Electrical, Electronic and Digital Principles (EEDP)

Lecture 5

- **Multistage Amplifiers and Coupling And Amplifier Classes**

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Multistage Amplifiers

- Two or more amplifiers can be connected in a cascaded arrangement with the output of one amplifier driving the input of the next.
- The basic purpose of using multistage is to increase the overall voltage gain.

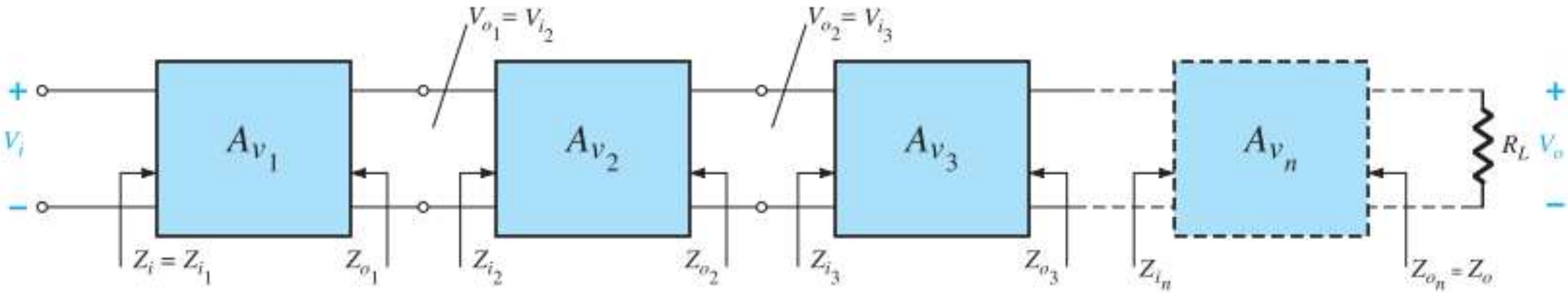


FIG. 5.67
Cascaded system.

$$A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots$$

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

$$A_{v(\mathrm{dB})} = 20 \log A_v$$

- Total gain in dB is given by:

$$A'_{v(\mathrm{dB})} = A_{v1(\mathrm{dB})} + A_{v2(\mathrm{dB})} + \cdots + A_{vn(\mathrm{dB})}$$

Amplifiers Coupling

1. RC-Coupling
2. Transformer Coupling
3. Direct Coupling

The purpose of coupling device (*e.g.* a capacitor, transformer etc.) is

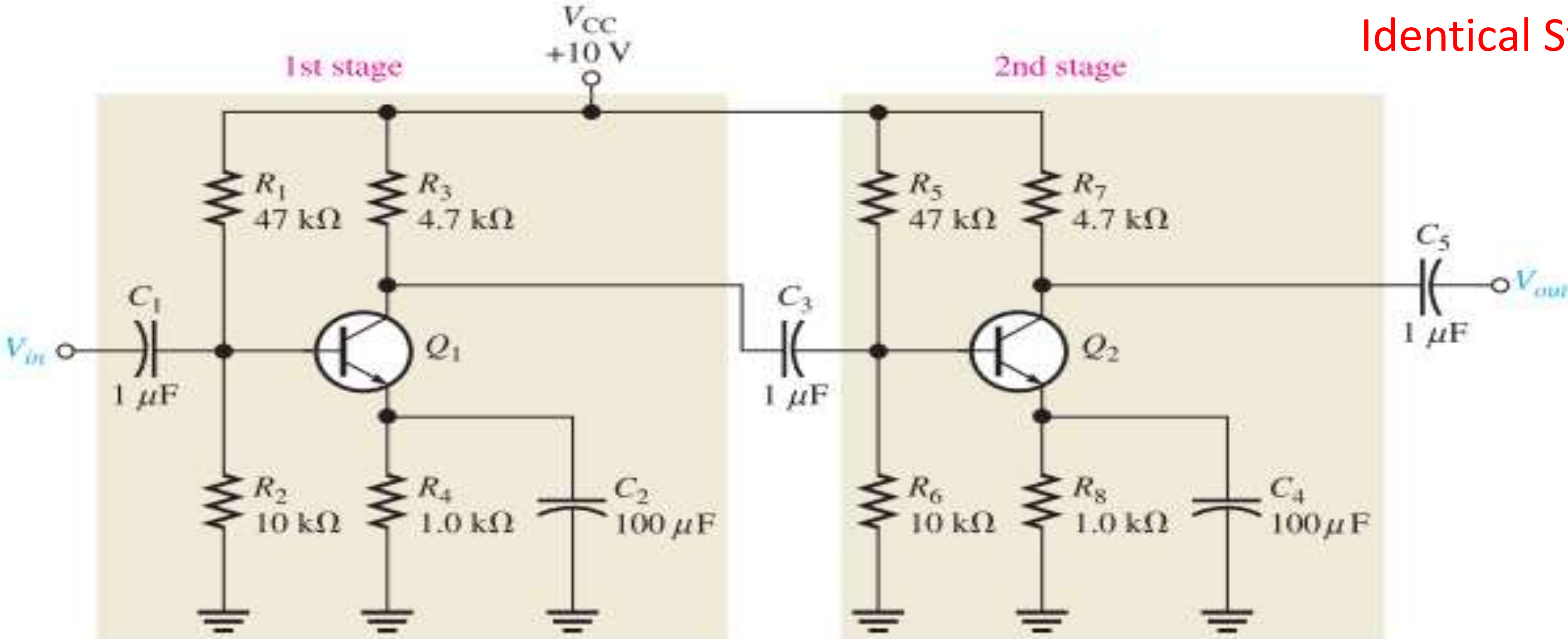
(*i*) to transfer a.c. output of one stage to the input of the next stage

(*ii*) to isolate the d.c. conditions of one stage from the next stage.

Capacitively-Coupled (R-C Coupling)

- The output of the first stage capacitively *coupled* to the input of the 2nd stage.
- Capacitive coupling prevents the dc bias of one stage from affecting that of the other but allows the ac signal to pass without attenuation

Identical Stages



$\beta_{DC} = \beta_{ac} = 150$ for Q_1 and Q_2

- Because the coupling capacitor C3 effectively appears as a short at the signal frequency, the total input resistance of the second stage presents an ac load to the first stage.

Capacitively-Coupled (R-C Coupling)

DC Analysis of each stage (Identical and capacitively coupled)

Since $\beta_{DC}R_4 \gg R_2$ and $\beta_{DC}R_8 \gg R_6$

the dc base voltage for Q_1 and Q_2 is

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{10\ k\Omega}{57\ k\Omega}\right)10\ V = 1.75\ V$$

The dc emitter and collector voltages are as follows:

$$V_E = V_B - 0.7\ V = 1.05\ V$$

$$I_E = \frac{V_E}{R_4} = \frac{1.05\ V}{1.0\ k\Omega} = 1.05\ mA$$

$$I_C \cong I_E = 1.05\ mA$$

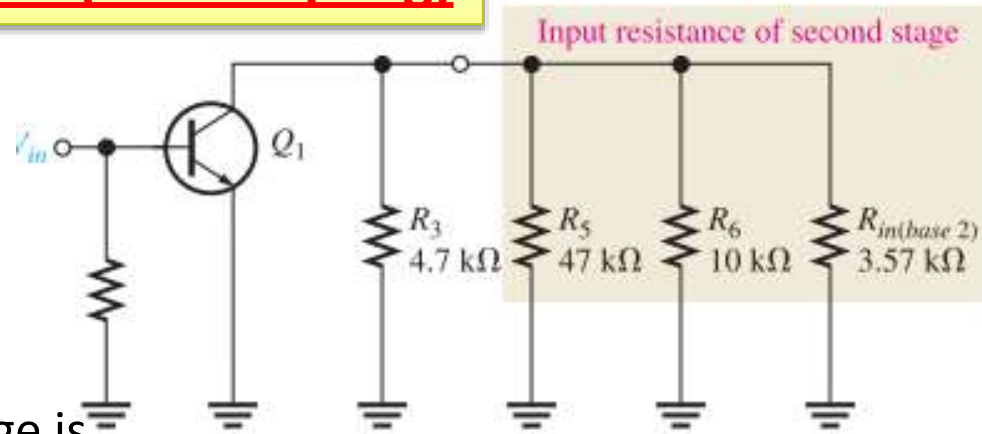
$$V_C = V_{CC} - I_C R_3 = 10\ V - (1.05\ mA)(4.7\ k\Omega) = 5.07\ V$$

$r'_e = 23.8\Omega,$ **= 25 mv/I_E**

$R_{in(base2)} = 3.57\ k\Omega$ **= B re**

Capacitively-Coupled (R-C Coupling)

- AC equivalent of first stage showing loading from second stage input resistance.



Voltage Gain of the First Stage

The ac collector resistance of the first stage is

$$R_{c1} = R_3 \| R_5 \| R_6 \| R_{in(base2)} \qquad R_{c1} = 4.7\,\text{k}\Omega \| 47\,\text{k}\Omega \| 10\,\text{k}\Omega \| 3.57\,\text{k}\Omega = 1.63\,\text{k}\Omega$$

$$A_{v1} = \frac{R_{c1}}{r'_e} = \frac{1.63\,\text{k}\Omega}{23.8\,\Omega} = 68.5$$

Voltage Gain of the Second Stage

- The second stage has no load resistor, so the ac collector resistance is R7, and the gain is

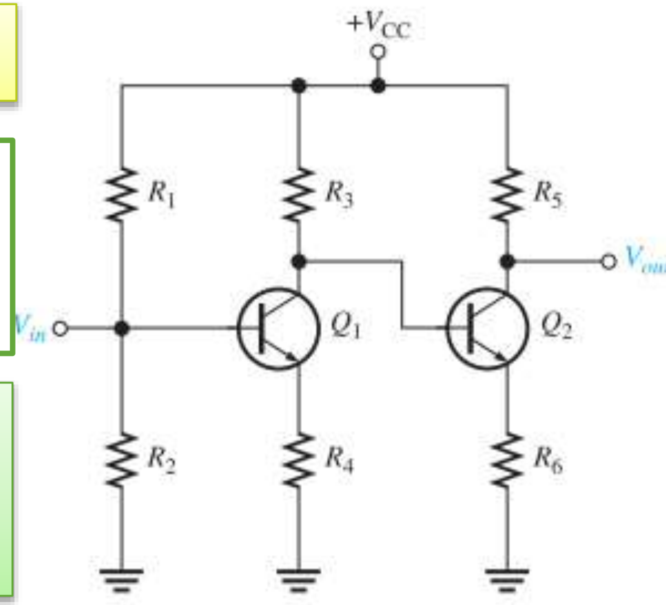
$$A_{v2} = \frac{R_7}{r'_e} = \frac{4.7\,\text{k}\Omega}{23.8\,\Omega} = 197$$

- Compare this to the gain of the first stage (Identical stages) , and
- Notice how much the loading from the second stage reduced the gain.

Overall Voltage Gain

$$A'_v = A_{v1}A_{v2} = (68.5)(197) \cong 13{,}495$$

Direct-Coupled Multistage Amplifiers



- There are no coupling or bypass capacitors
- The dc collector voltage of the first stage provides the base-bias voltage for the second stage.

- Because of the direct coupling, this type of amplifier has a better low-frequency response than the capacitively coupled type

- At Low Frequencies:
  - ✓ The reactance of coupling and bypass capacitors may become excessive.
  - ✓ The increased reactance of capacitors produces gain reduction in capacitively coupled amplifiers.

- Direct-coupled amplifiers can be used to amplify low frequencies all the way down to dc (0 Hz) without loss of voltage (no capacitors)

- The disadvantage of direct-coupled amplifiers, is that small changes in the dc bias voltages from temperature effects or power-supply variation are amplified by the succeeding stages, which can result in a significant drift in the dc levels throughout the circuit.

Classification Of Amplifiers

1. According to frequency capabilities.

Amplifiers are classified as audio amplifiers , radio frequency amplifiers

- **AF Amplifier** are used to amplify the signals lying in the audio range (i.e. 20 Hz to 20 kHz)
- **RF amplifiers** are used to amplify signals having very high frequency.

2. According to coupling methods.

- R-C coupled amplifiers,
- Transformer coupled amplifiers
- Direct Coupled

Classification Of Amplifiers

3. According to use.

a. Voltage amplifiers

- Amplify the input voltage, if possible with minimal current at the output.
- The power gain of the voltage amplifier is low.
- The main application is to strengthen the signal to make it less affected by noise and attenuation.
- Ideal voltage amp. have infinite input impedance & zero output impedance.

a. Power amplifiers

- Amplify the input power, if possible with minimal change in the output voltage
- Power amp. are used in devices which require a large power across the loads.
- In multi stage amplifiers, power amplification is made in the final stages
  - ✓ Audio amplifiers and RF amplifiers use it to deliver sufficient power the load.
  - ✓ Servo motor controllers use power it to drive the motors.

Classification Of Amplifiers

	Voltage amplifiers	Power amplifiers
current gain	low	high
Voltage gain	high	low
Heat dissipation	low	high
cooling mechanism	not required	required
Transistor Size	Small	Large to dissipate heat
Base Width	small	Wide to handle higher current
Beta	Usually high >100	Low usually < 20

Amplifier Classes (Mode of operation)

- In small-signal amplifiers, the main factors are usually amplification linearity and magnitude of gain.
- Large-signal or power amplifiers, on the other hand, primarily provide sufficient power to an output load to drive a speaker or other power device, typically a few watts to tens of watts.
- The main features of a large-signal amplifier are the circuit's power efficiency, the maximum amount of power that the circuit is capable of handling, and the impedance matching to the output device.
- Amplifier classes represent the amount the output signal varies over one cycle of operation for a full cycle of input signal.

Power Amplifier Classes:

1. **Class A**: The output signal varies for a full 360° of the input signal.
   - Bias at the half of the supply

2. **Class B**: provides an output signal varying over one-half the input signal cycle, or for 180° of signal.
   - Bias at the zero level

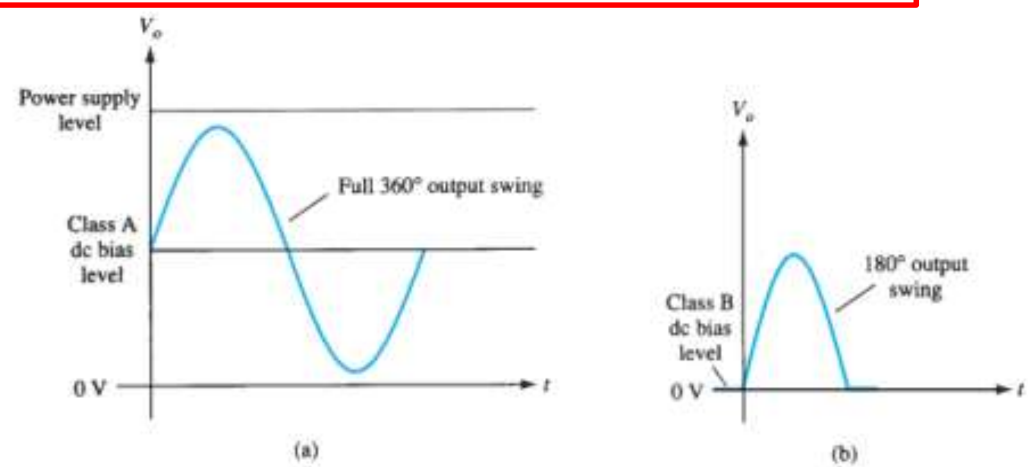


FIG. 12.1
Amplifier operating classes.

Amplifier Efficiency

Power Amplifier Classes …

3. **Class AB**: An amplifier may be biased at a dc level above the zero-base-current level of class B and above one-half the supply voltage level of class A.

4. **Class C:** The output of a class C amplifier is biased for operation at less than 180° of the cycle and will operate only with a tuned (resonant) circuit, which provides a full cycle of operation for the tuned or resonant frequency.

5. **Class D:** This operating class is a form of amplifier operation using pulse (digital) signals, which are on for a short interval and off for a longer interval.

- The **power efficiency** of an amplifier, defined as the ratio of power output to power input, improves (gets higher) going from class A to class D.

TABLE 12.1
Comparison of Amplifier Classes

	Class				
	A	AB	B	C[a]	D
Operating cycle	360°	180° to 360°	180°	Less than 180°	Pulse operation
Power efficiency	25% to 50%	Between 25% (50%) and 78.5%	78.5%		Typically over 90%

[a]Class C is usually not used for delivering large amounts of power, and thus the efficiency is not given here.

SERIES-FED CLASS A AMPLIFIER

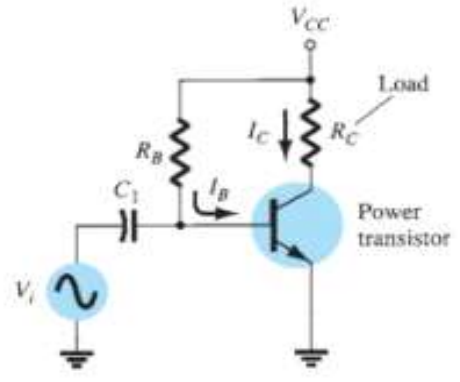


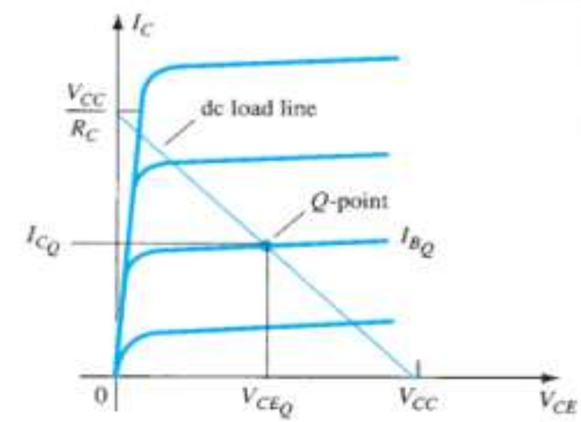
FIG. 12.2
Series-fed class A large-signal amplifier.

- DC Bias Operation

$$I_B = \frac{V_{CC} - 0.7\text{ V}}{R_B}$$

$$I_C = \beta I_B$$

$$V_{CE} = V_{CC} - I_C R_C$$



- AC Operation

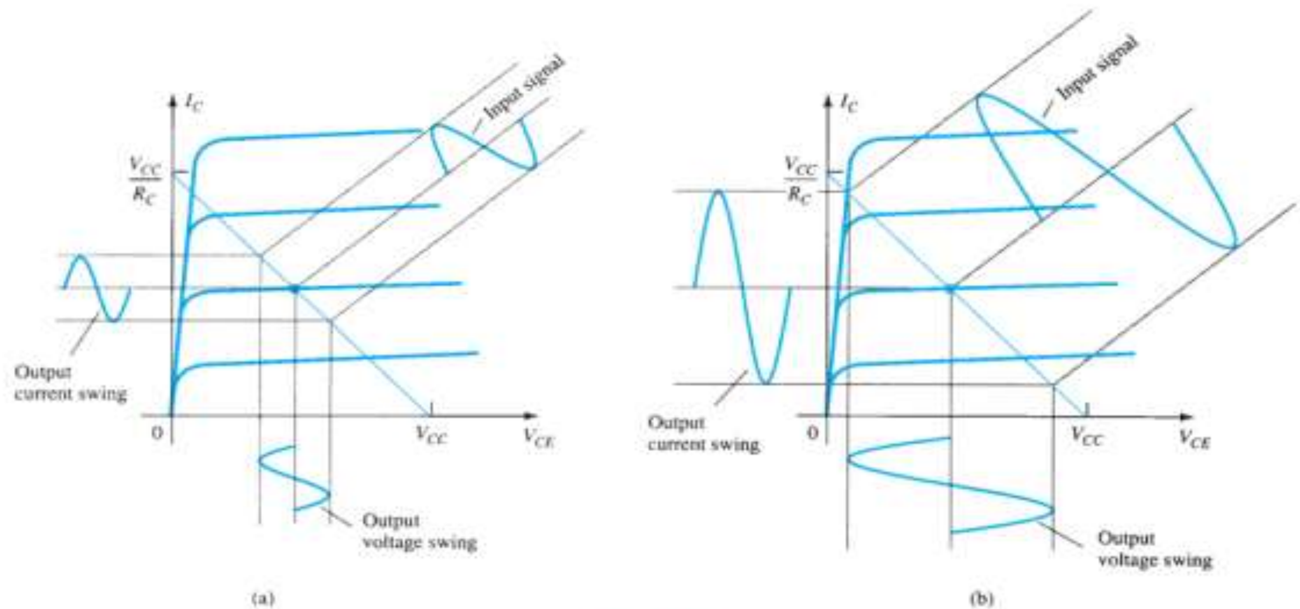


FIG. 12.4
Amplifier input and output signal variation.

Power Considerations

- Efficiency

$$\% \eta = \frac{P_o(\text{ac})}{P_i(\text{dc})} \times 100\%$$

- The power drawn from the supply is $P_i(\text{dc}) = V_{CC} I_{C_Q}$

- Output Power

$$P_o(\text{ac}) = V_{CE}(\text{rms}) I_C(\text{rms})$$

$$P_o(\text{ac}) = I_C^2(\text{rms}) R_C$$

$$P_o(\text{ac}) = \frac{V_C^2(\text{rms})}{R_C}$$

- Maximum Efficiency

$$\text{maximum } V_{CE}(\text{p-p}) = V_{CC}$$

$$\text{maximum } I_C(\text{p-p}) = \frac{V_{CC}}{R_C}$$

$$\text{maximum } P_o(\text{ac}) = \frac{V_{CC}(V_{CC}/R_C)}{8} = \frac{V_{CC}^2}{8R_C}$$

N.B.:

$$V_{\text{RMS}} = \frac{V_{\text{P}}}{\sqrt{2}}$$

$$\text{maximum } P_i(\text{dc}) = V_{CC}(\text{maximum } I_C) = V_{CC}\frac{V_{CC}/R_C}{2} = \frac{V_{CC}^2}{2R_C}$$

The maximum power input can be calculated using the dc bias current set to one-half the

$$\text{maximum } \% \eta = \frac{\text{maximum } P_o(\text{ac})}{\text{maximum } P_i(\text{dc})} \times 100\% = \frac{V_{CC}^2/8R_C}{V_{CC}^2/2R_C} \times 100\% = 25\%$$

The Class B and Class AB Push-Pull Amplifiers

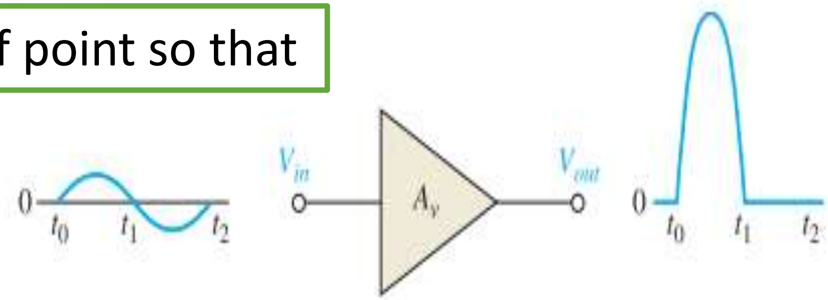
- Class B amplifier: When an amplifier is biased at cutoff so that it operates in the linear region for 180^o of the input cycle and is in cutoff for 180^o
- Class AB amplifiers: are biased to conduct for slightly more than 180o
- Both are more efficient than a class A amplifier;

- A disadvantage of class B or class AB is that it is more difficult to implement the circuit in order to get a linear reproduction of the input waveform.
- The term **push-pull** refers to a common type of class B or class AB amplifier circuit in which two transistors are used on alternating half-cycles to reproduce the input waveform at the output.

Class B Operation

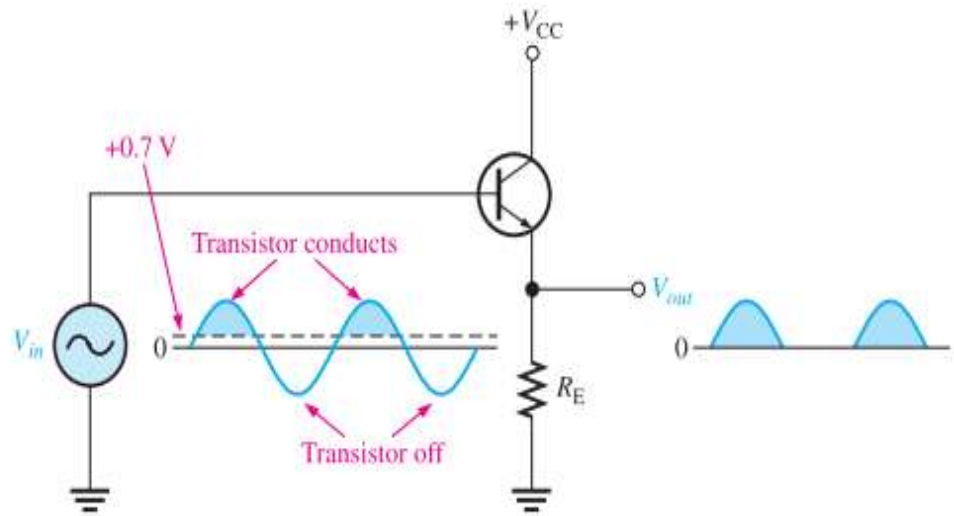
- The class B amplifier is biased at the cutoff point so that

$$I_{CQ} = 0 \text{ and } V_{CEQ} = V_{CE(cutoff)}.$$



- It is brought out of cutoff and operates in its linear region when the input signal drives the transistor into conduction.

- The Circuit only conducts for the positive half of the cycle.
- Can not amplify the entire cycle



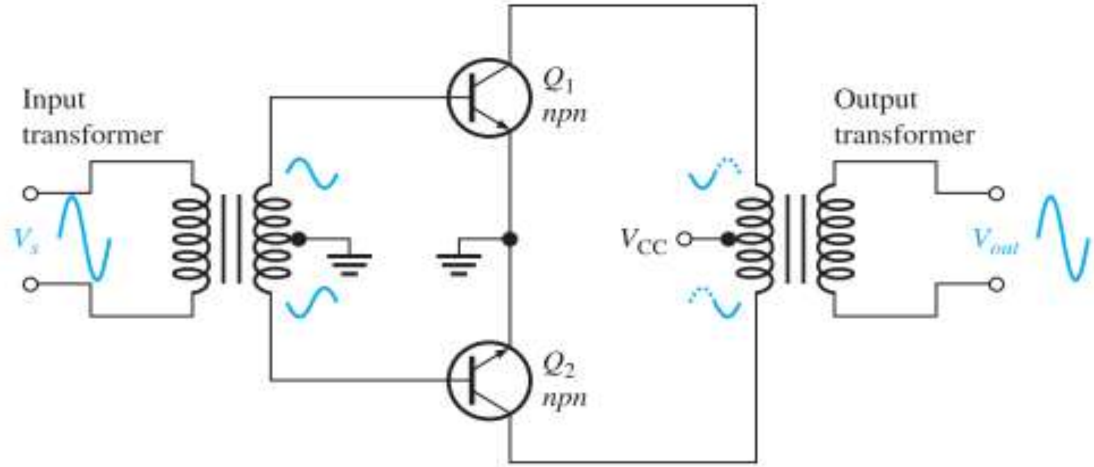
emitter-follower circuit

Class B Push-Pull Operation

- To amplify the entire cycle, it is necessary to add a second class B amplifier that operates on the negative half of the cycle.
- The combination of two class B amplifiers working together is called push-pull operation
- There are **two common approaches** for using push-pull amplifiers to reproduce the entire waveform.

1. Transformer Coupling

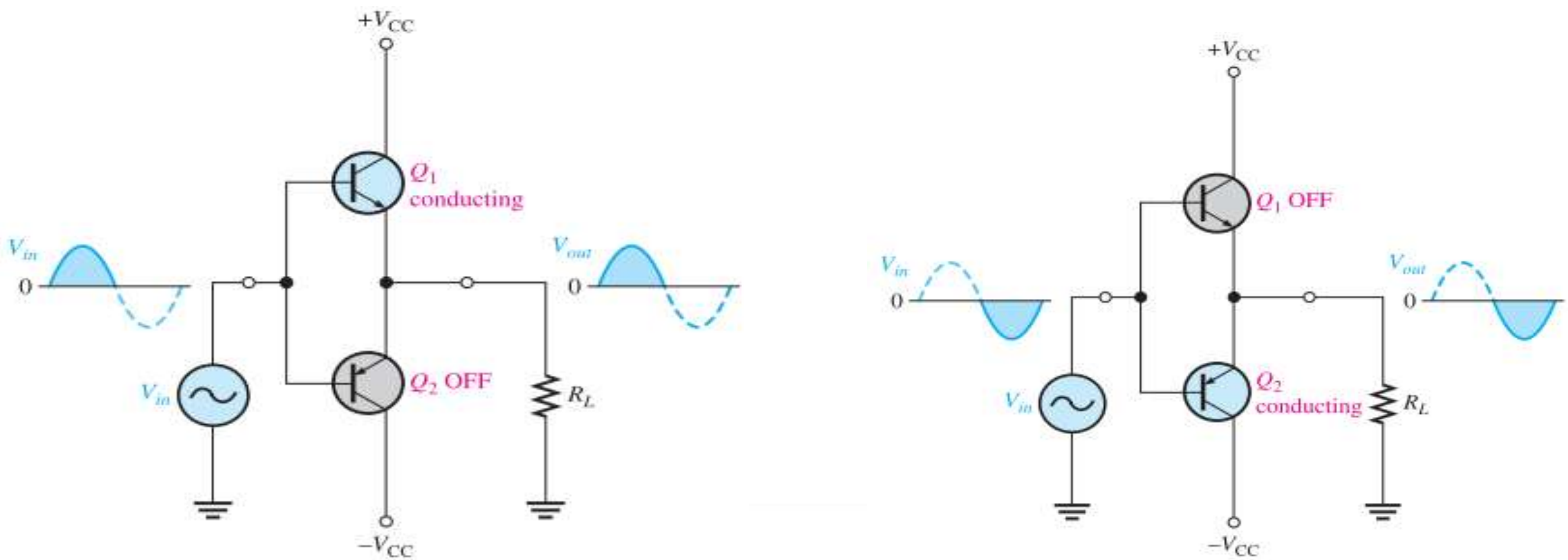
- ✓ The input transformer thus converts the input signal to two out-of-phase signals for the two npn transistors.



- ✓ The output transformer combines the signals by permitting current in both directions, even though one transistor is always cut off.

2. Complementary Symmetry Transistors

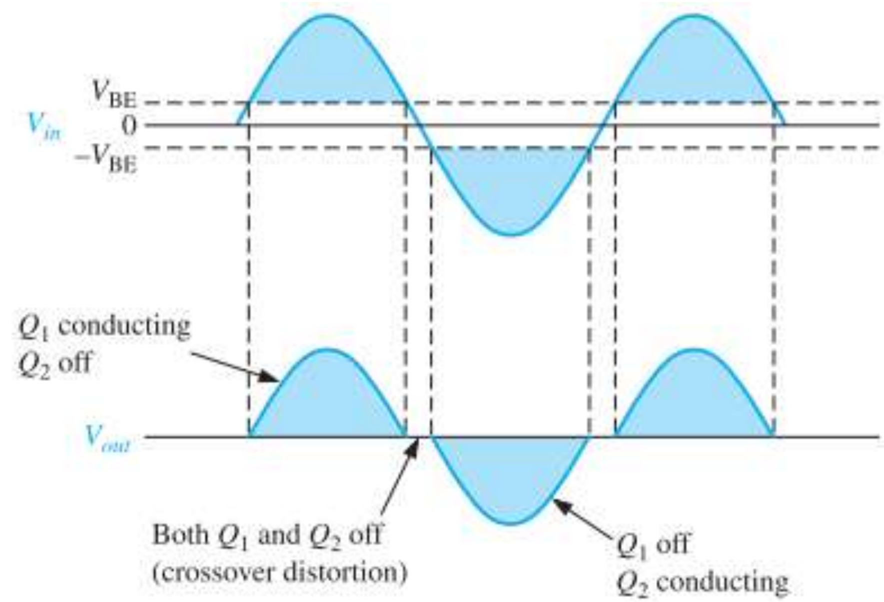
- ✓ The figure shows one of the most popular types of push-pull class B amplifiers using two emitter-followers and both positive and negative power supplies.
- ✓ This is a complementary amplifier because one emitter-follower uses an npn transistor and the other a pnp, which conduct on opposite alternations of the input cycle.



(a) During a positive half-cycle (b) During a negative half-cycle

Crossover Distortion

- ✓ When the dc base voltage is zero, both transistors are off and the input signal voltage must exceed V_{BE} before a transistor conducts.
- ✓ Because of this, there is a time interval between the positive and negative alternations of the input when neither transistor is conducting, as shown in Figure.
- ✓ The resulting distortion in the output waveform is called **crossover distortion**.

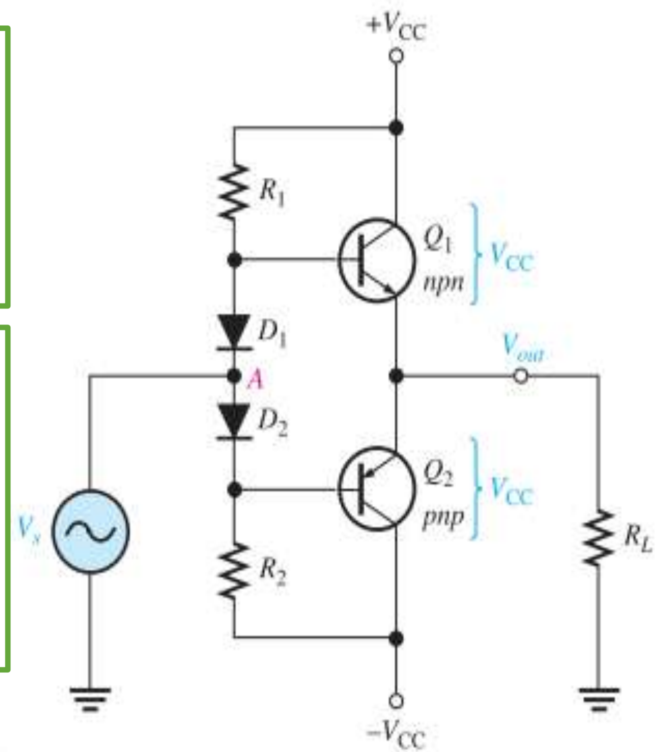


Biasing the Push-Pull Amplifier for **Class AB Operation**

- ✓ To overcome crossover distortion, the biasing is adjusted to just overcome the VBE of the transistors
- ✓ In class AB operation, the push-pull stages are biased into slight conduction, even when no input signal is present.
- ✓ This can be done with a voltage-divider and diode arrangement, as shown

- ➢ Using equal values of R1 and R2 the positive and negative supply voltages forces the voltage at point A to equal 0 V and eliminates the need for an input coupling capacitor.

- ➢ When the diode characteristics of D1 and D2 are closely matched to the characteristics of the transistor BE junctions, the current in the diodes and the current in the transistors are the same; **((current mirror.))**



The diode current will be the same as ICQ

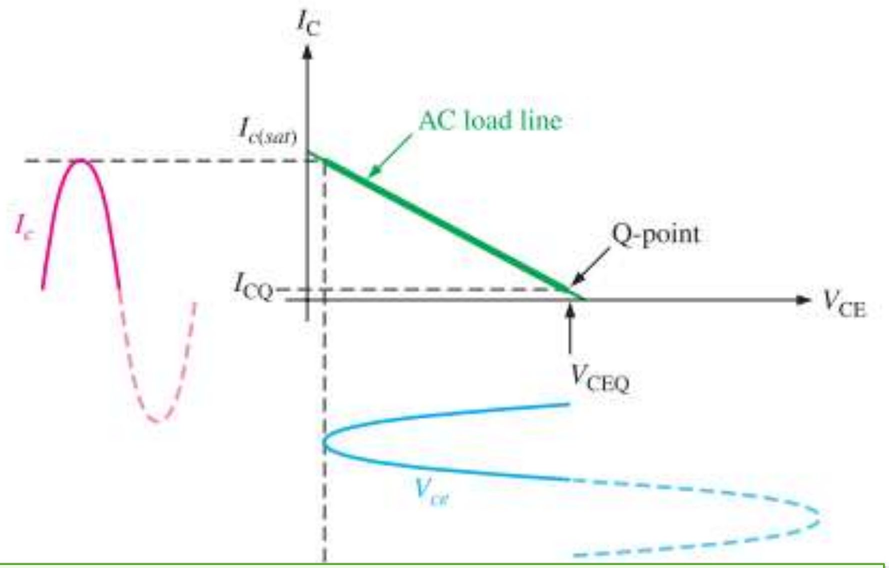
$$I_{CQ} = \frac{V_{CC} - 0.7\ \text{V}}{R_1}$$

Biasing the Push-Pull Amplifier for Class AB Operation

✓ AC Operation

- The Q-point is slightly above cutoff. (In a true class B amplifier, the Q-point is at cutoff.)
- The ac cutoff voltage is at Vcc
- The ac saturation current is:

$$I_{c(sat)} = \frac{V_{CC}}{R_L}$$



- ✓ In class A , the Q-point is near the middle and there is significant current in the transistors even with no signal.
- ✓ In class B , when there is no signal, the transistors have only a very small current and therefore dissipate very little power.
- ✓ Thus, the efficiency of a class B amplifier can be much higher than a class A amplifier.

The ideal maximum peak output voltage is

$$V_{out(peak)} \cong V_{CEQ} \cong V_{CC}$$

The ideal maximum peak current is

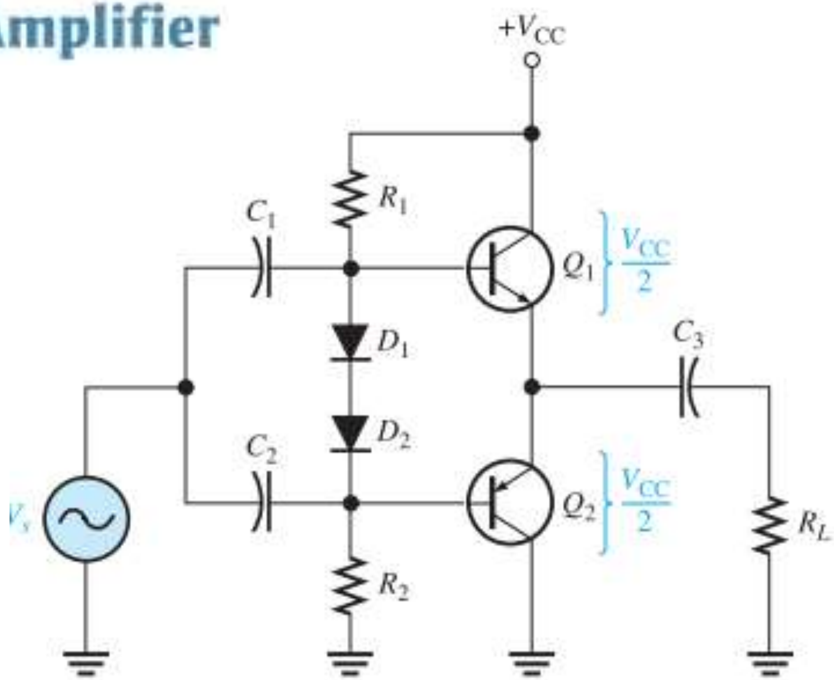
$$I_{out(peak)} \cong I_{c(sat)} \cong \frac{V_{CC}}{R_L}$$

Single-Supply Push-Pull Amplifier

- The circuit operation is the same as that described previously, except the bias is set to force the output emitter voltage to be

$$V_{out(peak)} \cong V_{CEQ} = \frac{V_{CC}}{2}$$

$$I_{out(peak)} \cong I_{c(sat)} = \frac{V_{CEQ}}{R_L}$$



Maximum Output Power

$$P_{out} = I_{out(rms)}V_{out(rms)}$$

$$I_{out(rms)} = 0.707I_{out(peak)} = 0.707I_{c(sat)}$$

$$V_{out(rms)} = 0.707V_{out(peak)} = 0.707V_{CEQ}$$

$$P_{out} = 0.5I_{c(sat)}V_{CEQ}$$

Substituting $V_{CC}/2$ for V_{CEQ}, the maximum average output power is

$$\mathbf{P_{out} = 0.25I_{c(sat)}V_{CC}}$$

DC Input Power

The dc input power comes from the V_{CC} supply and is

$$P_{DC} = I_{CC}V_{CC}$$

Since each transistor draws current for a half-cycle, the current is a half-wave signal with an average value of

$$I_{CC} = \frac{I_{c(sat)}}{\pi}$$

$$P_{DC} = \frac{I_{c(sat)}V_{CC}}{\pi}$$

Efficiency

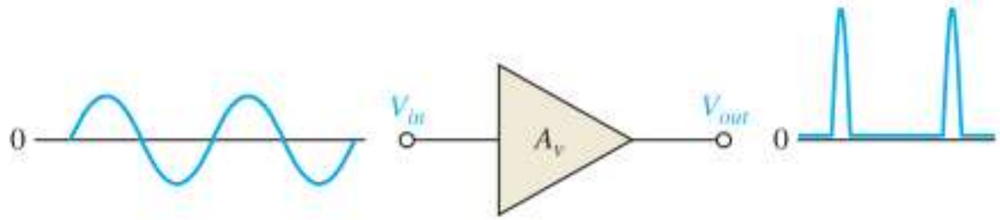
$$\eta = \frac{P_{out}}{P_{DC}}$$

$$\eta_{max} = \frac{P_{out}}{P_{DC}} = \frac{0.25I_{c(sat)}V_{CC}}{I_{c(sat)}V_{CC}/\pi} = 0.25\pi$$

$$\mathbf{\eta_{max} = 0.79}$$

Class C amplifiers

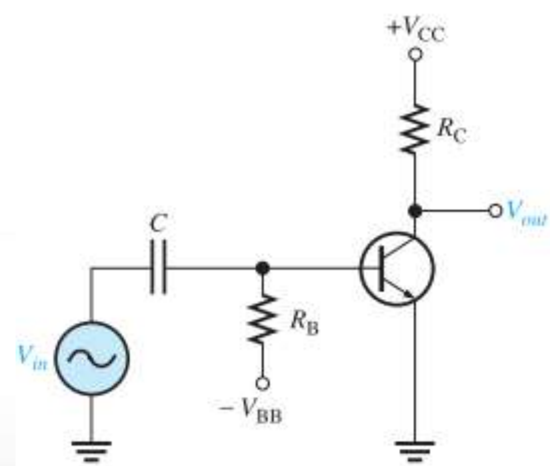
- Class C amplifiers are biased so that conduction occurs for much less than 180o
- Class C amplifiers are more efficient than either class A , B, or AB



- The output amplitude is a nonlinear function of the input, so class C amplifiers are not used for linear amplification.
- They are generally used in radio frequency (RF) applications, including resonance circuits

Basic Class C Operation

- A class C amplifier is normally operated with a resonant circuit load, so the resistive load is used only for the purpose of illustrating the concept.
- The ac source voltage has a peak value that exceeds the barrier potential of the base-emitter junction for a short time near the positive peak of each cycle,

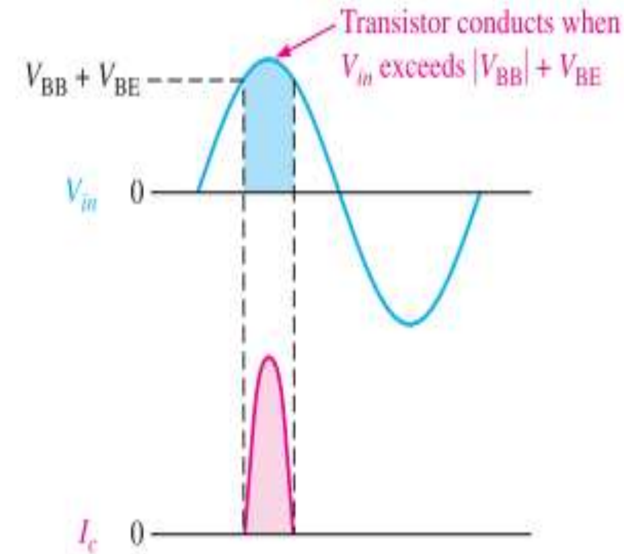


(a) Basic class C amplifier circuit

Class C amplifiers

Basic Class C Operation

- During this short interval, the transistor is turned on.
- The power dissipation of the transistor in a class C amplifier is low because it is on for only a small percentage of the input cycle



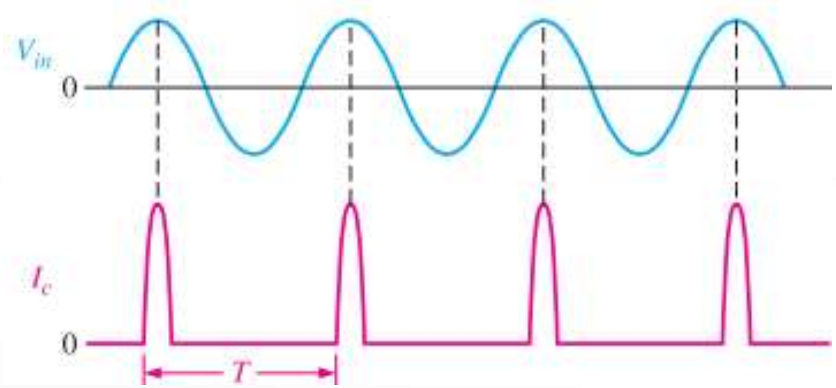
(b) Input voltage and output current waveforms

- The power dissipation during the on time is

$$P_{D(on)} = I_{c(sat)} V_{ce(sat)}$$

- The power dissipation averaged over the entire cycle is

$$P_{D(avg)} = \left(\frac{t_{on}}{T}\right) P_{D(on)} = \left(\frac{t_{on}}{T}\right) I_{c(sat)} V_{ce(sat)}$$

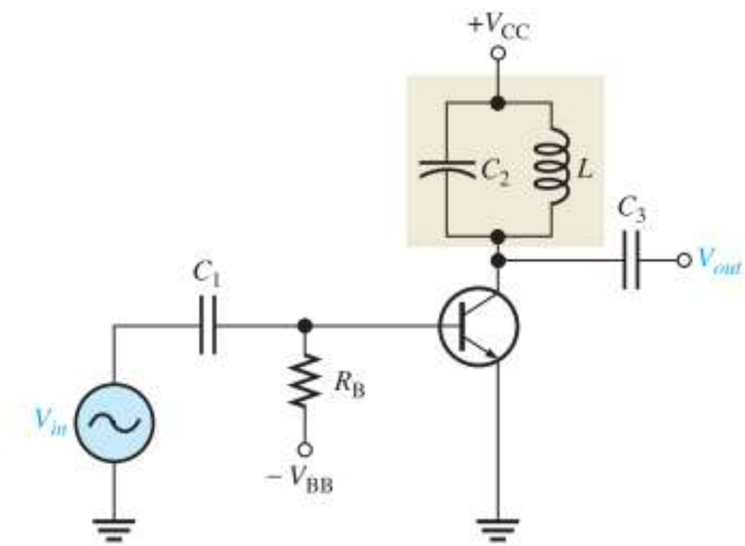


Check EXAMPLE 7–7 (Floyde)

Tuned Class C Operation

- Because the collector voltage (output) is not a replica of the input, the resistively loaded class C amplifier alone is of no value in linear applications.
- It is therefore necessary to use a class C amplifier with a parallel resonant circuit (tank), as shown

- The short pulse of collector current on each cycle of the input initiates and sustains the oscillation of the tank circuit so that an output sinusoidal voltage is produced



(a) Basic circuit