," and greater distortion level. The sole technical advantage of this simple arrangement is its relatively high gain.

As might be anticipated, the Fig. 3 circuit has low tolerance to variations in parameter values. For example, if R_{b1} increases in value from 26,700 to 28,000 ohms, V_c rises from 15.2 to 20.2 volts. This is a tolerance of less than 5 percent on the rated value of resistor R_{b1}.

"Thermal runaway" is the technical term for the rapid increase in dc beta that occurs when a transistor starts to heat up appreciably when it is overdriven. In the absence of negative feedback, the beta value "mushrooms" and excessive current flow damages or destroys the transistor.

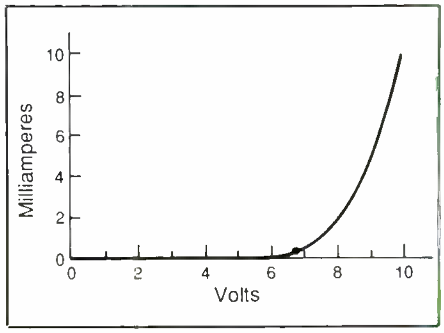

Fig. 4. A typical base-emitter junction characteristic in graphed form.

The 0.75-volt base potential of the Fig. 3 circuit results from voltage-divider action between V_{bb} and ground. Resistor R_{b1} has a rated value of 26,500 ohms in this example, and rated base potential is 0.75 volt. Thus, effective base input resistance is 1,405 ohms.

In Fig. 4, base input resistance is the ratio of V_b/I_b at the operating point on the base-emitter E/I junction characteristic. The bottom line is that Ohm's law calls the shots.

In this example, the transistor has a rated input resistance of approximately 1,500 ohms. However, measured values correspond to an input resistance of 1,405 ohms. There are two reasons for this discrepancy. One is that the rated input resistance of the transistor is specified on the basis of a short-circuited output. In practice, though, the output is not

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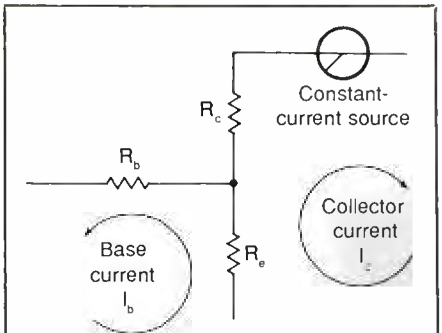
short circuited but (in this example) the collector output is returned to ground via the 1,000-ohm load resistor. As will be demonstrated, base input resistance is a function of collector load resistance.

We will also show that base resistance is a function of the transistor's dc beta value. In Fig. 5, it is helpful to observe the traditional resistive (r) parameter symbol and to disregard the modern symbol for a moment. When an input (bias) voltage is applied between the base and emitter terminals, base current I_b flows. Also, since the base circuit functions as a valve, collector current I_c also flows. This collector current is equal to base current I_b multiplied by the dc beta of the transistor, which is 200 in this example. In turn, total emitter current I_e, is equal to the sum of base current I_b and collector current I_c.

Observe that in the common-emitter circuit configuration R_e is common to both base and collector currents. Accordingly, when I_c flows through R_e, a voltage drop is produced that assists the applied bias voltage. Since Ohm's law states that resistance is an E/I ratio, it is evident that the flow of I_c increases effective base input resistance. Moreover, inasmuch as an increase in the value of R_L causes a reduction in I_c, it follows that base input resistance will decrease as the value of R_L increases.

It is also evident that if beta decreases, there will be less amplification of the base input current and I_c will decrease. When the latter occurs, there is less current through R_e and the effective base input resistance increases as beta decreases.

From the foregoing, you can see that base bias voltage depends upon the rated base input resistance of the transistor, the value of the load resistance being used and the effective prevailing dc beta value. However, in the first analysis, you can disregard second-order effects and assume that the transistor's base input resistance is the rated h_{ie} value given in the



LEGEND:
R_b = Base resistance of transistor
R_c = Collector resistance of transistor
R_e = Emitter resistance of transistor
Total emitter current $I_c = I_b + I_e$

Fig. 5. The traditional r-parameter symbol for a transistor.

manufacturer's data sheet. In our example, h_{ie} is rated at 1,500 ohms.

With Voltage and Current Feedback

You are now in a good position to consider troubleshooting procedures for the basic collector-bias circuit with emitter feedback, as illustrated by the circuit shown in Fig. 6. This circuit employs both voltage feedback and current feedback, with R_{b1} providing the former and R_e providing the latter.

In collector-bias circuits, no V_{bb} source is provided. Collector voltage V_c serves this purpose in its stead. As might be anticipated, the Fig. 4 circuit has very good bias stability and is quite tolerant of variations in parameter values. It also has low inherent distortion. Its chief disadvantage is that the circuit has relatively low gain.

As far as base voltage is concerned in Fig. 6, you should note that voltage feedback has the effect of lowering base input resistance and that current feedback has the effect of raising it. Therefore, in the first analysis, you assume that base input resistance will be comparable with the rated h_{ie} of the transistor. A check of C_c leakage can be made as previously described by monitoring the base voltage while a temporary short circuit is placed between the left-hand end of the coupling capacitor and circuit ground.

The possibility of leakage resistance R_{cb1} usually requires a "last-resort" procedure in which one end of R_{b1} is disconnected from the circuit and its resistance is measured with an ohmmeter. The only exception occurs in the case where the R_L circuit can be switched completely open so that the apparent resistance of R_{b1} can be measured in-circuit with a low-power ohmmeter. (Keep in mind, though, that filter capacitors can cause prolonged ohmmeter "crawl" in which the meter reading continues to change.)

Table 2 lists the dc voltage distribution patterns for the Fig. 6 circuit arrangement. There is only one unique group of conditions in this table and that is when beta is low, V_c goes high, V_e goes high, and V_b goes low. Thus, it is easy for you to spot a low beta value, although the other four groups are ambiguous in the first analysis. Stated differently, when V_c is low with V_b and V_e high, the cause could be R_{b1} low or R_{b2} high; when V_c is high with V_b and V_e low, the fault could be R_{b1} high or R_{b2} low. When V_c, V_b and V_e are all high, the

Table 2. Dc Voltage-Distribution For Circuit With Voltage & Current Feedback

	R_{b1} High	R_{b1} Low	R_{b2} High	R_{b2} Low	R_L High	R_L Low	R_e High	R_e Low	Beta Low
V_c	High	Low	Low	High	Low	High	High	Low	High
V_b	Low	High	High	Low	Low	High	High	Low	Low
V_e	Low	High	High	Low	Low	High	High	Low	High

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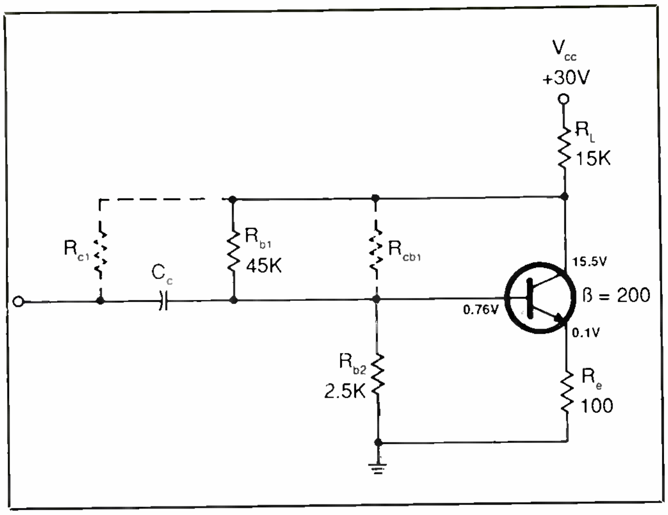

Fig. 6. Basic collector-bias circuit in which no V_{bb} or V_{ee} source is used.

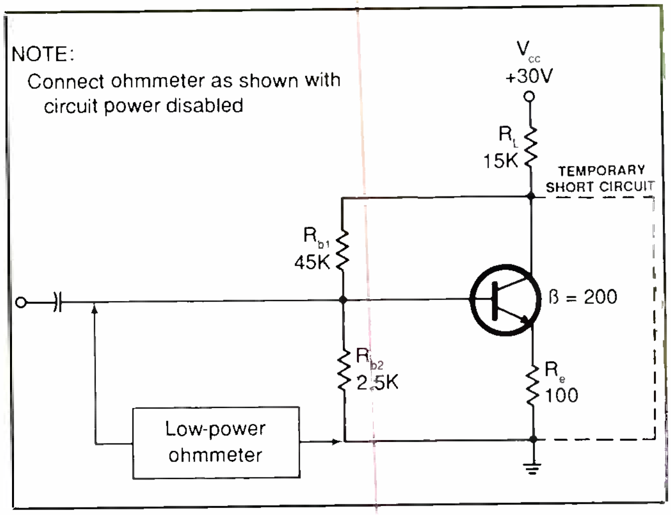

Fig. 7. Test setup for measurement of Thevenin resistance for the bias voltage divider.

fault could be R_L low or R_e high; when V_c, V_e and V_b are all low, the fault could be R_L high or R_e low.

At first glance, the dc voltage distribution patterns listed in Table 2 seem to present a "tough-dog" problem. However, there is an independent test that you can use that easily distinguishes between R_{be} high and R_{b2} low and vice-versa. This novel trick of the trade consists of comparison between the measured Thevenin resistance of the R_{b1}/R_{b2} voltage divider and the theoretical Thevenin resistance of the divider.

The measured Thevenin resistance is the net resistance of R_{b1} and R_{b2} connected in parallel with each other. The theoretical Thevenin resistance is calculated from the rated resistor values by means of the product-over-sum formula, which can easily be punched out on a pocket calculator.

You will discover that the measured Thevenin resistance will differ from the theoretical Thevenin resistance in the event that R_{b1} is high or R_{b2} is low. Put another way, if R_{b1} is high, the measured/theoretical ratio will be high and vice-versa. The theoretical value is a median value; the measured value will be higher or lower than the median value. As shown in Fig. 7, a low-power ohmmeter is used to make these measurements to avoid turning on the base-emitter junction of the transistor.

It is helpful to consider a practical example at this point. From service data or resistor color coding, we note that R_{b1} has a rated value of 45,000 ohms and that R_{b2} has a rated value of 2,500 ohms. In turn, the parallel resistance value of these two resistors is theoretically approximately 2,368 ohms. This ideal value is greater than the measured Thevenin resistance when the value of R_{b2} is low and is less than the measured Thevenin resistance when the value of R_{b2} is high.

If the value of R_{b1} is 45,000 ohms and the value of R_{b2} is 1,500 ohms, the measured Thevenin resistance is 1,452 ohms. On the other hand, if the value of R_{b1} is 70,000 ohms and the value of R_{b2} is 2,500 ohms, the measured Thevenin resistance will be 2,414 ohms.

Since 1,452 ohms is considerably less than 2,368 ohms and 2.414 ohms is considerably greater than 2,368 ohms, the ambiguity is clearly resolved. This trick is based upon the circumstance that the Thevenin resistance consists of a product divided by a sum. With R_b high, the product increases out of proportion to the sum, and with R_{b2} low, the product decreases out of proportion to the sum. These conflicting proportions "finger" the cause of the trouble and eliminate the time-consuming "shotgun" troubleshooting procedure often used. **ME**

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