SCIENCE PROJECT

Basic Transistor Operation

Transistors require proper sources of voltage to keep currents at a safe value. Output energy must be coupled into some form of load in order to appear at the correct circuit point. Other components must be chosen so power is efficiently transferred from one section of the circuit to another.

An effective way to gain insight into over-all transistor operation is the construction of a simple one-transistor amplifier. As it is adjusted, varied, and measured, the underlying transistor action may be observed. As stated earlier, this is its ability to utilize a small current flowing between base and emitter to control a much larger flow between emitter and collector. Such an amplifier and its construction details are described in this chapter. As the idea of amplification becomes clear, it is an easy matter to modify the circuit so it performs as an oscillator; an important application evolving from the transistor's inherent ability to amplify.

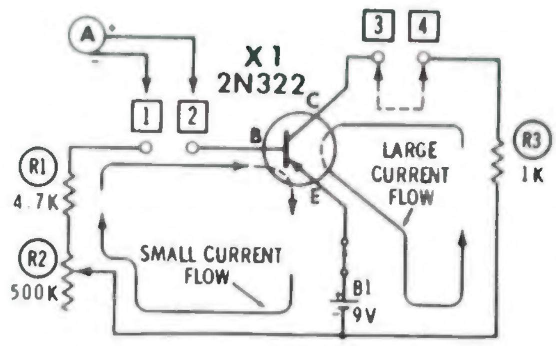
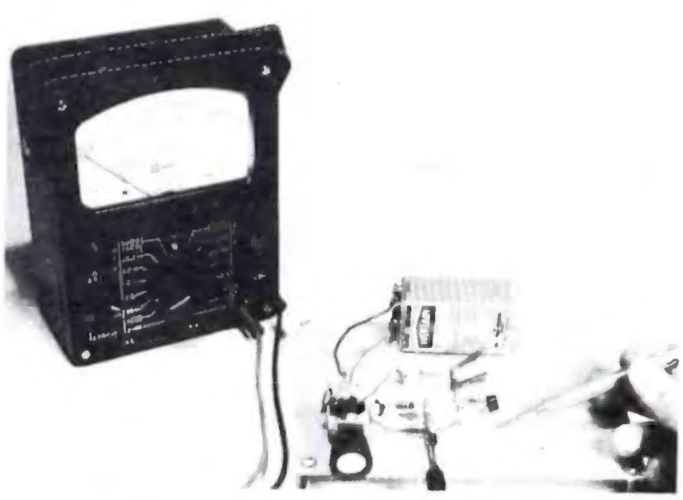


Fig. 1. Common-emitter amplifier circuit.

COMMON-EMITTER AMPLIFIER

The example chosen to demonstrate amplification represents the most widely used circuit configuration; the *common emitter.* This is shown in the schematic of Fig. 1. The name is derived from the fact that the emitter is common to both the input (the section of the circuit that receives a signal) and output (the area where amplified energy appears). The transistor itself is a PNP type 2N322, which is typical of the numerous general-purpose units that are popular among experimenters.

To set up a working demonstration, follow the construction details set forth in Fig. 2 and the following Parts List.



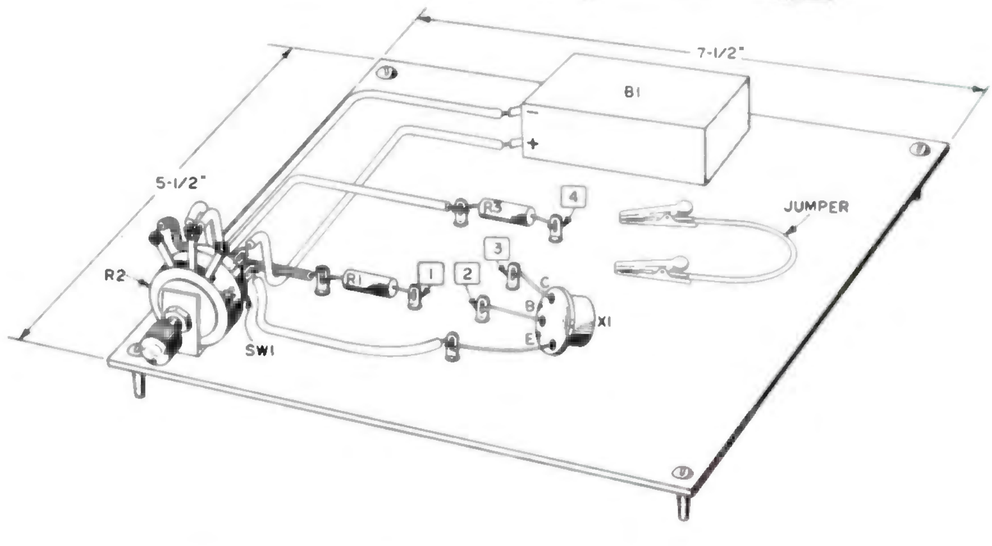


Fig. 2. Pictorial drawing of common-emitter amplifier.

PARTS LIST

R1—4.7K ½-watt resistor (962 B 1800 $.12)
R2—500K potentiometer with switch (961 B 1714 $1.50)
R3—1K ½-watt resistor (962 B 1800 $.12)
X1—2N322 transistor ($.64)
B1—9-volt transistor-type battery (23-464 $.35)
SW1—Switch for R2 (961 B 5400 $.99)
Misc.—Perforated board; circuit push-in terminals (270-1394 $1.59 per 100); battery clips (270-325 $.60/pkg. of 5)

The chassis is simply a piece of perforated board to which various circuit components are mounted. The leads supported by small metal clips, terminal strips or simply threaded through board holes. The potentiometer control is bracket-mounted in one corner by means of a strip of scrap metal. Two connections in the circuit are purposely incomplete. They provide test points for connecting meter leads to measure current flow at the input and output sides of the transistor. Notice that points 1 and 2 allow current readings to be taken at the base of the transistor; 3 and 4 are in the collector circuit. Whenever the meter is connected to measure current at one set of test points, the other set must be shorted. This is done with a small jumper made by attaching alligator clips to both ends of a piece of hookup wire. The jumper may then be shifted back and forth between collector and base, as is the meter.

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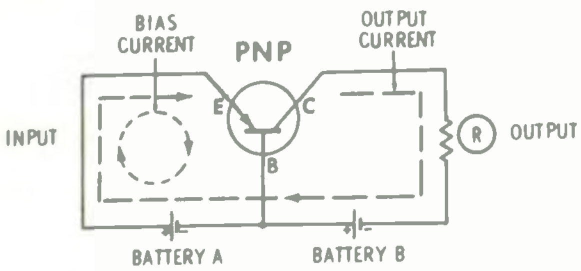

Fig. 3 – Common-base amplifier circuit.

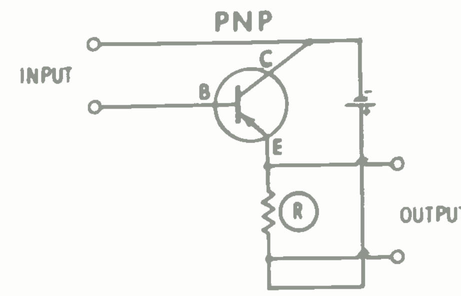

Fig. 4 – Common-collector amplifier circuit.

Caution: Remember that the meter range switch must be changed to prevent slamming the needle. A recommended procedure is to start with the meter on the highest range and then switch to a lower range that provides the best indication.

The meter is a VOM (volt-ohm-milliammeter). It is the most valuable single instrument used by the electronic hobbyist to analyze, adjust and troubleshoot home-built circuits. While a relatively inexpensive VOM is adequate for checking many transistor circuits. the sensitive 20,000 ohms-per-volt model should be considered if the hobbyist contemplates any significant amount of experimentation.

The basic layout of the amplifier contains various elements already described in terms of theory, plus new components which make it a practical circuit. Notice the position of the 9-volt battery in the schematic. The negative terminal can apply voltage to the base through resistor R1, potentiometer R2, and test points 1 and 2. The emitter connects to the positive battery terminal through on-off switch SW1. Thus, the forward bias requirements of a PNP transistor are met. The collector-emitter circuit receives correct bias voltage from the battery. The purpose of the three resistors should become apparent as the circuit is placed into operation. The over-all object is to discover if a small input current to the base circuit will result in a large current flow in the collector circuit. The action may be followed by actually performing the following steps, or tracing out the schematic in Fig. 1.

EXPERIMENT TESTS

First, the meter is set to read at least 100 microamperes, and its negative probe is clipped to test point 1. The positive probe goes to point 2. Test points 3 and 4 are connected with the jumper. Turn on the power by rotating potentiometer R2 and observe the current indicated by the meter. It should be possible to vary the reading from nearly zero up to 90 or 100 microamperes. Note the action of the potentiometer; its slider determines how much resistance, and thus voltage drop, occurs between the base and negative battery terminal. The lower the resistance, the greater the voltage difference there is between base and emitter. As forward bias between these elements is increased, the current in the base-emitter circuit increases. The fixed resistor, R1, serves as a current-limiting device. It keeps a small amount of resistance between base and battery at all times. Otherwise, full battery voltage at the base might cause a current flow beyond the maximum rating of the transistor.

Base currents may now be compared with those flowing in the collector. As a starting point, adjust the potentiometer so 20 microamperes is indicated on the meter. Don't disturb the potentiometer and transfer the meter leads to test points 3 and 4 – positive probe to 3 and negative to 4. Shift jumper to points 1 and 2. Collector current should be on the order of .5 milliampere (500 microamperes). This is only an approximate figure, since wide variations between transistors are normal.

One highly significant conclusion may be drawn from these simple steps: If a base current of 20 microamperes causes the collector to conduct .5 milliampere, then the collector current is approximately 25 times greater than that flowing in the base. This represents the DC current gain of the transistor, more precisely termed *DC beta,* and is a measure of the transistor's ability to amplify. As mentioned in an earlier chapter, the original source of current is the battery. The arrows in the schematic of Fig. 1 point out the principal directions taken by electrons from the battery.

The demonstration circuit can reveal another major characteristic of the amplifier. This is an ability to recreate the shape of the current being amplified. To prove this for yourself, restore the board to its original setup by returning the jumper to test points 3 and 4 and the major leads to 1 and 2. Adjust the potentiometer for a reading of 40 microamperes in the base circuit, exactly double that of the earlier step. If collector current is now measured it will be found to be conducting about 1 milliampere, also double the previous value. A third check can be made by adjusting R2 for a base current of 80 microamperes. In this case, collector current should rise to 2 milliamperes. Thus, it may be seen that the 2N107 not only amplifies by a factor of approximately 25, but does this in a ***linear*** manner. This is true over a range of input currents which fall within the transistor's normal ratings. Linearity in the transistor in many applications is important. For example, if small voice currents from a microphone are to be amplified, the large output currents from the transistor should bear the same basic shape as the input, or distortion will result.

With the existing setup, a characteristic peculiar to the common-emitter amplifier can be examined. Although a signal passing through a transistor wired in this manner is amplified faithfully, the output is actually a mirror image of the input. A process of *phase reversal* occurs. It is easy to demonstrate. Both test points on the board are jumpered, one with the clip lead already made up, the other with a short piece of bare hookup wire. The VOM is adjusted to read 9 volts DC and the probes connected; positive to the positive battery terminal and negative to the transistor collector. When the power is turned on, the meter reads the voltage between emitter and collector – approximately 9 volts. But, as the potentiometer is rotated to increase base current, note that collector voltage proceeds to drop It reaches nearly zero when the potentiometer is at full clockwise.

Thus, it may be seen that an increase of negative voltage applied to the base causes a corresponding decrease of nega-

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tive voltage at the collector. In effect, the collector is shifting to an opposite, or in a more positive, direction from that of the base. The net effect is that a negative-going signal applied to a common-emitter amplifier creates a positive-going signal at the output.

COMMON-BASE AMPLIFIER

This arrangement is encountered less often than the common emitter, but finds some application in oscillator circuits. There is no phase change in a signal as it is transferred from input to output of a common-base amplifier, *and current gain is always less than one.* This last statement does not mean that the transistor fails to amplify. Although current may be greater at the input, voltage changes are greater at the output than at the input.

The basic action of the common-base connection is shown in Fig. 3. Note that the base is common to both emitter and collector circuits. Battery A supplies the necessary current to bias the emitter in the forward direction. The other voltage source, Battery B, provides the reverse bias required by the collector. Bias current, indicated by the light arrows, is a relatively small circulation between emitter and base. Tracing the larger circulation of collector current, we find that it also flows in the input circuit, traveling from collector, through the two batteries, to the emitter. Thus, it may be seen that output current also flows in the input. If bias current at the base were made to increase, over-all current would also rise. The load resistor (R) in the collector circuit displays an increasing voltage drop as added current flows through it.

COMMON-COLLECTOR AMPLIFIER

This is the final arrangement in the three basic amplifier connections. The input signal (see Fig. 3) is applied between base and collector. As the signal grows increasingly negative, current flow in the output (emitter-collector) also rises. The direction of the signal at the output is the same as for the input which accounts for the lack of phase reversal in the common-collector amplifier.

IMPEDANCE

This term is used often in conjunction with transistor amplifiers. It is a relationship between voltage and current, as determined by the amount of opposition presented to current flow. In general, where relatively large currents flow, impedance is low. The value is measured in ohms and is increasingly significant when signals must be transferred in and out of the transistor amplifier at maximum efficiency. Optimum power transfer occurs when the signal source has the same impedance as the input impedance of the transistor. Of equal importance is the impedance of the load, which should extract maximum energy from the transistor. It, too, must display an impedance as nearly equal to the transistor's output impedance as possible.

This largely accounts for the application of the three different amplifier arrangements just described. In the common-emitter circuit, input impedance is characteristically low, on the order of a few hundred ohms. The reason is that the base is biased in a forward direction and the opposition, or resistance, to current flow is also low. Output impedance is considered to be medium, a few thousand ohms; the collector circuit is reverse-biased and exercises greater opposition.

The other amplifier arrangements, as a consequence of their current flows, display different characteristic impedances. In the common-base, for example, it is extremely low at the input, extremely high at the output. The condition is exactly reversed in the common collector amplifier — very high input impedance, very low output impedance. Through choice of amplifier arrangement, the designer can choose a configuration which best serves the needs of a particular circuit. It must be realized, however, that there is a limitation inherent in this process since voltage and current amplification are also variable factors. This helps to explain the popularity of the common-emitter amplifier; it yields relatively high gain when considered in terms of voltage, current, or power.

AC AMPLIFIERS

For the sake of simplicity, the transistor has been described here as a device capable of amplifying a DC, or direct current, signal. In practice, however, AC amplification is far more commonplace. The input signal often takes the form of a rapidly changing current flow which alternates directions providing positive and negative values. Fig. 5 illustrates a typical AC amplifier. Note that it is similar to the earlier version of the common-emitter PNP amplifier, except for the addition of capacitors C1 and C2.

Resistor R1 acts as the base bias resistor. Its value is selected so a nominal amount of current results in the collector and through load resistor R2. Collector current at rest is shown by the dotted line marked "Static Current." Up to this point, we have a basic DC amplifier. The current through it is steady and unchanging. The application of an input AC signal alters this condition. This is shown as a varying current shifting between plus and minus at the left. As the AC signal reaches the base (through capacitor C1 which offers no opposition to AC), it will oppose or aid base bias current. When the positive part of the AC cycle is applied, it cancels some of the negative-going bias and current in the collector circuit drops. The opposite effect occurs, when the negative-going part of the cycle adds to the base bias; collector current increases. Therefore, collector current is made to vary in strength around its static, or resting, value. Notice that output current is an accurate reproduction of the AC input, though much larger in amplitude, or strength. There is the phase change, which typifies the common-emitter amplifier, but it is of little concern in this application.

The function of the two capacitors in the circuit is to preserve the operating biases applied to the transistor by the battery. Capacitors have the ability to block steady DC, while presenting little opposition to a varying (AC) signal; thus the original biases cannot be lost through the input and output pathways.

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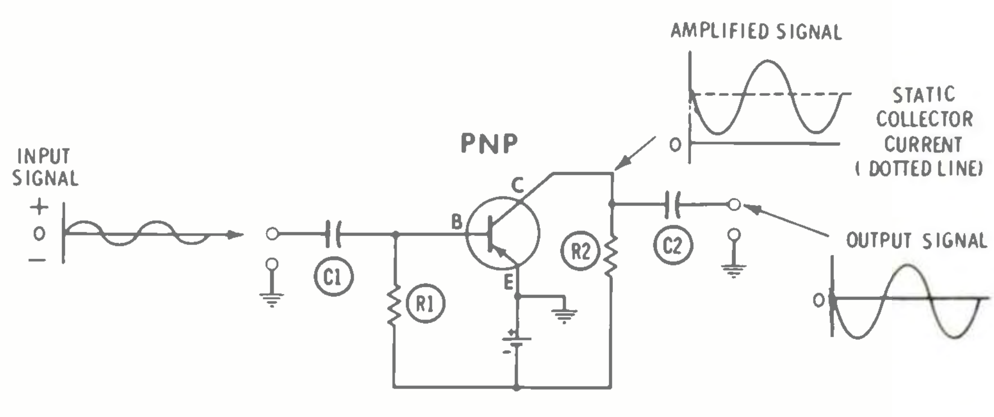

Fig. 5 – Basic AC amplifier circuit.

An examination of the amplified output reveals an interesting phenomenon. Notice that the waveform of the collector signal lies completely above the zero current line. Although it is a recreation of the input, it has been changed from AC to pulsating DC. This occurs since the signal is, in effect, a changing of static collector current which can only flow through the transistor collector-emitter circuit in one direction. The output capacitor passes pulsating DC in much the same manner as the original AC input. DC is blocked and the zero reference is preserved.

The next section presents a description of how you can construct a practical amplifier to illustrate these principles just discussed.

AC AMPLIFIER EXPERIMENT

The common-emitter circuit in Fig. 1 is readily converted to a demonstration model for AC amplification. The additional items needed are:

(1.) a .1-mfd tubular capacitor

(2.) one earphone, 1,000-ohm magnetic type

(3.) additional hookup wire

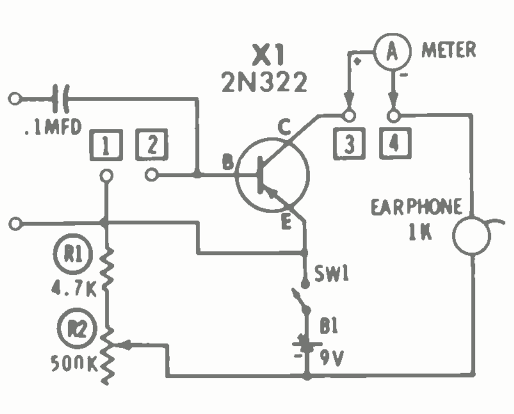

Fig. 6 – Practical AC amplifier circuit.

The altered circuit is shown in Fig. 6. The AC signal to be amplified can be obtained from the speaker leads of a radio (or phonograph). Connect two lengths of hookup wire to the terminals of the speaker and bring them near the circuit board. As a preliminary test, connect the earphone to the ends of these leads and listen to the signal. The radio volume control should be left at a low level throughout these steps, providing just enough volume to be barely audible in the earphone. If you find it difficult to differentiate between the sound from the radio speaker and that from the earphone, disconnect one speaker lead, being certain that it is rejoined to the piece of hookup wire.

Next, wire the earphone into the collector circuit of the transistor to serve as a load. (The 1,000-ohm resistor used for the earlier demonstration should be removed completely during this step.)

Set the VOM to read approximately 1 milliampere of current and connect its probes to test points 3 and 4. (Observe the polarity given in the schematic.) Once the on-off switch is turned on, the potentiometer which controls base bias is rotated for a collector current of exactly 1 milliampere. This amount of current establishes a Class-A mode of operation for the transistor.

Now the signal may be applied to the input. Note that this is introduced through the .1-mfd blocking capacitor fastened to the base of X1. The other input connection is the piece of hookup wire to the emitter.

Listen in the headphone – the volume of the program should sound considerably louder than when it was obtained directly from the radio. If there is distortion, lower the volume control setting on the radio to avoid overloading the transistor input. (This is best accomplished while listening to a voice program.)

In addition to the concept of amplification, the circuit demonstrates other characteristics. Note that the meter needle, which is indicating collector current, remains fixed at 1 milliampere while the program is being amplified. Although the input AC signal is causing a great fluctuation in collector current, this occurs above and below the 1-ma static collector value. The needle cannot move at the rapid audio rate of the program and therefore settles down at the average 1-ma value. This current level remains the same no matter what the level of input signal, as determined by the radio volume control setting. It is, of course, possible to overload the transistor by increasing the input beyond the current-handling ability of the base circuit.

EDITOR'S NOTE: The foregoing article was reprinted in part from an outstanding little handbook entitled Understanding Transistors and Transistor Projects. It provides a practical introduction to the "inner workings" of the transistor in a number of interesting circuits which can be built at school or at home. It explains basic transistor circuitry and then brings this knowledge to life with a series of experimental and practical projects. The handbook is available at Radio Shack Stores throughout the U.S. and some areas of Canada. Its cost is listed at 95 cents.