Lecture 8
Power Amplifier (Class A)

- Induction of Power Amplifier
- Power and Efficiency
- Amplifier Classification
- Basic Class A Amplifier
- Transformer Coupled Class A Amplifier

Introduction

- 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**.
- 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.

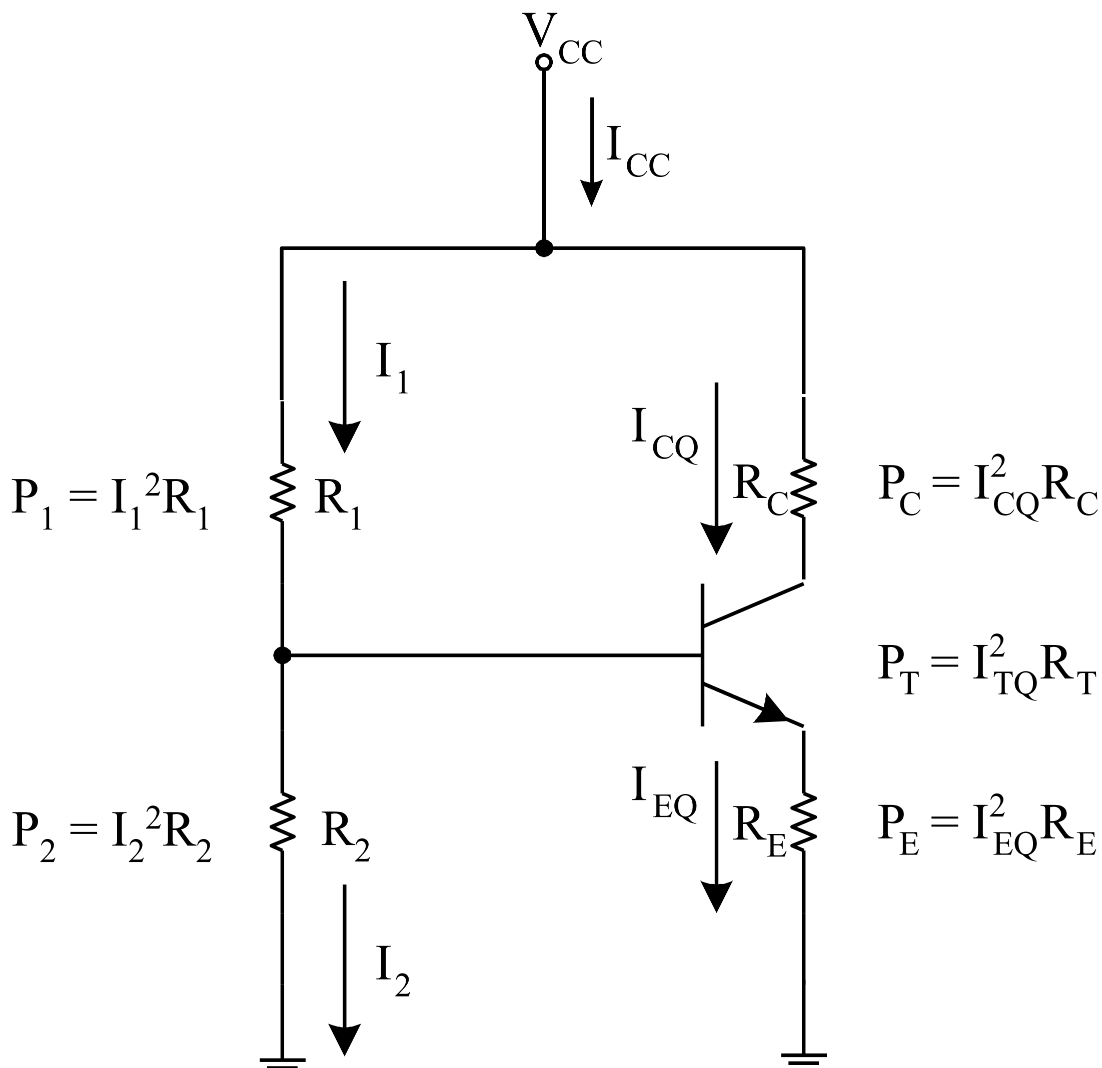
Amplifier Power Dissipation

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

$$\boldsymbol{P_{tot} = P_1 + P_2 + P_C + P_T + P_E}$$

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**.

⇒ **Amplifier Efficiency** $\boldsymbol{\eta}$



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 :

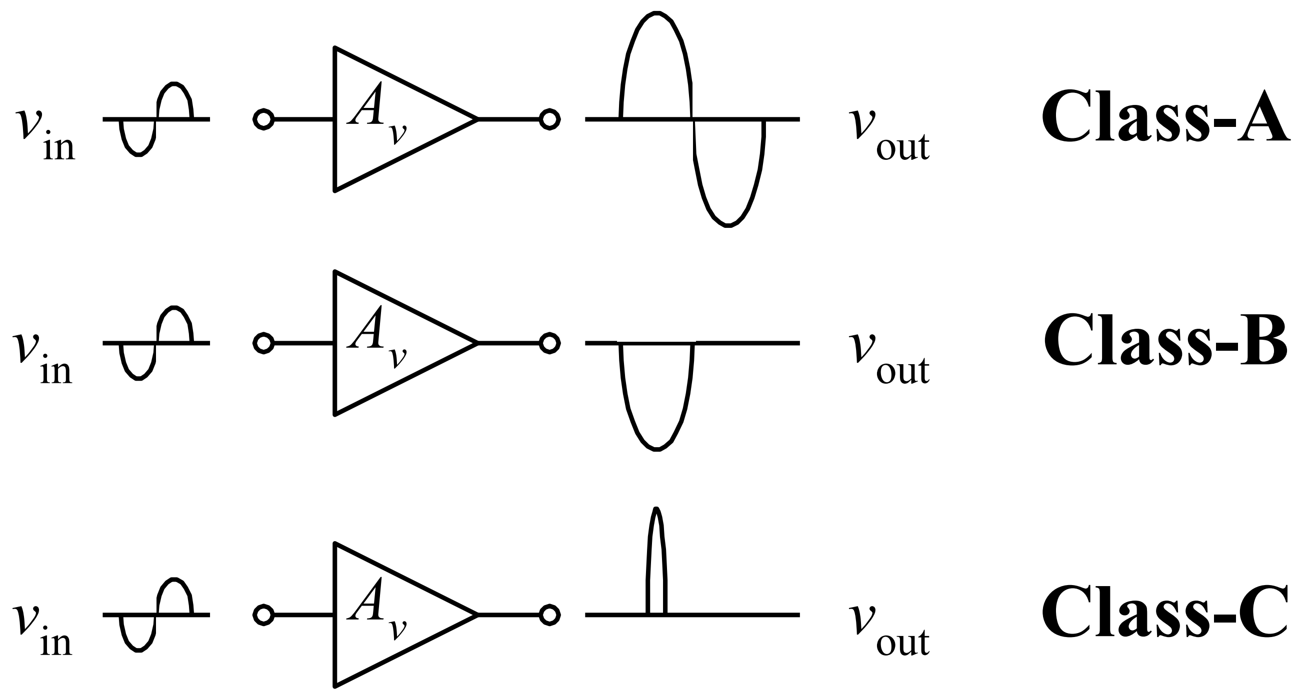
$$\eta = \frac{ac \quad output \quad power}{dc \quad input \quad power} \times 100\% = \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

- 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**

Amplifier Classifications

- 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.

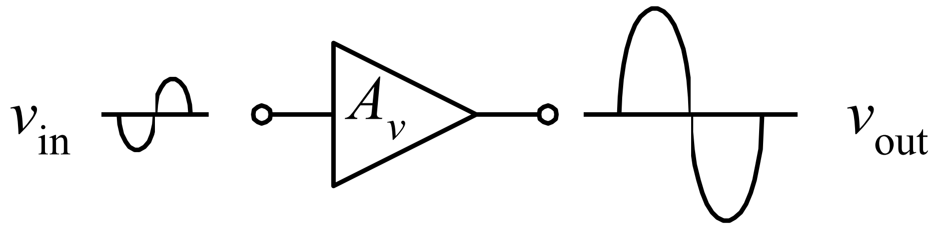


Efficiency Ratings

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

Amplifier	Maximum Theoretical Efficiency, η_{max}
Class A	25%
Class B	78.5%
Class C	99%

Class A Amplifier



- ν_{output} waveform → **same shape** → ν_{input} waveform + **π phase shift.**

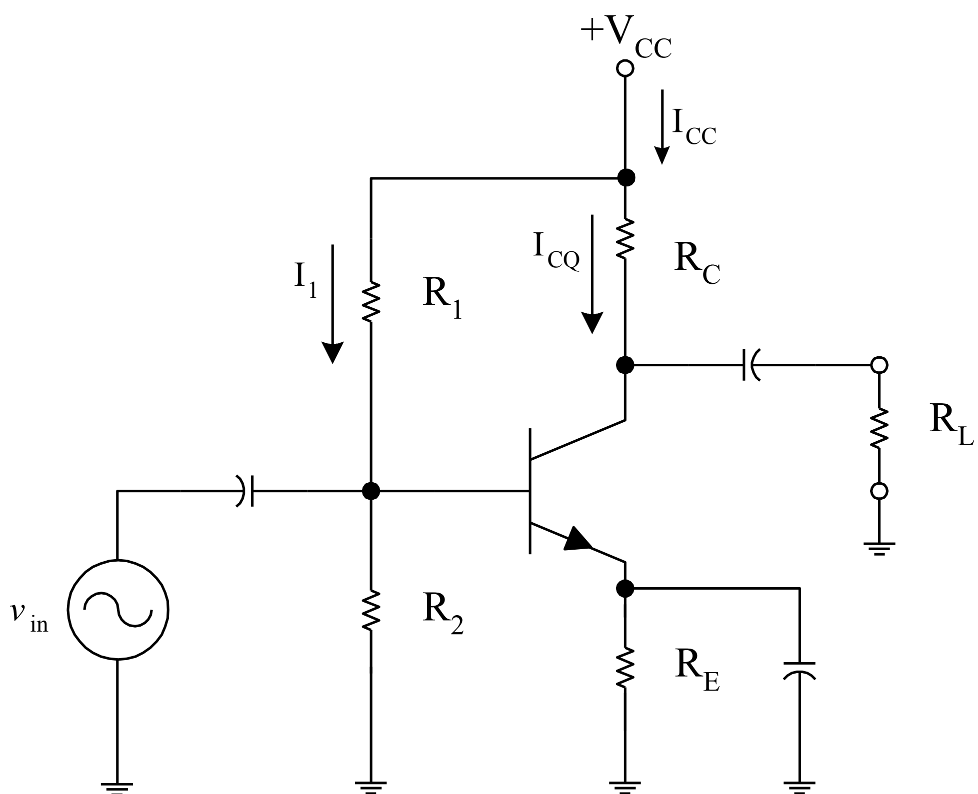
- The collector current is **nonzero** 100% of the time.

  → **inefficient**, since even with zero input signal, I_{CQ} is nonzero

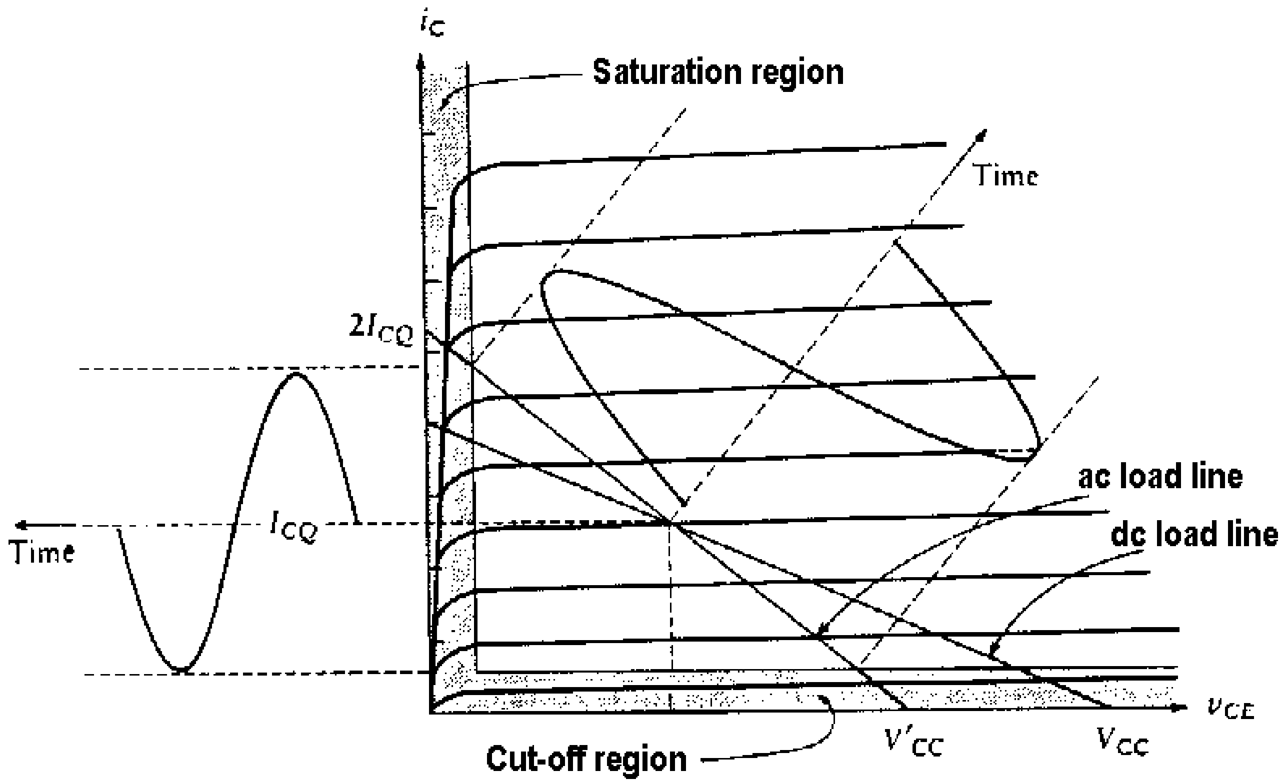
  (i.e. transistor dissipates power in the rest, or quiescent, condition)

Basic Operation

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



Typical Characteristic Curves for Class-A Operation



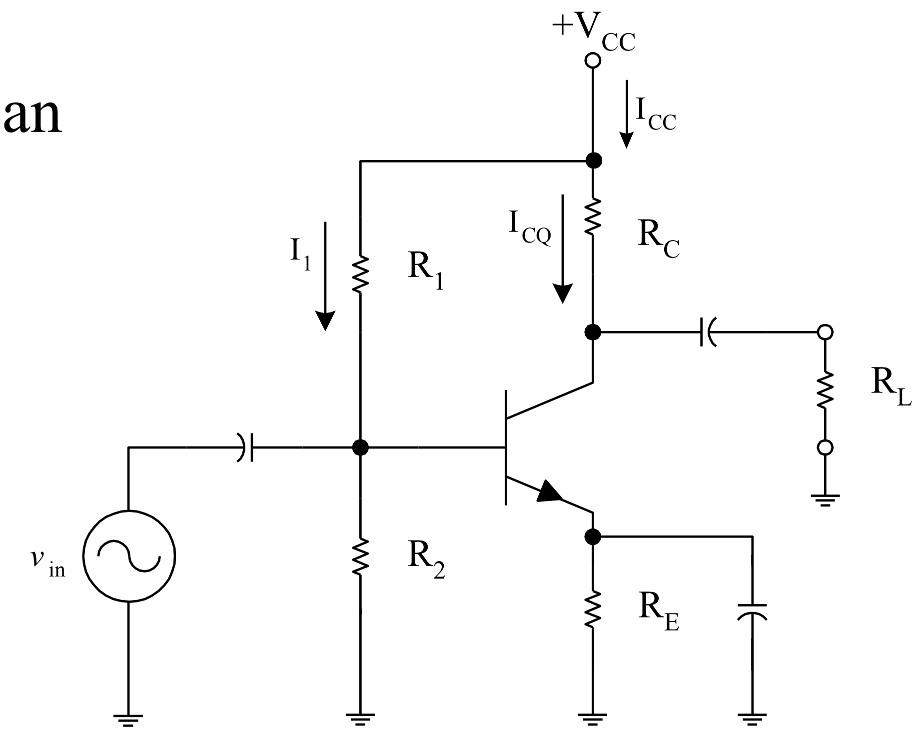
Typical Characteristic

- Previous figure shows an example of a sinusoidal input and the resulting collector current at the output.
- The current, I_{CQ} , is usually set to be in the **center** of the ac load line. Why?

(DC and AC analyses $\rightarrow$ discussed in previous sessions)

DC Input Power

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



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

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

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

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

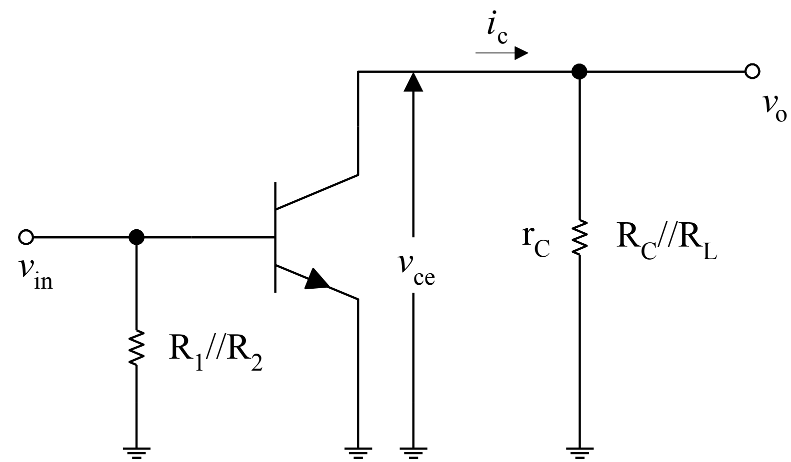
Note that this equation is valid for most amplifier power analyses. We can rewrite for the above equation for the **ideal** amplifier as

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

AC Output Power

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

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

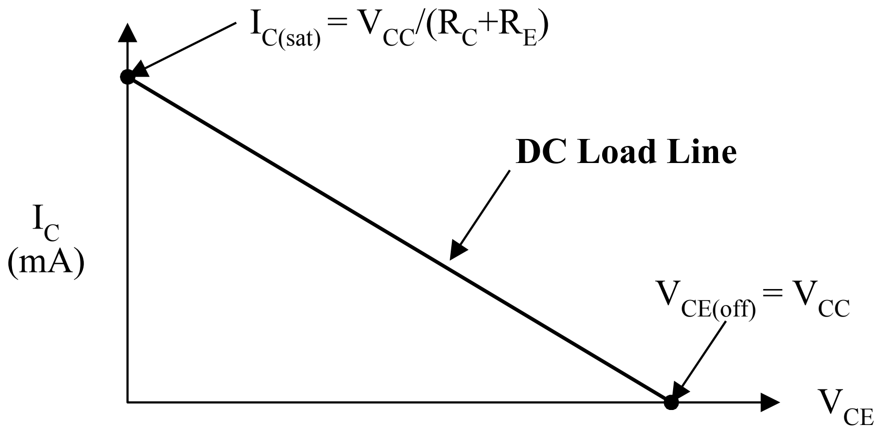


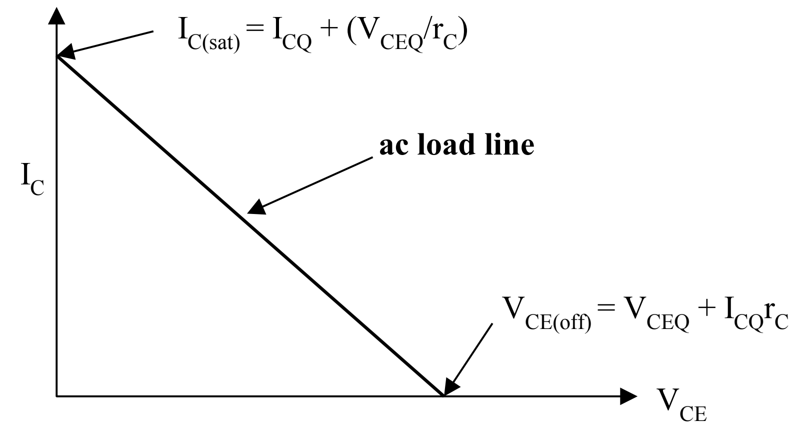
Above equations can be used to calculate the **maximum** possible value of ac load power. HOW??

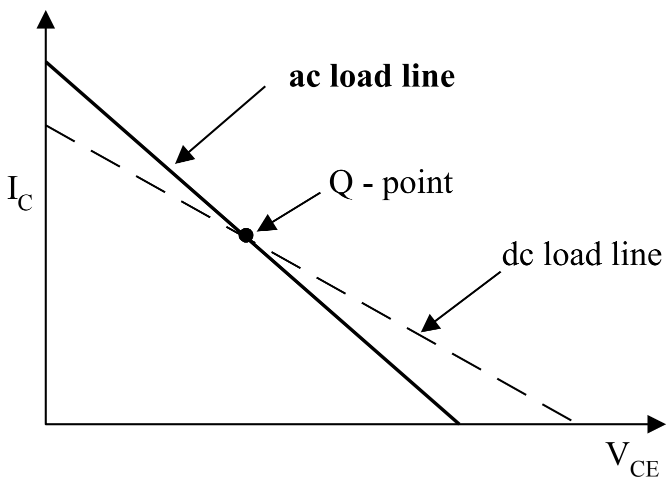
Disadvantage of using class-A amplifiers is the fact that their efficiency ratings are so low, $\eta_{max} \approx$ **25%** .

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

$\rightarrow$ **Class-B Amplifier**



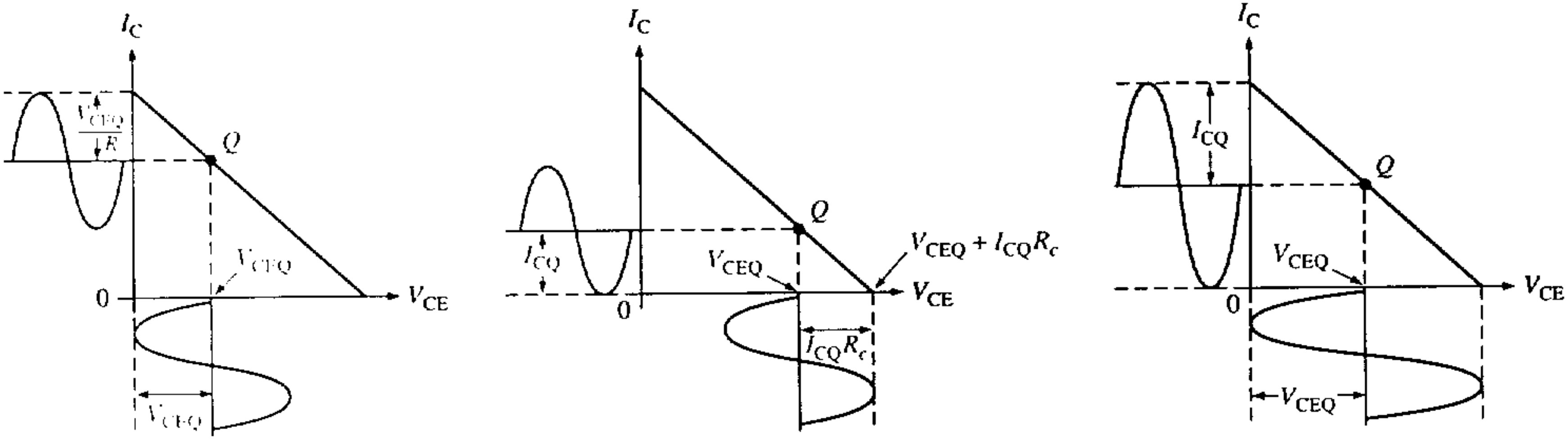




$$P_o(ac) = \left(\frac{V_{CEQ}}{\sqrt{2}}\right)\left(\frac{I_{CQ}}{\sqrt{2}}\right) = \frac{1}{2}V_{CEQ}I_{CQ} = \frac{V_{PP}^2}{8R_L}$$

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

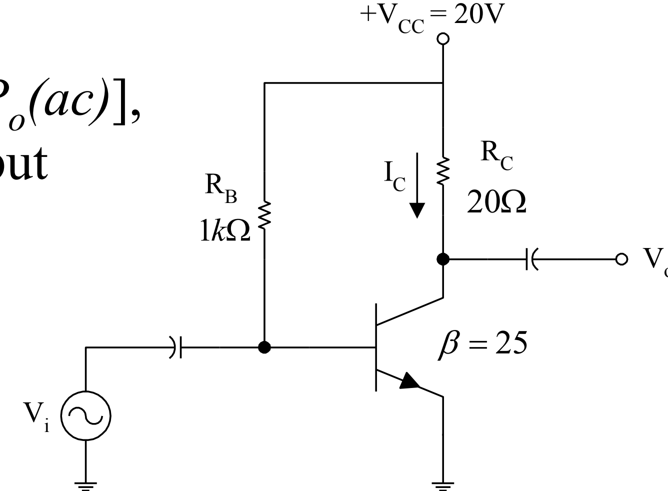
Limitation



(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 [η] of the amplifier circuit for an input voltage that results in a base current of 10mA peak.



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

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

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

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

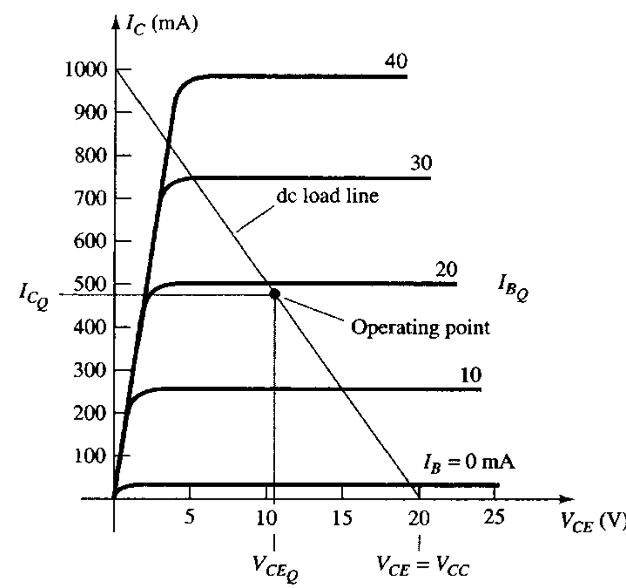
$$V_{CE(cutoff)} = V_{CC} = 20V$$

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

$$P_{o(ac)} = \frac{I^2_{C(peak)}}{2} R_C = \frac{\left(250\times10^{-3}A\right)^2}{2}(20\Omega) = 0.625W$$

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

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



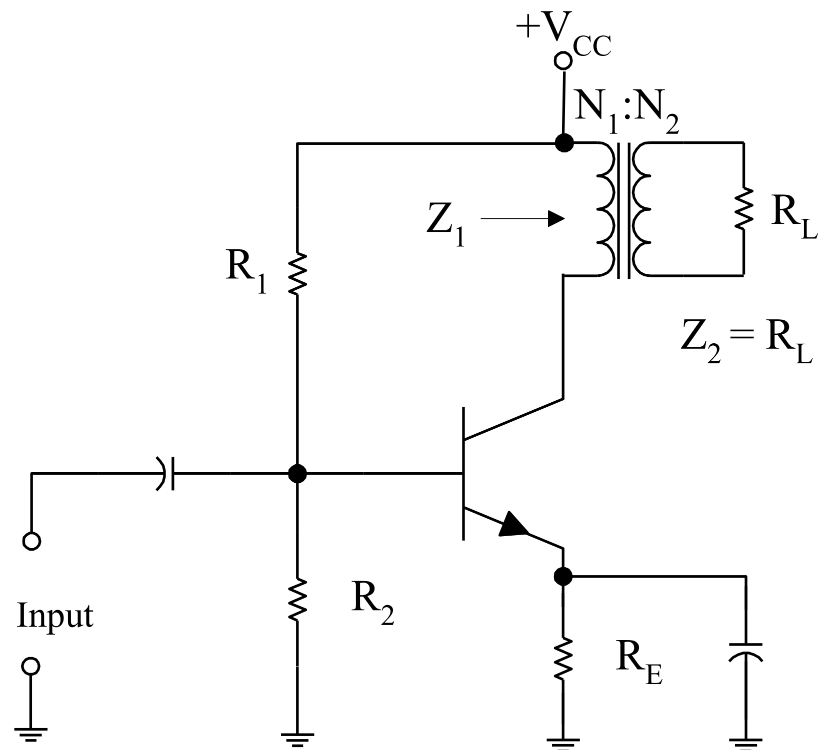
Transformer-Coupled Class-A Amplifier

A transformer-coupled class-A amplifier uses a transformer to couple the output signal from the amplifier to the load.

The relationship between the primary and secondary values of voltage, current and impedance are summarized as:

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

$$\left(\frac{N_1}{N_2}\right)^2 = \frac{Z_1}{Z_2} = \frac{Z_1}{R_L}$$

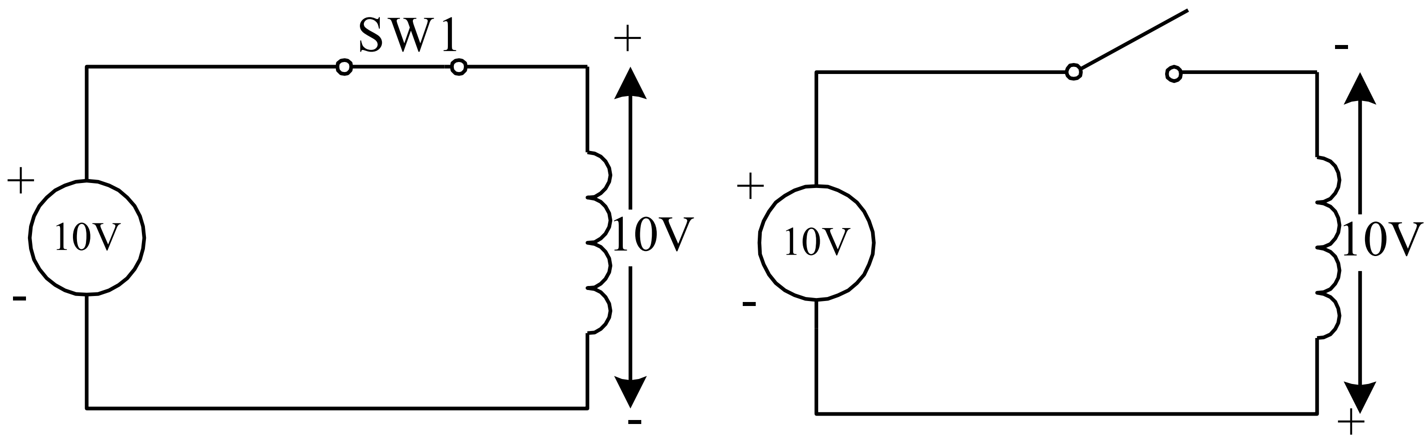


N_1, N_2 = the number of turns in the primary and secondary
V_1, V_2 = the primary and secondary voltages
I_1, I_2 = the primary and secondary currents
Z_1, Z_2 = the primary and seconadary impedance ($Z_2 = R_L$)

Transformer-Coupled Class-A Amplifier

- An **important** characteristic of the transformer is the ability to produce a **counter emf**, or **kick** emf.
- When an inductor experiences a rapid change in supply voltage, it will produce a voltage with a polarity that is opposite to the original voltage polarity.
- The counter emf is caused by the electromagnetic field that surrounds the inductor.

Counter emf



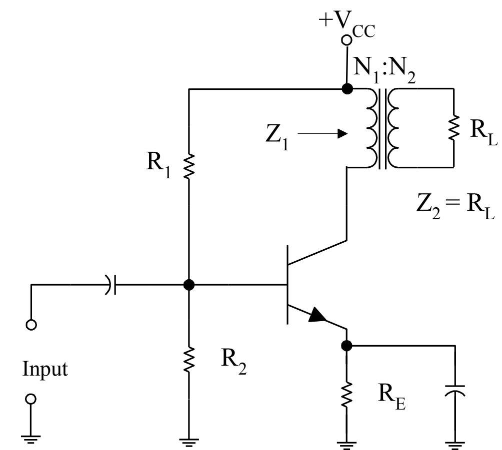
This counter emf will be present only for an instant.

As the field collapses into the inductor the voltage decreases in value until it eventually reaches 0V.

DC Operating Characteristics

The dc biasing of a transformer-coupled class-A amplifier is very similar to any other class-A amplifier with **one important exception** :

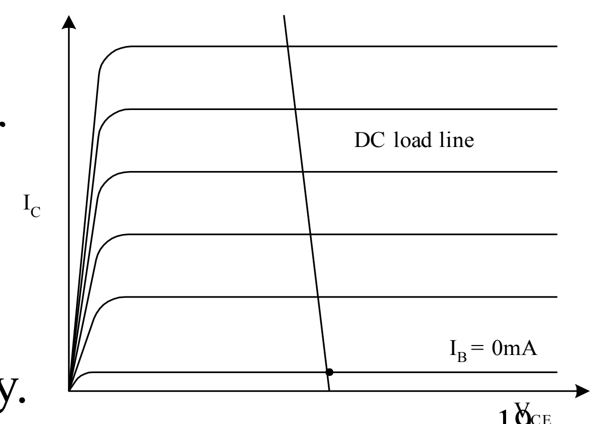
→ the value of V_{CEQ} is **designed** to be as close as possible to V_{CC}.



The dc load line is very close to being a vertical line indicating that V_{CEQ} will be approximately equal to V_{CC} for all the values of I_C.

The nearly **vertical** load line of the transformer-coupled amplifier is caused by the **extremely low dc resistance** of the transformer primary.

$$V_{CEQ} = V_{CC} - I_{CQ}(R_C + R_E)$$



The value of R_L is **ignored** in the dc analysis of the transformer-coupled class-A amplifier. The reason for this is the fact that transformer provides **dc isolation** between the primary and secondary. Since the load resistance is in the secondary of the transformer it **dose not** affect the dc analysis of the primary circuitry.

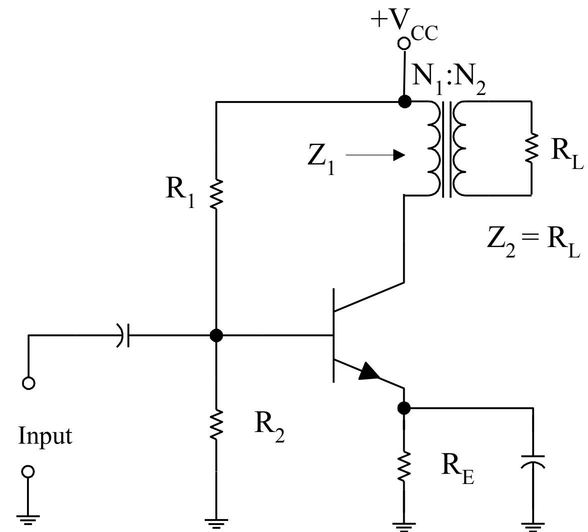
AC Operating Characteristics

1. Determine the maximum possible change in V_{CE}

 •Since V_{CE} cannot change by an amount greater than $(V_{CEQ} - 0V)$, $v_{ce} = V_{CEQ}$.

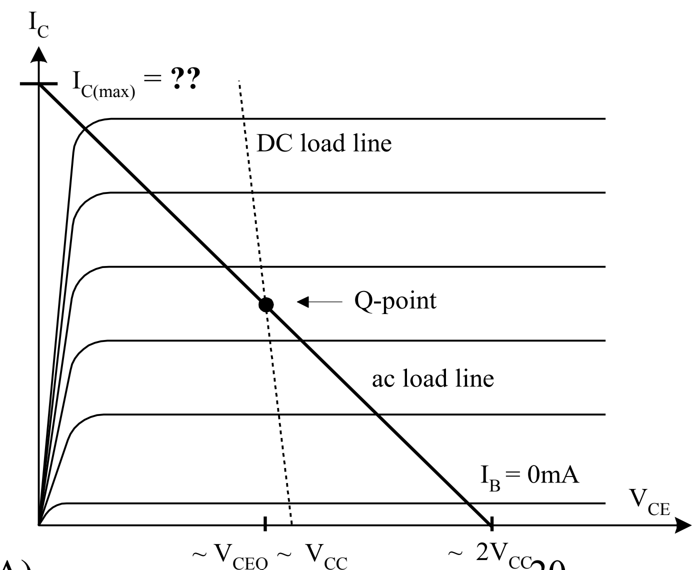
2. Determine the corresponding change in I_C

 •Find the value of Z_1 for the transformer: $Z_1 = (N_1/N_2)^2 Z_2$ and $i_c = v_{ce} / Z_1$

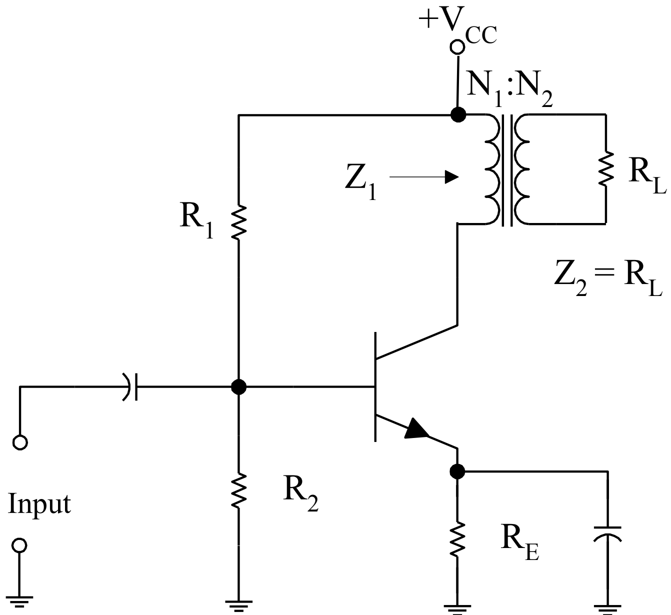


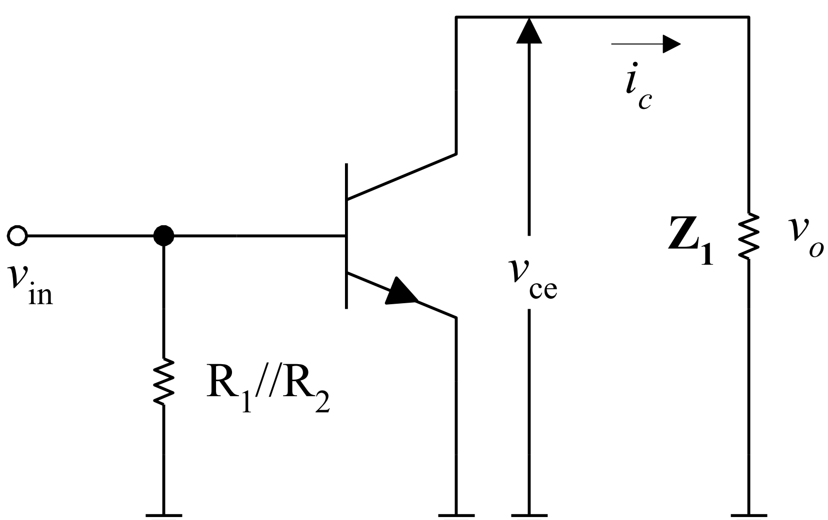
3. Plot a line that passes through the Q-point and the value of $I_{C(max)}$.

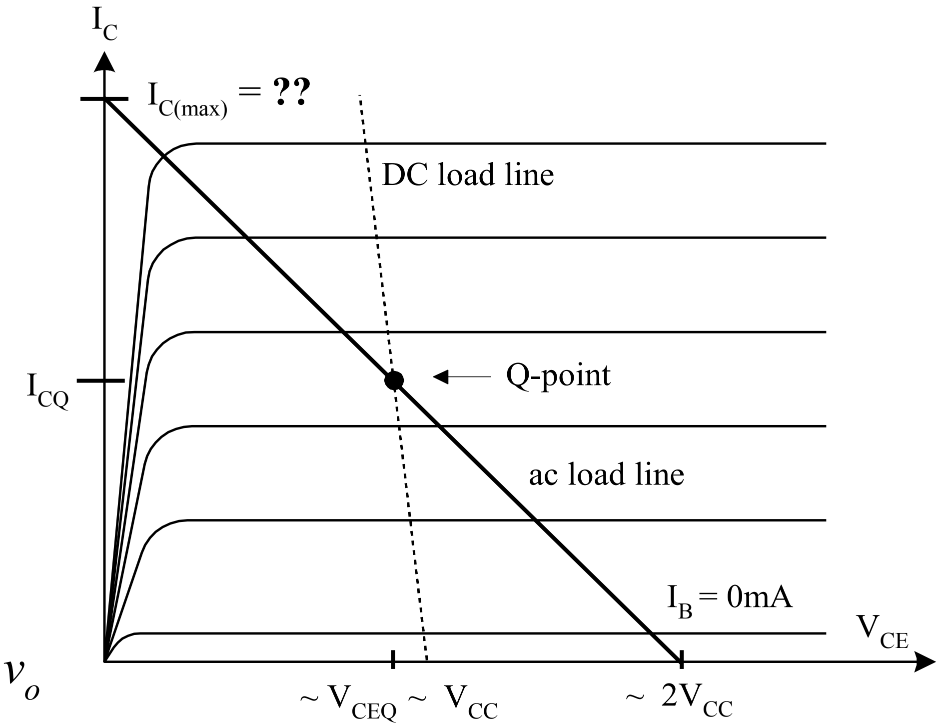
 •$I_{C(max)} = I_{CQ} + i_c$



4. Locate the two points where the load line passes through the lies representing the minimum and maximum values of I_B. These two points are then used to find the maximum and minimum values of I_C and V_{CE}


+VCC
N1:N2
Z1
RL
R1
Z2 = RL
Input
R2
RE


ic
vin
vce
Z1
vo
R1//R2


IC
IC(max) = ??
DC load line
ICQ
Q-point
ac load line
IB = 0mA
VCE
~ VCEQ ~ VCC
~ 2VCC

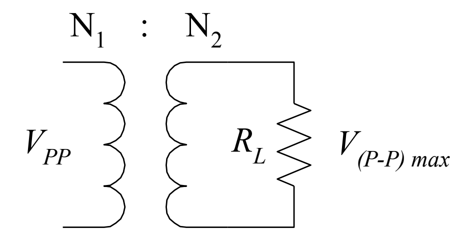
Maximum load power and efficiency

The Power Supply for the amplifier : $\boldsymbol{P_S = V_{CC} I_{CC}}$

Maximum peak-to-peak voltage across the primary of the transformer is approximately equal to the difference between the values of $V_{CE(max)}$ and $V_{CE(min)}$: $\boldsymbol{V_{PP} = V_{CE(max)} - V\text{-}_{CE(min)}}$

Maximum possible peak-to-peak **load voltage** is found by

$$\boldsymbol{V_{(P\text{-}P)max} = (N_2 / N_1) V_{PP}}$$



The **actual efficiency** rating of a transformer-coupled class-A amplifier will generally be **less than 40%**.

There are several reasons for the difference between the practical and theoretical efficiency ratings for the amplifier :

1. The derivation of the $\eta = 50\%$ value assumes that $V_{CEQ} = V_{CC}$. In practice, V_{CEQ} will always be some value that is less the V_{CC}.
2. The transformer is subject to various power losses. Among these losses are couple loss and hysteresis loss. These transformer power losses are not considered in the derivation of the $\eta = 50\%$ value.

- One of the **primary advantages** of using the transformer-coupled class-A amplifier is the **increased efficiency** over the RC-coupled class-A circuit.
- **Another advantage** is the fact that the transformer-coupled amplifier is **easily converted into** a type of amplifier that is used extensively in communications :- the **tuned amplifier**.
- A tuned amplifier is a circuit that is designed to have a specific value of power gain over a **specific range of frequency**.