G. PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

Accredited by NAAC with ‘A’ Grade of UGC, Approved by AICTE, New Delhi & Permanently Affiliated to JNTUA, Ananthapuramu.

(Recognized by UGC under 2(f) and 12(B) & ISO 9001:2008 Certified Institution)

Nandikotkur Road, Venkayapalli, Kurnool – 518452

Department of Electronics and Communication Engineering

Bridge Course

On

Linear Integrated Circuits and Applications

1. AMPLIFIERS

1.0 Introduction:

Amplification is the process of linearly increasing the amplitude of an electrical signal and is one of the major properties of a transistor. As you learned, a BJT exhibits current gain (called β). When a BJT is biased in the active (or linear) region, as previously described, the BE junction has a low resistance due to forward bias and the BC junction has a high resistance due to reverse bias.

1.1 DC and AC Quantities

Before discussing the concept of transistor amplification, the designations that we will use for the circuit quantities of current, voltage, and resistance must be explained because amplifier circuits have both dc and ac quantities.

In this text, italic capital letters are used for both dc and ac currents (I) and voltages (V). This rule applies to rms, average, peak, and peak-to-peak ac values. AC current and voltage values are always rms unless stated otherwise. Although some texts use lowercase *i* and *v* for ac current and voltage, we reserve the use of lowercase *i* and *v* only for instantaneous values. In this text, the distinction between a dc current or voltage and an ac current or voltage is in the subscript.

DC quantities always carry an uppercase roman (nonitalic) subscript. For example, I_{B}, I_{C}, and I_{E} are the dc transistor currents. VBE, VCB, and VCE are the dc voltages from one transistor terminal to another. Single subscripted voltages such as V_{B}, V_{C}, and V_{E} are dc voltages from the transistor terminals to ground.

AC and all time-varying quantities always carry a lowercase italic subscript. For example, I_b, I_c, and I_e are the ac transistor currents. V_{be}, V_{cb}, and V_{ce} are the ac voltages from one transistor terminal to another. Single subscripted voltages such as *Vb*, *Vc*, and *Ve* are ac voltages from the transistor terminals to ground.

The rule is different for *internal* transistor resistances. As you will see later, transistors have internal ac resistances that are designated by lowercase with an appropriate subscript. For example, the internal ac emitter resistance is designated as. Circuit resistances external to the transistor itself use the standard italic capital *R* with a subscript that identifies the resistance as dc or ac (when applicable), just as for current and voltage. For example R_{E} is an external dc emitter resistance and *Re* is an external ac emitter resistance.

A transistor amplifies current because the collector current is equal to the base current multiplied by the current gain, b. The base current in a transistor is very small compared to the collector and emitter currents. Because of this, the collector current is approximately equal to the emitter current. With this in mind, let's look at the circuit in Figure 1.1. An ac voltage, V_s, is superimposed on the dc bias voltage V_{BB} by capacitive coupling as shown. The dc bias voltage V_{CC} is connected to the collector through the collector resistor, R_{C}.

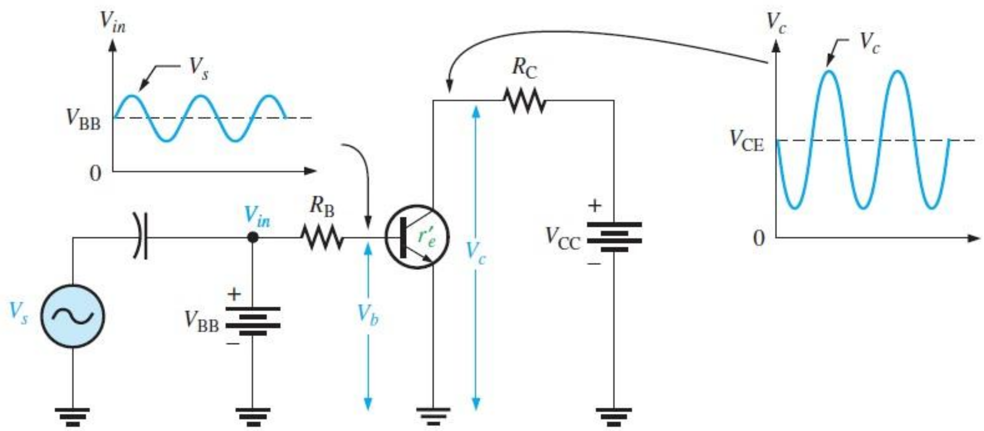


Figure 1.1: Basic transistor amplifier circuit with ac source voltage Vs and dc bias voltage V_{BB} superimposed

The ac input voltage produces an ac base current, which results in a much larger ac collector current. The ac collector current produces an ac voltage across *R*C, thus producing an amplified, but inverted, reproduction of the ac input voltage in the active region of operation, as illustrated in Figure 1.1.

The forward-biased base-emitter junction presents a very low resistance to the ac signal. This internal ac emitter resistance is designated r_e' in Figure 1.1 and appears in series with R_B. The ac base voltage is

$$V_b = I_e r_e' \qquad \text{-------- (1.1)}$$

The ac collector voltage, V_c, equals the ac voltage drop across R_C.

$$V_c = I_c R_C$$

Since $I_c \cong I_e$, the ac collector voltage is

$$V_c \cong I_e R_C \qquad \text{-------- (1.2)}$$

V_b can be considered the transistor ac input voltage where $V_b = V_s - I_b R_B$. V_c can be considered the transistor ac output voltage. Since *voltage gain* is defined as the ratio of the output voltage to the input voltage, the ratio of V_c to V_b is the ac voltage gain, A_v, of the transistor.

$$A_v = \frac{V_c}{V_b} \qquad \text{-------- (1.3)}$$

Substituting $I_e R_C$ for V_c and I_e for V_b yields

$$A_v = \frac{V_c}{V_b} \cong \frac{I_e R_C}{I_e r_e'}$$

The I_e terms cancel; therefore,

$$A_v \cong \frac{R_C}{r_e'} \qquad \text{-------- (1.4)}$$

Equation 1.4 shows that the transistor in Figure 4–21 provides amplification in the form of voltage gain, which is dependent on the values of R_C and r_e'.

Since *R*C is always considerably larger in value than r_e', the output voltage for this configuration is greater than the input voltage.

1.2 Transistor as a Switch

In the previous section, you saw how a BJT can be used as a linear amplifier. The second major application area is switching applications. When used as an electronic switch, a BJT is normally operated alternately in cutoff and saturation. Many digital circuits use the BJT as a switch.

1.2.1 Switching Operation

Figure 1.2 illustrates the basic operation of a BJT as a switching device. In part (a), the transistor is in the cutoff region because the base-emitter junction is not forward-biased. In this condition, there is, ideally,

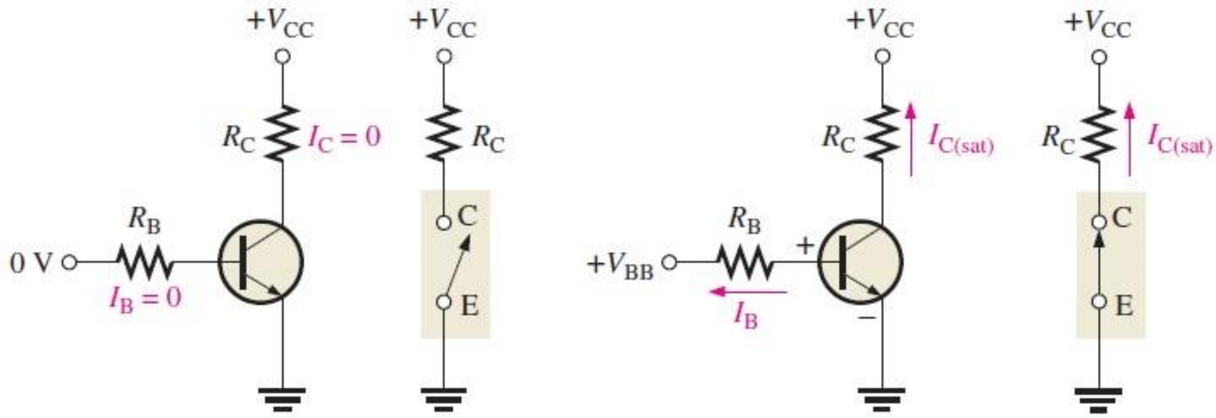


Figure 1.2: (a) Cut-off open switch (b) Saturation – closed switch

an *open* between collector and emitter, as indicated by the switch equivalent. In part (b), the transistor is in the saturation region because the base-emitter junction and the base-collector junction are forward-biased and the base current is made large enough to cause the collector current to reach its saturation value. In this condition, there is, ideally, a *short* between collector and emitter, as indicated by the switch equivalent. Actually, a small voltage drop across the transistor of up to a few tenths of a volt normally occurs, which is the saturation voltage, $V_{CE(sat)}$.

Conditions in Cutoff As mentioned before, a transistor is in the cutoff region when the base-emitter junction is not forward-biased. Neglecting leakage current, all of the currents are zero, and V_{CE} is equal to V_{CC}.

$$V_{CE(cutoff)} = V_{CC} \qquad \text{-------- (1.4)}$$

Conditions in Saturation As you have learned, when the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. The formula for collector saturation current is

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} \qquad \text{-------- (1.5)}$$

Since $V_{CE(sat)}$ is very small compared to VCC, it can usually be neglected.

The minimum value of base current needed to produce saturation is

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} \qquad \text{-------- (1.6)}$$

Normally, I_B should be significantly greater than $I_{B(min)}$ to ensure that the transistor is saturated.

1.2.2 A Simple Application of a Transistor Switch

The transistor in Figure 1.3 is used as a switch to turn the LED on and off. For example, a square wave input voltage with a period of 2 seconds is applied to the input as indicated. When the square wave is at

0 V, the transistor is in cutoff; and since there is no collector current, the LED does not emit light. When the square wave goes to its high level, the transistor saturates. This forward-biases the LED, and the resulting collector current through the LED causes it to emit light. Thus, the LED is on for 1 second and off for 1 second.

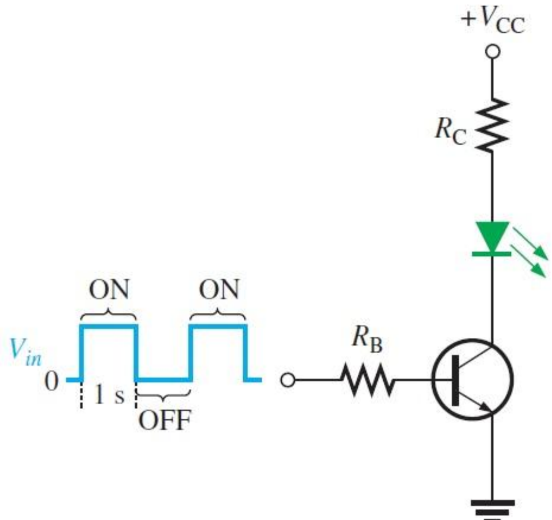


Figure 1.3: A transistor used to switch an LED on and off.

1.3 The Common-Emitter Amplifier

As you have learned, a BJT can be represented in an ac model circuit. Three amplifier configurations are the common-emitter, the common-base, and the common-collector. The common-emitter (CE) configuration has the emitter as the common terminal, or ground, to an ac signal. CE amplifiers exhibit high voltage gain and high current gain.

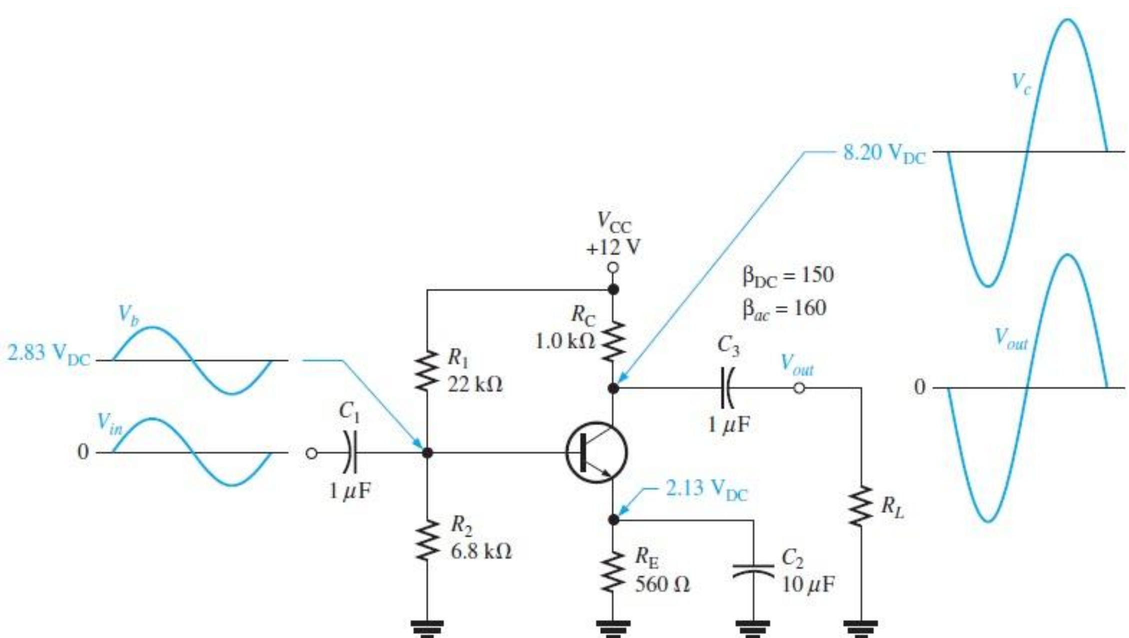


Figure 1.4: A Common – Emitter Amplifier

Figure 1.4 shows a **common-emitter** amplifier with voltage-divider bias and coupling capacitors C_1 and C_3 on the input and output and a bypass capacitor, $C2$, from emitter to ground. The input signal, V_{in}, is capacitively coupled to the base terminal, the output signal, V_{out}, is capacitively coupled from the collector to the load. The amplified output is 180° out of phase with the input. Because the ac signal is applied to the base terminal as the input and taken from the collector terminal as the output, the emitter is common to both the input and output signals. There is no signal at the emitter because the bypass capacitor effectively shorts the emitter to ground at the signal frequency. All amplifiers have a combination of both ac and dc operation, which must be considered, but keep in mind that the common-emitter designation refers to the ac operation.

Phase Inversion The output signal is 180° out of phase with the input signal. As the input signal voltage changes, it causes the ac base current to change, resulting in a change in the collector current from its Q-point value. If the base current increases, the collector current increases above its Q-point value, causing an increase in the voltage drop across *R*C. This increase in the voltage across *R*C means that the voltage at the collector decreases from its Q-point. So, any change in input signal voltage results in an opposite change in collector signal voltage, which is a phase inversion.

1.3.1 DC Analysis

To analyze the amplifier in Figure 1.3, the dc bias values must first be determined. To do this, a dc equivalent circuit is developed by removing the coupling and bypass capacitors because they appear open as far as the dc bias is concerned. This also removes the load resistor and signal source. The dc equivalent circuit is shown in Figure 1.3.

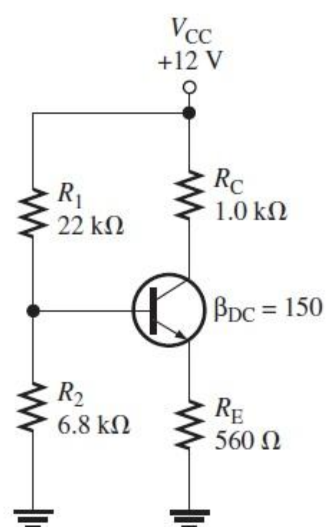


Figure 1.5: DC equivalent circuit for the amplifier in Figure 1.6

Theveninizing the bias circuit and applying Kirchhoff's voltage law to the base-emitter circuit,

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(6.8\ k\Omega)(22\ k\Omega)}{6.8\ k\Omega + 22\ k\Omega} = 5.19\ k\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{6.8\ k\Omega}{6.8\ k\Omega +\ 22\ k\Omega}\right)12\ V = 2.8\ V$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + {R_{TH}}/{\beta_{DC}}} = \frac{2.83\ V - 0.7\ V}{560\ \Omega + 34.6\ \Omega} = 3.58\ mA$$

$$I_C = I_E = 3.58\ mA$$

$$V_E = I_E R_E = (3.58\ mA)(560\ \Omega) = 2\ V$$

$$V_B = V_E + 0.7\ V = 2.7\ V$$

$$V_C = V_{CC} - I_C R_C = 12\ V - (3.58\ mA)(1.0\ k\Omega) = 8.42\ V$$

$$V_{CE} = V_C - V_E = 8.42\ V - 2\ V = 6.42\ V$$

1.3.2 AC Analysis

To analyze the ac signal operation of an amplifier, an ac equivalent circuit is developed as follows:

1. The capacitors C_1, C_2, and C_3 are replaced by effective shorts because their values are selected so that X_C is negligible at the signal frequency and can be considered to be 0 Ω.
2. The dc source is replaced by ground.

A dc voltage source has an internal resistance of near 0 Ω because it holds a constant voltage independent of the load (within limits); no ac voltage can be developed across it so it appears as an ac short. This is why a dc source is called an **ac ground**.

The ac equivalent circuit for the common-emitter amplifier in Figure 1.3 is shown in Figure 1.6(a). Notice that both R_C and R_1 have one end connected to ac ground (red) because, in the actual circuit, they are connected to V_{CC} which is, in effect, ac ground.

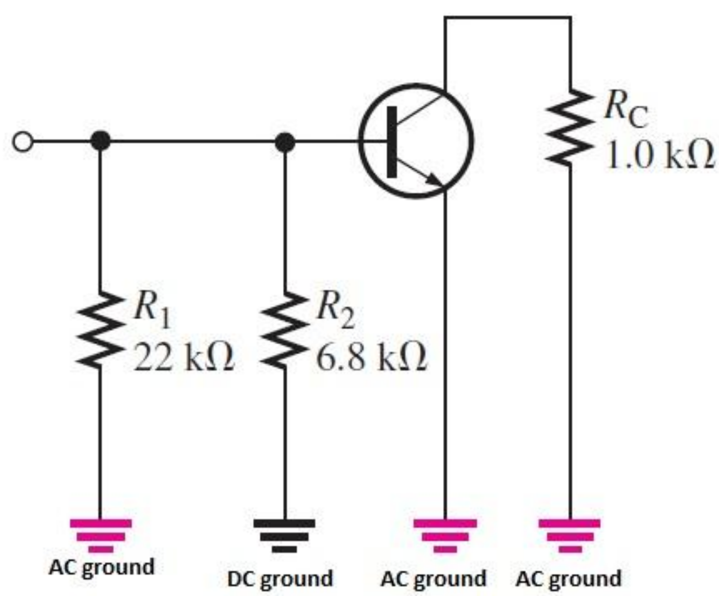


Figure 1.6 (a) Without ac input signal voltage.

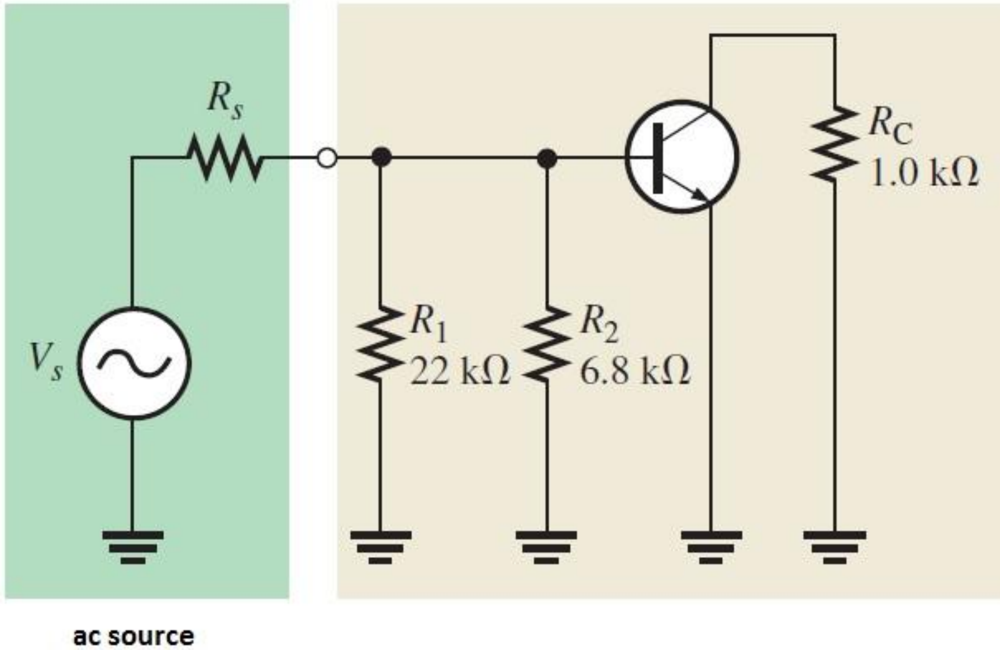
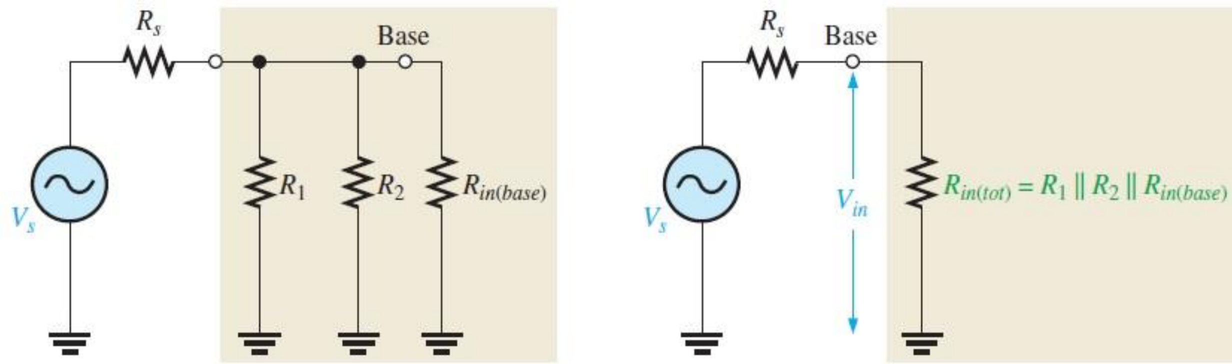


Figure 1.6 (b) : With an input signal voltage.

In ac analysis, the ac ground and the actual ground are treated as the same point electrically. The amplifier in Figure 1.6 is called a common-emitter amplifier because the bypass capacitor C_2 keeps the emitter at ac ground. Ground is the common point in the circuit.

Signal (AC) Voltage at the Base An ac voltage source, *Vs*, is shown connected to the input in Figure 1.6(b). If the internal resistance of the ac source is 0 Ω, then all of the source voltage appears at the base terminal. If, however, the ac source has a nonzero internal resistance, then three factors must be taken into account in determining the actual signal voltage at the base. These are the *source resistance* (R_s), the *bias resistance* (R_1 // R_2), and the *ac input resistance* at the base of the transistor This is illustrated in Figure 1.7(a) and is simplified by combining *R*1, *R*2, and $R_{in(base)}$ in parallel to get the total **input resistance**, $R_{in(tot)}$, which is the resistance "seen" by an ac source connected to the input, as shown in Figure 1.7(b). A high value of input resistance is desirable so that the amplifier will not excessively load the signal source. This is opposite to the requirement for a stable Q-point, which requires smaller resistors. The conflicting requirement for high input resistance and stable biasing is but one of the many trade-offs that must be considered when choosing components for a circuit. The total input resistance is expressed by the following formula:

$$R_{in(tot)} = R_1 \,//\, R_2 \,//\, R_{in(base)}$$



(a) (b)

Figure 1.7: AC equivalent of the base circuit.

As you can see in the figure, the source voltage, *Vs*, is divided down by *Rs* (source resistance) and *Rin*(*tot*) so that the signal voltage at the base of the transistor is found by the voltage-divider formula as follows: $R_{in(base)} = \frac{V_{in}}{I_{in}} = \frac{V_b}{I_b}$

The base voltage is $V_b = I_e r_e'$

and since $I_e \cong I_c$ $\quad I_b \cong \frac{I_c}{\beta_{dc}}$

Substituting for V_b and I_b,

$$R_{in(base)} = \frac{V_b}{I_b} = \frac{I_e r_e'}{I_e/\beta_{ac}}$$

Cancelling I_e $\quad R_{in(base)} = \beta_{ac} r_e'$ -------- (1.7)

Output Resistance The **output resistance** of the common-emitter amplifier is the resistance looking in at the collector and is approximately equal to the collector resistor. $R_{out} \cong R_C$ -------- (1.8)

Actually, $R_{out} = R_C // r_c'$, but since the internal ac collector resistance of the transistor, is typically much larger than *R*C, the approximation is usually valid.

1.3.3 Voltage Gain

The ac voltage gain expression for the common-emitter amplifier is developed using the model circuit in

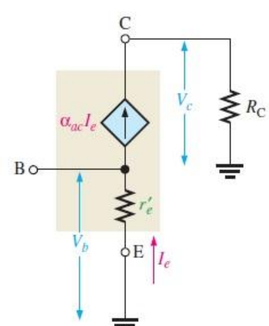


Figure 1.8: Model circuit for obtaining ac voltage gain

Figure 1.8. The gain is the ratio of ac output voltage at the collector (V_c) to ac input voltage at the base (V_b).

$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_c}{V_b}$$

Notice in the figure that $V_c = \alpha_{ac} I_e R_C \cong I_e R_C$ and $V_b = I_e r_e'$. Therefore,

$$A_v = \frac{I_e R_C}{I_e r_e'}$$

The Ie terms cancel, so

$$A_v = \frac{R_C}{r_e'} \qquad \text{-------- (1.8)}$$

1.3.4 Multistage Voltage Gain

The overall voltage gain, A_v' of cascaded amplifiers, as shown in Figure 1.9, is the product of the individual voltage gains.

$$A_v' = A_{v1} A_{v2} A_{v3} A_{v4} \cdots A_{vn} \qquad \text{-------- (1.9)}$$

where *n* is the number of stages.

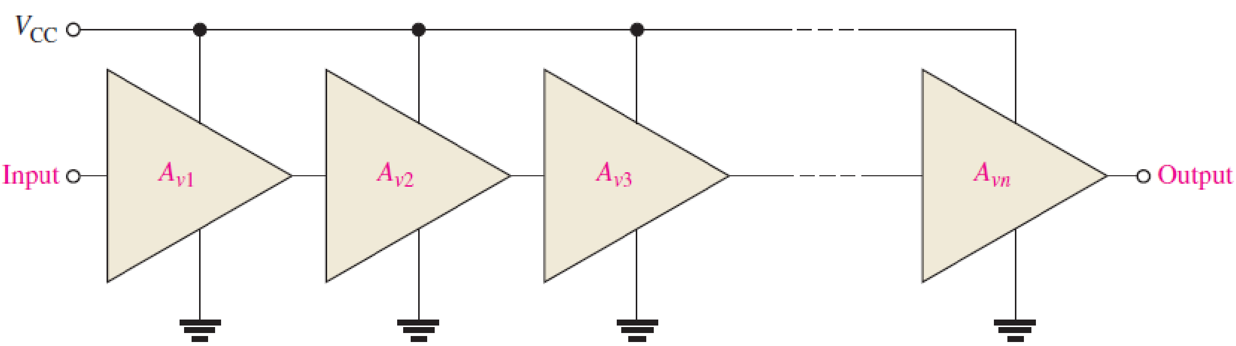


Figure 1.9: Cascaded Amplifier (each triangular symbol represents a separate amplifier)

Amplifier voltage gain is often expressed in **decibels** (dB) as follows:

$$A_v(\text{dB}) = 20 \log A_v \qquad \text{-------- (1.10)}$$

This is particularly useful in **multistage** systems because the overall voltage gain in dB is the sum of the individual voltage gains in dB.

$$A_v'(\text{dB}) = A_{v1}(\text{dB}) + A_{v2}(\text{dB}) + A_{v2}(\text{dB}) + A_{vn}(\text{dB}) \qquad \text{-------- (1.11)}$$

1.4 FET Amplifiers

Because of their extremely high input resistance and low noise, FET amplifiers are a good choice for certain applications, such as amplifying low-level signals in the first stage of a communication receiver. FETs also have the advantage in certain power amplifiers and in switching circuits because biasing is simple and more efficient. The standard amplifier configurations are common-source (CS), common-drain (CD) and common-base (CB), which are analogous to CE, CC, and CB configurations of BJTs. FETs can be used in any of the amplifier types introduced earlier (class A, class B, and class C). In some cases, the FET circuit will perform better; in other cases, the BJT circuit is superior because BJTs have higher gain and better linearity.

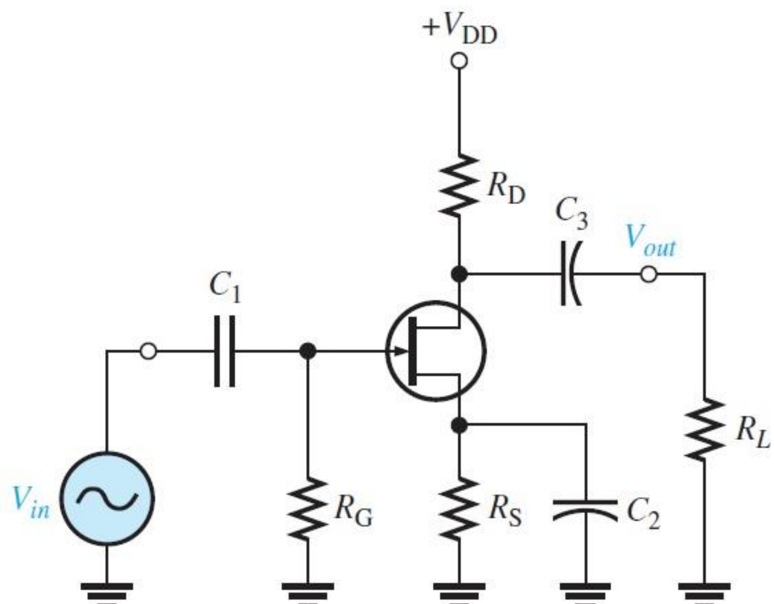
Another type of amplifier (class D) is introduced in this chapter because FETs are always superior to BJTs in class D and you will rarely see BJTs used in class D. The class D amplifier is a switching amplifier that is normally either in cutoff or saturation. It is used in analog power amplifiers with a circuit called a pulse-width modulator. FETs are superior to BJTs in nearly all switching applications. Various switching circuits—analog switches, analog multiplexers, and switched capacitors—are discussed. In addition, common digital switching circuits are introduced using CMOS (complementary MOS).

1.5 The Common-Source Amplifier

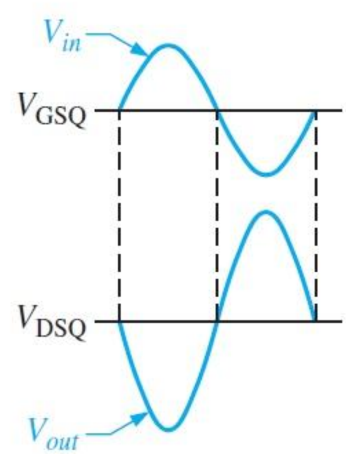
When used in amplifier applications, the FET has an important advantage compared to the BJT due to the FET's extremely high input impedance. Disadvantages, however, include higher distortion and lower gain. The particular application will usually determine which type of transistor is best suited. The common-source (CS) amplifier is comparable to the common-emitter BJT amplifier.

1.5.1 JFET Amplifier Operation

A **common-source** JFET amplifier is one in which the ac input signal is applied to the gate and the ac output signal is taken from the drain. The source terminal is common to both the input and output signal. A common-source amplifier either has no source resistor or has a bypassed source resistor, so the source is connected to ac ground. A self-biased common-source *n*-channel JFET amplifier with an ac source capacitively coupled to the gate is shown in Figure 1.10 (a). The resistor, R_G, serves two purposes: It keeps the gate at approximately 0 V dc (because *I*GSS is extremely small), and its large value (usually several mega ohms) prevents loading of the ac signal source. A bias voltage is produced by the drop across *R*S. The bypass capacitor, *C*2, keeps the source of the JFET at ac ground.



(a) Schematic diagram

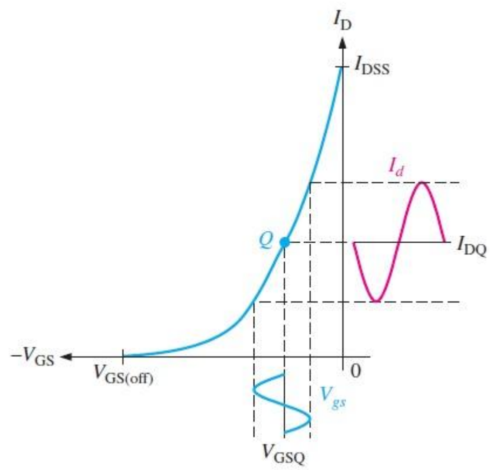


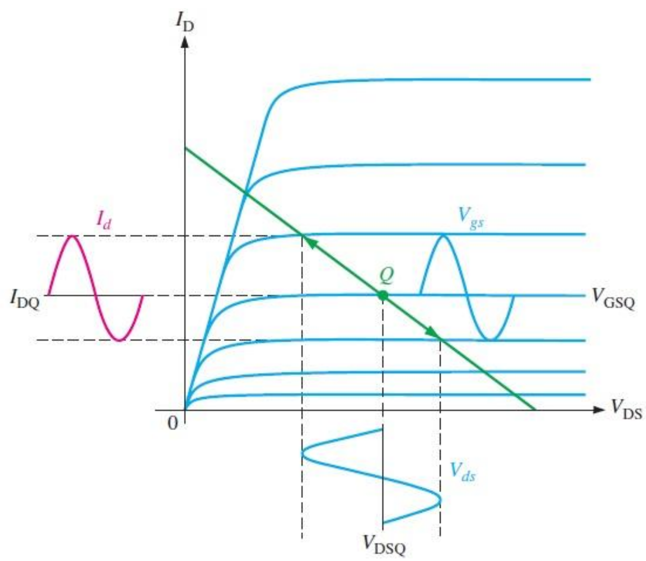
(b) Voltage waveform relationships

Figure 1.10: JFET Common-Source Amplifier

The input signal voltage causes the gate-to-source voltage to swing above and below its Q-point value (V_{GSQ}), causing a corresponding swing in drain current. As the drain current increases, the voltage drop across R_D also increases, causing the drain voltage to decrease. The drain current swings above and below its Q-point value in phase with the gate-to-source voltage. The drain-to-source voltage swings above and below its Q-point value (V_{DSQ}) and is 180° out of phase with the gate-to-source voltage, as illustrated in Figure 1.10(b).

A Graphical Picture The operation just described for an *n*-channel JFET is illustrated graphically on both the transfer characteristic curve and the drain characteristic curve in Figure 1.13. Part (a) shows how a sinusoidal variation, V_{gs}, produces a corresponding sinusoidal variation in *Id.* As V_{gs} swings from its Q-point value to a more negative value, *Id* decreases from its Q-point value. As V_{gs} swings to a less negative value, I_d increases. Figure 1.13(b) shows a view of the same operation using the drain curves.





(a) JFET (n-channel) transfer characteristic curve *(b) JFET (n-channel) drain curves*

Figure 1.13 : JFET Characteristics Curves

The signal at the gate drives the drain current above and below the Q-point on the load line, as indicated by the arrows. Lines projected from the peaks of the gate voltage across to the I_D axis and down to the V_{DS} axis indicate the peak-to-peak variations of the drain current and drain-to-source voltage, as shown. Because the transfer characteristic curve is nonlinear, the output will have some distortion. This can be minimized if the signal swings over a limited portion of the load line.

Voltage Gain The expression for JFET voltage gain to the common-source amplifier.

$$A_v = g_m R_d \qquad \text{-------- (1.12)}$$

The output signal voltage V_{ds} at the drain is $V_{out} = V_{ds} = A_v V_{gs}$ -------- (1.13)

or

$$V_{out} = g_m R_d V_{in} \qquad \text{-------- (1.14)}$$

where $R_d = R_D // R_L$ and $V_{in} = V_{gs}$.

2. OSCILLATORS

2.0 Introduction

Oscillators are electronic circuits that generate an output signal without the necessity of an input signal. They are used as signal sources in all sorts of applications. Different types of oscillators produce various types of outputs including sine waves, square waves, triangular waves, and sawtooth waves. In this chapter, several types of basic oscillator circuits using both discrete transistors and op-amps as the gain element are introduced. Also, a popular integrated circuit, the 555 timer, is discussed in relation to its oscillator applications. Sinusoidal oscillator operation is based on the principle of positive feedback, where a portion of the output signal is fed back to the input in a way that causes it to reinforce itself and thus sustain a continuous output signal. Oscillators are widely used in most communications systems as well as in digital systems, including computers, to generate required frequencies and timing signals. Also, oscillators are found in many types of test instruments like those used in the laboratory.

An **oscillator** is a circuit that produces a periodic waveform on its output with only the dc supply voltage as an input. A repetitive input signal is not required except to synchronize oscillations in some applications. The output voltage can be either sinusoidal or non-sinusoidal, depending on the type of oscillator. Two major classifications for oscillators are feedback oscillators and relaxation oscillators.

Essentially, an oscillator converts electrical energy from the dc power supply to periodic waveforms. A basic oscillator is shown in Figure 2.1.

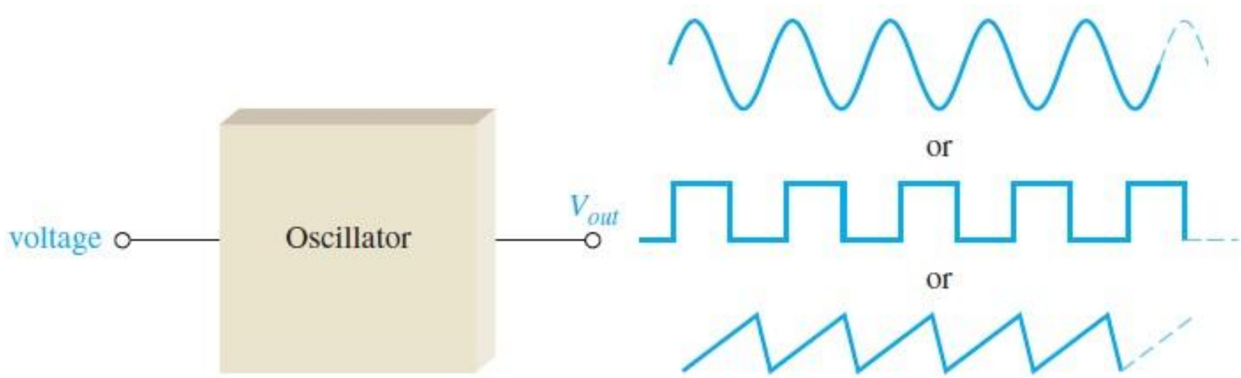


Figure 2.1: The basic oscillator concept showing output waveforms: sine wave, square wave, and sawtooth.

2.1 *Feedback Oscillators*

One type of oscillator is the **feedback oscillator**, which returns a fraction of the output signal to the input with no net phase shift, resulting in a reinforcement of the output signal. After oscillations are started, the loop gain is maintained at 1.0 to maintain oscillations. A feedback oscillator consists of an amplifier for gain (either a discrete transistor or an op-amp) and a positive feedback circuit that produces phase shift and provides attenuation, as shown in Figure 2.2.

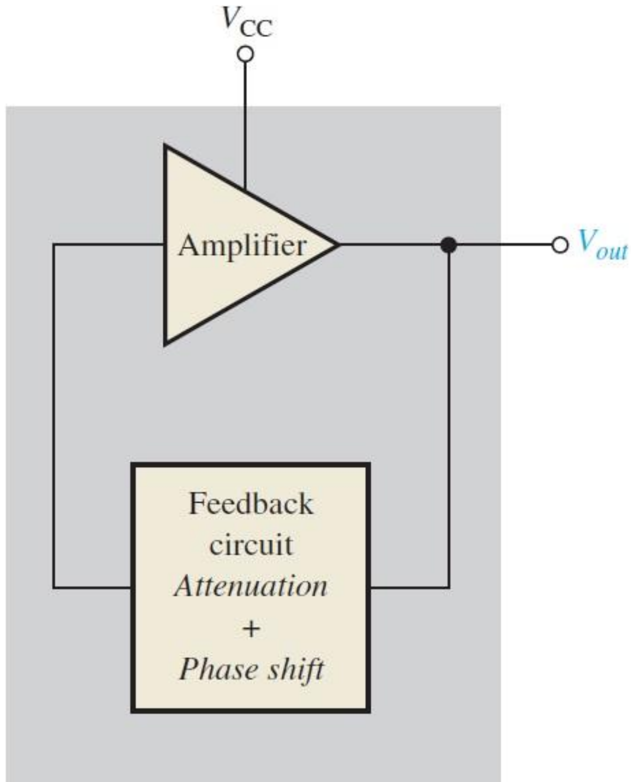


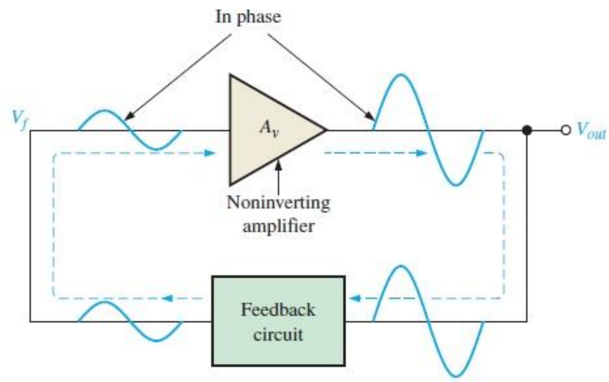
Figure 2.2: Basic elements of a feedback oscillator.

Relaxation Oscillators A second type of oscillator is the **relaxation oscillator**. Instead of feedback, a relaxation oscillator uses an *RC* timing circuit to generate a waveform that is generally a square wave or other nonsinusoidal waveform. Typically, a relaxation oscillator uses a Schmitt trigger or other device that changes states to alternately charge and discharge a capacitor through a resistor.

2.1.1 Positive Feedback

Feedback oscillator operation is based on the principle of positive feedback. In this section, we will examine this concept and look at the general conditions required for oscillation to occur. Feedback oscillators are widely used to generate sinusoidal waveforms.

Positive feedback is characterized by the condition wherein a portion of the output voltage of an amplifier is fed back to the input with no net phase shift, resulting in a reinforcement of the output signal. This basic idea is illustrated in Figure 2.3(a).



(a) *(b)*

Figure 2.3: Positive feedback produces oscillation.

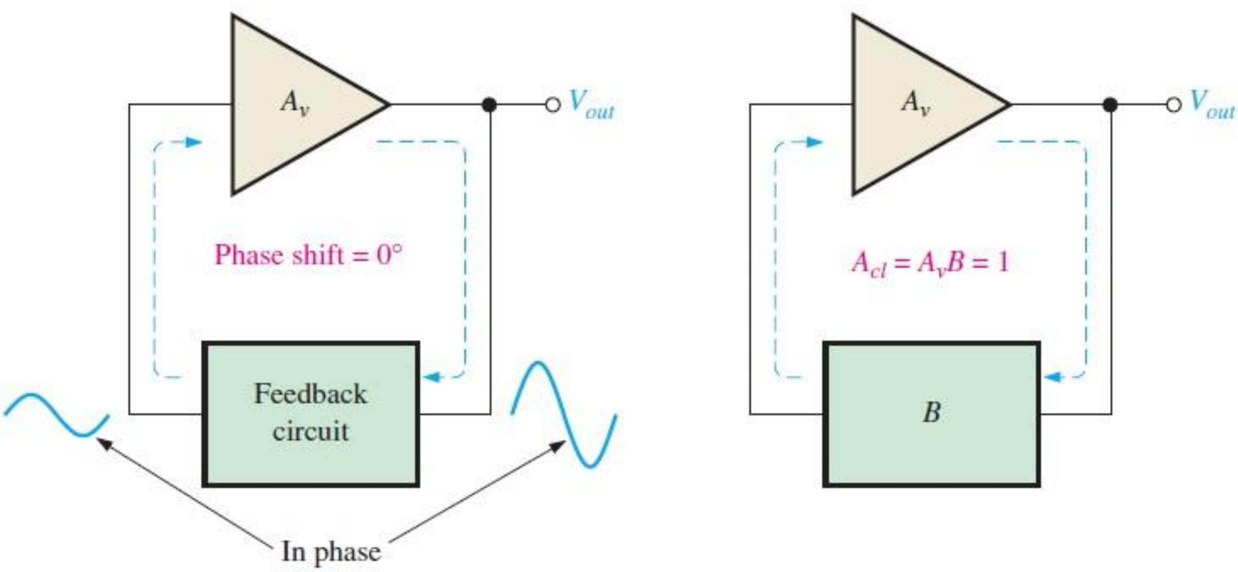
As you can see, the in-phase feedback voltage, is amplified to produce the output voltage, which in turn produces the feedback voltage V_f. That is, a loop is created in which the signal sustains itself and a continuous sinusoidal output is produced. This phenomenon is called *oscillation.* In some types of amplifiers, the feedback circuit shifts the phase 180° and an inverting amplifier is required to provide another phase shift 180° so that there is no net phase shift. This is illustrated in Figure 2.3(b).

2.1.2 Conditions for Oscillation

Two conditions, illustrated in Figure 2.4, are required for a sustained state of oscillation:

1. The phase shift around the feedback loop must be effectively 0°.

2. The voltage gain, A_{cl}, around the closed feedback loop (loop gain) must equal 1 (unity).



(a) The phase shift around the loop is 0°. *(b) The closed loop gain is 1.*

Figure 2.4: General conditions to sustain oscillation

The voltage gain around the closed feedback loop, A_{cl}, is the product of the amplifier gain, A_v, and the attenuation, *B*, of the feedback circuit. $A_{cl} = A_vB$

If a sinusoidal wave is the desired output, a loop gain greater than 1 will rapidly cause the output to saturate at both peaks of the waveform, producing unacceptable distortion. To avoid this, some form of gain control must be used to keep the loop gain at exactly 1 once oscillations have started. For example, if the attenuation of the feedback circuit is 0.01, the amplifier must have a gain of exactly 100 to overcome this attenuation and not create unacceptable distortion (0.01X100 = 1). An amplifier gain of greater than 100 will cause the oscillator to limit both peaks of the waveform.

2.2 Types of Oscillators

The different types of oscillators and are mentioned some applications below:

1. RC Phase Shift Oscillator

   FET phase-shift oscillator is used for generating signals over a wide frequency range. The frequency may be varied from a few Hz to 200 Hz by employing one set of resistor with three capacitors ganged together to vary over a capacitance range in the 1 : 10 ratio. Similarly the frequency ranges of 200 Hz to 2 kHz, 2 kHz to 20 kHz and 20 kHz to 200 kHz can be obtained by using other sets of resistors.

2. Hartley Oscillator:
   - This oscillation will produce a desired range of frequencies
   - The Hartley oscillators are used in the radio frequency in a range of the 30Mhz
   - In radio receiver, this oscillator is used and it has a wide range of frequency

3. Colpitts Oscillator
   - It is used to generate the sinusoidal output signals with a very high frequency
   - Very wide range of frequencies is involved
   - It is used in the radio and mobile communications
   - In commercial purpose, many applications are used

4. Multi-Wave Oscillator
   - The healing action of this oscillation is very bad because of the holistically work
   - The healing process is done by all parts of the body
   - The MWO is used in many countries worldwide by individual
   - This oscillator is applied for the treatment of the cancer