

**Elementary
Electricity**
and
Electronics
component by component
Mannie Horowitz

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Common Base Circuit

The basic circuit used in the *common-base* arrangement is shown in Fig. 8-4. The base terminal is the common or reference point. A negative voltage is applied to the emitter with respect to the base so that this junction is forward biased. Voltage between the collector and base is of such polarity as to reverse bias this junction. Resistor R_E in conjunction with E_{EE} sets the emitter current, I_E . The arrow at I_E shows the direction in which conventional current flows in the base-emitter circuit.

Because current flows through the base-emitter circuit 0.7 volt is across this junction. The total voltage in this section of the circuit outside the transistor is $E_{EE} - 0.7$. The emitter current is equal to this voltage divided by the total resistance in this circuit. Here, this resistance is only R_E .

Emitter current is equal to the sum of the base and collector currents. Because very little base current flows compared to the collector current, the collector current, I_C , is essentially equal to the emitter current, I_E . With the current at the input equal to the current at the output, the current gain, I_C/I_E , is just about equal to 1. It is actually equal to the alpha of the transistor, which is close to 1. Voltage at the collector with respect to the base is equal to E_{CC} minus the voltage developed across R_C due to I_C , or $E_{CC} - I_C R_C$.

Transistor circuits are usually designed to amplify an ac input voltage rather than dc current. In this type of arrangement, the ac is superimposed on the dc. The dc is used to establish specific quiescent emitter and collector currents. These *bias currents* should set the idling voltage (voltage before ac is applied to the circuit) at the collector at one-half of E_{CC} . Because the collector voltage, V_C , is equal to $E_{CC} - I_C R_C$, V_C should be idling at about $E_{CC}/2$.

Now lets place an ac voltage, V_{in} , in series with the existing dc voltage in Fig. 8-4. This is illustrated in Fig. 8-5. Here, it is as-

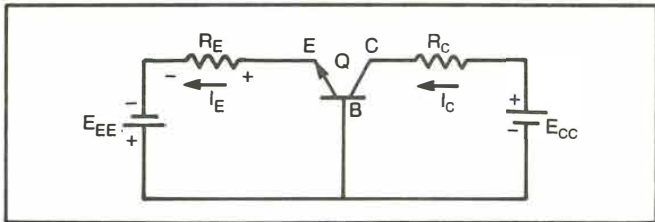


Fig. 8-4. Basic common-base circuit.

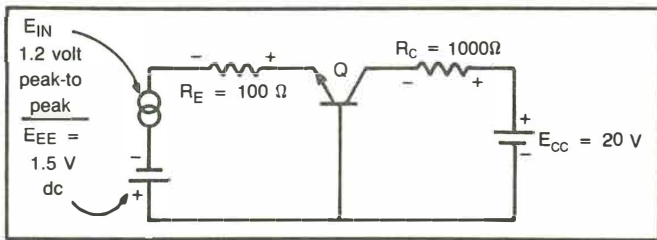


Fig. 8-5. Common-base ac amplifier.

sumed that the emitter supply voltage is fixed at 1.5 volt and that an ac with a 1.2 volt peak-to-peak level is superimposed on the dc. This combination is applied to the base-emitter circuit.

Adding ac sinusoidal voltage to dc voltage can be accomplished graphically. An example of this is shown in Fig. 8-6. For this illustration, it is assumed that the ac input signal varies from 0 volt to a peak of +1 volt and to a crest of -1 volt. The dc voltage, E_{EE} , is chosen at different fixed levels.

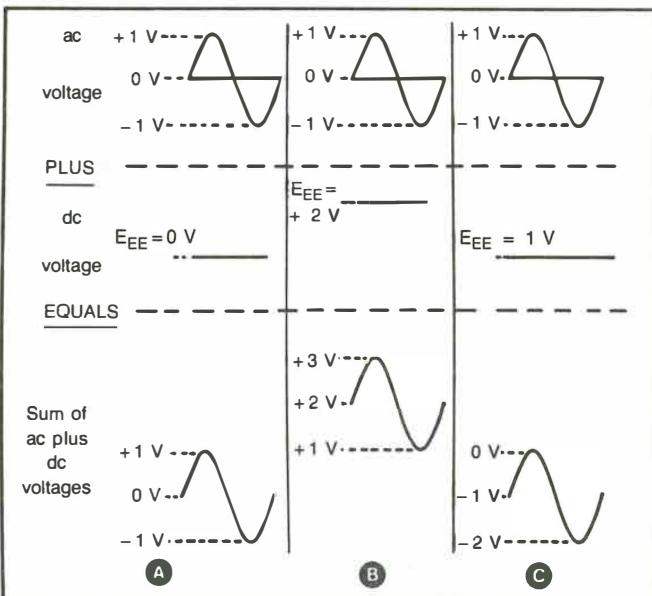


Fig. 8-6. Ac voltage added graphically to a dc voltage. A. Dc is 0 volt. B. Dc is +2 volts. C. Dc is -1 volt.

In Fig. 8-6A, E_{EE} is set at 0 volt. The total ac superimposed upon this is thereby equal to and due entirely to the ac voltage. There is no dc to add to it because the dc is at 0 volt. In Fig. 8-6B, the dc level is +2 volts. With +1 volt to -1 volt peak-to-peak of ac superimposed upon this, the sum of the peaks of the ac signal with dc is +2 volts dc plus +1 volt ac or +3 volts, and the sum at the crest of the ac signal is +2 volts dc plus -1 volt ac or +1 volt. In Fig. 8-6C, the identical situation exists except that now the dc voltage is negative and equals -1 volt. Adding the ac to this gives a peak of -1 volt dc, plus 1 volt ac, or 0 volt and a crest of -1 volt dc, plus 1 volt ac, or -2 volts. In all instances, the total output voltage varies between the crest and peak during different parts of the cycle. It follows the cyclic variations of the pure ac at the input.

Getting back to the circuit in Fig. 8-5, let us use the numbers there to illustrate the addition of the ac signal to the dc bias voltage and discuss how the circuit performs its amplifying function. The ac-input-signal voltage is given here as 1.2 volt peak-to-peak. The peak voltage is one-half of this or 0.6 volt, so the ac varies from a -0.6 volt crest to a +0.6 volt peak for a total variation of 1.2 volt. The rms average, E_{RMS} , of this voltage is 0.6 volt/1.414 = 0.42 volt. Also note that, as before, E_{EE} is negative with respect to the common terminal, the base.

Bias or idling conditions are established when there is no ac voltage at the input of the circuit, or $E_{in} = 0$. At this time, only the dc emitter supply voltage less the base-emitter voltage is across R_E , the only component in this circuit that is outside of the transistor. This voltage is -1.5 volt minus 0.7 volt, or -0.8 volt. Thus, -0.8 volt is across R_E . Emitter current is now equal to -0.8 volt/100 ohms = -0.008 A. Because this is just about equal to the collector current, the voltage across R_C is (-0.008 A) (1000 ohms) = -8 volts. The polarity is as shown at the resistor. When this voltage is subtracted from E_{CC} , 20 volts minus 8 volts, or as much as 12 volts, is at the collector of transistor Q.

Now apply the ac signal voltage to the input. When it is at the crest of its cycle, the -1.5-volt dc is added to the -0.6 volt at the crest of the ac signal for a total of -1.4 volt. Since 0.7 volt is at the base-emitter junction, -1.4 volt is across R_E . At this instant, current in the collector and emitter circuits are -1.4 volt/100 ohms = -0.014 A. The voltage across R_C is (0.014 A) (1000 ohms) = 14 volts, so the voltage at the collector of Q is (20 volts) - (14 volts) = 6 volts.

When the applied ac voltage is at its positive peak in the cycle, the +0.6 volt ac is added to the -1.5 = volt dc, for a total of 0.9 volt. Subtracting the 0.7 volt that is at the base-emitter junction, -0.2 volt is across R_E . I_E and I_C are at this instant equal to $(-0.2 \text{ volt}) / (100 \text{ ohms}) = -0.002 \text{ A}$. The voltage across R_C is $(0.002 \text{ A}) (1000 \text{ ohms}) = 2 \text{ volts}$. Now the voltage at the collector is 20 volts minus the 2 volts across R_C or 18 volts.

Voltage calculated to be at the collector must never drop below 0 volt or exceed the supply voltage—20 volts in this example. If either of these happen when ac voltage is at the input, the voltage across R_C or between the collector and base of the transistor would differ in shape from the voltage applied to the input. A good amplifier provides an output signal that looks exactly like the input. They differ only in that the output and input may have different overall magnitudes due to amplification by the transistor circuit.

Dc voltage at the collector is E_{CC} minus the voltage across R_C . If the collector current (current through R_C) were so high as to make the voltage across R_C greater than E_{CC} , our calculations would show that a negative voltage is at the collector of the transistor. But this cannot happen because collector voltage cannot drop below the zero volt at the base reference terminal under any circumstances.

Now let's see what happens when an ac signal is applied to the input. Assume that during a portion of the ac cycle, the sum of the ac voltage and dc bias voltage is sufficient to increase I_C to the level where calculations will show that the voltage across R_C exceeds E_{CC} . During this interval, the voltage at the collector of the transistor would theoretically drop below zero. But this cannot happen. It remains at its 0-volt minimum. The output will not follow the cyclic variation of the input in this portion of the cycle. It remains fixed at 0 volt. This portion of the waveform is distorted.

The same is true if during a portion of the cycle the sum of the ac input voltage and the dc bias voltage adds to a magnitude that is below zero volt. During this portion of the cycle, I_E and I_C would stay at zero, putting the voltage across R_C at zero volt. Now the collector voltage remains fixed at E_{CC} . During this interval, the output voltage is a distorted version of the input signal.

To avoid these problems or minimize the chances of this happening, the dc idling current is adjusted so that the collector bias voltage is at about one-half of E_{CC} . Now the output voltage can vary over its maximum range from zero to E_{CC} volts. R_E is also chosen so that the emitter and collector currents are limited to

values where the $I_C R_L$ voltage never exceeds E_{CC} even when the ac input voltage is at its peak. The total current must be less than E_{CC}/R_L or less than $(E_{EE} - 0.7)/E_E$.

Getting back to our example, note that the voltage across R_C varies from 14 volts to 2 volts, while the ac input signal varies from -0.6 volt to $+0.6$ volt. Therefore, the peak-to-peak output was $14 \text{ volts} - 2 \text{ volts} = 12 \text{ volts}$ while the peak-to-peak input was $0.6 \text{ volt} - (-0.6 \text{ volt}) = 1.2 \text{ volt}$. The voltage gain of the circuit is the output voltage divided by the input voltage or $12 \text{ volts}/1.2 \text{ volt} = 10$. But also note that the ratio of R_C to R_E is $1000 \text{ ohms}/100 \text{ ohms} = 10$. You can therefore conclude that the ac voltage gain of the common-base circuit is equal to R_C/R_E .

Using Equation 3-5, you know that the power across the output circuit is $I_C^2 R_C$, and the power at the input circuit is $I_E^2 R_E$. Because I_E is just about equal to I_C , the power gain or ratio of the power at the output to the power at the input is $I_C^2 R_C / I_E^2 R_E = R_C/R_E$. Because this ratio is the same as the voltage gain, the power gain and voltage gain are identical.

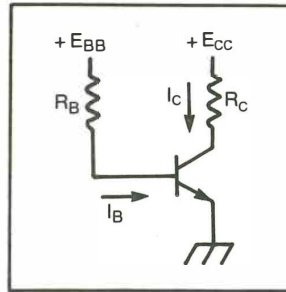
When the ac voltage at the emitter is at its peak with respect to the base, the voltage at the collector is also at its peak with respect to the base. The crests of the ac signal also exist at the same time at the emitter and collector. You can therefore conclude that the ac output from a common-base circuit is in phase with the ac input to that circuit.

Common-Emitter Circuit

The common-base arrangement is used primarily as a high-frequency amplifier. Common-emitter circuits are used more frequently than are the common-base circuits. These arrangements are applied to most applications in the audio band. Common-emitter circuits are also used in some very high-frequency equipment.

The positive voltages applied to the base and collector in the common-emitter arrangement are with respect to the emitter. This is shown in Fig. 8-7 where the emitter terminal of the transistor is connected to ground. The base supply, E_{BB} , in conjunction with R_B , sets the idling current, I_B , in the base. It is equal to E_{BB} minus the 0.7 volt between the base and emitter divided by R_B , the only resistance in this portion of the circuit. This current, multiplied by beta, is equal to the idling collector current, I_C . Because I_C flows through R_C , voltage is developed across that resistor in the collector circuit. As was true in the common-base circuit, it is also desirable here to let the voltage at the collector terminal in this circuit

Fig. 8-7. Common-emitter circuit.



idle at $E_{CC}/2$ volts. To do this, the idling voltage across R_C must be equal to half of the supply voltage, or $I_C R_C = E_{CC}/2$. Because I_C is related to I_B , I_B is set by the designer of the circuit to equal the desired I_C divided by beta. I_B can, of course, be set by using the proper base resistor, R_B , in the circuit.

Ac signal voltage is usually fed through a capacitor to the base and applied between the base and emitter to the transistor. The input voltage varies the base and hence collector current in step with the cyclic variations of the ac. A magnified version of the ac input voltage is developed across the collector resistor by the ac collector current flowing through it. Output voltage is fed from the collector through a capacitor to a load of some type. This is shown in Fig. 8-8. The load is drawn here as a resistor. A resistor has also been added between the emitter and ground to simulate the usual circuit. Instead of having a separate supply for the base current,

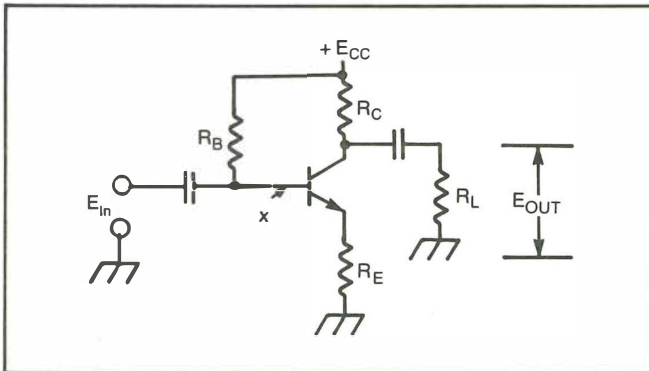


Fig. 8-8. Common-emitter ac amplifier. The beta of the transistor is an important factor in determining the operation of the circuit.

E_{CC} is used here as the supply for both the collector and base circuits.

Base idling current is established by the circuit involving E_{CC} , R_B , V_{BE} , and R_E . The voltage in this current is $E_{CC} - V_{BE}$, where $V_{BE} = 0.7$ volt. Current in R_B is I_B , while current in R_E is βI_B or I_E . In determining the base current, therefore, you can consider R_E as being in series with the base, replacing the lead at which arrow "x" is pointing. But before putting it there, R_E must be multiplied by beta. This is because the actual voltage developed across R_E is due to a current equal to beta multiplied by the current flowing in the base circuit. So in order for the same voltage to be developed across the resistor when moved to the base circuit as was developed across it in its original location, R_E must be multiplied by beta before being relocated. As a result, the total resistance in the base circuit is $R_B + \beta R_E$. Base idling current is $(E_{CC} - 0.7)\text{volts}/(R_B + \beta R_E)\text{ohms} = I_B$. Idling collector and emitter currents, I_C and I_E , are both about equal to beta times I_B .

As indicated, I_C should be of such magnitude as to establish a collector-emitter voltage and idling voltage at the collector equal to about one-half of E_{CC} . This is achieved when $I_C(R_C + R_E) = E_{CC}/2$.

The ac input signal adds a variable current to the dc idling current in the base. It is amplified by the transistor so that a magnified version of the ac input is across R_C . When the voltage at the base is at its peak in the cycle, the collector current is also at its peak. Because the voltage across R_C is the product of the collector current with R_C , this voltage is also at its maximum level. Subtracting the peak voltage across R_C from E_{CC} , you will find the voltage at the collector of the transistor at this instant. This is its minimum with respect to ground. Because the output voltage is at a minimum when the input voltage is at a maximum, you can conclude that the input and output voltages are 180° out of phase. This is the situation that exists with common-emitter circuits. Despite the fact that the input and output voltages are out of phase, the magnitude of the ac voltage at the output of the transistor is usually greater than it is at the input.

For example, let $R_C = 5000$ ohms, $R_L = \partial$ ohms, $R_E = 500$ ohms, $E_{CC} = 22$ volts, and the beta of the transistor be equal to 100. The total resistance in the collector-emitter circuit is $R_C + R_E = 5000$ ohms + 500 ohms = 5500 ohms. If the idling voltage across the transistor is to be one-half E_{CC} or 11 volts, I_C must be equal to 11 volts/ 5500 ohms = 0.002 ampere. Now 11 volts will

be across the total resistance in the collector-emitter circuit or 5500 ohms, as well as between the collector and emitter of the transistor.

If 0.002 A (or 2 mA) is to flow in the collector circuit, that current divided by beta must be in the base circuit. Because $I_C = 0.002$ A, $I_B = 0.002 \text{ A}/\beta = 0.002\text{A}/100 = 0.00002\text{A} = 2 \times 10^{-5}$ A. Therefore, the resistance in the base circuit must be $(E_{CC} - 0.7)/I_B = 21.3 \text{ volts}/2 \times 10^{-5}\text{A} = 10.65 \times 10^5 \text{ ohms} = 1,065,000 \text{ ohms}$. R_E appears in the base circuit as if it were beta times what it actually is or $100 \times 500 \text{ ohms} = 50,000 \text{ ohms}$. Because this resistance plus R_B is the total resistance in the base circuit, R_B must be equal to $1,065,000 \text{ ohms} - 50,000 \text{ ohms}$ or $1,010,000 \text{ ohms}$. A minor 1% error will occur if you let R_B equal $1,000,000 \text{ ohms}$ or 1 megohm.

Current gain of this circuit is equal to the beta of the transistor. If 0.02 mA of current is fed to the base, beta times 0.02 mA is at the collector. In this example, with beta equal to 100, $100 \times 0.02 \text{ mA} = 2 \text{ mA}$ flows through the collector (and emitter) circuit.

In order to determine the ac voltage gain, you must take into account the *ac emitter resistance* that is present inside the transistor. It is equal to $0.026/I_E$, with I_E , the idling current, expressed in amperes. Thus, if $I_E = I_C = 2 \text{ mA} = 0.002\text{A}$, the ac emitter resistance, r_e , in this example is $0.026/0.002 = 13 \text{ ohms}$. When ac flows in the circuit, this resistance is usually significant. As far as the ac is concerned, the total resistance in the emitter circuit is $R_E + r_e$. This is equal to $500 \text{ ohms} + 13 \text{ ohms} = 513 \text{ ohms}$. The dc resistance of the emitter circuit remains fixed at R_E . Here it is 500 ohms.

Using 513 ohms as the total ac resistance in the emitter circuit, lets determine the ac voltage gain of the circuit. Assuming E_{in} has a peak of 0.5 volt and a crest of -0.5 volt, the peak-to-peak variation of the input signal is 1 volt. This variation is applied to the series circuit consisting of the base-emitter junction, r_e and R_E . Because the input voltage is in the base circuit, it sees the 513 ohms in the emitter multiplied by the beta of the transistor or $51,300 \text{ ohms}$. The base current swing due to the E_{in} variation of 1 volt is $1 \text{ volt}/51,300 \text{ ohms} = 1.95 \times 10^{-5}\text{A}$. The transistor current is not cut off even when the swing of E_{in} is down to -0.5 volt at its crest because the base is biased by the dc to idle at $2 \times 10^{-5} \text{ mA}$. The negative crest of the input signal tends to reduce the current at that instant of the cycle, but it will not counter the dc idling current enough to stop the transistor from conducting.

The ac collector current swing is beta multiplied by the base

current swing. Because beta is 100, the collector current swing is $1.9 \times 10^{-5} \text{A} \times 100 = 1.9 \times 10^{-3} \text{A}$. The peak-to-crest voltage developed across R_C due to the collector current swing is $(1.95 \times 10^{-3} \text{A}) (5000 \text{ ohms}) = 9.75 \text{ volts}$. The ratio of the output voltage across R_C to the input voltage is $9.75 \text{ volts}/1 \text{ volt} = 9.75$. This is the ac voltage gain, A_v , of the transistor circuit.

By looking at the circuit, you can find a very simple way of determining the voltage gain. It is approximately equal to $R_C/(R_E + r_e)$. Here, it is $5000 \text{ ohms}/513 \text{ ohms} = 9.75$. This is the same gain number calculated using the longer procedure above.

The power at the input to the transistor is the rms base current multiplied by the applied voltage, or $I_b E_{\text{rms}}$. At the output, the ac power is the rms collector current multiplied by the rms voltage developed across R_C , or $I_C E_{\text{rms}}$. The power gain of the circuit is the ratio of the output power to the input power or $I_C E_{\text{OUT}}/I_b E_{\text{rms}}$. Because I_C/I_b is equal to beta and $E_{\text{OUT}}/E_{\text{rms}}$ is equal to the voltage gain, the power gain, G , is beta times the voltage gain or βA_v . In this example, it is $100(9.75) = 975$.

When dealing with practical circuits, three additional factors usually require some consideration. One is the signal source. Like the battery, the ac signal source is not perfect. It has some internal resistance. If this resistance is substantial, it must be taken into account when calculating the gain of the overall circuit.

The second factor is the dc supply. In all circuits, whether the supply is a battery or a converted ac arrangement, a capacitor is connected across it. Because a capacitor passes ac and behaves as an open circuit for the dc, the supply is a short circuit for the ac. The negative terminal of the $+E_{\text{CC}}$ supply in Fig. 8-8, is at ac ground (unless shown otherwise). As far as the ac or signal voltage is concerned, the top terminal of R_C and R_B are both at ground.

A load resistor, R_L , is wired across R_C through a capacitor. The capacitor behaves as a short circuit for the ac, letting it pass freely. The end of R_C that is connected to $+E_{\text{CC}}$ is at ac ground. One end of R_L is also connected to ground. R_L is effectively in parallel with R_C through the coupling capacitor. The output load for the ac signal is the equivalent resistance of the parallel combination of R_L and R_C . R_L is usually so large as to be negligible when compared to R_C , but not always. The loading by R_L on the output circuit is the third factor of concern to us here.

So now let's modify Fig. 8-8 and change it to the circuit shown in Fig. 8-9. C1 conducts the ac from E_{in} to the base, and C2 con-

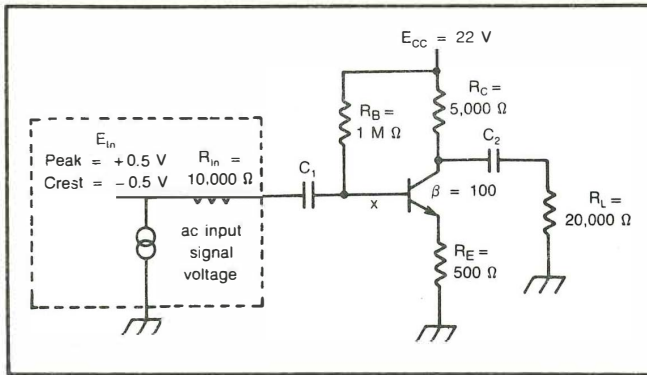


Fig. 8-9. Practical common-emitter circuit.

ducts the ac from the collector to R_L . These capacitors are again essentially short circuits for ac and open circuits for dc. Because of this, they do not let dc from the transistor circuit enter the E_{in} supply or the R_L load. They also do not let the resistance of the supply or load upset the dc bias and idling conditions established by E_{CC} and resistors R_B , R_E , and R_C .

In Fig. 8-9, all components in the dc circuit are identical to those used in the previous example. All idling currents are unchanged. $I_B = 2 \times 10^{-5}A$, and $I_C = 2 \times 10^{-3}A$. Because r_e is the ac emitter resistance of the transistor it does not affect dc currents or bias voltages.

The ac input "sees" resistor R_B between the base and ground. The resistance between the junction of R_B and the base is $\beta(R_E + r_e) = 51,300$ ohms. The connection at the base is effectively at ground, for all resistors and resistances between the emitter and the ground, $R_E + r_e$, have been moved to the left side of the base. This leaves the emitter at ground. Therefore, E_{in} sees the 51,300 ohms as if it were a resistance between the R_B/C_1 junction and ground. In the actual circuit, this resistance is shown as wired between the base terminal and ground.

The 51,300 ohms appears to shunt R_B , the 1 M Ω base resistor. Thus, the resistance at the input of the transistor is equal to the parallel combination of both items, or $(1,000,000 \text{ ohms})(51,300 \text{ ohms}) / (1,000,000 \text{ ohms} + 51,300 \text{ ohms}) = 48,797$ ohms, or approximately 49,000 ohms. Considering this resistance in conjunction with the 10,000 ohm resistance of E_{in} , a voltage divider is formed and Equation 3-2 applies. This circuit is shown in Fig. 8-10A.

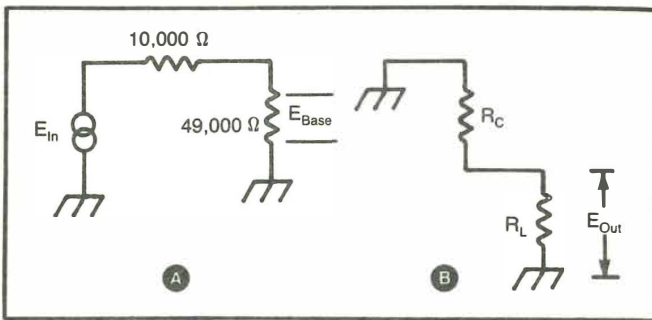


Fig. 8-10. Effects of the ac portion of the circuit in Fig. 8-9. A. Equivalent of input circuit. B. Equivalent of output circuit.

The total ac input voltage, E_{in} , is applied to the divider and base of the transistor through its internal 10,000 ohm resistance. The load presented to this circuit is 49,000 ohms. Using the voltage divider equation, $E_{BASE} = 49,000 \text{ ohms} / (49,000 \text{ ohms} + 10,000 \text{ ohms}) = 0.83$ multiplied by E_{in} . If the peak and crest voltages supplied by E_{in} are 0.5 volt, the peak and crest voltages at the base are $0.83 \times 0.5 \text{ volt} = 0.415 \text{ volt}$ for a peak-to-peak voltage swing of $2 \times 0.415 \text{ volt}$ or 0.83 volt.

The ac load resistance in the collector circuit consists of R_C in parallel with R_L . This is because the upper terminal of R_C is effectively at ac ground and C2 behaves as if it were a short circuit for the signal voltage. This is shown in Fig. 8-10B. The equivalent resistance of the combination is $(5000 \text{ ohms}) (20,000 \text{ ohms}) / (5000 \text{ ohms} + 20,000 \text{ ohms}) = 4,000 \text{ ohms}$.

Gain is approximately equal to the ratio of the impedance in the collector circuit to the impedance in the emitter circuit. In this example, the gain of the transistor circuit is $4000 \text{ ohms} / 513 \text{ ohms} = 7.8$. So with peak-to-crest voltage of 0.83 at the base of the transistor, $7.8 \times 0.83 \text{ volt} = 6.5 \text{ volts}$ is the peak-to-crest voltage across R_C and R_L . With this as the output voltage, the gain of the overall arrangement is $6.5 \text{ volts} / 1 \text{ volt} = 6.5$. This gain figure takes into account the resistors in the dc portion of the circuit as well as the input impedance of the supply and the ac load due to the presence of R_L . Note how much lower this gain is than the gain in the original example when R_{in} and R_L were not being considered. There, the gain was taken as being simply $R_C / (R_E + r_e) = 5000 / 513 = 9.75$. This figure is $9.75 / 6.5$ or 1.5 times the actual gain of the circuit.