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EEE109: Electronic Circuits

Output Stages and Power Amplifiers

Contents of Chapter 8

- Describe the concept of a power amplifier.
- Describe the characteristics of BJT and MOSFET power transistors
  - analyze the temperature and heat flow characteristics of devices using heat sinks.
- Define the various classes of power amplifiers and determine the maximum power efficiency of each class of amplifier.
  - class-A power amplifiers.
  - class-AB power amplifiers.
- Design an output stage using power MOSFETs as the output devices.

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Outlines

- Introduction of Power Amplifier
- Power Efficiency and Amplifier Classification
- Basic Class A Amplifier

Introduction (1)

- An electronic **power amplifier**, amplifier, or (informally) amp is an electronic device that **increases** the **power of a signal**.

- It does this by taking energy from a power supply and controlling the output to *match* the input signal shape but with a **large amplitude**. In this sense, an amplifier modulates the output of the power supply.

Introduction (2)

- Power amplifiers are used to deliver a relatively **high amount of power**, usually to a **low resistance load**.

- Typical load values range from 300W (for transmission antennas) to 8W (for audio speaker).

- Although these load values do not cover every possibility, they do illustrate the fact that power amplifiers **usually drive low-resistance loads**.

Introduction (3)

- Typical output power rating of a power amplifier will be **1W or higher**.

- **Ideal** power amplifier will deliver **100%** of the power it draws from the supply to load. In **practice**, this can never occur.

- The reason for this is the fact that the *components* in the amplifier will all **dissipate** some of the power that is being drawn form the *supply*.

Introduction (4)

- Numerous types of electronic amplifiers are specialized to various applications.

- An amplifier can refer to anything from an electrical circuit that uses a single active component, to a complete system such as a packaged audio hi-fi amplifier.

Introduction (5)

- In general a power amplifier is designated as the **last amplifier** in a transmission chain (the **output stage**) and is the amplifier stage that typically requires most attention to power efficiency.

- **Efficiency considerations** lead to various classes of power amplifier based on the **biasing** of the **output transistors.**

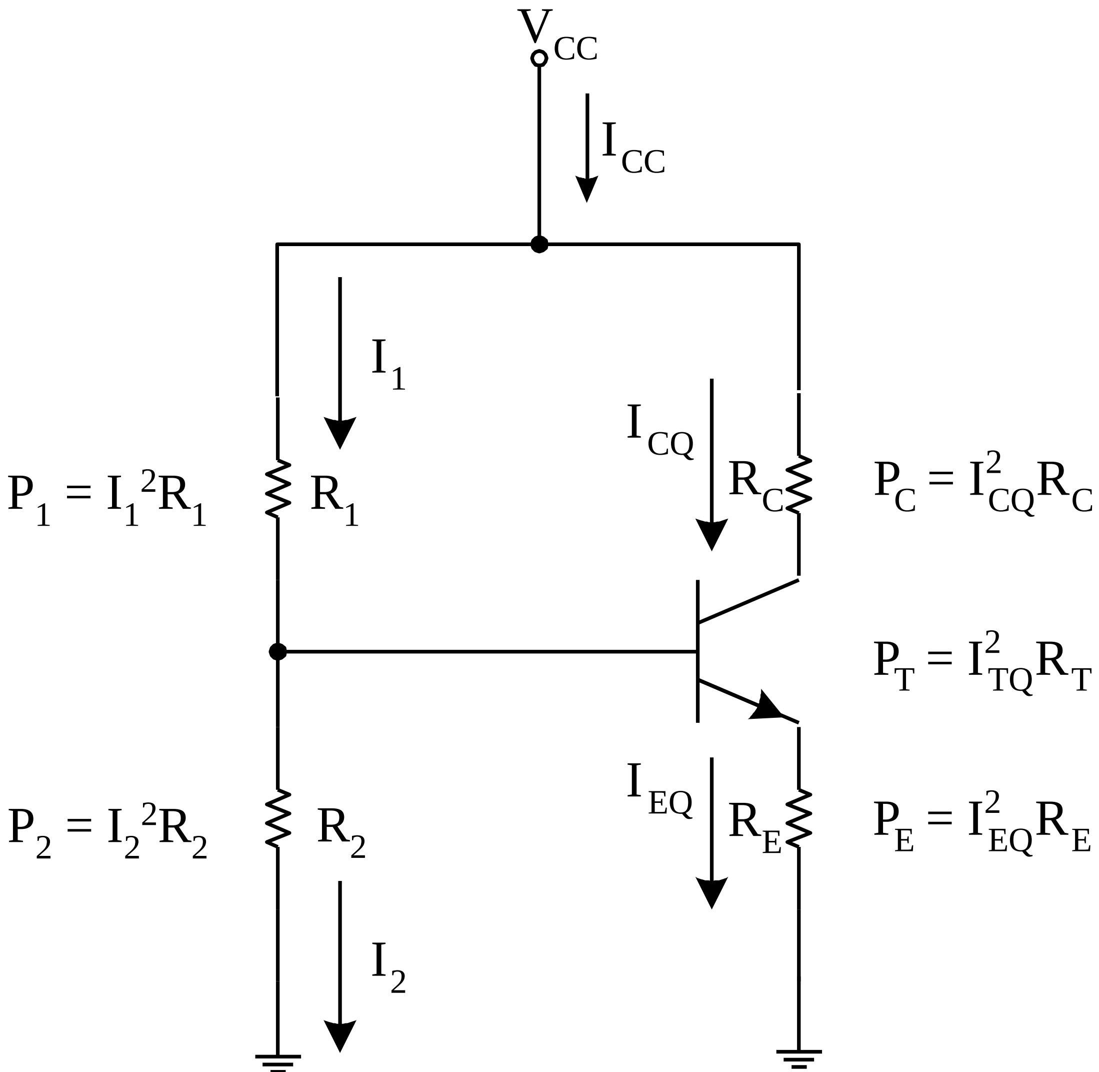
Amplifier Power Dissipation

The **total** amount of power being dissipated by the amplifier, $\boldsymbol{P_S}$, is

$$P_S = P_1 + P_2 + P_C + P_T + P_E$$

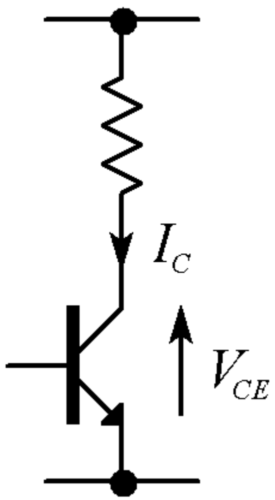
The difference between this total value and the total power being drawn from the supply is the power that actually goes to the **load – i.e. output power**.

$\Rightarrow$ **Amplifier Efficiency** η



Efficiency / Dissipation

The efficiency, η , of an amplifier is the ratio between the power delivered to the load and the total power supplied: $\eta = \frac{P_L}{P_S}$



Power supply requirements and transistor power dissipation ratings depend on the efficiency.

Power that isn't delivered to the load will be dissipated by the output device(s) in the form of heat.

$$P_D = P_S - P_L$$

$$= V_{CE} I_C$$

(for amplifier shown)

Amplifier Efficiency η

- A **figure of merit** for the power amplifier is its efficiency, η .
- **Efficiency (η)** of an amplifier is defined as the ratio of ac output power (power delivered to load) to dc input power .
- By formula :

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

- As we will see, certain amplifier configurations have much higher efficiency ratings than others.
- This is primary consideration when deciding which type of power amplifier to use for a specific application.

- $\Rightarrow$ **Amplifier Classifications**

Power amplifier classes

- Power amplifiers are classified according to the **percent of time** that **collector current** is **nonzero**.

- The amount the ***output*** signal varies over **one cycle** of operation for a **full cycle** of ***input*** signal.

- Power amplifier circuits (output stages) are classified as **A**, **B**, **AB** and **C** for analog designs, and class **D** and **E** for switching designs based on the proportion of each input cycle (**conduction angle**), during which an amplifying device is *passing current*.

Conduction Angle

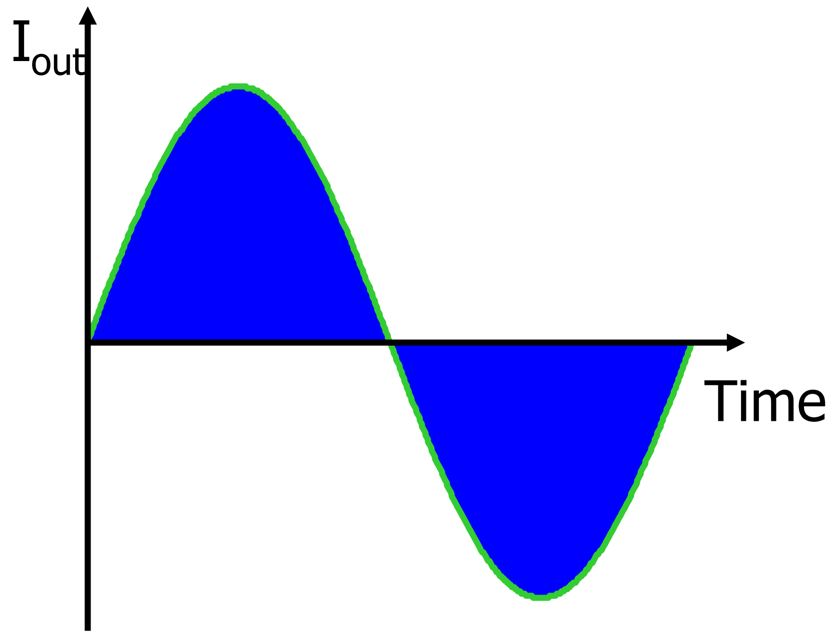
- The image of the conduction angle is derived from amplifying a sinusoidal signal.

- If the device is always on, the conducting angle is 360°.

- If it is on for only half of each cycle, the angle is 180°.

- The angle of flow is closely related to the amplifier **power efficiency**.

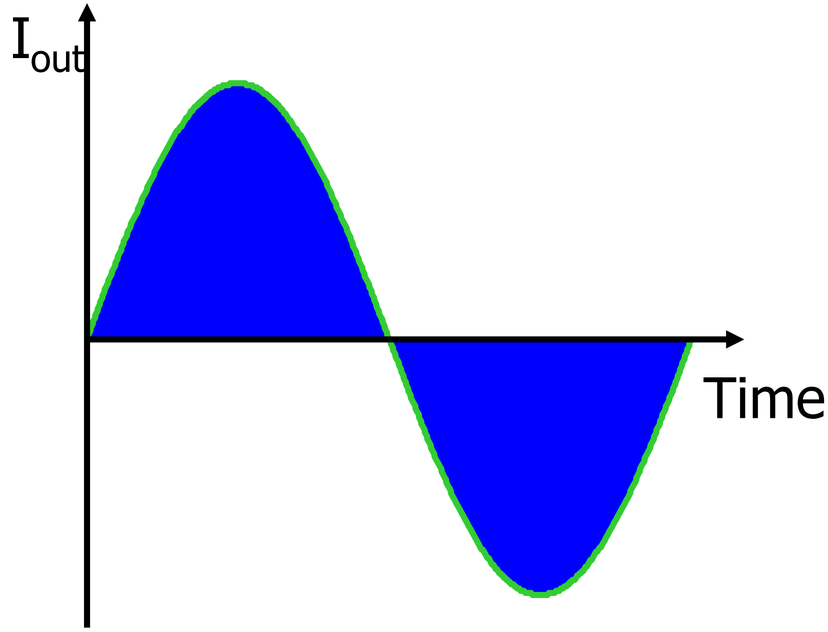
Class A Operating Mode



One device conducts for the whole of the a.c. cycle.
Conduction angle = 360 ° .

The Class A stage must be biased at a current greater than the amplitude of the signal current.

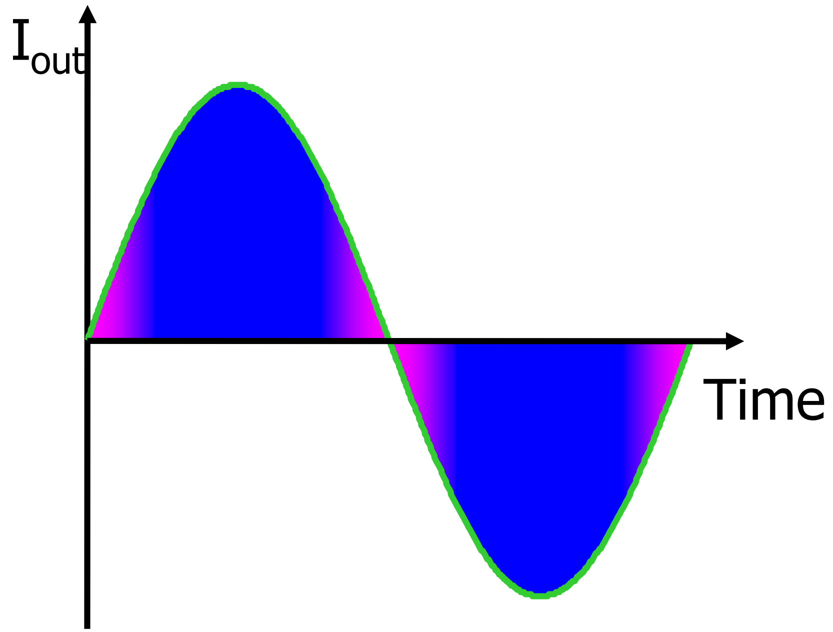
Class B Operating Mode



Two devices, each conducting for half of the a.c. cycle.

Conduction angle = 180 ° .

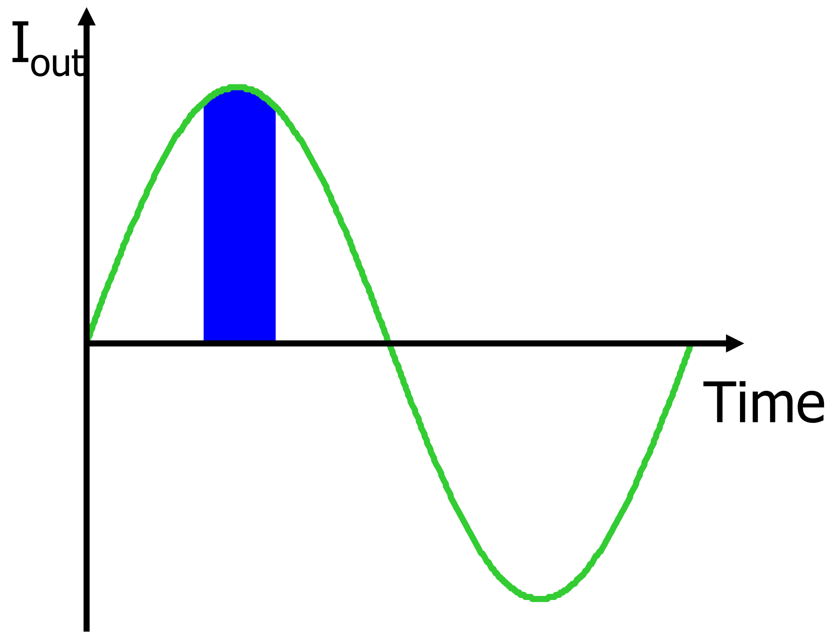
Class AB Operating Mode



Two devices, each conducting for just over half of the a.c. cycle.

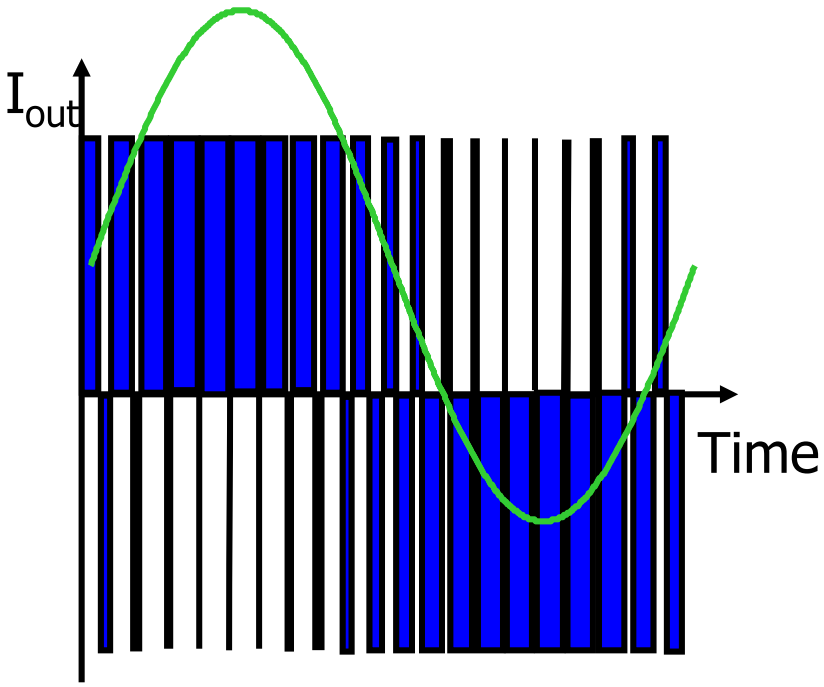
Conduction angle > 180° but << 360°.

Class C Operating Mode



One device conducts a small portion of the a.c. cycle.
Conduction angle << 180°.

Class D Operating Mode



Each output device always either fully on or off – theoretically zero power dissipation.
Example: The built-in speaker in a PC is driven by a Class D type “on/off’ circuit.

Efficiency Ratings

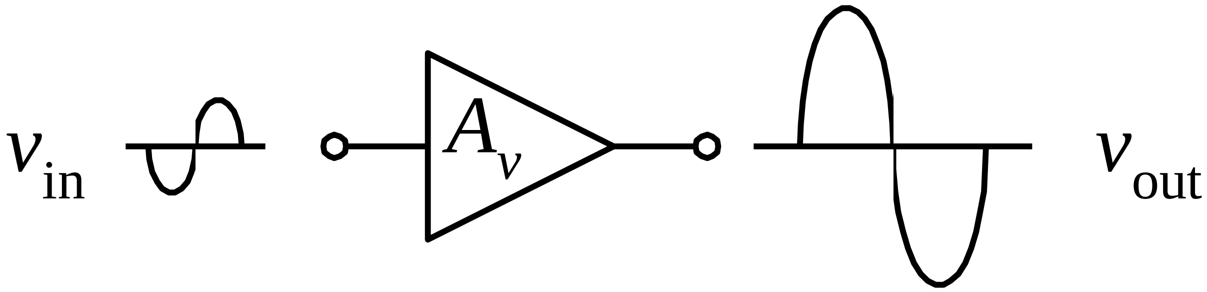
- The **maximum theoretical efficiency** ratings of class-A, B, and C amplifiers are:

Amplifier	Maximum Theoretical Efficiency, $\eta_{\mathbf{max}}$
Class A	25%
Class B	78.5%
Class C	99%

Differences Between Classes

- Class A : Linear operation, very inefficient.
- Class B : High efficiency, non-linear response.
- Class AB : Good efficiency and linearity, more complex than classes A or B though.
- Class C : Very high efficiency but requires narrow band load.
- Class D : Very high efficiency but requires low pass filter on load. Complex and expensive to get high quality results.

Class A Amplifier



- v_{output} waveform $\rightarrow$ **same shape** $\rightarrow$ v_{input} waveform **+ 180° phase shift.**

- The collector current is **nonzero** 100% of the time.

- The active element remains conducting all of the time.

Class A Amplifier

- 100% of the input signal is used (conduction angle $\Theta = 360^\circ$).

- Amplifying devices operating in class A conduct over the whole of the input cycle.

- A class-A amplifier is distinguished by the **output stage** being biased into class A.

$\rightarrow$ **inefficient**, since even with zero input signal, I_{CQ} is nonzero (i.e. transistor dissipates power in the rest, or quiescent, condition)

Advantages of class-A amplifiers

- Class-A designs are **simpler** than other classes; for example class-AB and –B designs require two devices (push–pull output) to handle both halves of the waveform; Class A can use a single device single-ended.

- Because the device is never shut off completely there is no "turn on" time, little problem with charge storage, and generally better high frequency performance and feedback loop stability (and usually **fewer high-order harmonics**).

Disadvantages of class-A amplifiers

- They are very **inefficient**.

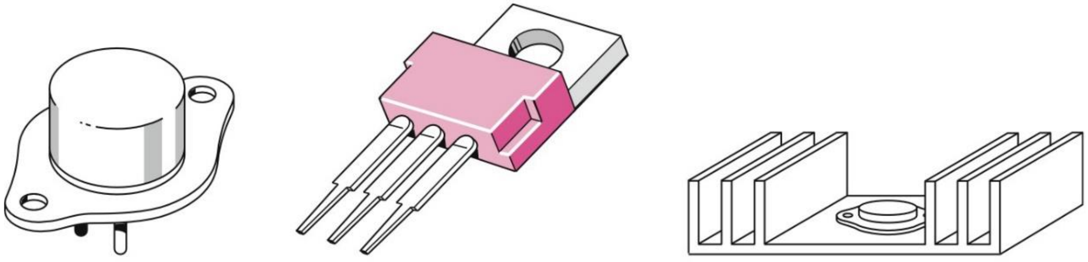
- A theoretical maximum of 50% is obtainable with **inductive** output coupling and only 25% with **capacitive** coupling.

- If **high output powers** are needed from a class-A circuit, the **power waste** (and the accompanying heat) becomes ***significant***.

Disadvantages of class-A amplifiers

- For **every watt** delivered to the load, the amplifier itself, at best, dissipate **another watt**.

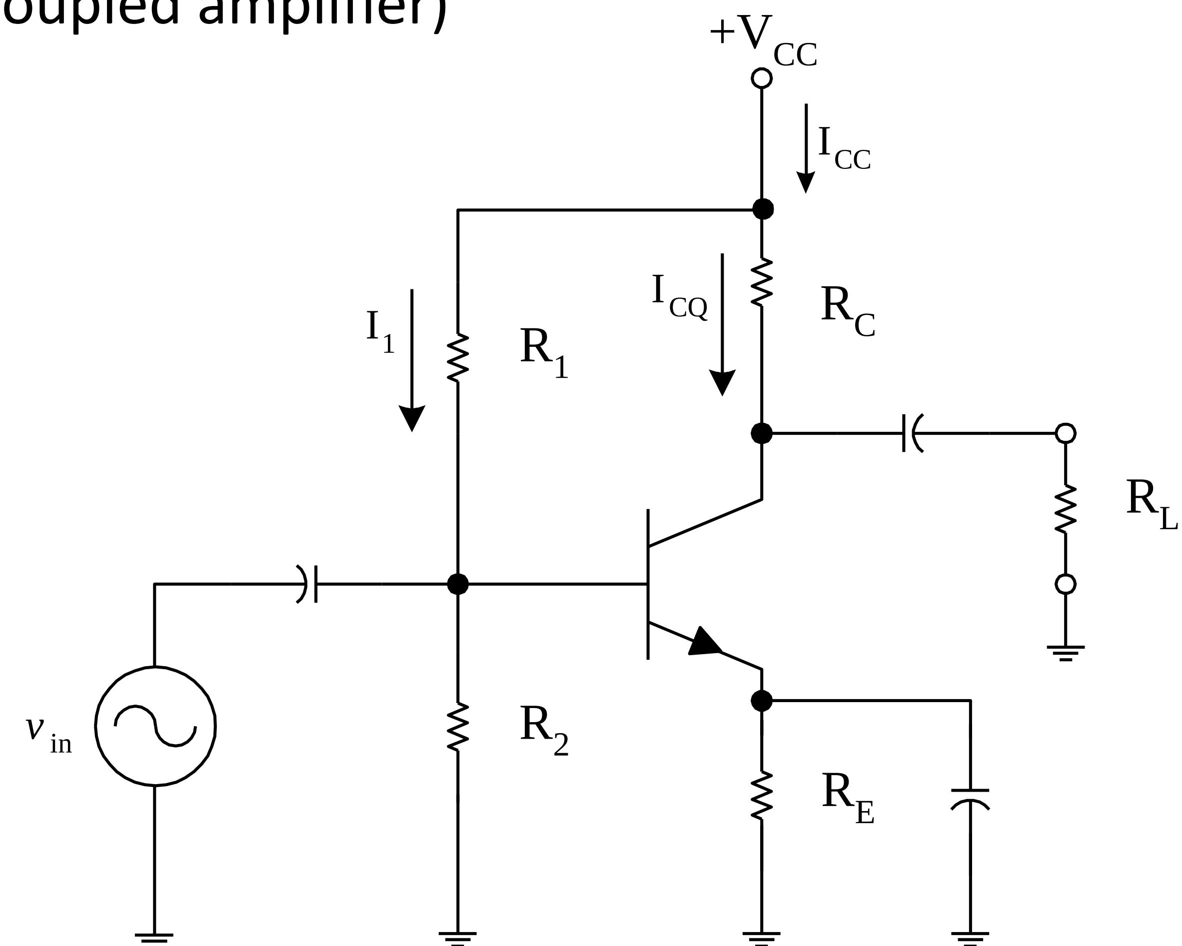
- For large powers this means very large and *expensive* **power supplies** and **heat sinking**.



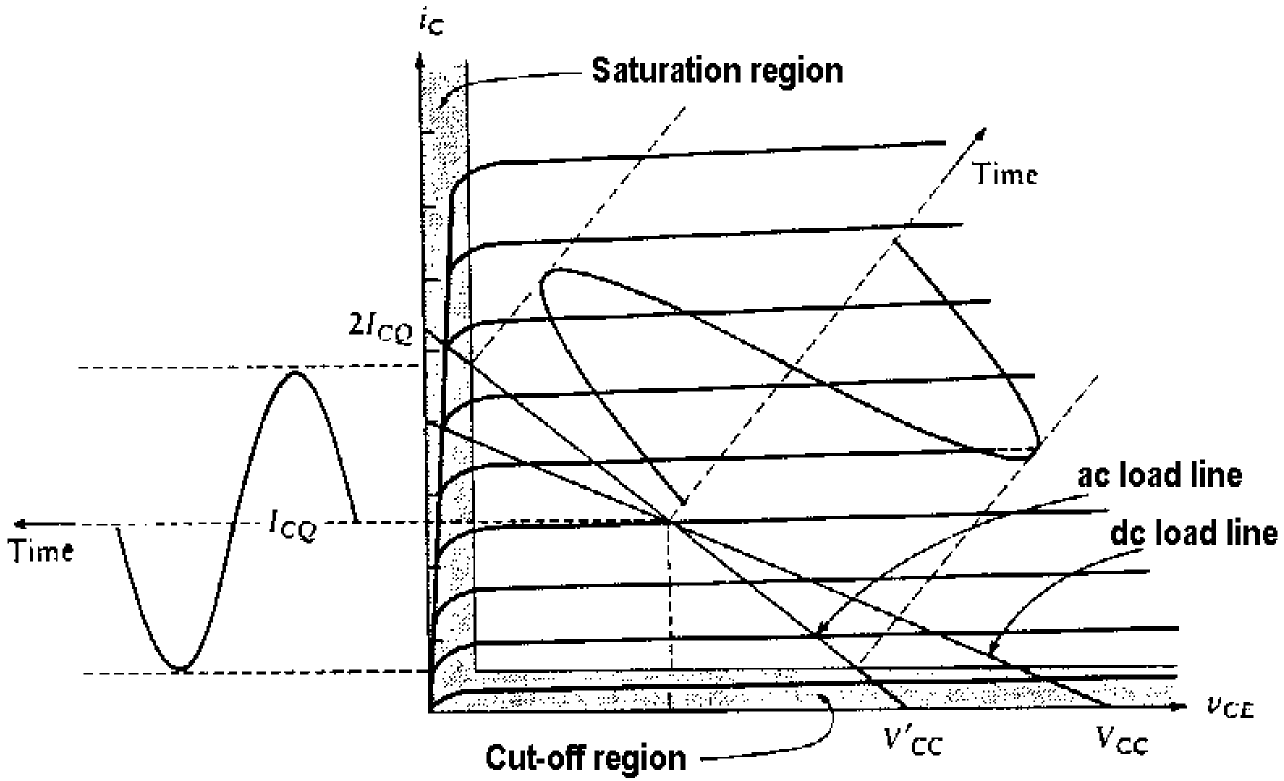
(a) (b) (c)

Basic Operation of Class-A Amplifier with CE Configuration

- Common-emitter (voltage-divider) configuration (RC-coupled amplifier)



Typical Characteristic Curves for Class-A Operation



The current, I_{CQ} , is usually set to be in the **center** of the ac load line.

DC Input Power

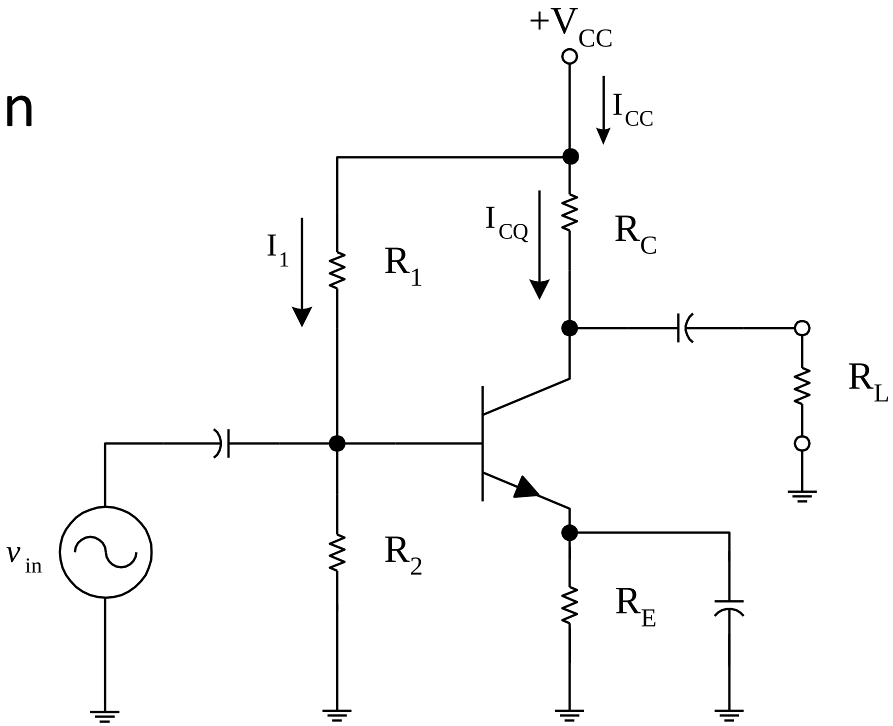
The total dc power, $P_i(dc)$, that an amplifier draws from the power supply :

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

$$I_{CC} = I_{CQ} + I_1$$

$$I_{CC} \approx I_{CQ} \qquad (I_{CQ} >> I_1)$$

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



Note that this equation is valid for most amplifier power analyses.

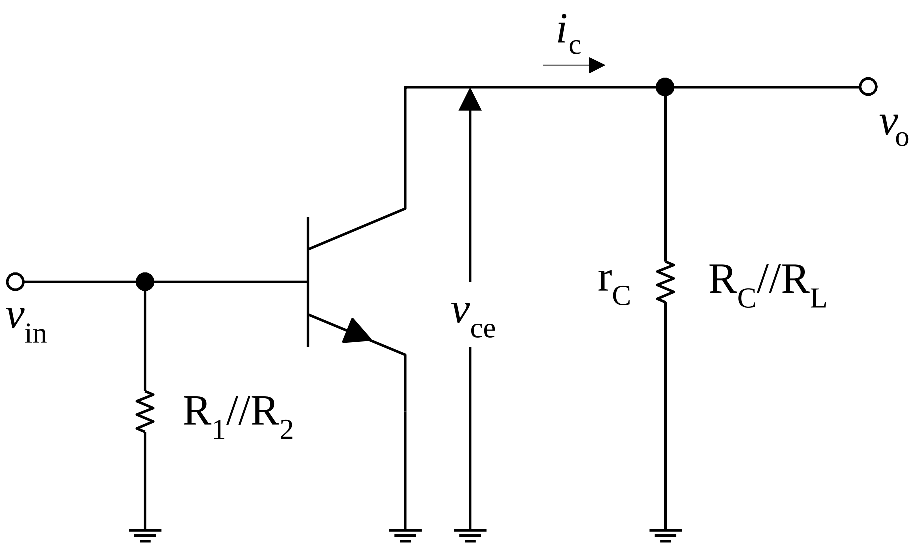
We can rewrite for the above equation for the **ideal** amplifier as

$$P_i(dc) = 2V_{CEQ} I_{CQ}$$

AC Output Power

AC output (or load) power, $P_o(ac)$

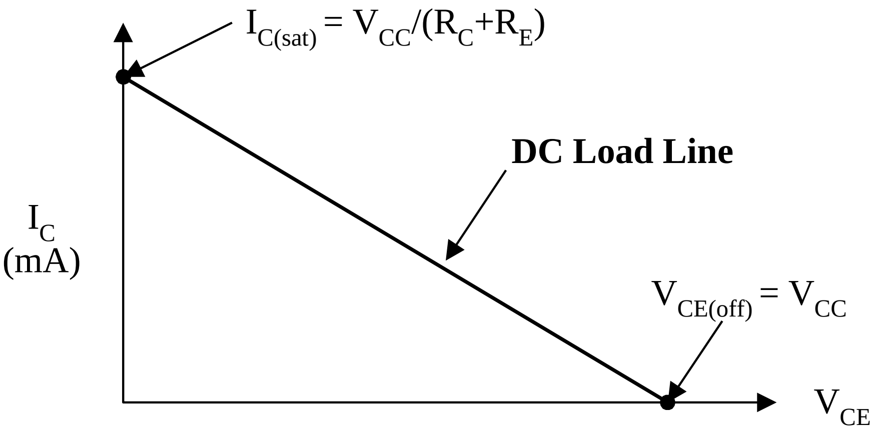
$$P_o(ac) = i_{c(rms)} v_{o(rms)} = \frac{v_{o(rms)}^2}{R_L}$$

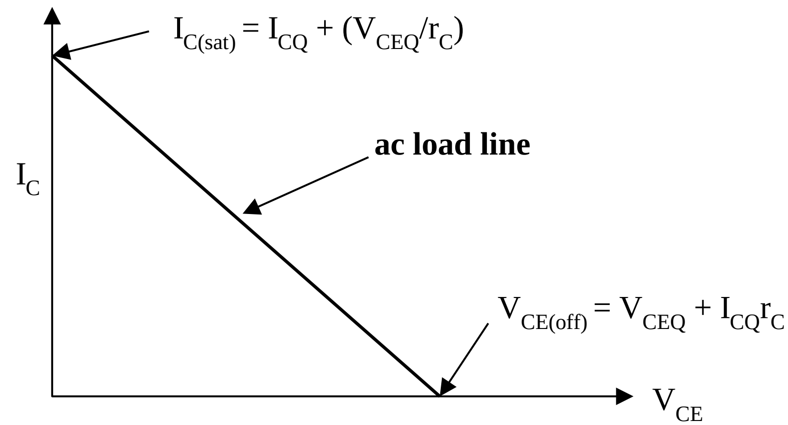


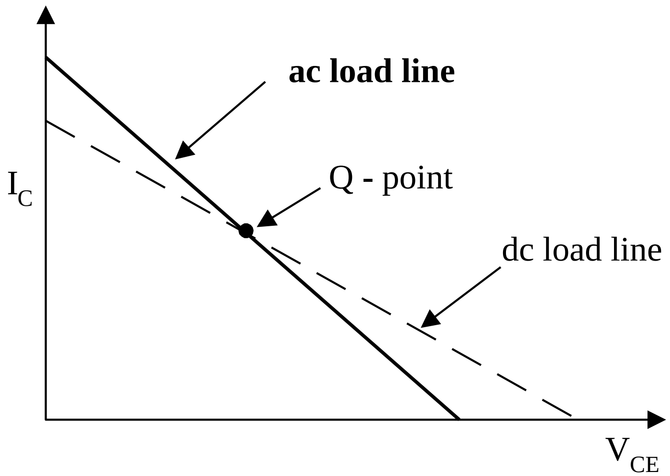
Above equations can be used to calculate the **maximum** possible value of ac load power.

Disadvantage of using class-A amplifiers is the fact that their efficiency ratings are so low, $\eta_{max} \approx$ **25%** .

A majority of the power that is drawn from the supply by a class-A amplifier is used up by the amplifier itself.



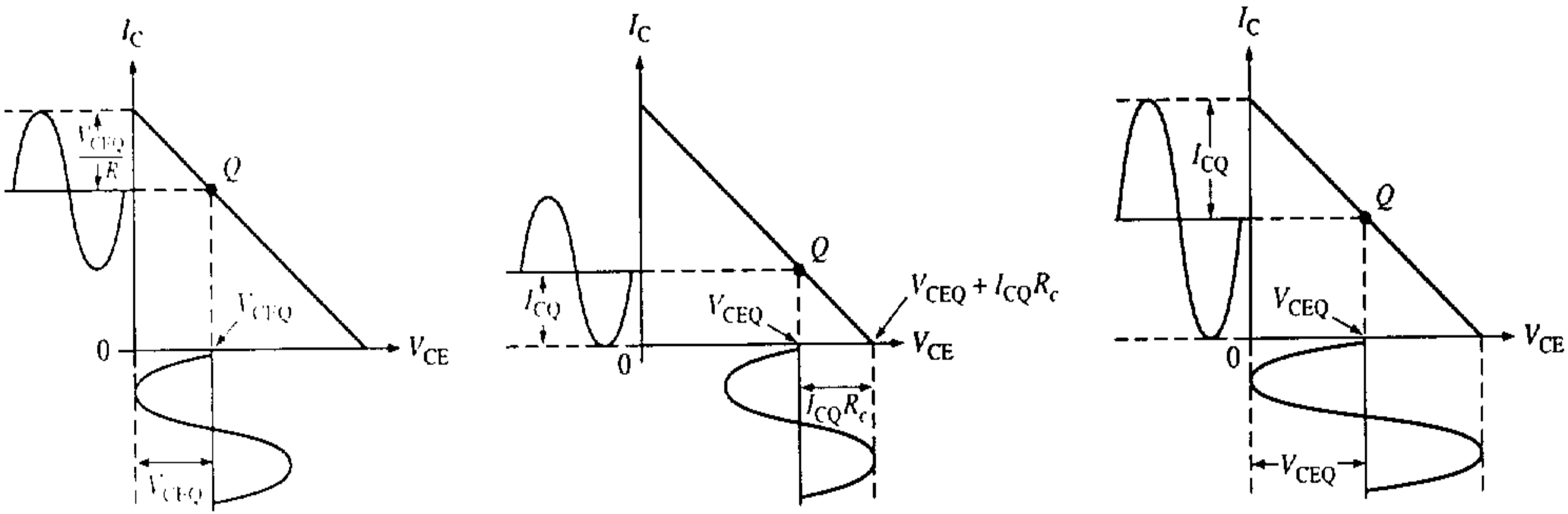




$$P_o(ac) = \left(\frac{V_{CEQ}}{\sqrt{2}}\right)\left(\frac{I_{CQ}}{\sqrt{2}}\right) = \frac{1}{2}V_{CEQ}I_{CQ} = \frac{V_{PP}^2}{8R_L}$$

$$\eta = \frac{P_{o(ac)}}{P_{i(dc)}} \times 100\% = \frac{\frac{1}{2}V_{CEQ}I_{CQ}}{2V_{CEQ}I_{CQ}} \times 100\% = 25\%$$

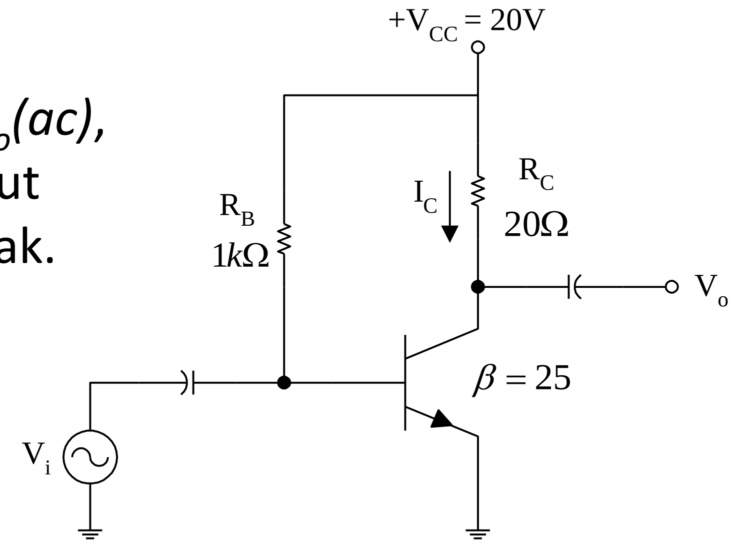
Limitation



(a) Limited by saturation (b) Limited by cutoff (c) Centered Q-point

Example

Calculate the input power $P_i(dc)$, output power $P_o(ac)$, and efficiency ***h*** of the amplifier circuit for an input voltage that results in a base current of 10mA peak.



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

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

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

$$I_{c(sat)} = \frac{V_{CC}}{R_C} = \frac{20V}{20\Omega} = 1000mA = 1A$$

$$V_{CE(cutoff)} = V_{CC} = 20V$$

$$I_{C(peak)} = \beta I_{b(peak)} = 25(10mA\ peak) = 250mA\ peak$$

$$P_{o(ac)} = \frac{I_{C(peak)}^2}{2} R_C = \frac{\left(250 \times 10^{-3} A\right)^2}{2}(20\Omega) = 0.625W$$

$$P_{i(dc)} = V_{CC} I_{CQ} = (20V)(0.48A) = 9.6W$$

$$\eta = \frac{P_{o(ac)}}{P_{i(dc)}} \times 100\% = 6.5\%$$