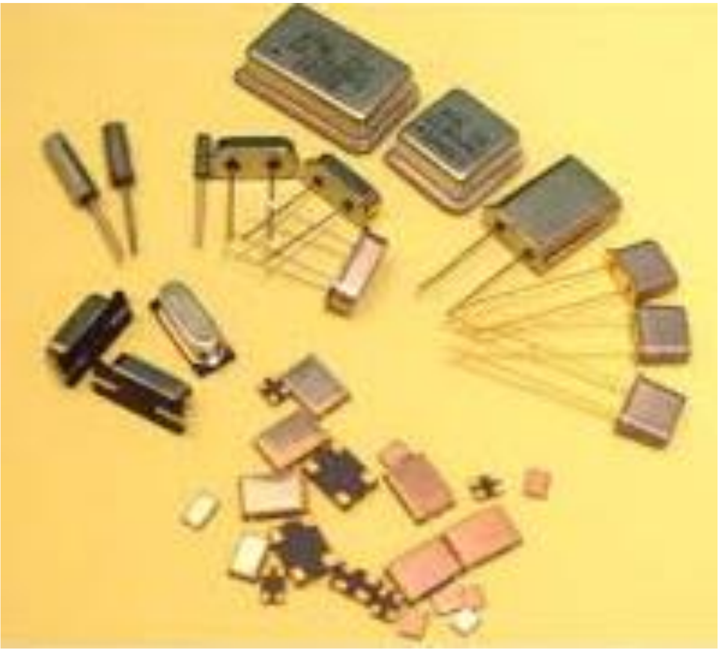
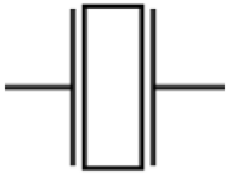
Crystal Oscillator

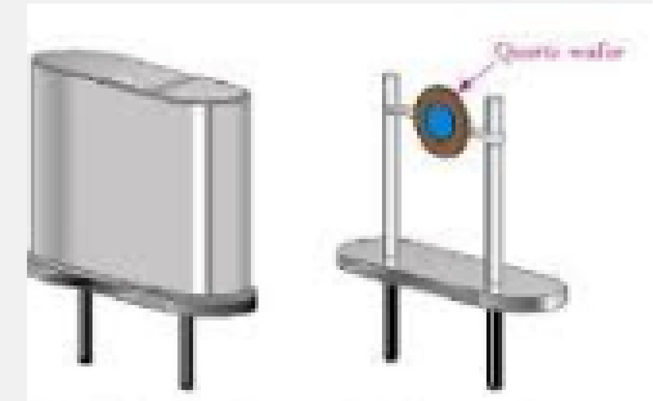
Crystal Oscillator

- Piezoelectric crystal (quartz)
- Operates as a resonant circuit
- Shows great stability in oscillation frequency
- **<u>Piezoelectric effect :</u>** When mechanical stress is applied accross one of its faces, a differential potential developes accross the opposite faces
- Similarly, a voltage applied accross one set of faces of crystal causes mechanical distortion in the crystal shape

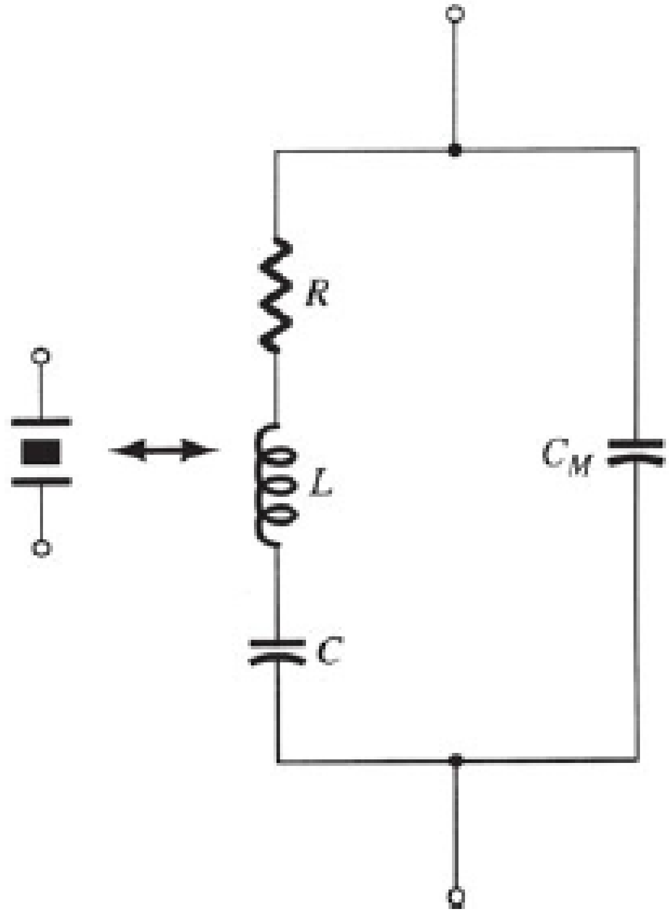




Circuit symbol

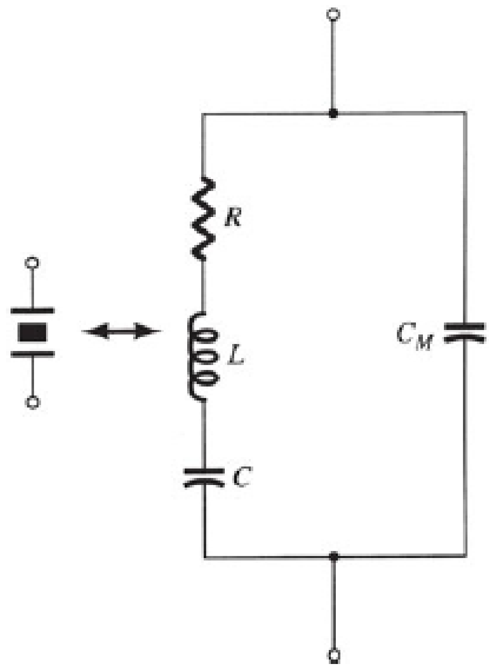


Crystal Oscillator

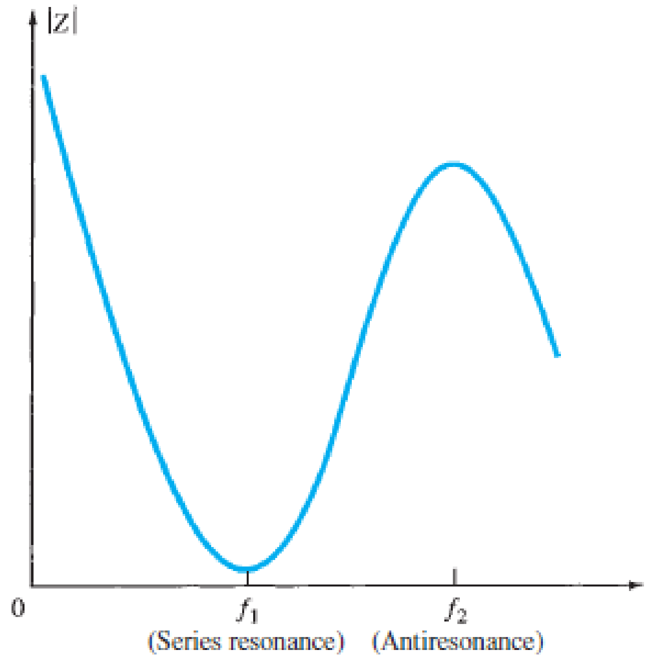


- When alternating voltage is applied to a crystal, mechanical vibrations are set up
- These vibrations have a natural resonant frequency dependent on the crystal
- The crystal action can be represented by an equivalent electrical resonant circuit as shown in the figure

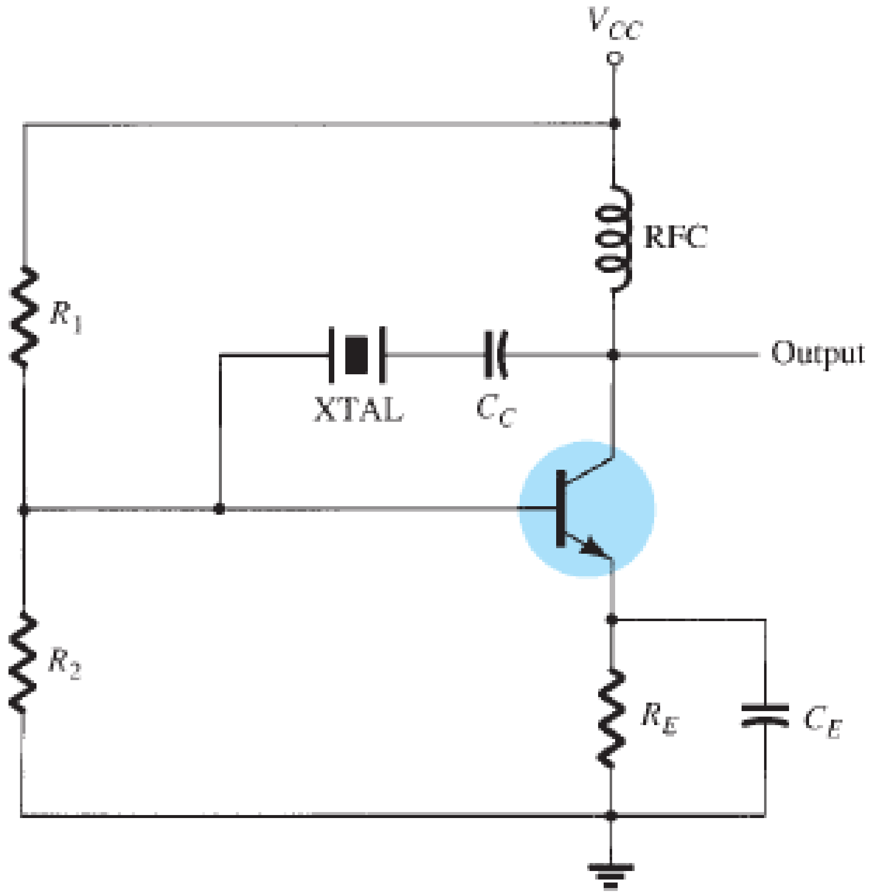
Crystal Oscillator



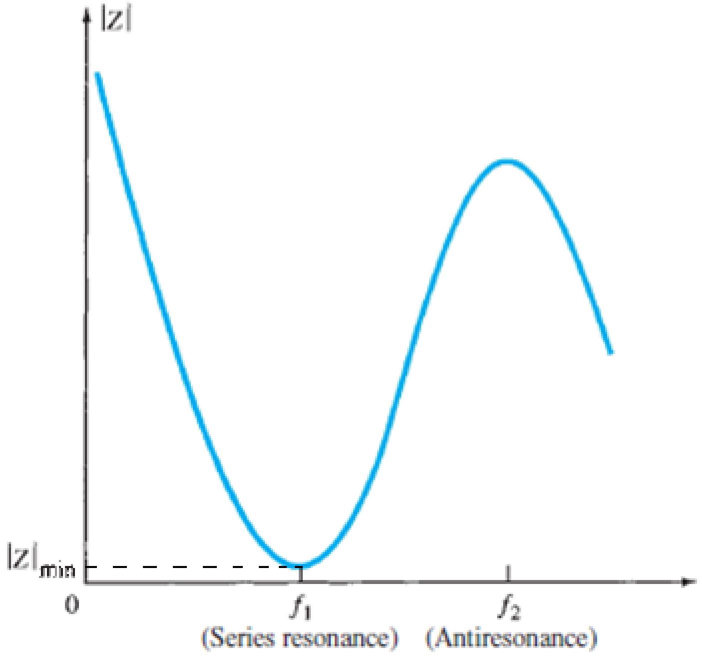
- Such a crystal can have two resonant frequencies
- One occurs when the reactances of the series *RLC* leg are equal (and opposite)
- For this condition, the *series-resonant* impedance is very low (equal to *R*)
- The other resonant condition occurs at a higher frequency when the reactance of the series-resonant leg equals the reactance of capacitor C_M
- This is a parallel resonance or antiresonance condition of the crystal
- At this frequency, the crystal offers a very high impedance to the external circuit as shown in the figure on the right



Crystal Oscillator



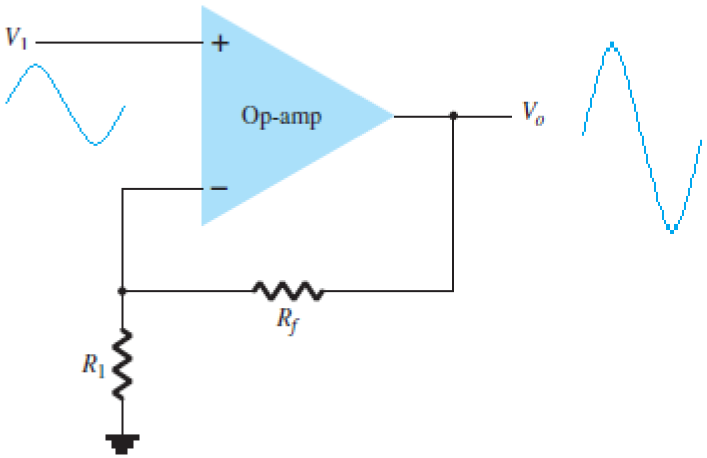
- Figure on the left depicts Crystal-controlled oscillator using a crystal (XTAL) in a series-feedback path
- The current fed back reaches its maximum when XTAL is at its minimum impedance $|Z_{min}|$
- This occurs at $f = f_1 = f_{resonance}$ of XTAL.



Power Amplifiers

Power Amplifiers

- We have seen linear amplifiers so far
- Signal amplitude is changed and a phase shift (delay in time domain) are introduced



For $V_i = 3V_{p-p}$, $R_1 = 1K\Omega$ and $R_f = 3K\Omega$

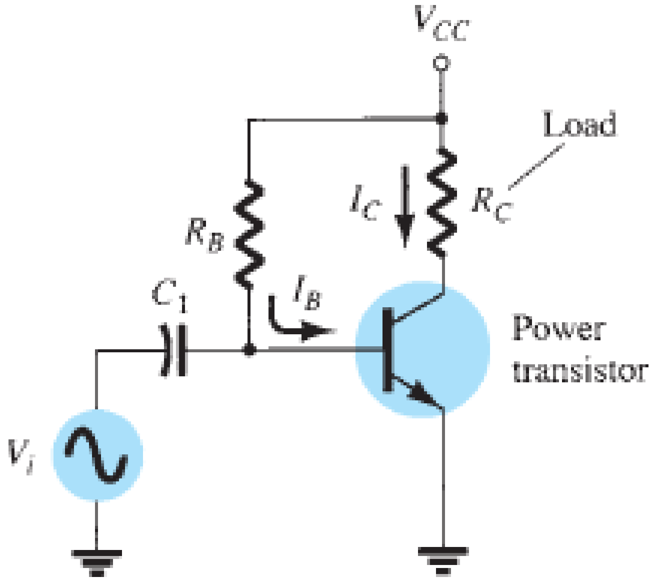
$$V_o = 3 \times \left(1 + \frac{3K}{1K}\right) = 12\ V_{p-p}$$

The focus is on the amplification, not the power

Power Amplifiers

- In small-signal amplifiers, main factors are usually amplification linearity and magnitude of gain
- Since signal voltage and current are small, the amount of power-handling capacity and power efficiency are of little concern
- 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
- In this lecture, we concentrate on amplifier circuits used to handle large-voltage signals at moderate to high current levels
- 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

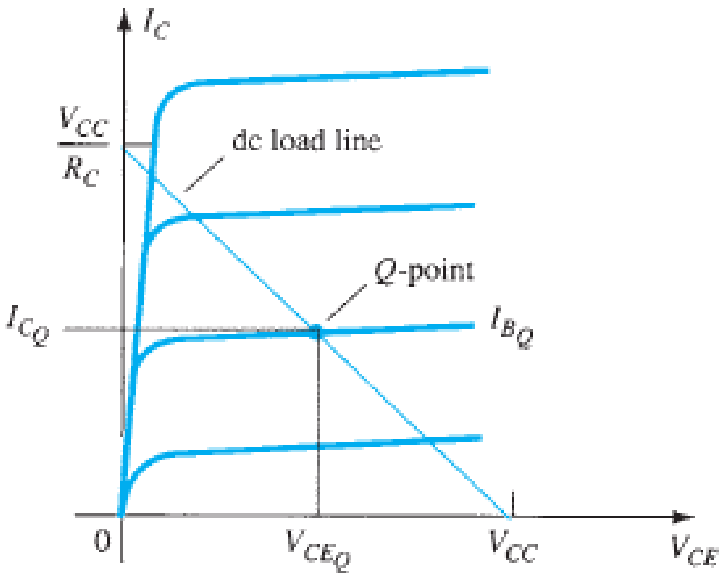
Power Amplifiers



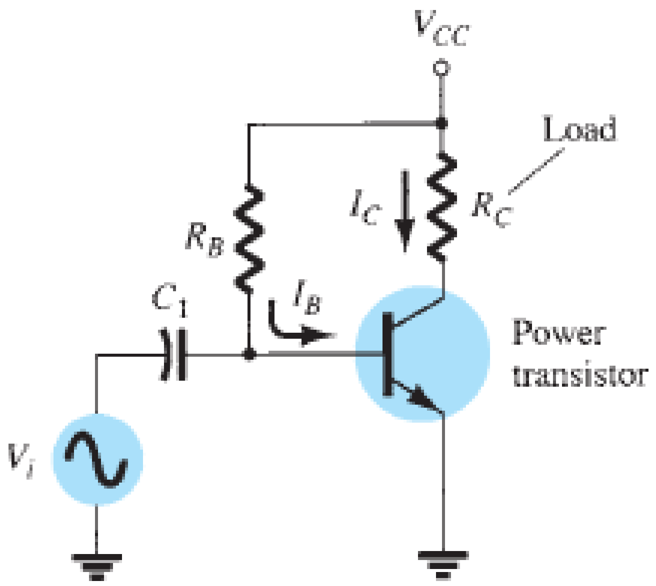
DC Operation

- A dc load line is drawn using the values of V_{CC} and R_C
- The intersection of the dc bias value of *IB* with the dc load line then determines the operating point (Q -point) for the circuit
- The quiescent-point values are those calculated using

$$I_B = \frac{V_{CC} - 0.7}{R_B}$$
$$I_C = \beta I_B$$
$$V_{CE} = V_{CC} - I_C R_C$$

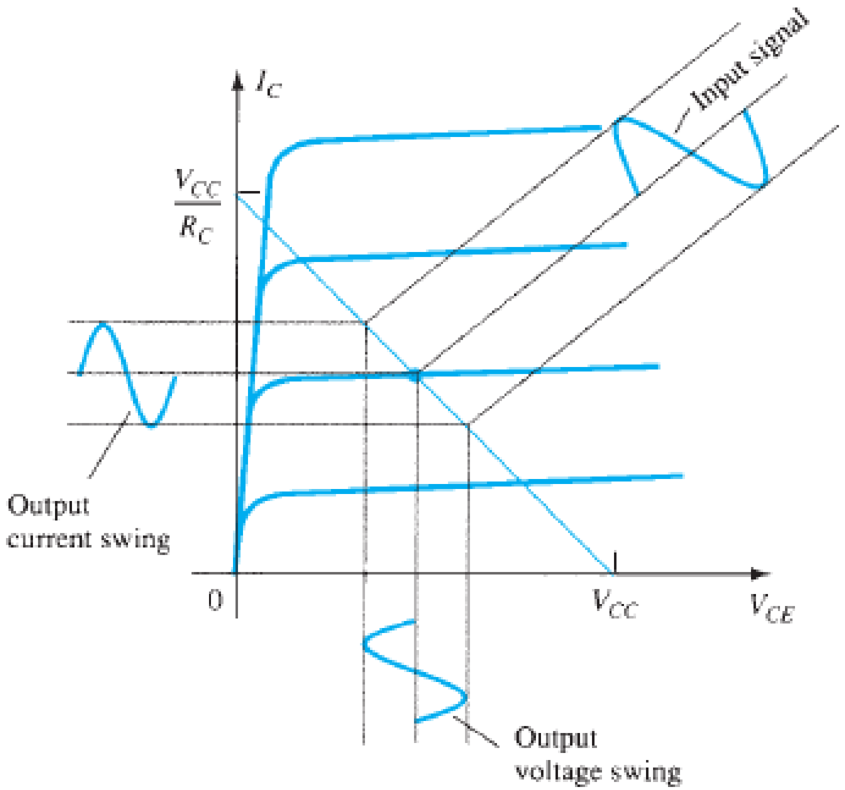


Power Amplifiers

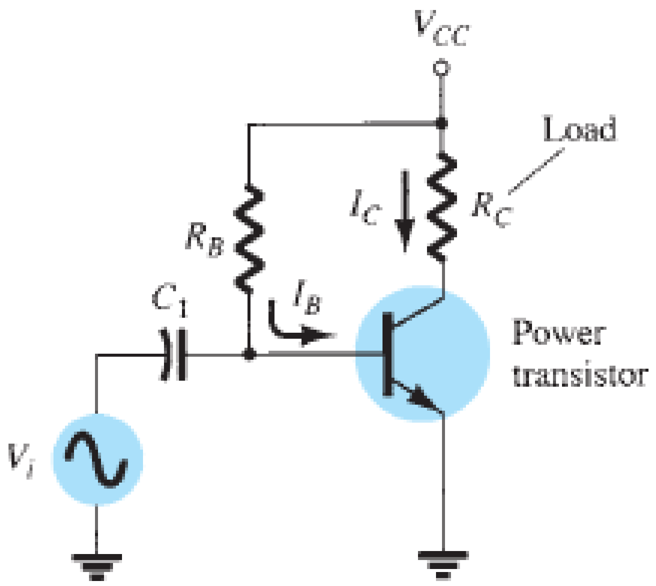


AC Operation

- When an input ac signal is applied to the amplifier on the left , the output will vary from its dc bias operating voltage and current
- A small input signal, as shown in Fig on the right, will cause the base current to vary above and below the dc bias point
- This will then cause the collector current (output) to vary from the dc bias point set as well as the collector–emitter voltage to vary around its dc bias value

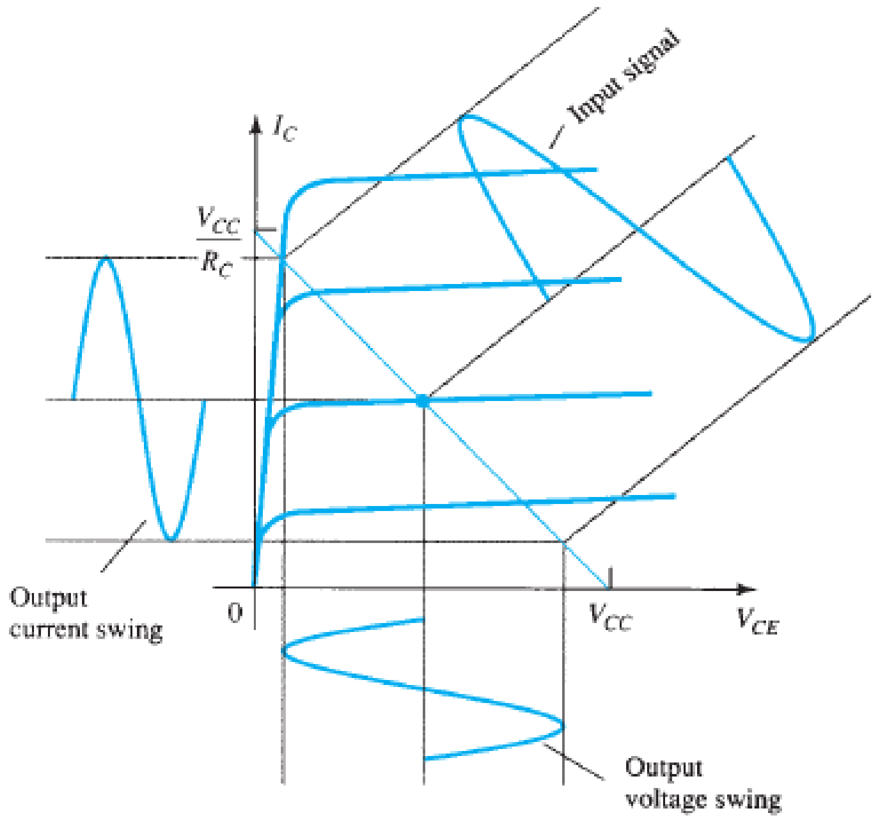


Power Amplifiers

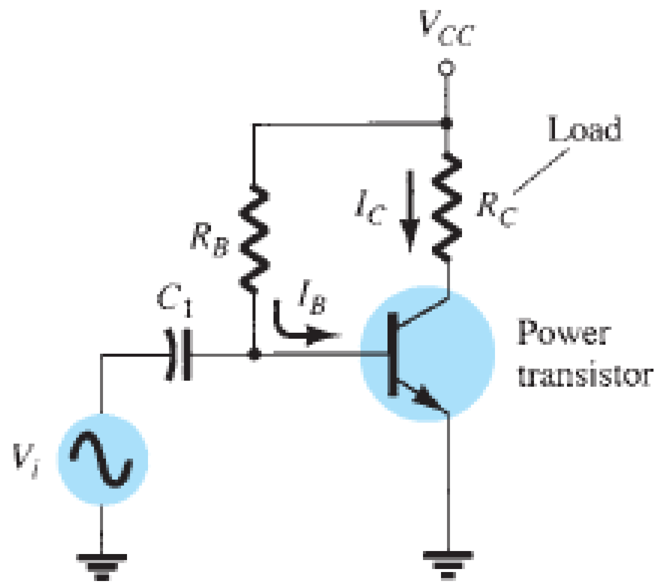


AC Operation

- As the input signal is made larger, the output will vary further around the established dc bias point until either the current or the voltage reaches a limiting condition
- For the current this limiting condition is
  - zero current at the low end
  - V_{CC}/R_C at the high end of its swing
- For the collector–emitter voltage, the limit is
  - 0 V at the low end
  - the supply voltage, V_{CC} at the high end



Power Amplifiers

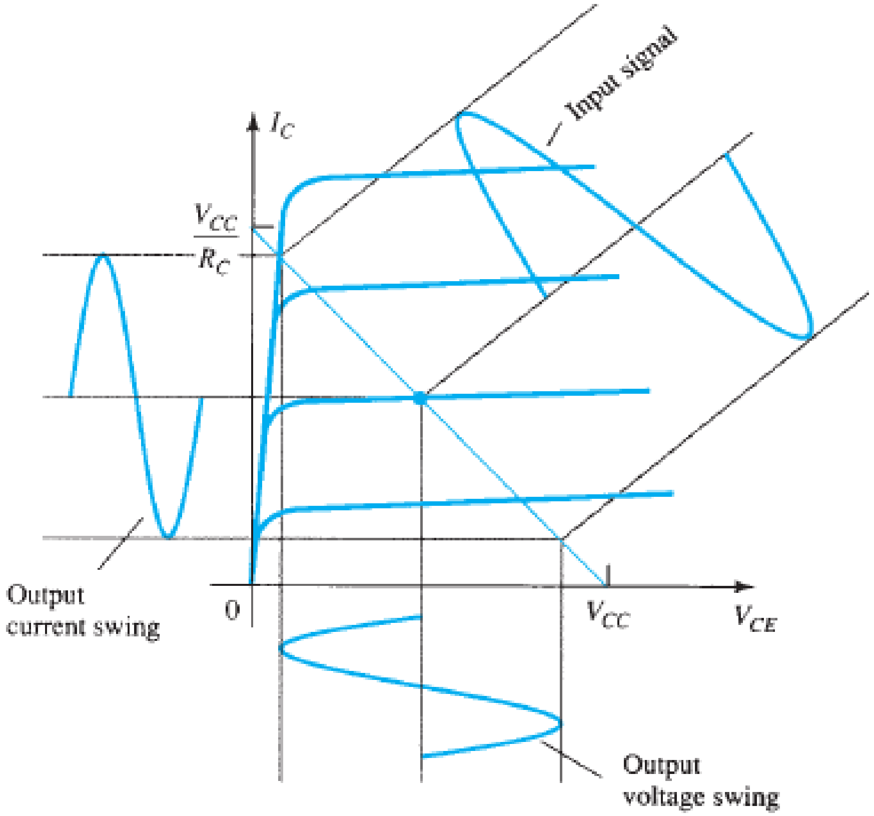


When the signal amplitudes get larger, we are concerned more with the power than the amplification.

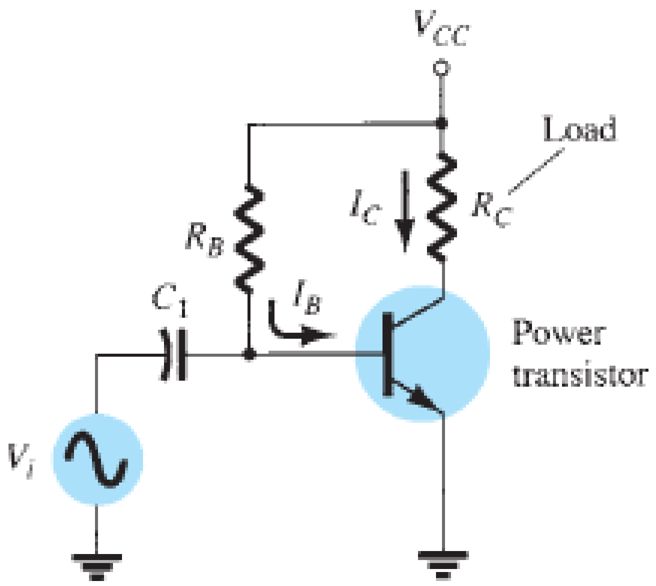
Our concerns are:

- How much input power is consumed?
- What is the power efficiency?
- Will transistors withstand these powers?

etc.



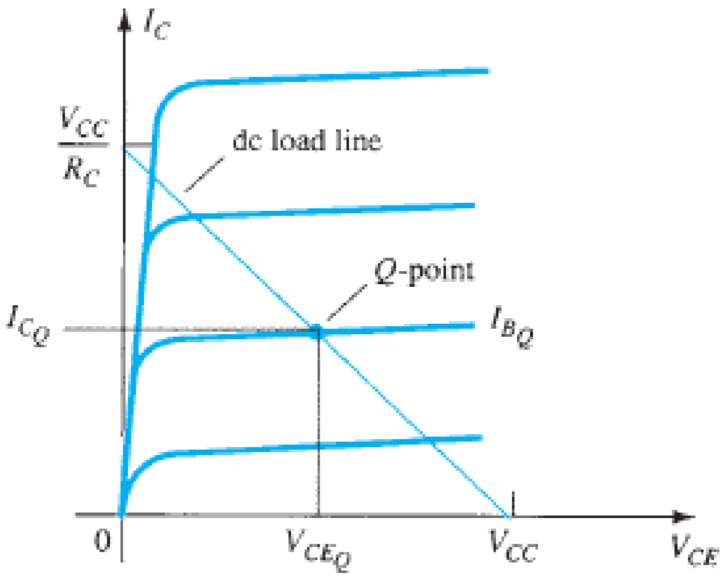
Power Amplifiers



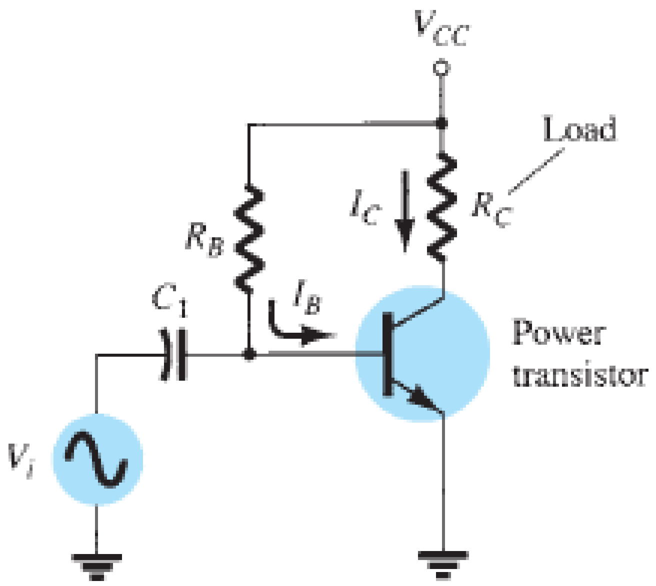
Power Considerations

- The power into an amplifier is provided by the supply voltage
- With no input signal, the dc current drawn is the collector bias current I_{CQ}
- The power then drawn from the supply is

$$\boxed{P_i(\text{dc}) = V_{CC} I_{C_Q}}$$

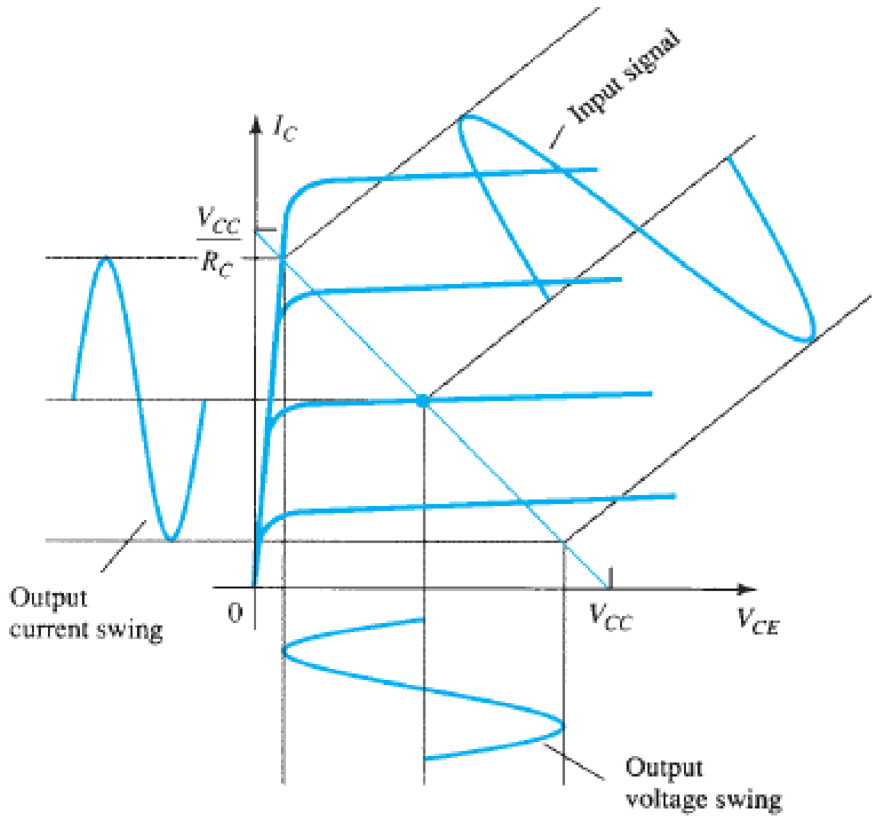


Power Amplifiers



Power Considerations

- The output voltage and current varying around the bias point provide ac power
- This ac power is delivered to the load R_C
- The ac signal V_i causes the base current to vary around the dc bias current and the collector current around its quiescent level I_{CQ}
- The ac power delivered to the load (R_C) may be expressed using RMS values



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

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

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

Power Amplifiers

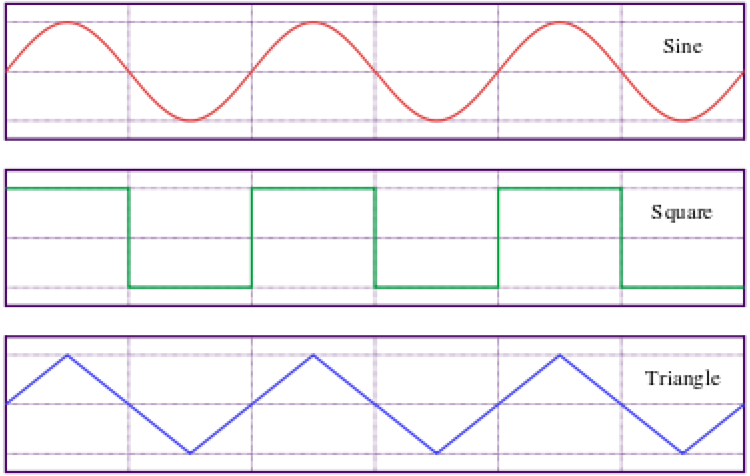
Root Mean Square (RMS)

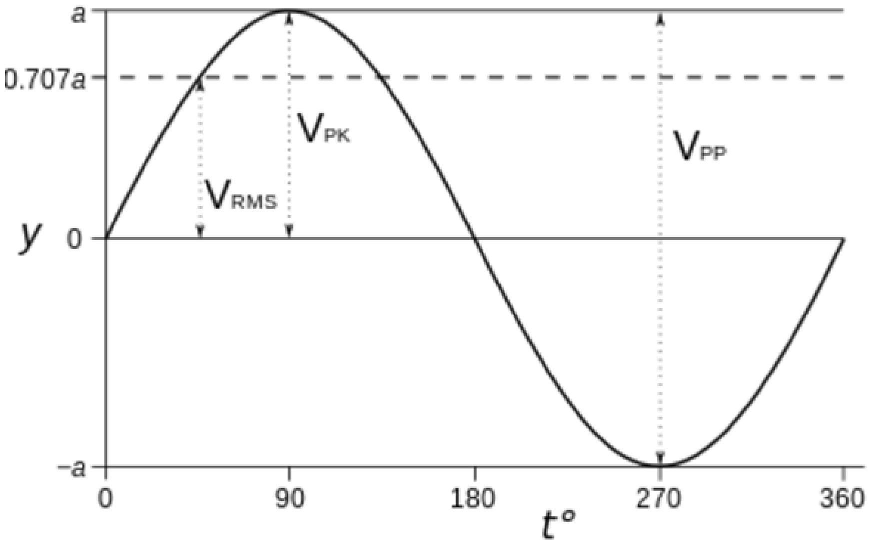
- The RMS value is the square root of the arithmetic mean of the square of the function that defines the continuous waveform.

$$f_{\mathrm{rms}} = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} [f(t)]^2 \, dt}$$

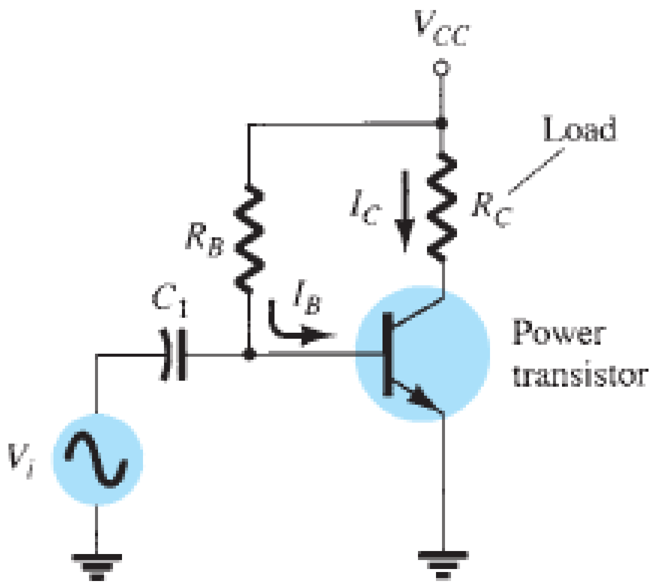
Function	RMS
Sine with peak V_p	$\frac{V_p}{\sqrt{2}}$
Square with peak V_p	V_p
Triangle with peak V_p	$\frac{V_p}{\sqrt{3}}$

$$V_{rms} = \frac{V_p}{\sqrt{2}} = \frac{V_{pp}}{2\sqrt{2}}$$





Power Amplifiers



Efficiency

The efficiency of an amplifier represents the amount of ac power delivered (transferred) from the dc source

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

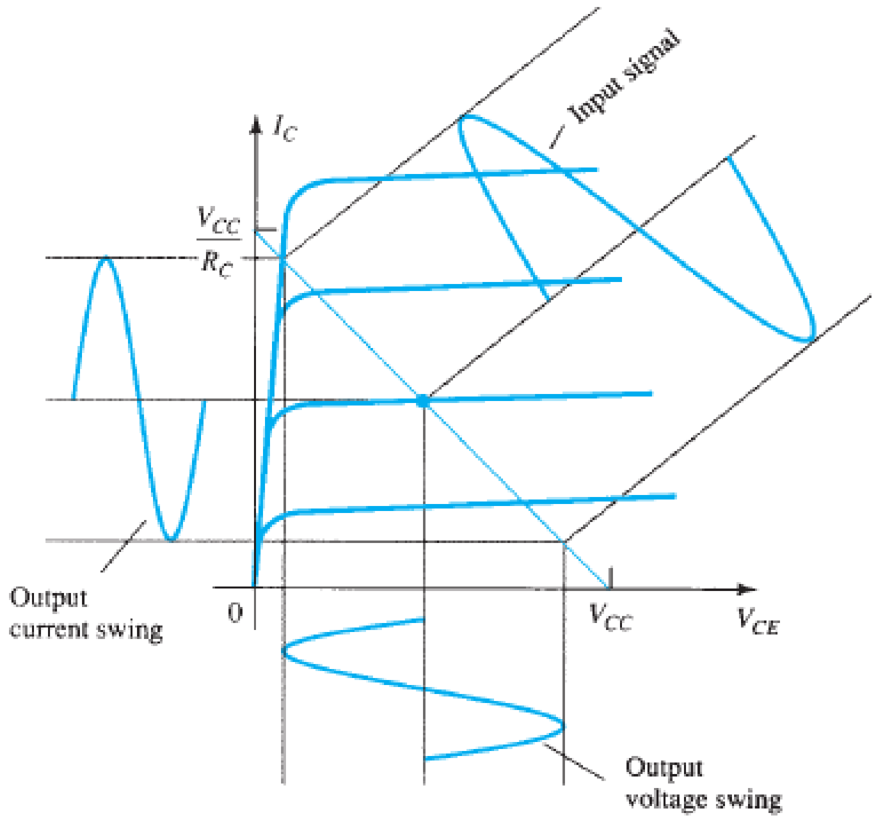
Maximum Efficiency

Maximum efficiency can be determined using the maximum voltage and current swings

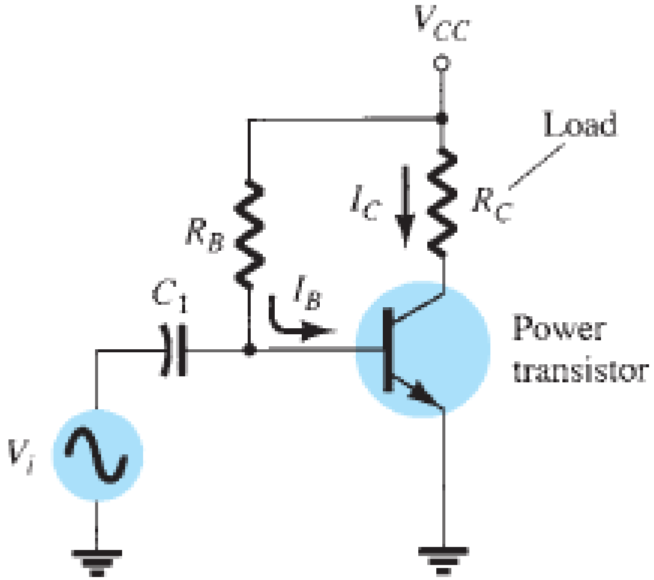
$$V_{CE(\max)} = V_{CC} \Rightarrow V_{CEQ(RMS)} = \frac{V_{CC}}{2\sqrt{2}}$$

$$\mathrm{I}_{\mathrm{CC(max)}} = \frac{\mathrm{V_{CC}}}{\mathrm{R_C}} \Rightarrow I_{CCQ(RMS)} = \frac{V_{CC}}{R_C 2\sqrt{2}}$$

$$P_o(ac) = I_{o(RMS)} \times V_{o(RMS)} = \frac{V_{CC}^2}{8R_C}$$



Power Amplifiers



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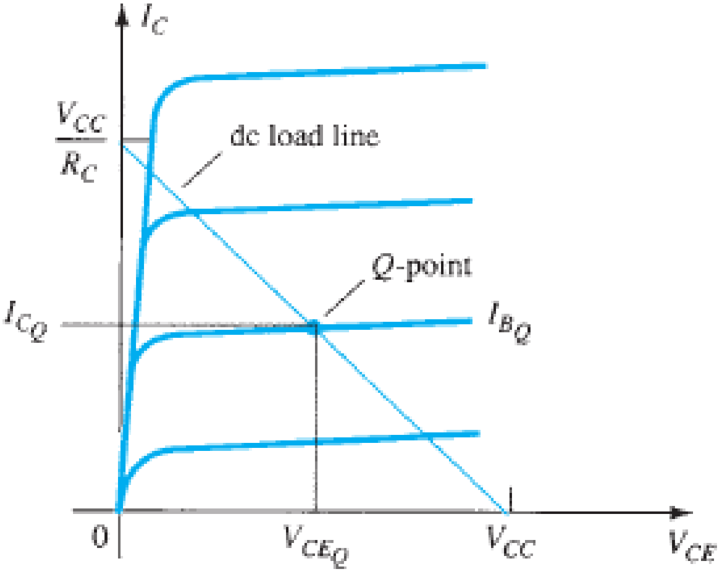
Maximum Efficiency

Maximum efficiency can be determined using the maximum voltage and current swings

$$V_{CEQ(\max)} = V_{CC}$$

$$\mathrm{I_{CQ(max)}} = \frac{\mathrm{V_{CC}}}{\mathrm{2R_C}}$$

$$P_i(dc) = \frac{V_{CC}^2}{2R_C} \Rightarrow \eta = \frac{1}{4} = 0.25$$



Power Amplifiers

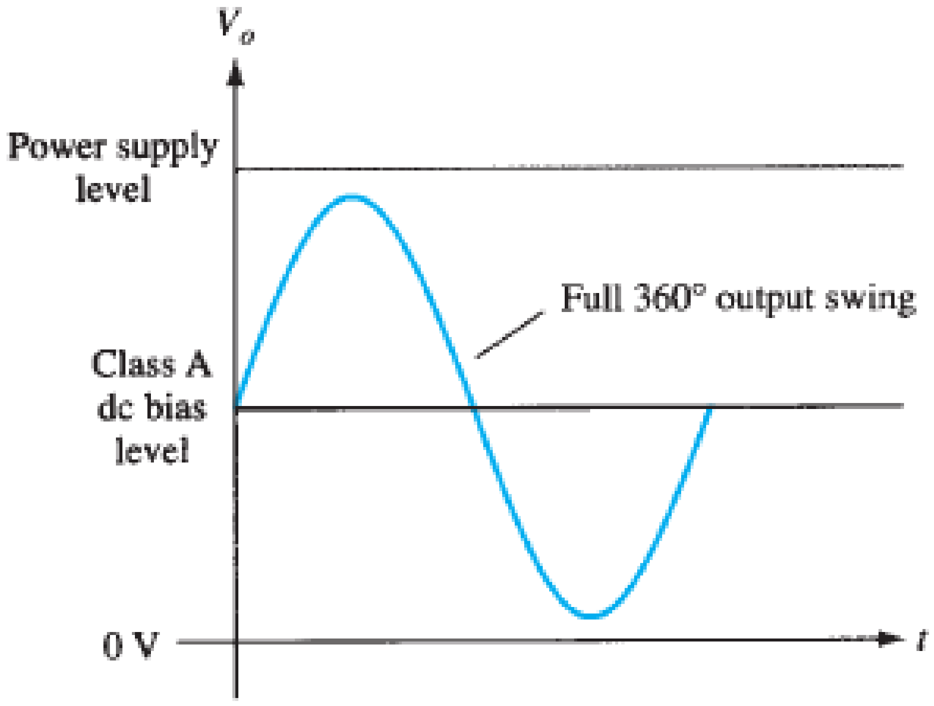
Efficiency

How can I increase efficiency?

Change operation point?

Amplifier Types:

- **Class A:** Output varies for a full 360° of the input
- Figure shows *Q* -point should be biased so that at least half the signal swing of the output may vary up and down without going to a high enough voltage to be limited by the supply voltage level or too low to approach the lower supply level, or 0 V in this description.

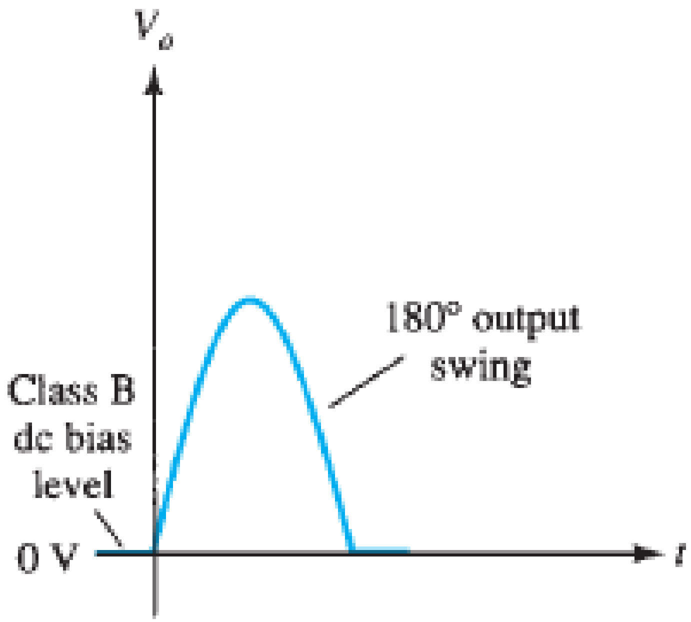


(a)

Power Amplifiers

Amplifier Types:

- **Class B:** Provides an output varying over one-half the input signal cycle, or for 180° of signal
- Figure shows DC bias point is at 0 V, with the output then varying from this bias point for a half-cycle
- Obviously, the output is not a faithful reproduction of the input if only one half-cycle is present
- Two class B operations—one to provide output on the positive-output half-cycle and another to provide operation on the negative-output half-cycle—are necessary
- The combined half-cycles then provide an output for a full 360° of operation. This type of connection is referred to as *push–pull operation.*



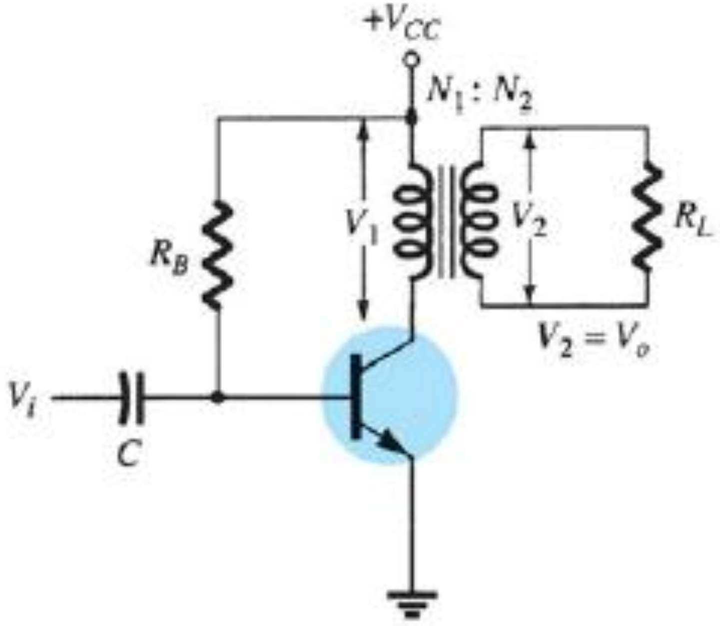
Power Amplifiers

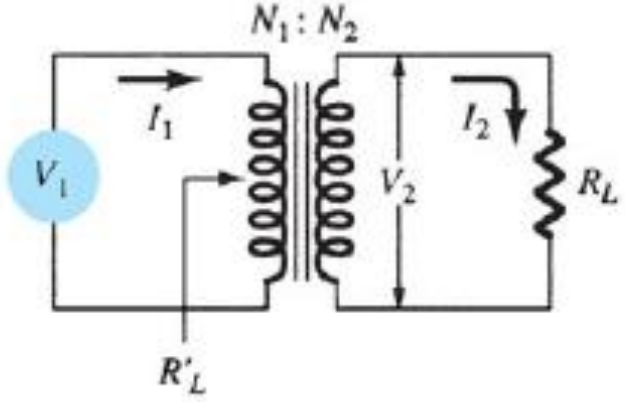
Amplifier Types:

- **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 -> this bias condition is class AB
- Class AB operation still requires a push–pull connection to achieve a full output cycle, but the dc bias level is usually closer to the zero-base-current level for better power efficiency
- For class AB operation, the output signal swing occurs between 180° and 360° and is neither class A nor class B operation
- **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
- This operating class is therefore used in special areas of tuned circuits, such as radio or communications.
- **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
- Using digital techniques makes it possible to obtain a signal that varies over the full cycle (using sampleand- hold circuitry) to recreate the output from many pieces of input signal
- The major advantage of class D operation is that the amplifier is “on” (using power) only for short intervals and the overall efficiency can practically be very high.

Power Amplifiers

Can we obtain better efficiency with an A-Class amplifier?





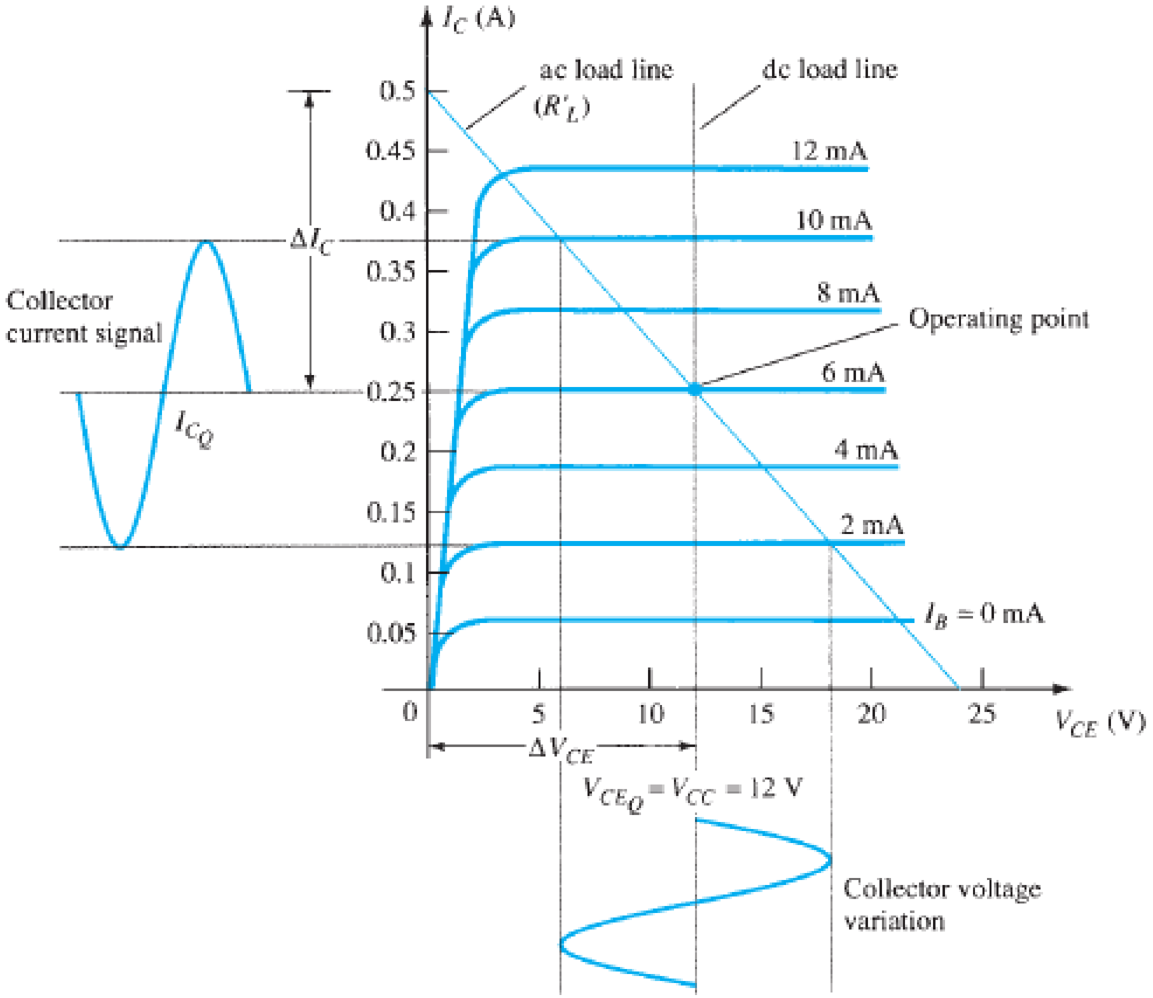
$$\frac{V_2}{V_1} = \frac{N_2}{N_1} \qquad \& \qquad \frac{I_2}{I_1} = \frac{N_1}{N_2} \qquad \Rightarrow \qquad \frac{R_L}{R_L'} = \frac{\frac{V_2}{I_2}}{\frac{V_1}{I_1}} = \left(\frac{N_2}{N_1}\right)^2 = a^2$$

$$R_1 = a^2 R_2 \quad or \quad R_L' = a^2 R_L$$

Power Amplifiers

Can we obtain better efficiency with an A-Class amplifier?

- Transformer winding resistance determines the dc load line
- Typically, this dc resistance is small (ideally $0\ \Omega$)
- A $0\ \Omega$ dc load line is a straight vertical line
- There is no dc voltage drop across the $0\ \Omega$ dc load resistance, and the load line is drawn straight vertically from the voltage point, $V_{CEQ} = V_{CC}$
- Q point can be obtained at the point of intersection of the dc load line and the base current set by the circuit
- For ac analysis, calculate ac load resistance "seen" looking into the primary side of the transformer (R_L')
- Draw the ac load line so that it passes through the operating point and has a slope equal to $-1/R_L'$
- Notice that the ac load line shows that the output signal swing can exceed the value of V_{CC}!



Power Amplifiers

Values of the peak-to-peak signal swings are

$$V_{CE}(p-p) = V_{CE_{max}} - V_{CE_{min}}$$
$$I_C(p-p) = I_{C_{max}} - V_{C_{min}}$$

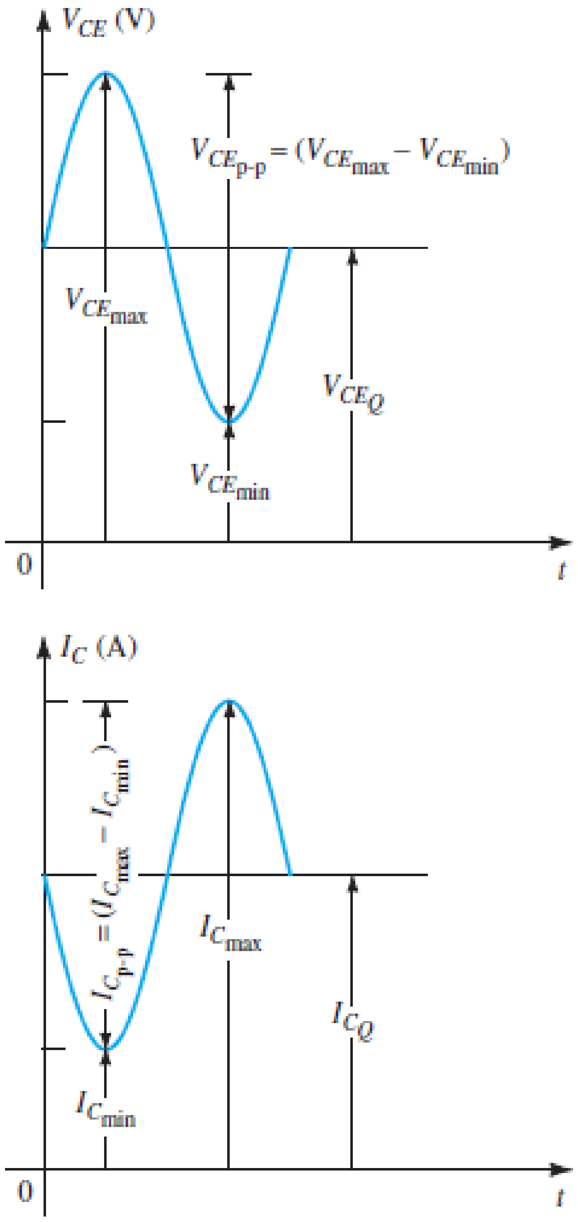
$$\boxed{P_o(\mathrm{ac}) = \frac{(V_{CE_{\max}} - V_{CE_{\min}})(I_{C_{\max}} - I_{C_{\min}})}{8}}$$

Voltage delivered to the load for an ideal transformer:

$$V_L = V_2 = \frac{N_2}{N_1} V_1 \quad \Rightarrow \quad P_L = \frac{V_L^2(rms)}{R_L}$$

or

$$I_L = I_2 = \frac{N_1}{N_2} I_C \quad \Rightarrow \quad P_L = I_L^2(rms) R_L$$



Power Amplifiers

Efficiency:

- So far we have considered calculating the ac power delivered to the load
- We next consider the input power from the battery, power losses in the amplifier, and the overall power efficiency of the transformer-coupled class A amplifier
- The input (dc) power obtained from the supply is calculated from the supply dc voltage and the average power drawn from the supply:

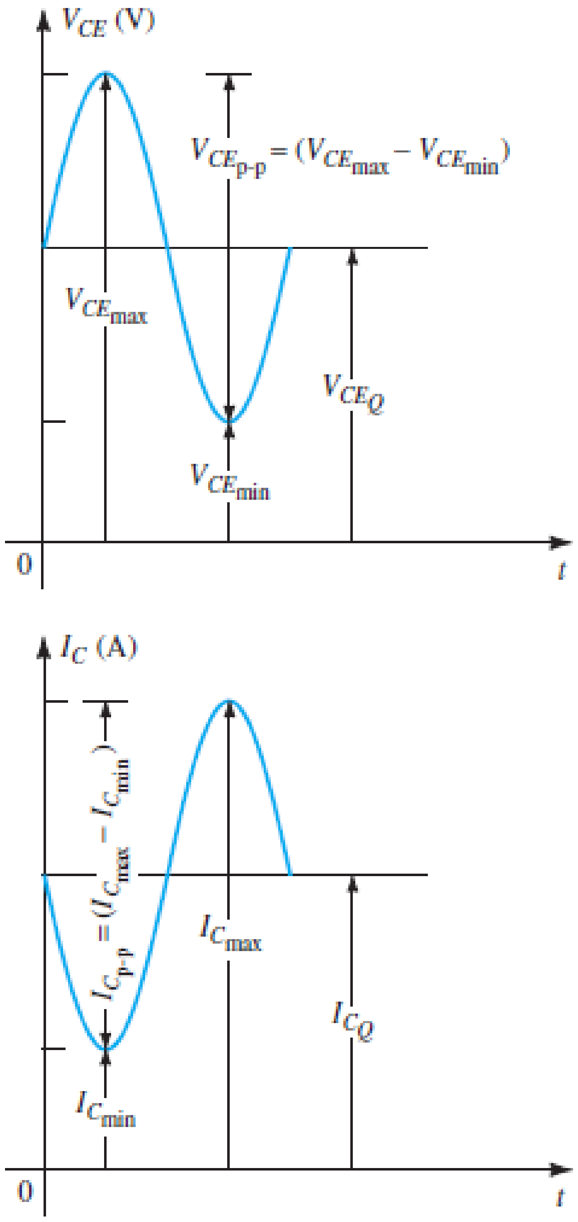
$$P_i(dc) = V_{CC}I_{CQ}$$

- For the transformer-coupled amplifier, the power dissipated by the transformer is small (due to the small dc resistance of a coil) and will be ignored
- Power loss considered is that dissipated by the power transistor

$$P_Q = P_i(dc) - P_o(ac)$$

Maximum Theoretical Efficiency: For a class A transformer-coupled amplifier, the maximum theoretical efficiency goes up to 50%. Based on the signals obtained using the amplifier, the efficiency can be expressed as

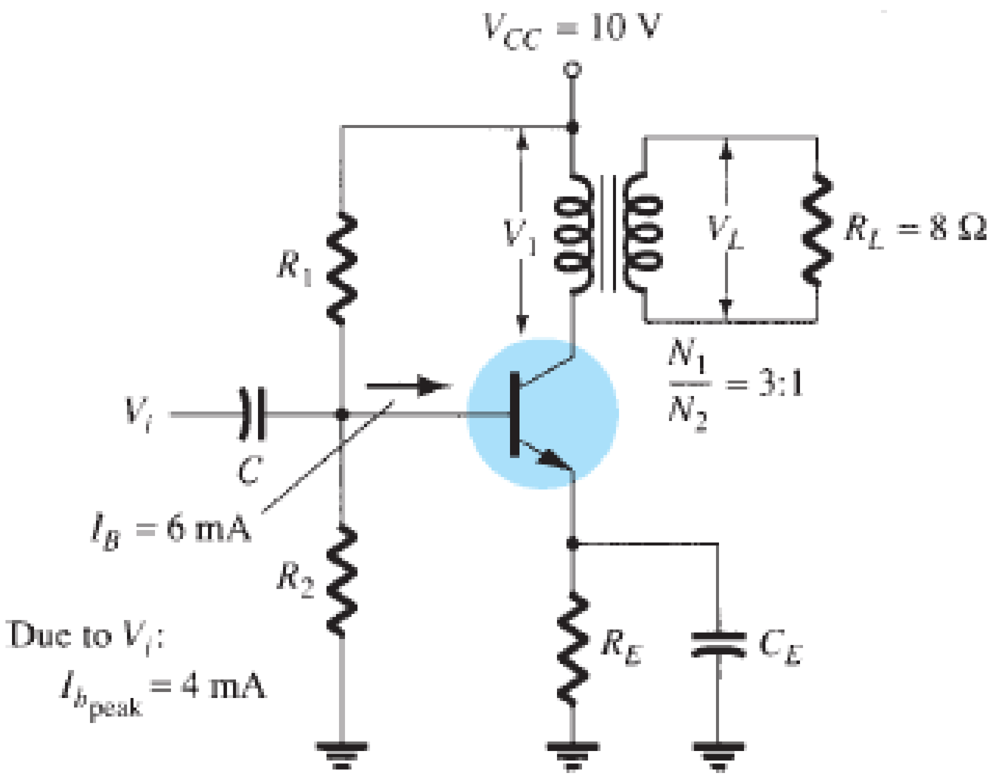
$$\%\,\eta = 50\left(\frac{V_{CE_{max}} - V_{CE_{min}}}{V_{CE_{max}} + V_{CE_{min}}}\right)^2 \%$$



Power Amplifiers

Example:

Calculate the ac power delivered to the 8-Ω speaker for the circuit. The circuit component values result in a dc base current of 6 mA, and the input signal (V_i) results in a peak base current swing of 4 mA.



Power Amplifiers

Example:

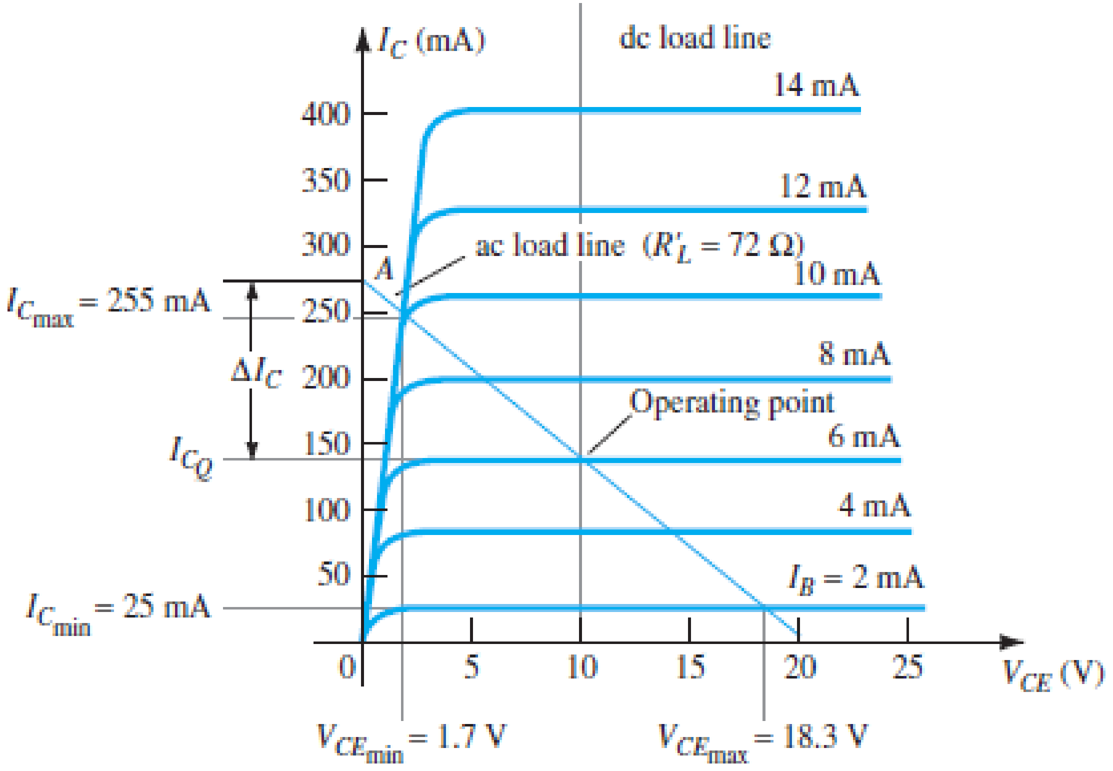
Calculate the ac power delivered to the 8-Ω speaker for the circuit. The circuit component values result in a dc base current of 6 mA, and the input signal (V_i) results in a peak base current swing of 4 mA.

Solution: The dc load line is drawn vertically from the voltage point:

$V_{CEQ} = V_{CC} = 10$ V

For $I_B = 6$ mA, the operating point is

$V_{CEQ} = 10$ V and $I_{CQ} = 140$ mA



Power Amplifiers

Solution: The effective ac resistance seen at the primary is

$$R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L = 72\ \Omega$$

The ac load line can then be drawn of slope -1/72 going through the indicated operating point

To help draw the load line, consider the following procedure:

Mark point *A* for a current swing of

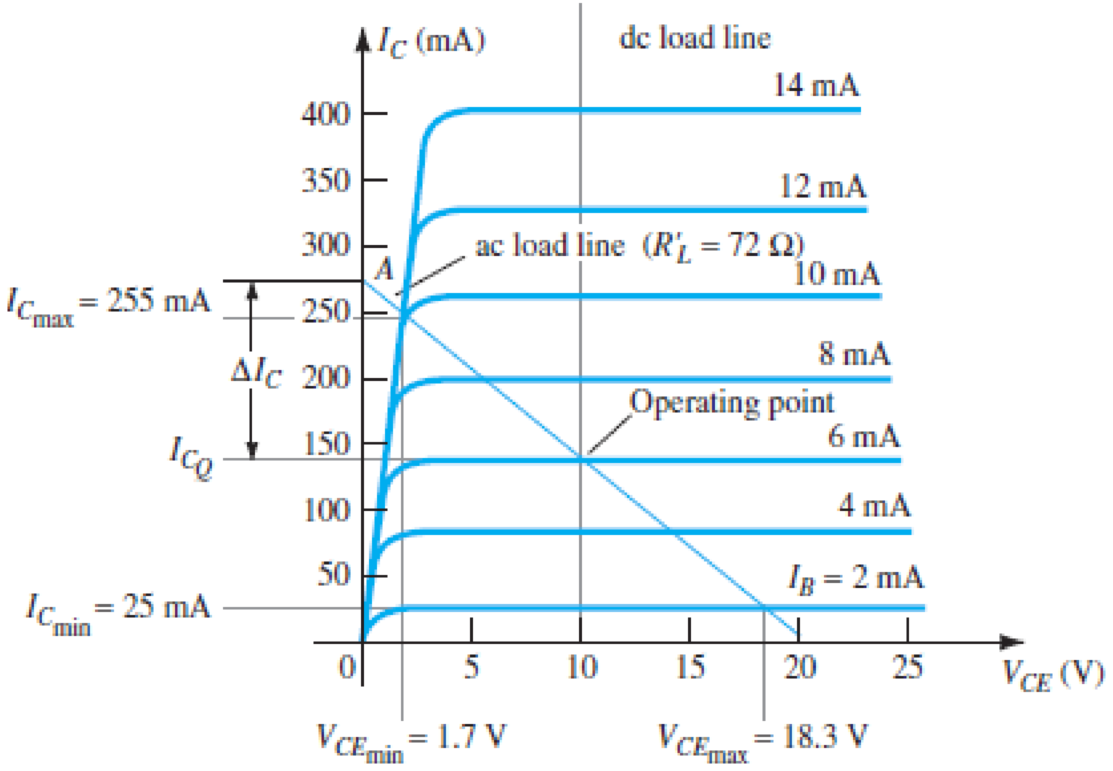
$$\mathrm{I_C} = \frac{\mathrm{V_{CE}}}{R_L{}'} = \frac{10\ V}{72\ \Omega} = 139\ mA$$

$I_{CEQ} + I_C = 140\ mA + 139\ mA = 279\ mA$ along the *y*-axis

Connect point *A* through the *Q* -point to obtain the ac load line

For the given base current swing of 4 mA peak, the max. and min. collector current and collector–emitter voltage obtained from the figure are, respectively,

$$V_{CE_{min}} = 1.7\ V \qquad I_{C_{min}} = 25\ mA$$
$$V_{CE_{max}} = 18.3\ V \qquad I_{C_{max}} = 255\ mA$$



Power Amplifiers

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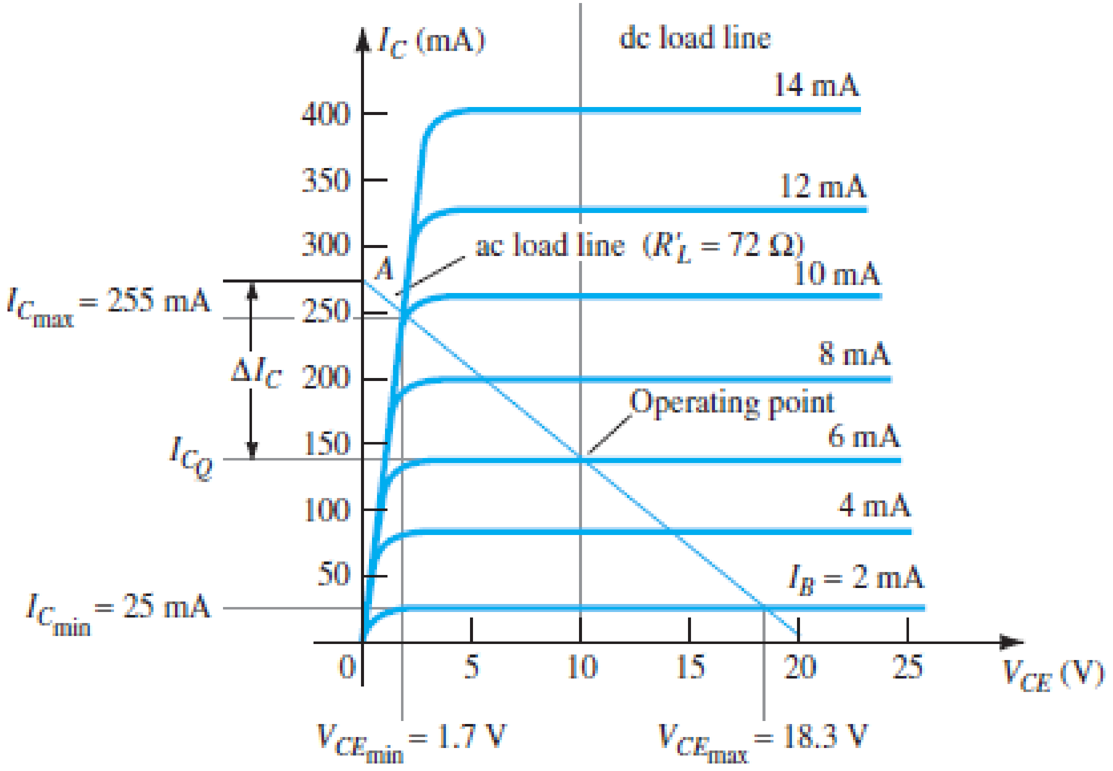
$$V_{CE_{max}} = 18.3\ V \qquad I_{C_{max}} = 255\ mA$$

The ac power delivered to the load can then be calculated as

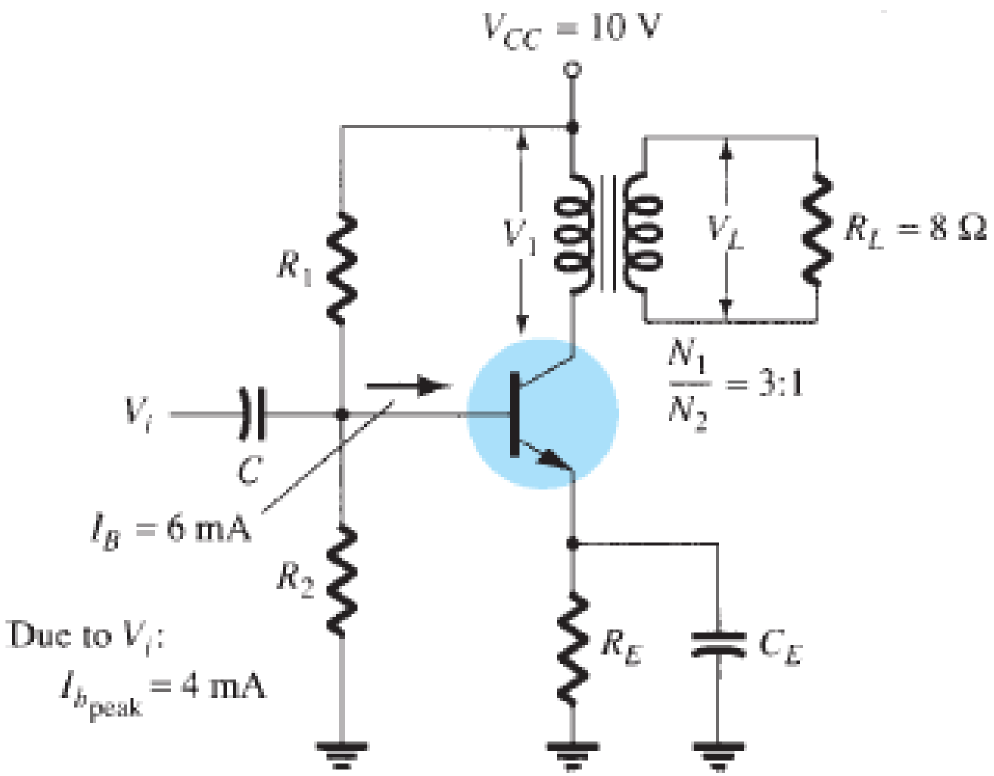
$$P_o(ac) = \frac{(V_{CE_{max}} - V_{CE_{min}})(I_{C_{max}} - I_{C_{min}})}{8}$$

$$= \frac{(18.3\ V - 1.7\ V)(255\ mA - 25\ mA)}{8} = 0.477\ W$$



Power Amplifiers

Example: Calculate the dc input power, power dissipated by the transistor, and efficiency of the circuit for the input signal



Power Amplifiers

Example: Calculate the dc input power, power dissipated by the transistor, and efficiency of the circuit for the input signal

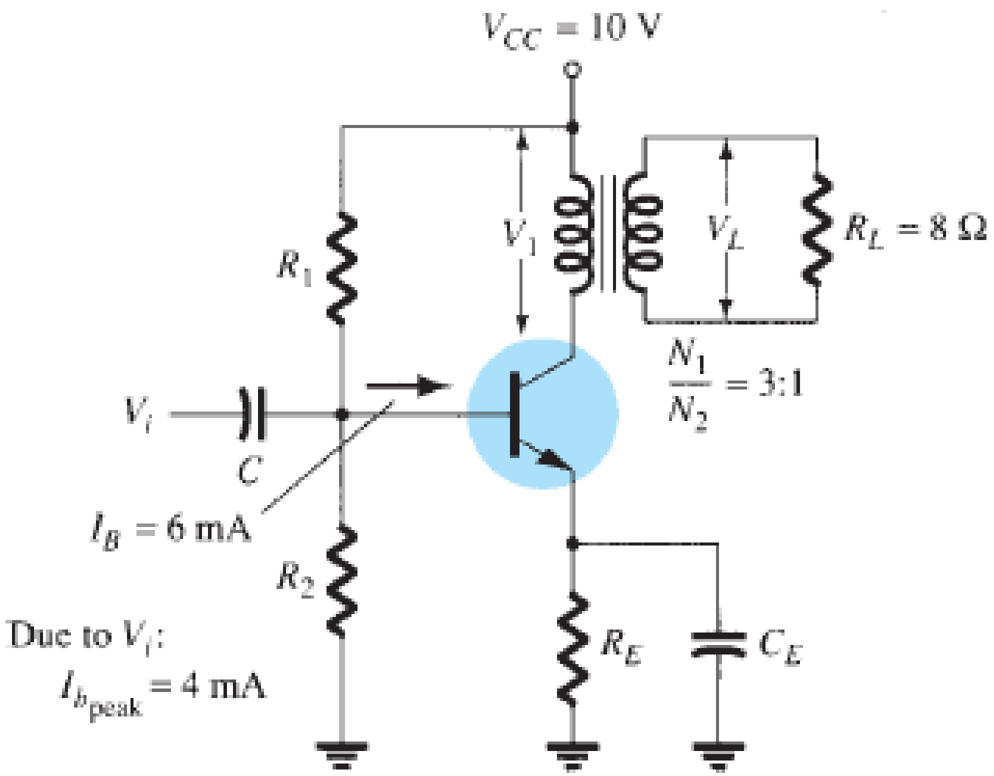
Solution:

$$P_i(dc) = V_{CC}I_{CQ} = (10\ V)(140\ mA) = 1.4\ W$$

$$P_Q(dc) = P_i(dc) - P_o(dc) = 1.4W - 0.477W = 0.92\ W$$

The efficiency of the amplifier is:

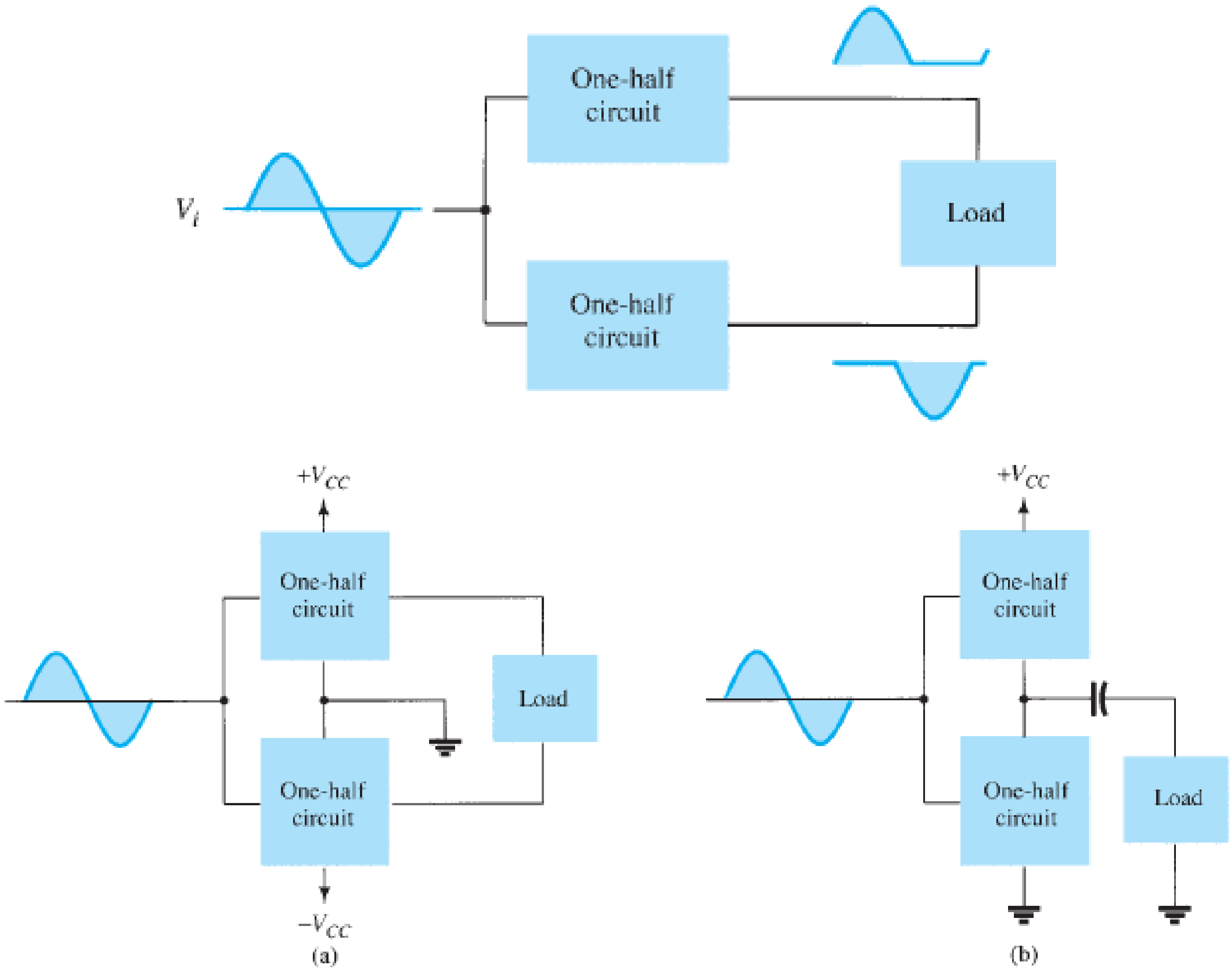
$$\%\eta = \frac{P_o(ac)}{P_i(dc)} \times 100\% = \frac{0.477\ W}{1.4\ W} \times 100\% = 34.1\%$$



Power Amplifiers

<u>**Class B Amplifiers:**</u> Class B operation is provided when the dc bias leaves the transistor biased just off, the transistor turning on when the ac signal is applied

- This is essentially no bias, transistor conducts current for only one-half of the signal cycle
- To obtain output for full cycle, use two transistors, have each conduct on opposite half-cycles
- Combined operation provides full cycle output
- Since one part of the circuit pushes the signal high during one half-cycle and the other part pulls the signal low during the other half-cycle, circuit is called a *push–pull circuit*
- Figure shows a diagram for push–pull operation



Connection of push–pull amplifier to load: (a) using two voltage supplies; (b) using one voltage supply.

Power Amplifiers

Class B Amplifiers – Input (DC) Power

The amount of this input power can be calculated as

$$P_i(dc) = V_{CC} I_{dc}$$

where I_{dc} is the average or dc current drawn from the power supplies and can be expressed as

$$I_{dc} = \frac{2}{\pi} I(p)$$

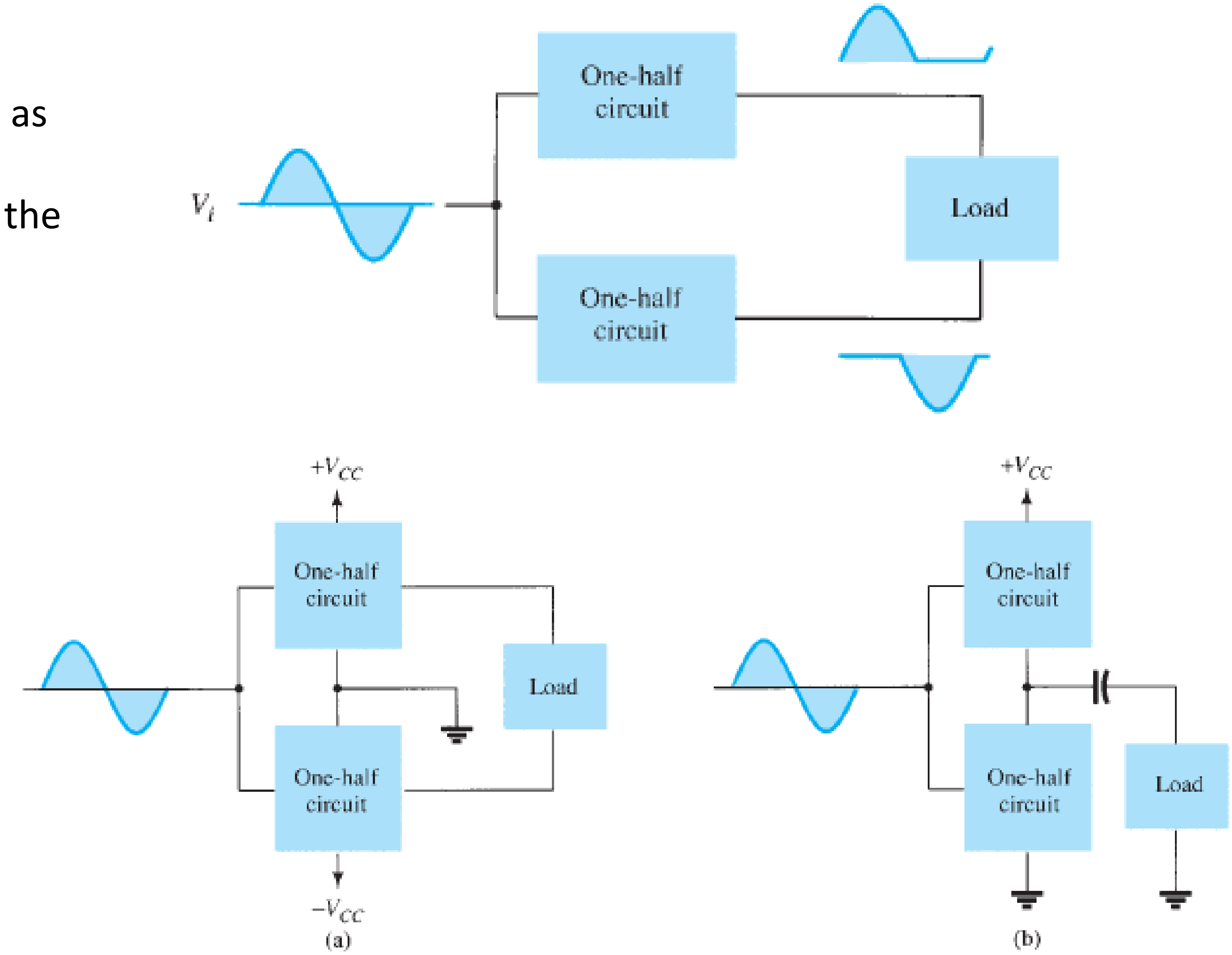
I (p) : peak value of the output current.

Then

$$P_i(dc) = V_{CC}\left(\frac{2}{\pi} I(p)\right)$$

Output (AC) Power

$$P_o(ac) = \frac{V_L^2(rms)}{R_L} = \frac{V_L^2(p-p)}{8R_L} = \frac{V_L^2(p)}{2R_L}$$



Connection of push–pull amplifier to load: (a) using two voltage supplies; (b) using one voltage supply.

Power Amplifiers

Class B Amplifiers – Efficiency

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

$$= \frac{V_L^2(p)/2R_L}{V_{CC}[(2/\pi)I(p)]} \times 100\%$$

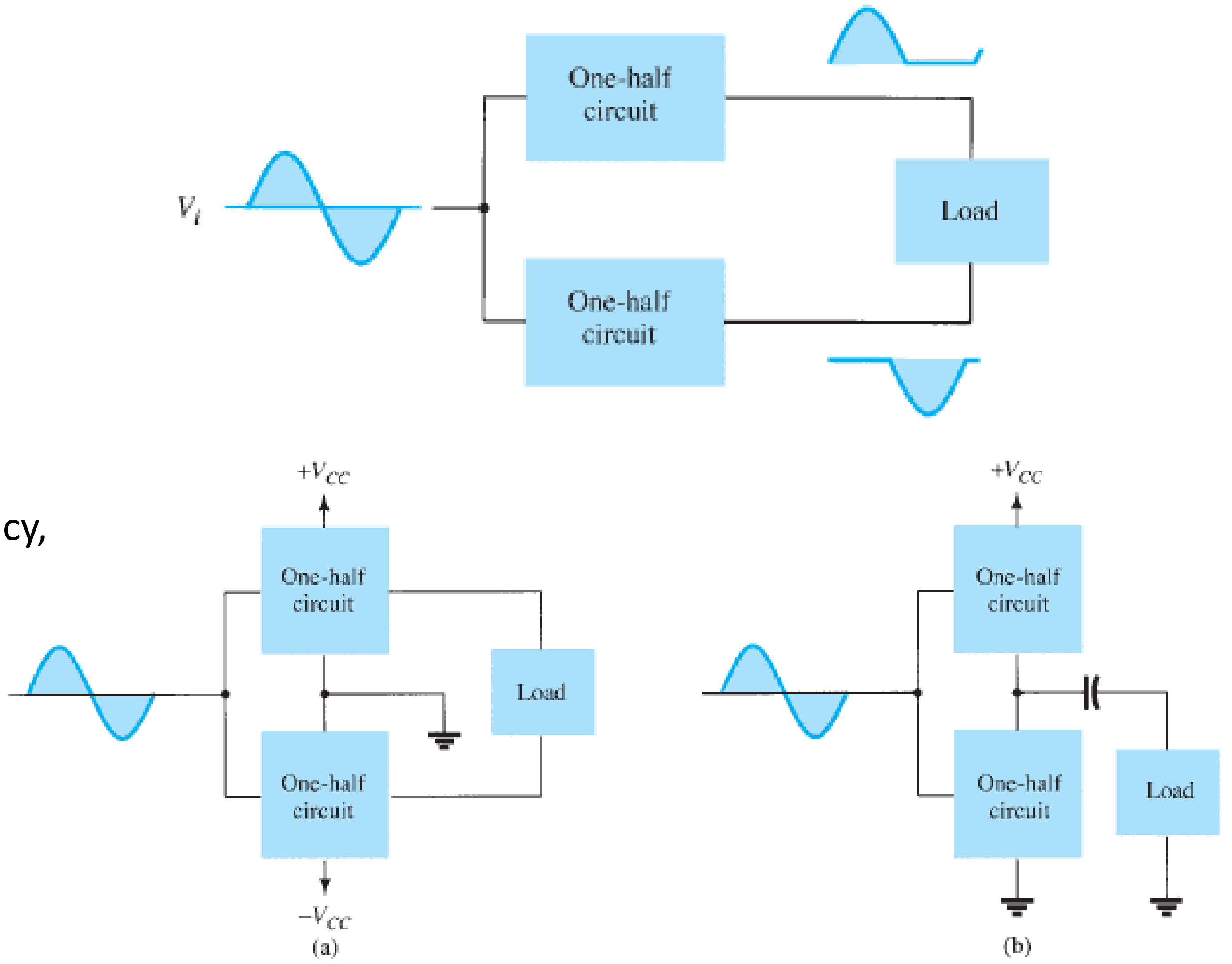
$$= \frac{\pi}{4}\frac{V_L(p)}{V_{CC}} \times 100\%$$

using $I(p) = V_L(p)/R_L$

The larger the peak voltage, the higher the efficiency, up to a maximum value when $V_L(p) = V_{CC}$, this maximum efficiency then being

$$maximum\ efficiency = \frac{\pi}{4} \times 100\%$$

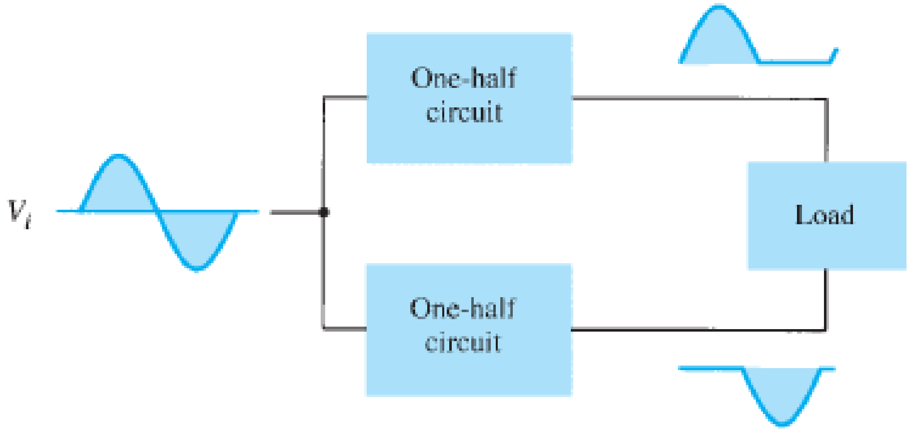
$$= 78.5\%$$

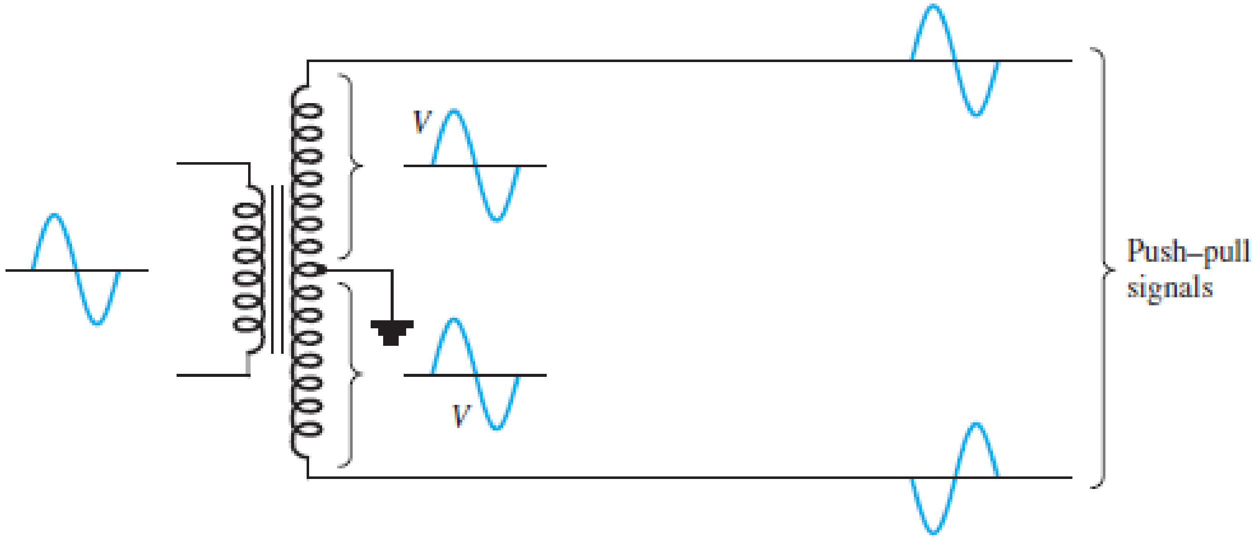


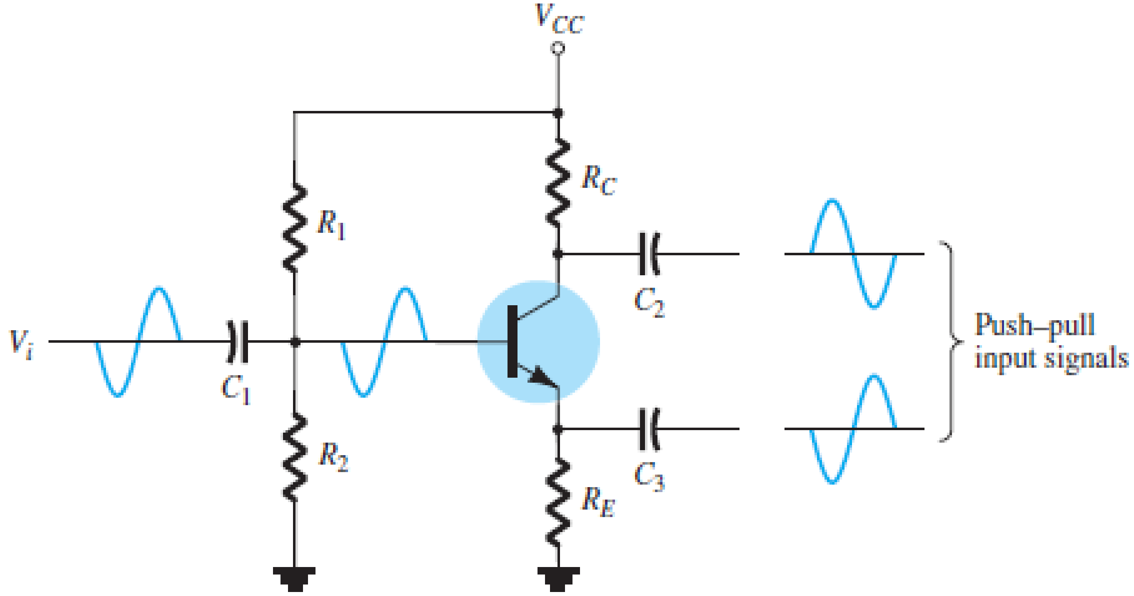
Connection of push–pull amplifier to load: (a) using two voltage supplies; (b) using one voltage supply.

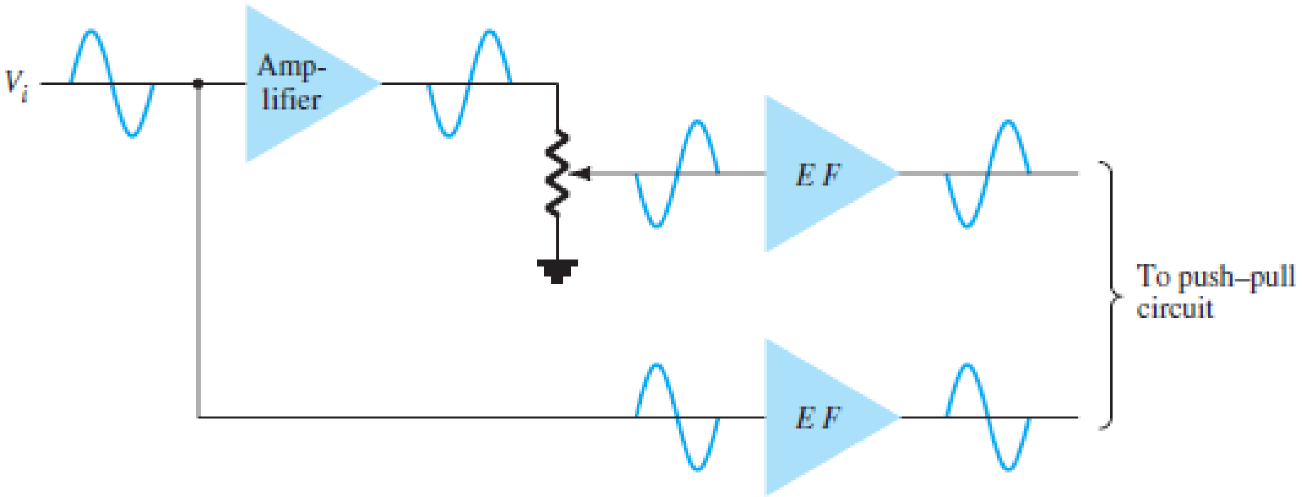
Power Amplifiers

Class B Amplifiers – Push-Pull Signals









Power Amplifiers

Class B Amplifiers – Push-Pull Signals