



BENHA UNIVERSITY
FACULTY OF ENGINEERING AT SHOUBRA

ECE-312
Electronic Circuits (A)

Lecture # 9
Power Amplifiers (Class A & B)

Instructor:
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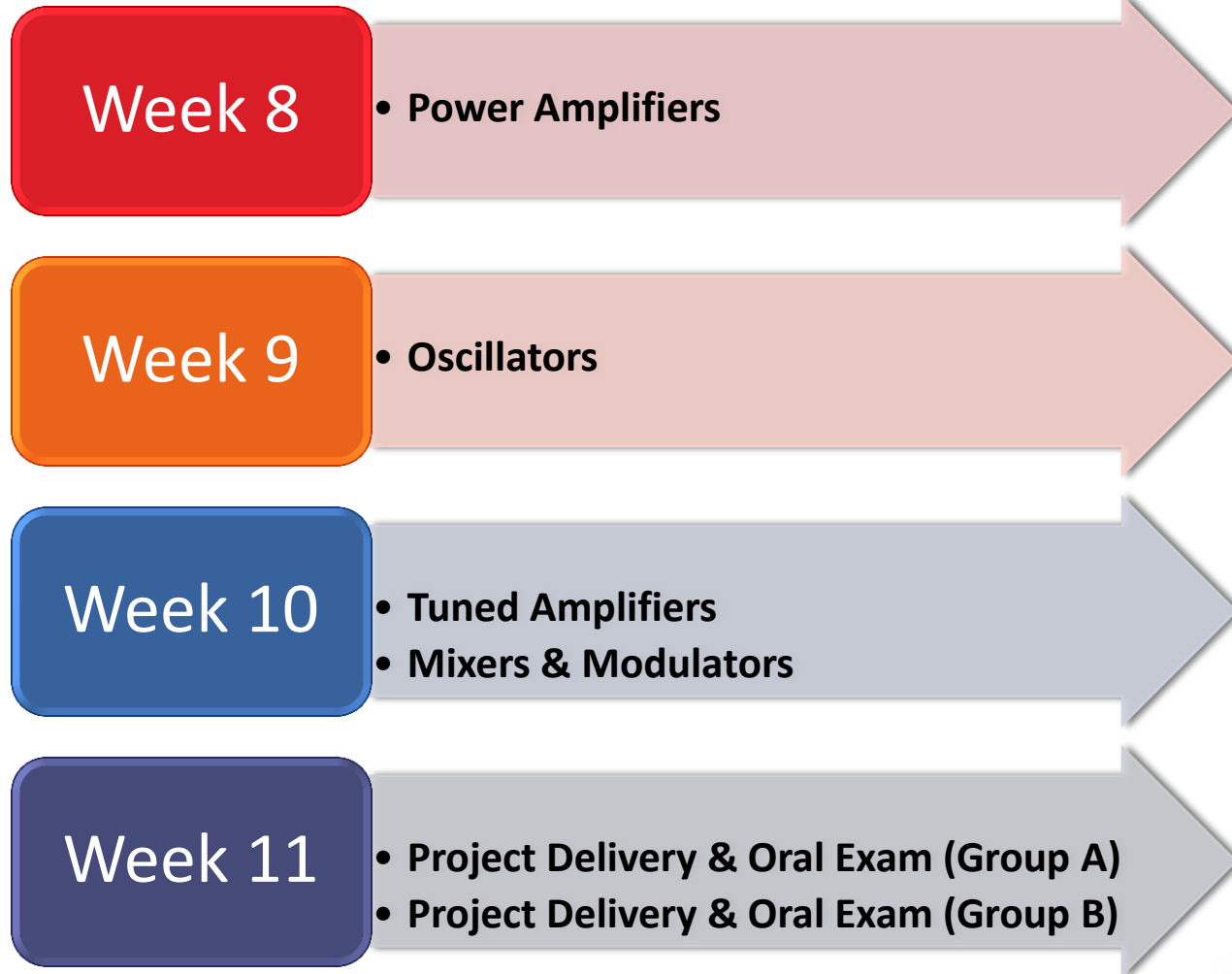


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Post Mid-Term Schedule



Agenda

- Introduction
- Series-Fed Class A Amplifier
- Transformer-Coupled Class A Amplifier
- Class B Amplifier Operation
- Class B Amplifier Circuits

INTRODUCTION



Amplifier Classes

- 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

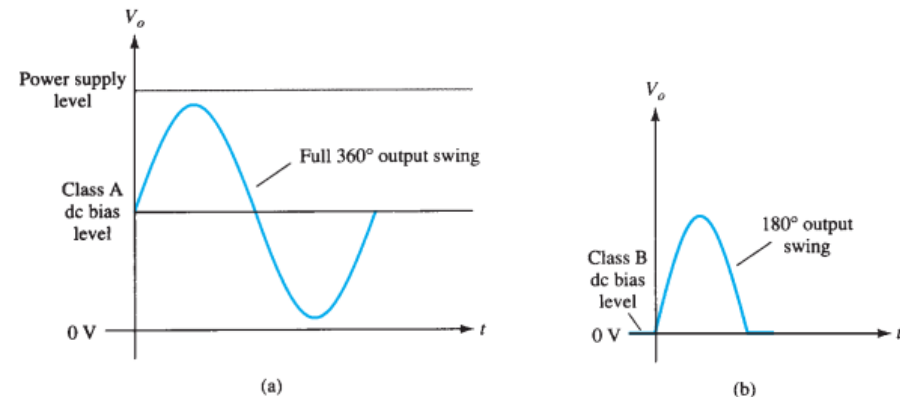


FIG. 12.1
Amplifier operating classes.

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

	A	AB	Class 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%

^aClass C is usually not used for delivering large amounts of power, and thus the efficiency is not given here.



SERIES-FED CLASS A AMPLIFIER



(7)

SERIES-FED CLASS A AMPLIFIER

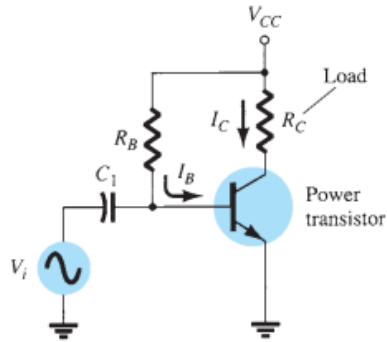


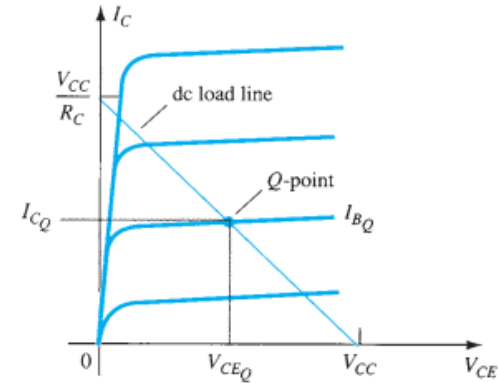
FIG. 12.2
Series-fed class A large-signal amplifier.

- 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

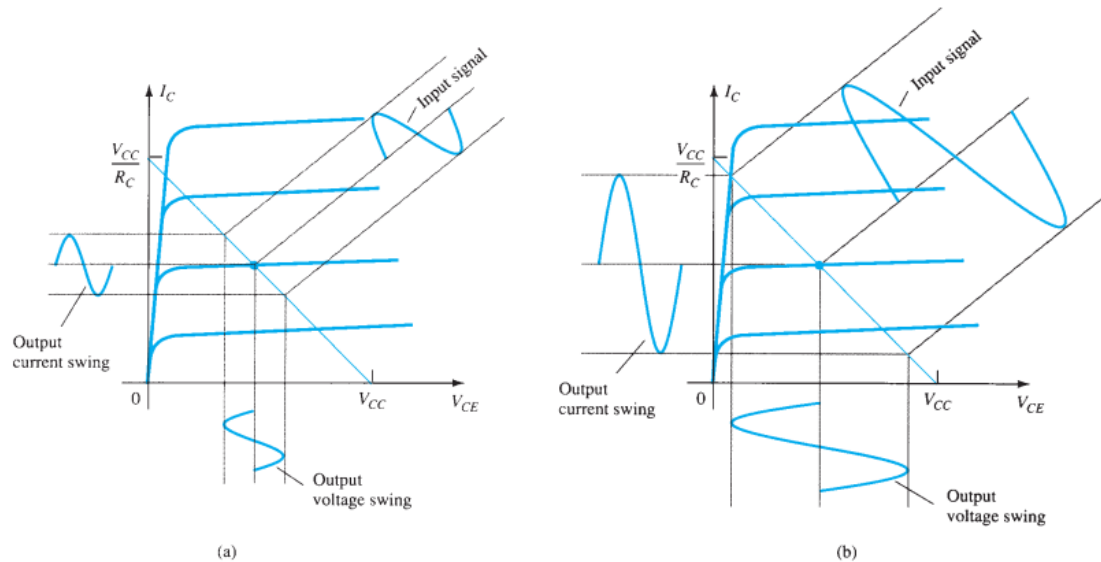


FIG. 12.4
Amplifier input and output signal variation.

Power Considerations

- The power drawn from the supply is

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

- Output Power

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

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

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

- Efficiency

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

- Maximum Efficiency

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

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

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

$$= \frac{V_{CC}^2}{8R_C}$$

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

$$= \frac{V_{CC}^2}{2R_C}$$

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

$$= \frac{V_{CC}^2/8R_C}{V_{CC}^2/2R_C} \times 100\%$$

$$= 25\%$$

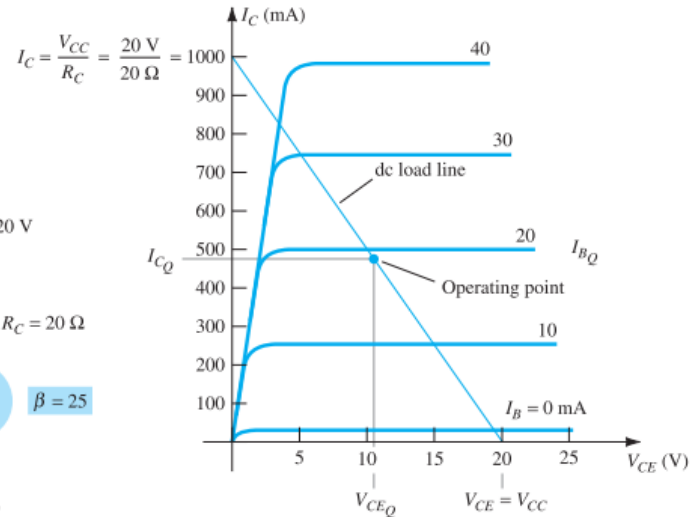
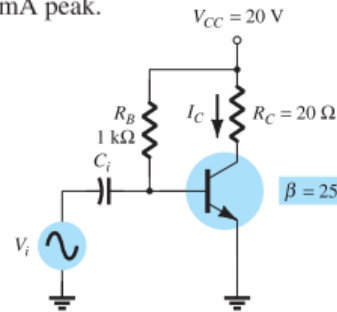
N.B.:

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



Example

EXAMPLE 12.1 Calculate the input power, output power, and efficiency of the amplifier circuit in Fig. 12.5 for an input voltage that results in a base current of 10 mA peak.



Solution: Using Eqs. (12.1) through (12.3), we can determine the Q -point to be

$$I_{BQ} = \frac{V_{CC} - 0.7 \text{ V}}{R_B} = \frac{20 \text{ V} - 0.7 \text{ V}}{1 \text{ k}\Omega} = 19.3 \text{ mA}$$

$$I_{CQ} = \beta I_B = 25(19.3 \text{ mA}) = 482.5 \text{ mA} \approx 0.48 \text{ A}$$

$$V_{CEQ} = V_{CC} - I_C R_C = 20 \text{ V} - (0.48 \text{ A})(20 \Omega) = 10.4 \text{ V}$$

This bias point is marked on the transistor collector characteristic of Fig. 12.5b. The ac variation of the output signal can be obtained graphically using the dc load line drawn on Fig. 12.5b by connecting $V_{CE} = V_{CC} = 20 \text{ V}$ with $I_C = V_{CC}/R_C = 1000 \text{ mA} = 1 \text{ A}$, as shown. When the input ac base current increases from its dc bias level, the collector current rises by

$$I_C(p) = \beta I_B(p) = 25(10 \text{ mA peak}) = 250 \text{ mA peak}$$

Using Eq. (12.6) yields

$$P_o(\text{ac}) = I_C^2(\text{rms})R_C = \frac{I_C^2(p)}{2}R_C = \frac{(250 \times 10^{-3} \text{ A})^2}{2}(20 \Omega) = \mathbf{0.625 \text{ W}}$$

Using Eq. (12.4) results in

$$P_i(\text{dc}) = V_{CC}I_{CQ} = (20 \text{ V})(0.48 \text{ A}) = \mathbf{9.6 \text{ W}}$$

The amplifier's power efficiency can then be calculated using Eq. (12.8):

$$\% \eta = \frac{P_o(\text{ac})}{P_i(\text{dc})} \times 100\% = \frac{0.625 \text{ W}}{9.6 \text{ W}} \times 100\% = \mathbf{6.5\%}$$



TRANSFORMER-COUPLED CLASS A AMPLIFIER



Transformer Action

- A transformer can increase or decrease voltage or current levels according to its turns ratio $a=N_1:N_2$
- The impedance connected to one side of a transformer can be made to appear either larger or smaller (step up or step down) at the other side of the transformer.

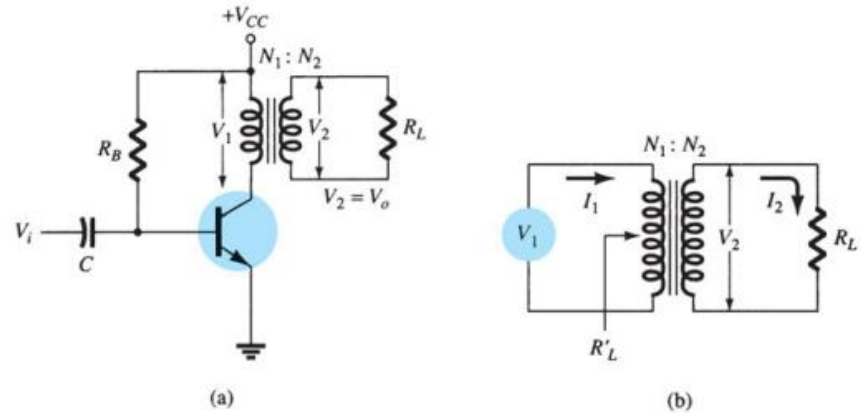


FIG. 12.6

Transformer-coupled audio power amplifier.

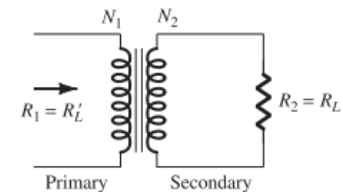
- Voltage Transformation

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

- Current Transformation

$$\frac{I_2}{I_1} = \frac{N_1}{N_2}$$

- Impedance Transformation



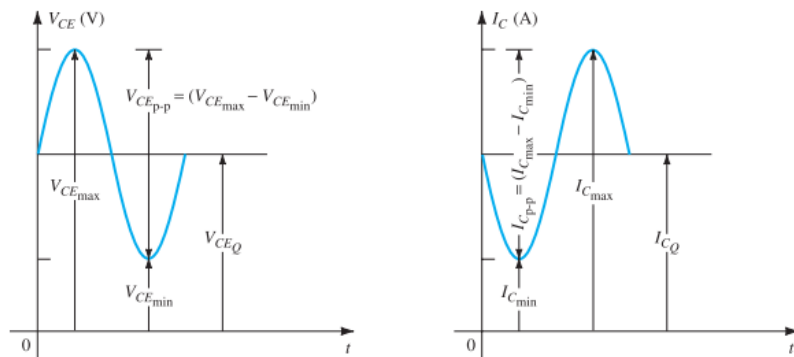
$$\frac{R_L}{R'_L} = \frac{R_2}{R_1} = \frac{V_2/I_2}{V_1/I_1} = \frac{V_2 I_1}{I_2 V_1} = \frac{V_2 I_1}{V_1 I_2} = \frac{N_2 N_2}{N_1 N_1} = \left(\frac{N_2}{N_1}\right)^2$$

$$\frac{R'_L}{R_L} = \frac{R_1}{R_2} = \left(\frac{N_1}{N_2}\right)^2 = a^2$$

$$R_1 = a^2 R_2 \quad \text{or} \quad R'_L = a^2 R_L$$

Operation of Amplifier Stage

- Signal Swing and Output AC Power



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

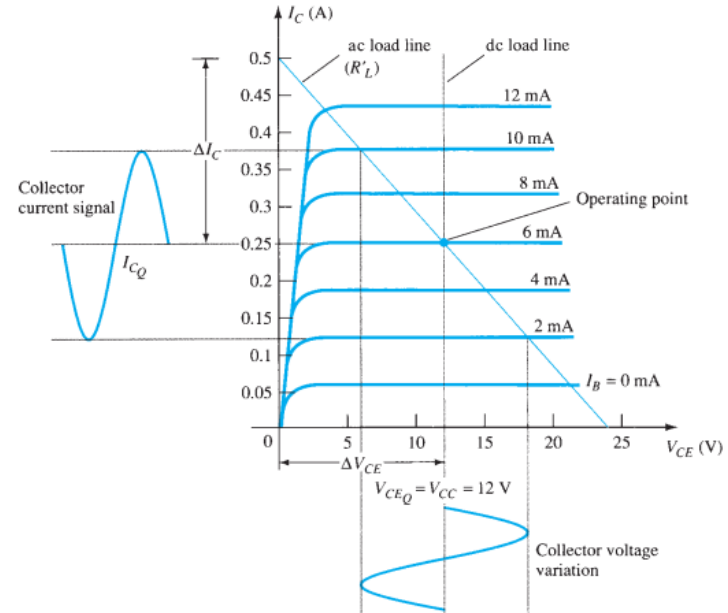
$$I_{C(p-p)} = I_{C_{max}} - I_{C_{min}}$$

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

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

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

- Check EXAMPLE 12.4 !



- Efficiency

$$P_i(dc) = V_{CC} I_{CQ} \quad \% \eta = \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

- power loss

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

- Maximum Theoretical Efficiency

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



CLASS B AMPLIFIER OPERATION



Push-Pull Amplifier

- 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, and the transistor conducts current for only one-half of the signal cycle.

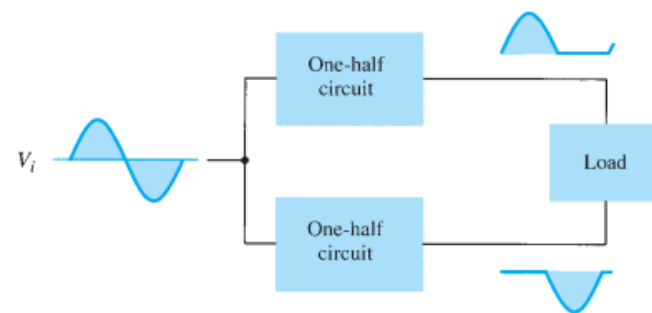


FIG. 12.12

Block representation of push-pull operation.

- Connection of push-pull amplifier to load

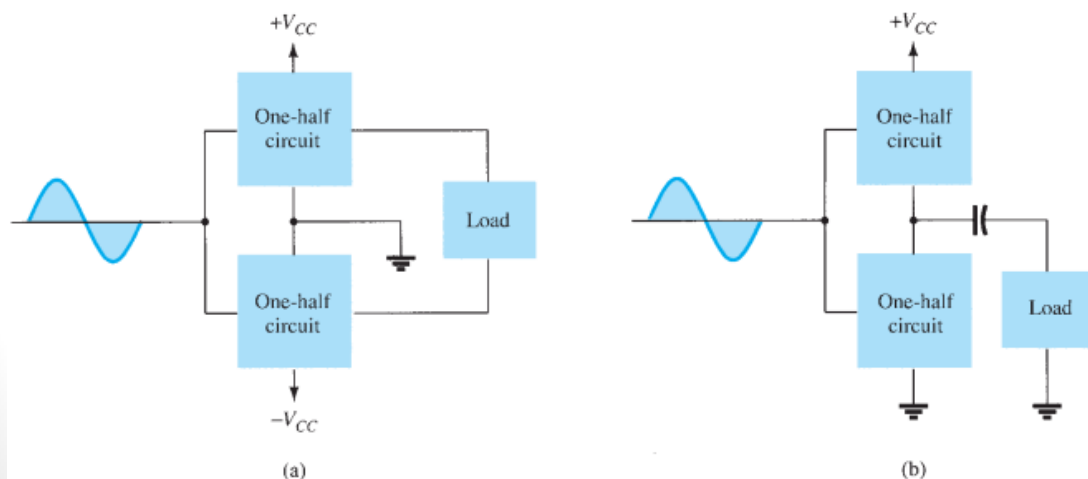


FIG. 12.13

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

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

- The current drawn from a single power supply has the form of a full-wave rectified signal
- whereas that drawn from two power supplies has the form of a half-wave rectified signal from each supply.

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

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



Efficiency & Power Consideration

$$P_o(\text{ac}) = \frac{V_L^2(\text{rms})}{R_L}$$

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

- Efficiency

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

$$\% \eta = \frac{P_o(\text{ac})}{P_i(\text{dc})} \times 100\% = \frac{V_L^2(\text{p})/2R_L}{V_{CC}[(2/\pi)I(\text{p})]} \times 100\% = \frac{\pi}{4} \frac{V_L(\text{p})}{V_{CC}} \times 100\%$$

$$V_L(\text{p}) = V_{CC}, \quad \text{maximum efficiency} = \frac{\pi}{4} \times 100\% = 78.5\%$$

- Power Dissipated by Output Transistors

$$P_{2Q} = P_i(\text{dc}) - P_o(\text{ac})$$

$$P_Q = \frac{P_{2Q}}{2}$$

- Maximum Power Considerations

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

$$I(\text{p}) = \frac{V_{CC}}{R_L}$$

$$\text{maximum } I_{\text{dc}} = \frac{2}{\pi} I(\text{p}) = \frac{2V_{CC}}{\pi R_L}$$

$$\text{maximum } P_i(\text{dc}) = V_{CC}(\text{maximum } I_{\text{dc}}) = V_{CC} \left(\frac{2V_{CC}}{\pi R_L} \right) = \frac{2V_{CC}^2}{\pi R_L}$$

$$\begin{aligned} \text{maximum } \% \eta &= \frac{P_o(\text{ac})}{P_i(\text{dc})} \times 100\% = \frac{V_{CC}^2/2R_L}{V_{CC}[(2/\pi)(V_{CC}/R_L)]} \times 100\% \\ &= \frac{\pi}{4} \times 100\% = \mathbf{78.54\%} \end{aligned}$$

$$V_L(\text{p}) = 0.636V_{CC} \quad \left(= \frac{2}{\pi} V_{CC} \right)$$

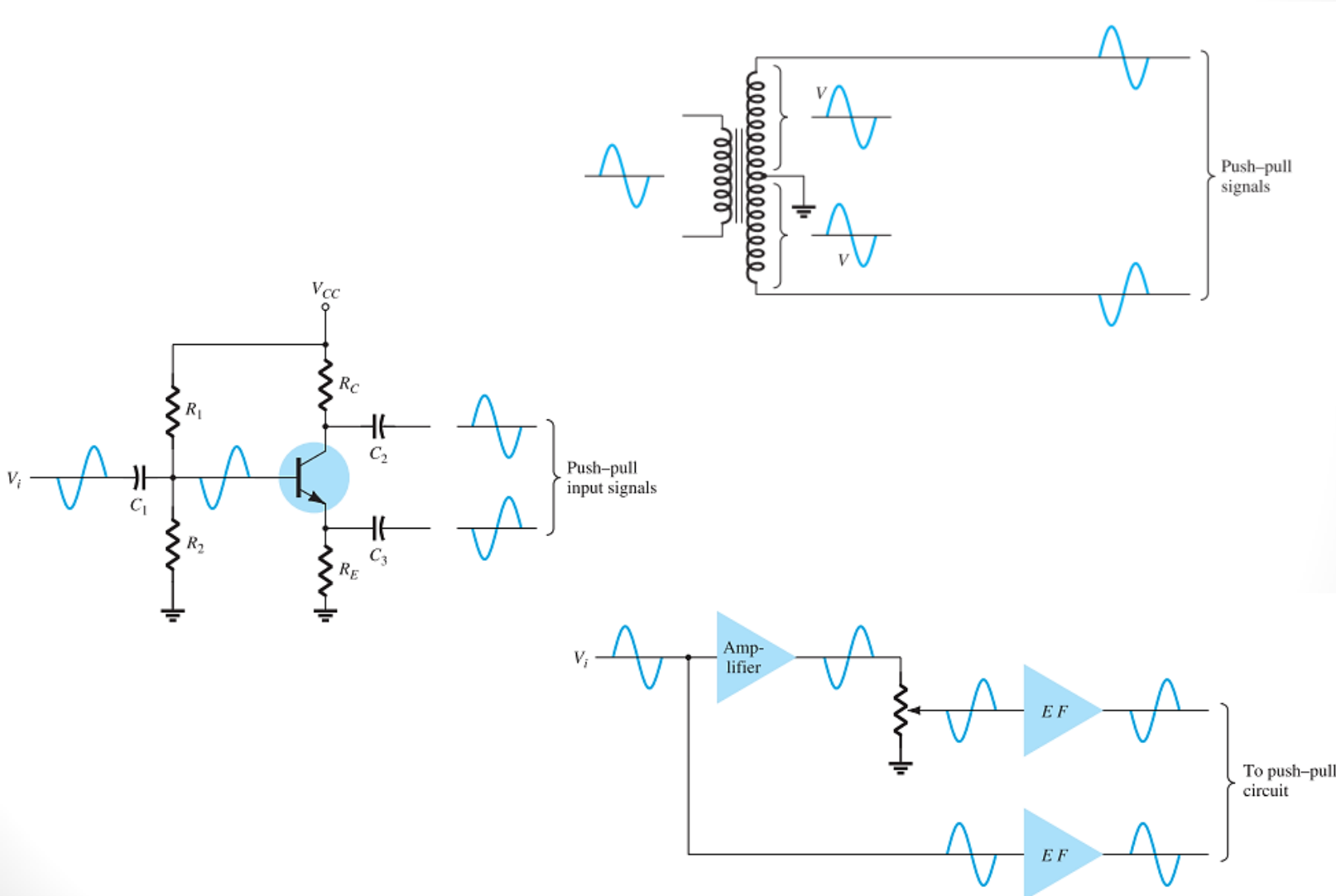
$$\text{maximum } P_{2Q} = \frac{2V_{CC}^2}{\pi^2 R_L}$$



CLASS B AMPLIFIER CIRCUITS

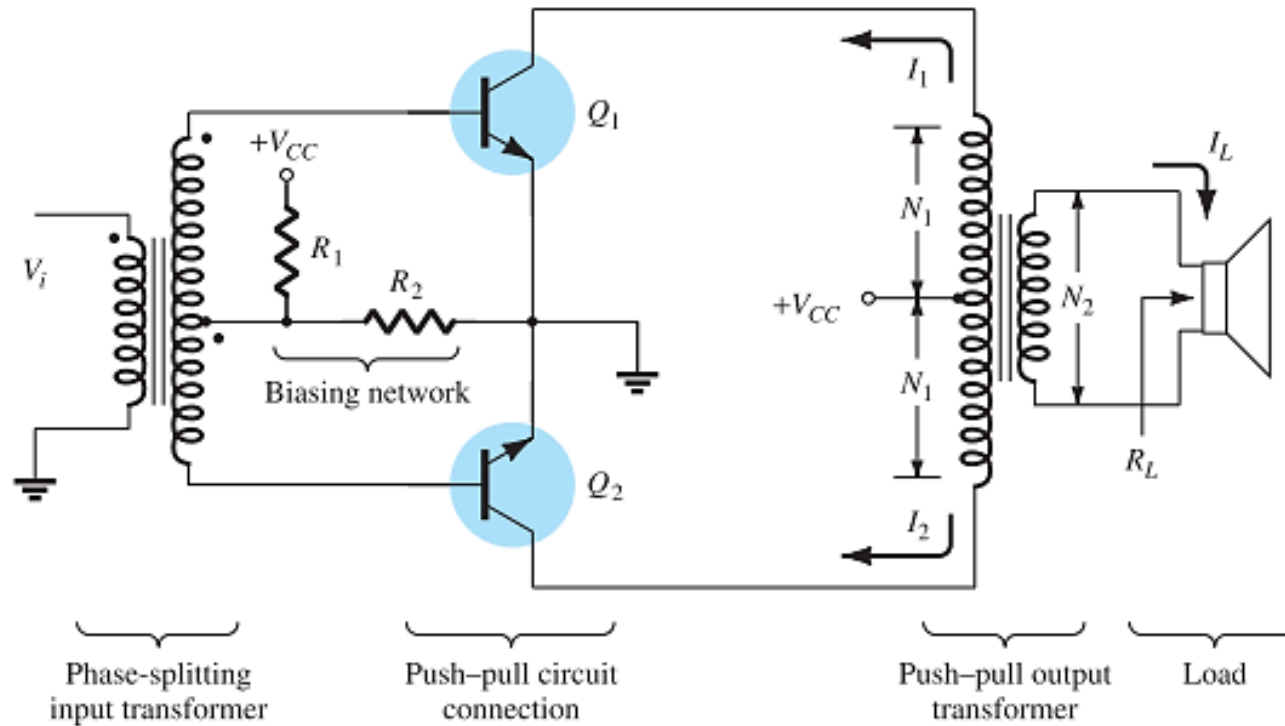


Phase-Splitter Circuits



Class B Amplifier Circuits

- Transformer-Coupled Push-Pull Circuits

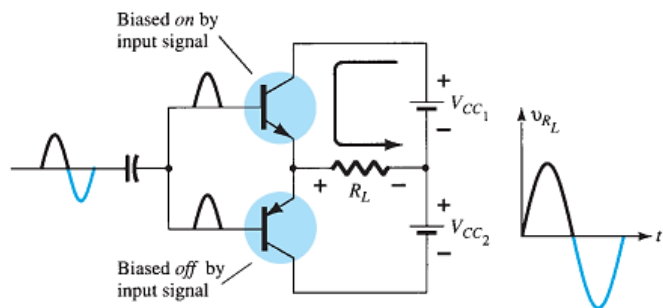
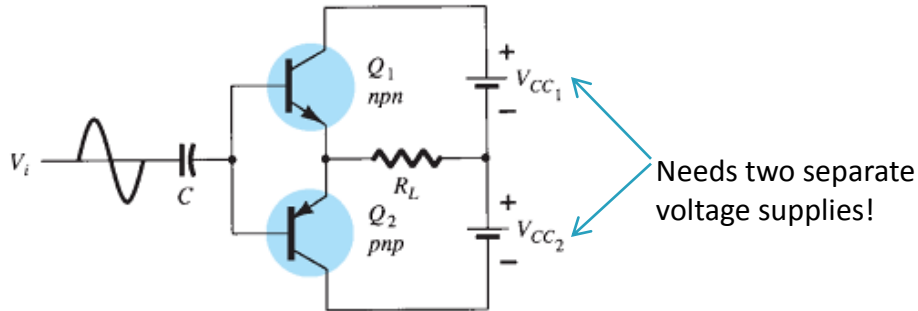


Transistors are bulky !

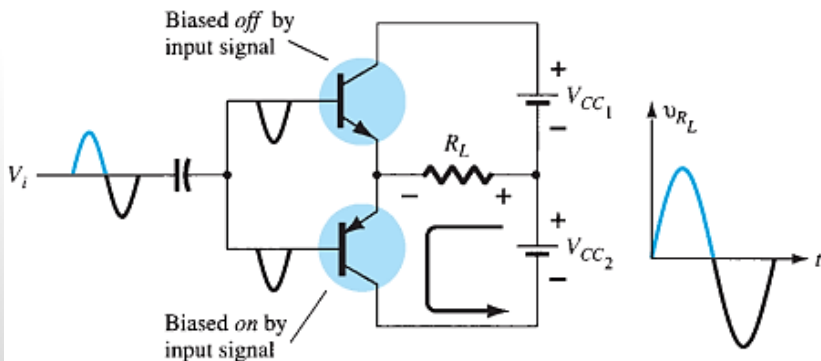


Class B Amplifier Circuits..

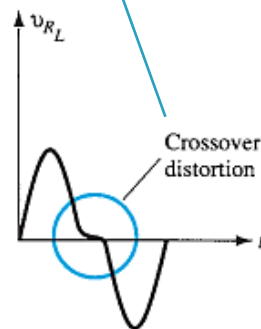
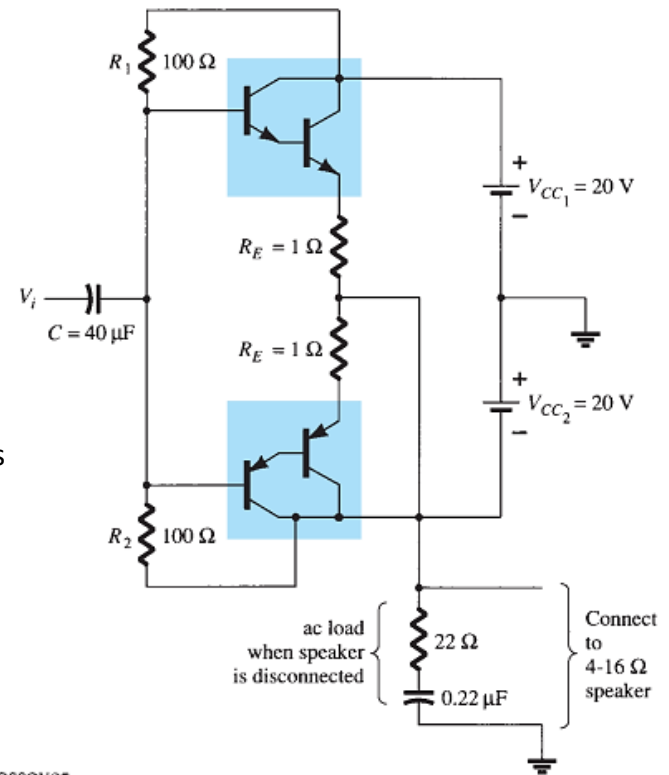
- Complementary-Symmetry Circuits



Biasing the transistors in class AB improves this operation



- Complementary-symmetry push-pull circuit using Darlington transistors.



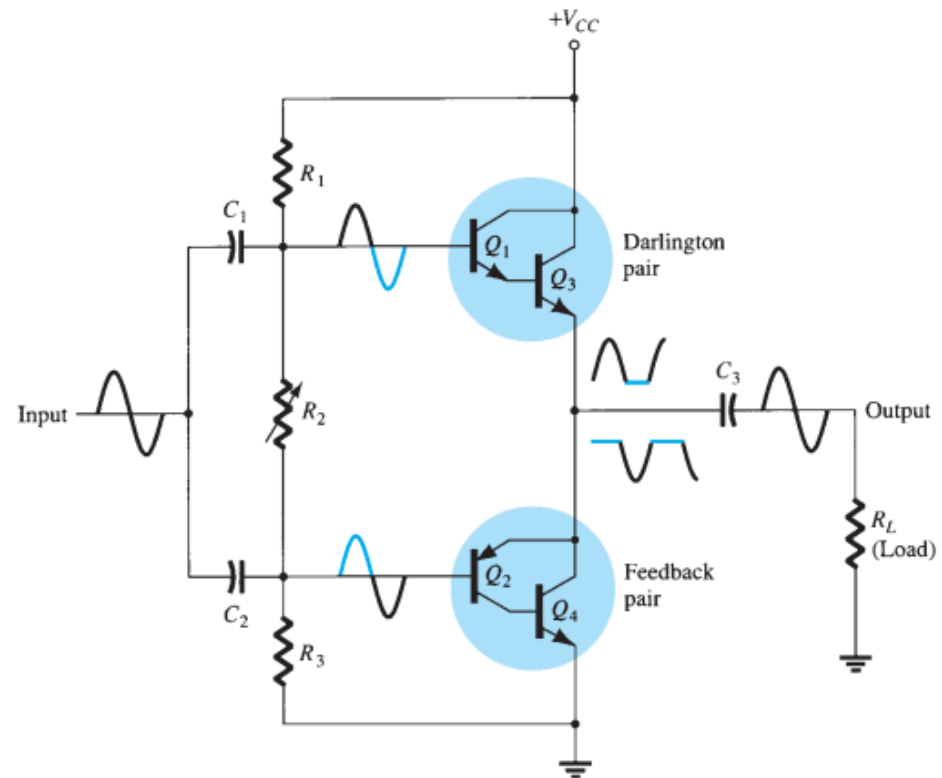
- higher output current
- lower output resistance.



Class B Amplifier Circuits...

- Quasi-Complementary Push-Pull Amplifier

- In practical power amplifier circuits, it is preferable to use npn transistors for both high-current-output devices.
- The push-pull operation is achieved by using complementary transistors (Q_1 and Q_2) before the matched npn output transistors (Q_3 and Q_4).
- R_2 can be adjusted to minimize crossover distortion.
- It is the most popular form of power amplifier



- Quasi-complementary push-pull transformerless power amplifier.

Example

EXAMPLE 12.10 For the circuit of Fig. 12.19, calculate the input power, output power, and power handled by each output transistor and the circuit efficiency for an input of 12 V rms.

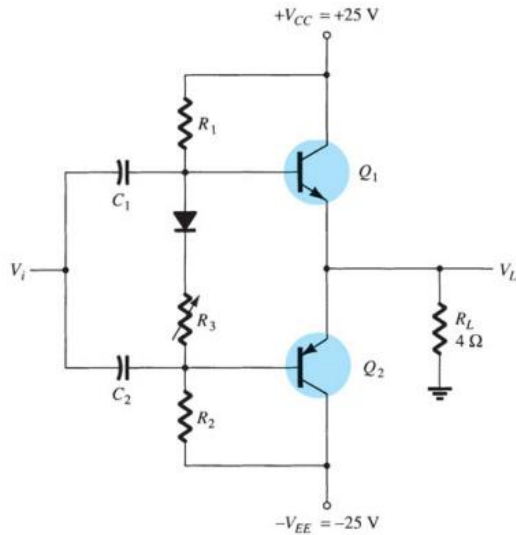


FIG. 12.19

Class B power amplifier for Examples 12.10 to 12.12.

Solution: The peak input voltage is

$$V_i(p) = \sqrt{2} V_i(\text{rms}) = \sqrt{2} (12 \text{ V}) = 16.97 \text{ V} \approx 17 \text{ V}$$

Since the resulting voltage across the load is ideally the same as the input signal (the amplifier has, ideally, a voltage gain of unity),

$$V_L(p) = 17 \text{ V}$$

and the output power developed across the load is

$$P_o(\text{ac}) = \frac{V_L^2(p)}{2R_L} = \frac{(17 \text{ V})^2}{2(4 \Omega)} = 36.125 \text{ W}$$

The peak load current is

$$I_L(p) = \frac{V_L(p)}{R_L} = \frac{17 \text{ V}}{4 \Omega} = 4.25 \text{ A}$$

from which the dc current from the supplies is calculated to be

$$I_{\text{dc}} = \frac{2}{\pi} I_L(p) = \frac{2(4.25 \text{ A})}{\pi} = 2.71 \text{ A}$$

so that the power supplied to the circuit is

$$P_i(\text{dc}) = V_{CC} I_{\text{dc}} = (25 \text{ V})(2.71 \text{ A}) = 67.75 \text{ W}$$

The power dissipated by each output transistor is

$$P_Q = \frac{P_{2Q}}{2} = \frac{P_i - P_o}{2} = \frac{67.75 \text{ W} - 36.125 \text{ W}}{2} = 15.8 \text{ W}$$

The circuit efficiency (for the input of 12 V, rms) is then

$$\% \eta = \frac{P_o}{P_i} \times 100\% = \frac{36.125 \text{ W}}{67.75 \text{ W}} \times 100\% = 53.3\%$$

- For more details, refer to:
 - Chapter 12 at R. Boylestad, **Electronic Devices and Circuit Theory**, 11th edition, Prentice Hall.
- The lecture is available online at:
 - <http://bu.edu.eg/staff/ahmad.elbanna-courses/11966>
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