Chapter 7
Power Amplifiers

7.1 Introduction

-- Definitions and Amplifier Types

In small-signal amplifiers, the main factors are:

- ***Amplification***
- ***Linearity***
- ***Gain***

Since large-signal, or power, amplifiers handle relatively large voltage signals and current levels, the main factors are:

- ***Efficiency***
- ***Maximum power capability***
- ***Impedance matching to the output device***

7.1 Introduction

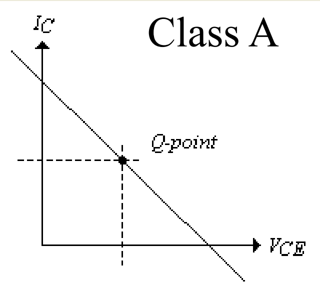
-- Power Amplifier Index

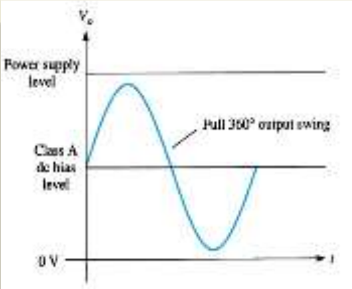
- *The power is sufficiently large.*
- *The efficiency is very high.*
- *Output signal is not distorted.*
- *The power amplifier has powerful load capacity.*
- *Safety precautions should be done very well.*

7.1 Introduction -- Power Amplifier Types

Class A

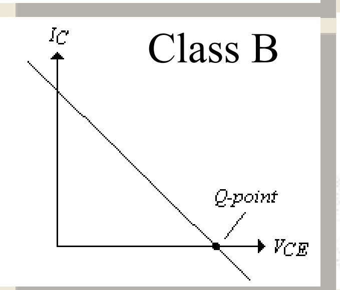
The amplifier conducts through the full 360° of the input. The Q-point is set near the middle of the load line.

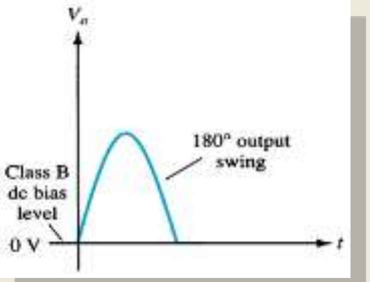




Class B

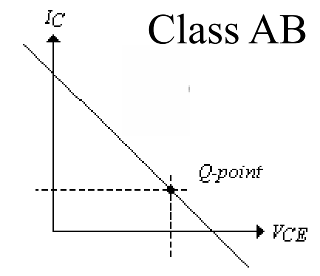
The amplifier conducts through 180° of the input. The Q-point is set at the cutoff point.





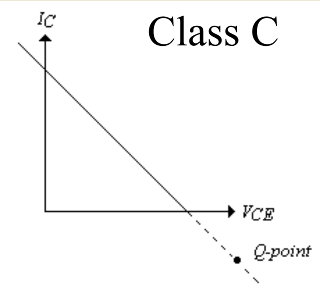
Class AB

This is a compromise between the class A and B amplifiers. The amplifier conducts somewhere between 180° and 360° . The Q-point is located between the mid-point and cutoff.



Class C

The amplifier conducts less than 180 of the input. The Q-point is located below the cutoff level.



Class D

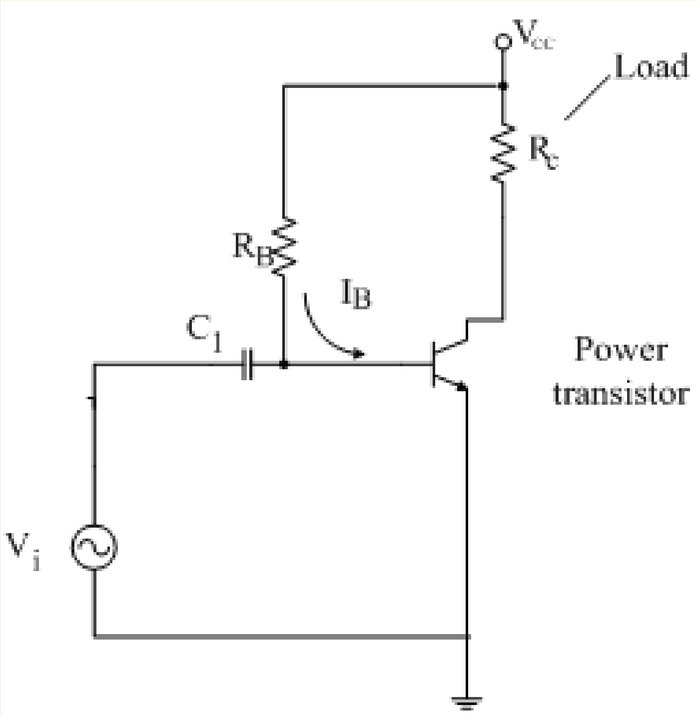
This is an amplifier that is biased especially for digital signals.

7.2 Class A Amplifier

- The transistor used is a high-power transistor.

- It will handle higher voltages.

- The analysis is similar to the small-signal amplifier.



DC Operation: Class A Amplifier

The DC bias is set by V_{CC} and R_B, the base current is

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

The collector current is

$$I_C = \beta I_B$$

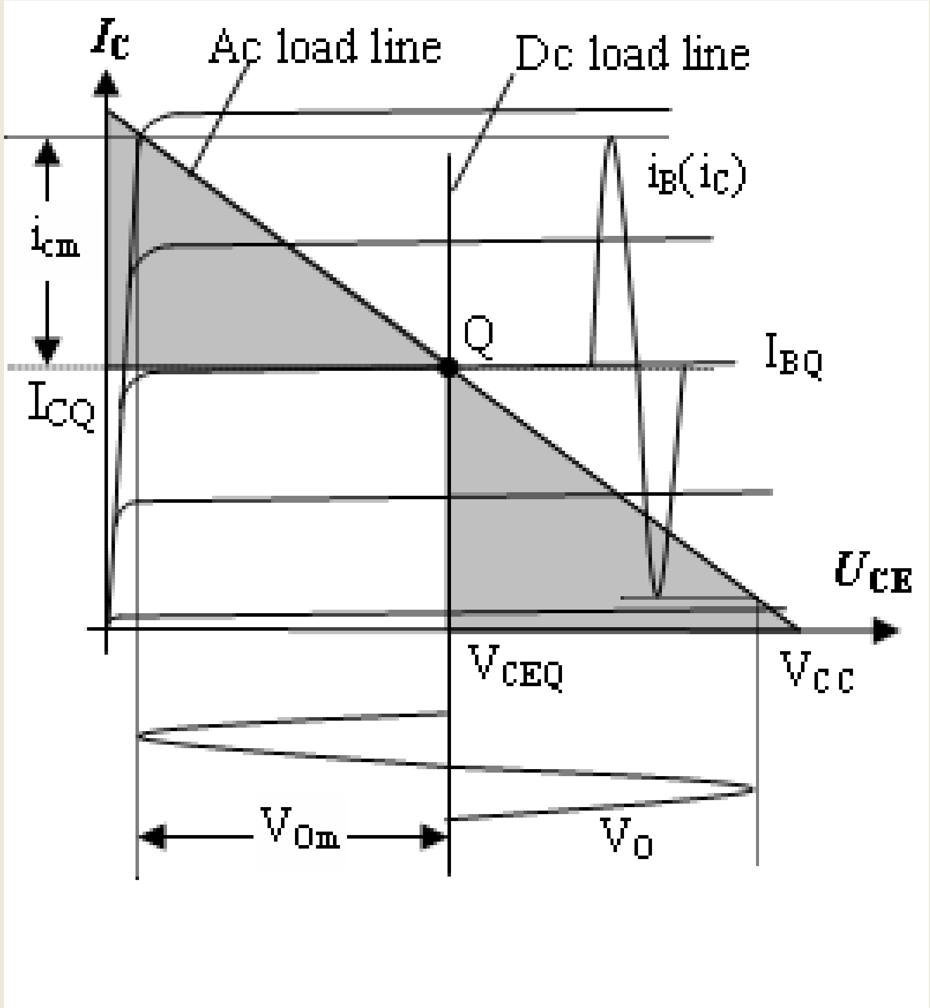
The collector-emitter voltage is

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

AC Operation: Class A Amplifier

A small input signal causes the output voltage to swing to a maximum of V_{cc} and a minimum of 0V.

The current can also swing from 0mA to I_{CSAT} (V_{cc}/R_C).



Class A Amplifier

Input Power

The power into the amplifier is from the DC supply. Without input signal, the DC current drawn is the collector bias current I_{CQ}.

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

Output Power

(rms mode) $$P_o(ac) = V_{CE}(rms) I_C(rms),\ P_o(ac) = I_C^2(rms) R_C,\ P_o(ac) = \frac{V_{CE}^2(rms)}{R_C}$$

(p mode) $$P_o(ac) = \frac{V_{CE}(p) I_C(p)}{2},\ P_o(ac) = \frac{I_C^2(p)}{2} R_C,\ P_o(ac) = \frac{V_{CE}^2(p)}{2R_C}$$

(p-p mode) $$P_o(ac) = \frac{V_{CE}(p-p) I_C(p-p)}{8},\ P_o(ac) = \frac{I_C^2(p-p)}{8} R_C,\ P_o(ac) = \frac{V_{CE}^2(p-p)}{8R_C}$$

Efficiency

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

Class A Amplifier

Maximum Efficiency

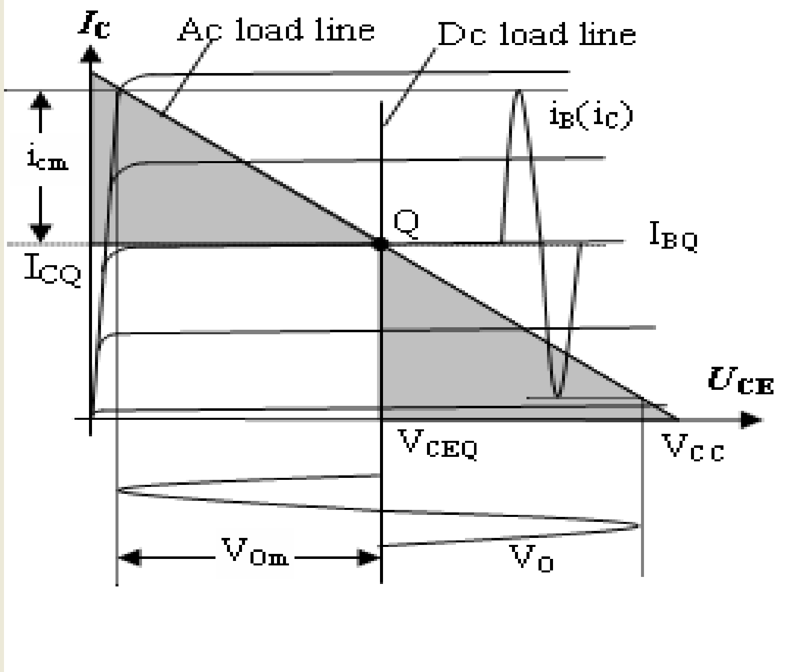
$$P_o(ac) = \frac{V_{CC}(V_{CC}/R_C)}{8} = \frac{V_{CC}^2}{8R_C}$$

(*p-p mode*: maximum p-p current is V_{CC}/R_C)

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

(dc bias current I_{CQ} equals to one-half maximum current value V_{CC}/R_C)

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



Example 7.1

Calculate the input power, output power and efficiency of Fig. 7.1 for an input of the base signal is 10mA peak.

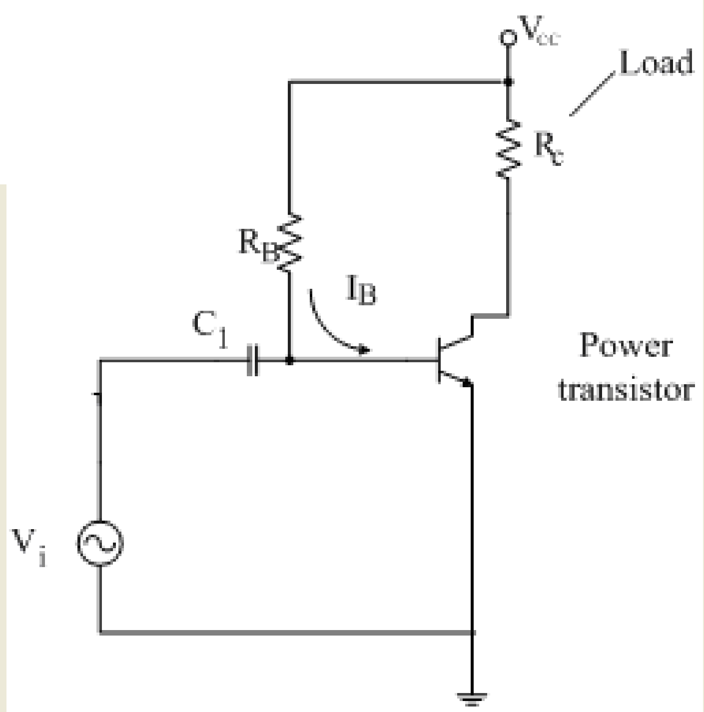
Solution:

First, we must determine the Q-point:

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

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

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



Example 7.1

When the input ac base current increases from its dc bias level, the collector current rises by

$$I_C(p) = \beta I_B(p) = 25(10mA) = 250mA(peak),$$

Then the ac power is

$$P_o(ac) = \frac{I_C^2(p)}{2} R_C = \frac{\left(250\times10^{-3}\right)^2}{2}(20\Omega) = 0.625W \quad ,$$ **(*p mode*)**

The dc power is

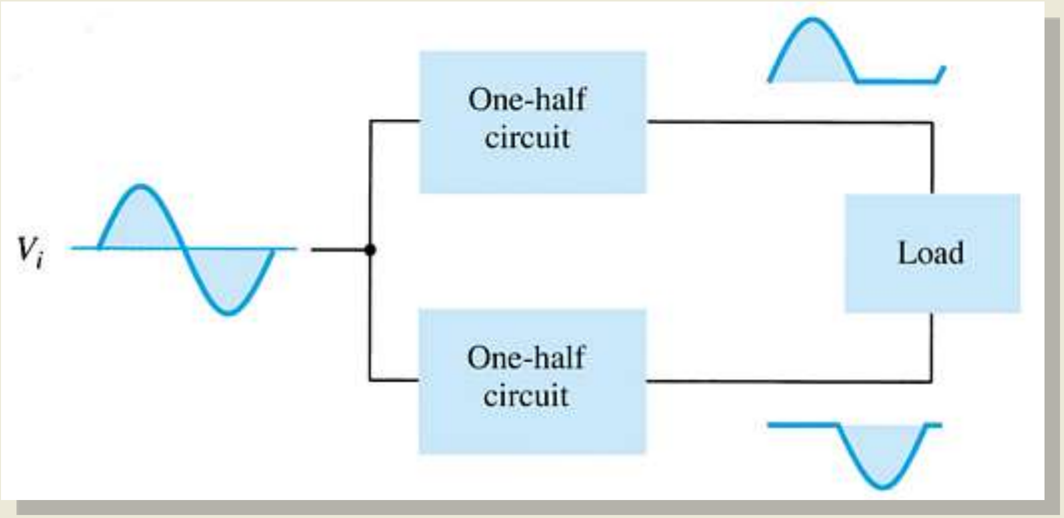
$$P_i(dc) = V_{CC} I_{CQ} = (20V)(0.48A) = 9.6W \quad ,$$

The amplifier's power efficiency is

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

7.3 Class B Amplifier

In class B, the dc bias leaves the transistor biased just off. The AC signal turns the transistor on. This is essentially *no bias*.



The transistor only conducts when it is turned on by one-half of the AC cycle.

In order to get a full AC cycle out of a class B amplifier, you need two transistors:

- ***One transistor provides the negative half of the AC cycle;***
- ***One transistor provides the positive half of the AC cycle;***
- ***Push-Pull Circuits.***

Class B Amplifier: Input Power

- I_{dc} is the *average or dc current* drawn from the power supplies.

- I_{dc} has the form of a full-wave rectified signal or half-wave rectified signal, can be expressed as

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} I(p)\sin t\,dt = \frac{2}{\pi} I(p)$$

- I(p) is the peak value of the output current waveform. The input power can be expressed as

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

Class B Amplifier: Output Power

- **The output power can be calculated as:**

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

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

For maximum output power, $V_L(p)=V_{cc}$

$$\eta\% = \frac{\pi}{4}\frac{V_{CC}}{V_{CC}} \times 100\% = 78.54\%$$

The maximum efficiency of Class B is 78.54%.

Example7.2

For a Class B amplifier providing a 10V peak signal to a 8Ω load and a supply of V_{CC}=20V, determine the input power, output power, and circuit efficiency.

Solution:

A 10V peak signal across a 8Ω load provides a peak load current of

$$I(p) = \frac{V_L(p)}{R_L} = \frac{10\text{V}}{8\Omega} = 1.25A$$

The dc value of the current drawn from the power supply is then

$$I_{dc} = \frac{2}{\pi} I(p) = \frac{2}{\pi} \times 1.25A = 0.796A$$

The input power delivered by the supply voltage is

$$P_i(dc) = V_{CC} I_{dc} = (20\text{V})(0.796\text{A}) = 15.92\text{W}$$

The output power delivered to the load is

$$P_o(ac) = \frac{V_L^2(p)}{2R_L} = \frac{(10V)^2}{2(8\Omega)} = 6.25W$$

For a resulting efficiency of

$$\eta\% = \frac{P_o(ac)}{P_i(dc)} \times 100\% = \frac{6.25W}{15.92W} \times 100\% = 39.3\%$$

Class B: Power Dissipated by Transistors

$$P_{2Q}(ac) = P_i(dc) - P_o(ac), P_Q(ac) = P_{2Q}(ac)/2$$

The maximum power dissipated by the transistors does not occur at the maximum power input or output condition.

$$\begin{aligned} P_{2Q}(ac) &= P_i(dc) - P_o(ac) \\ &= V_{CC}\frac{2}{\pi}I(p) - \frac{V_L^2(p)}{2R_L}, I(p) = \frac{V_L(p)}{R_L} \\ &= V_{CC}\frac{2}{\pi}\frac{V_L(p)}{R_L} - \frac{V_L^2(p)}{2R_L} \end{aligned}$$

To get the maximum value, we can take the derivative of above equation:

$$\frac{\partial P_{2Q}(ac)}{\partial V_L(p)} = \frac{2}{\pi}\frac{V_{CC}}{R_L} - \frac{V_L(p)}{R_L} = 0$$

Class B: Maximum Dissipated Power

The voltage for the maximum power dissipated by transistors will be:

$$V_L(p) = \frac{2}{\pi} V_{CC}$$

$$\begin{aligned} P_{2Q}(ac) &= P_i(dc) - P_o(ac) \\ &= V_{CC}\frac{2}{\pi} I(p) - \frac{V_L^2(p)}{2R_L}, \quad I(p) = \frac{V_L(p)}{R_L} \\ &= V_{CC}\frac{2}{\pi}\frac{V_L(p)}{R_L} - \frac{V_L^2(p)}{2R_L} \end{aligned}$$

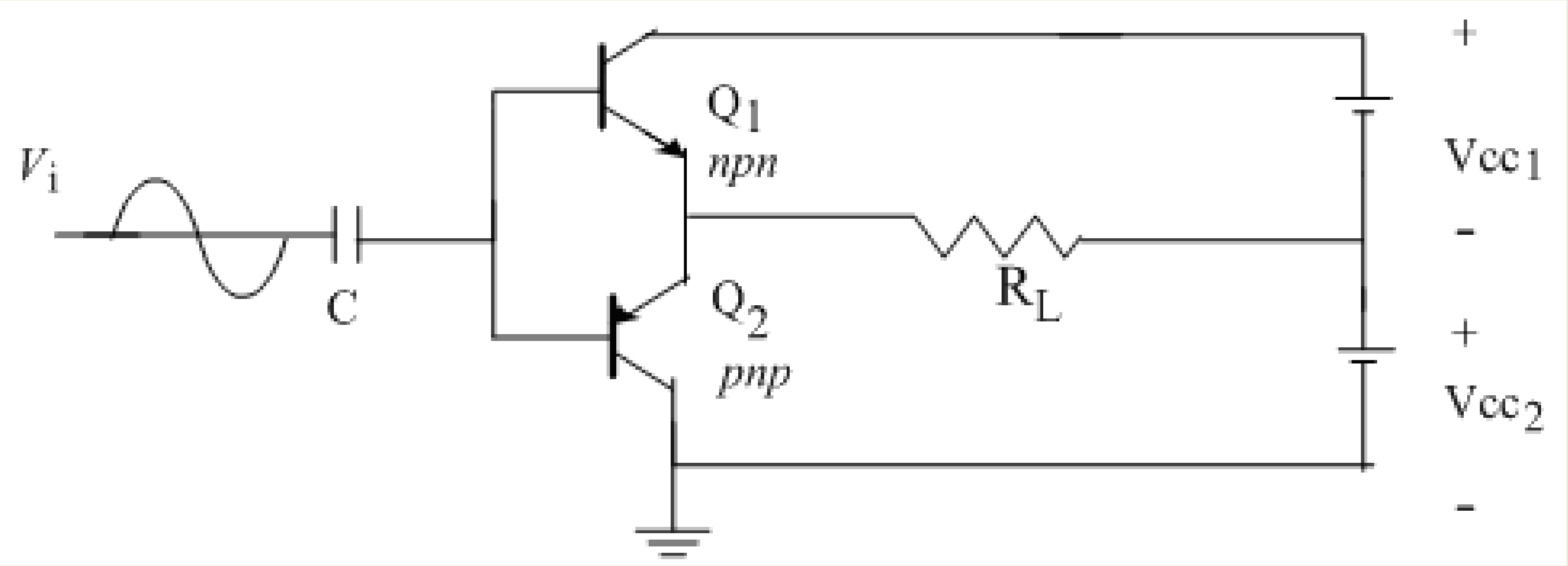
$$\max P_{2Q} = \frac{2V_{CC}^2}{\pi^2 R_L}$$

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

$$\eta\% = \frac{P_o(ac)}{P_i(dc)} \times 100\% = \frac{\pi}{4}\frac{V_L}{V_{CC}} \times 100\% = \frac{\pi}{4}\frac{2}{\pi} \times 100\% = 50\%$$

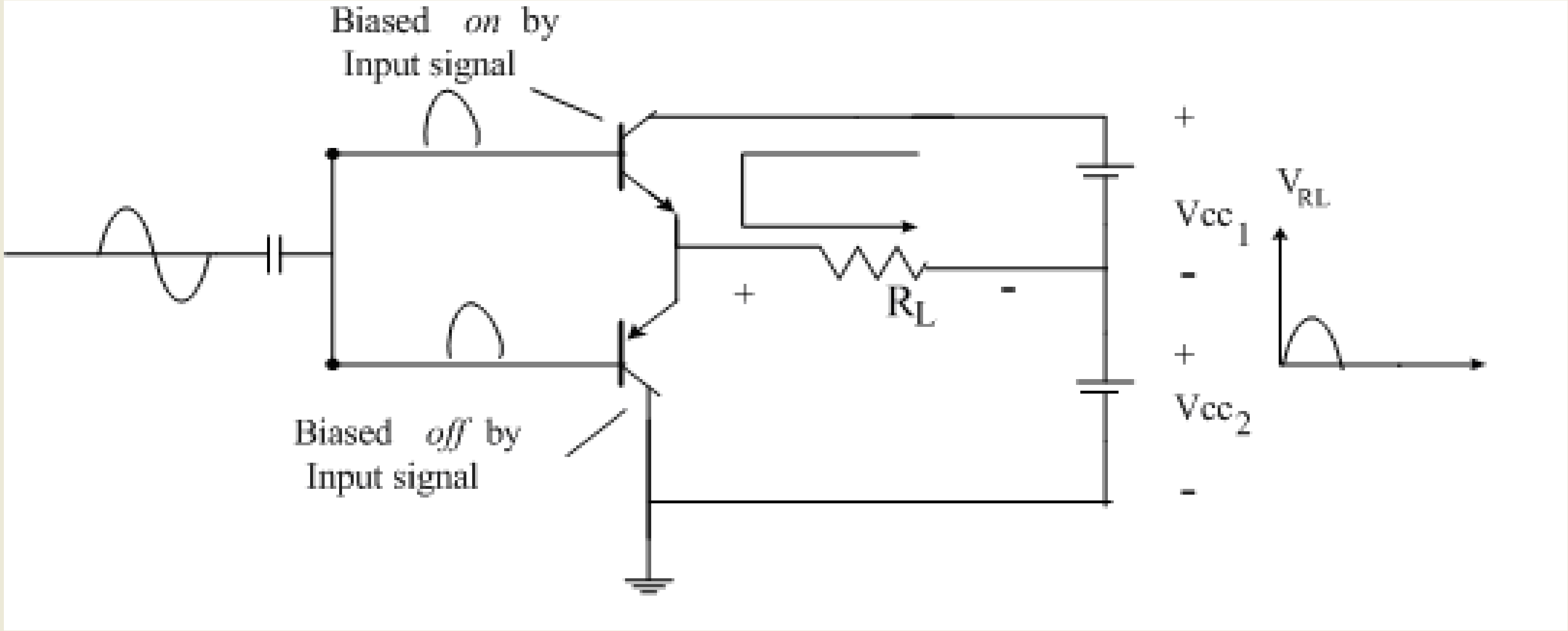
7.4 Push-Pull Class B Amplifier Circuit

Complementary BJT circuit (npn and pnp transistors)



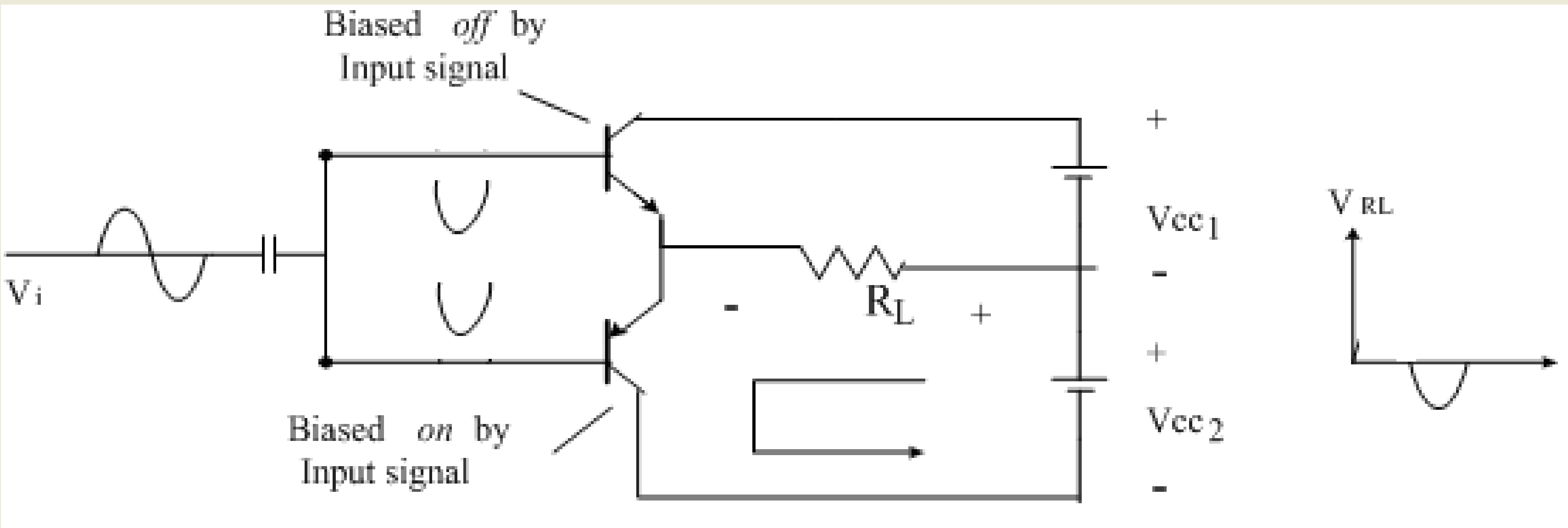
7.4 Push-Pull Class B Amplifier Circuit

The positive half cycle:



7.4 Push-Pull Class B Amplifier Circuit

The negative half cycle:

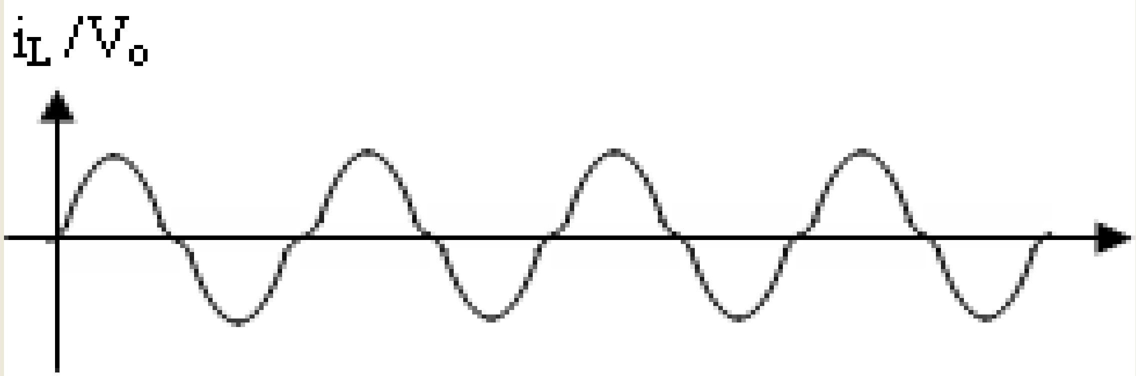


7.4 Push-Pull Class B Amplifier Circuit

There are two disadvantages:

- **One is the need for two separated voltage supplies.**
- **The other is the crossover distortion.**

Crossover Distortion: During the signal crossover from positive to negative (or vice versa), there is nonlinearity in the output.



Reason:

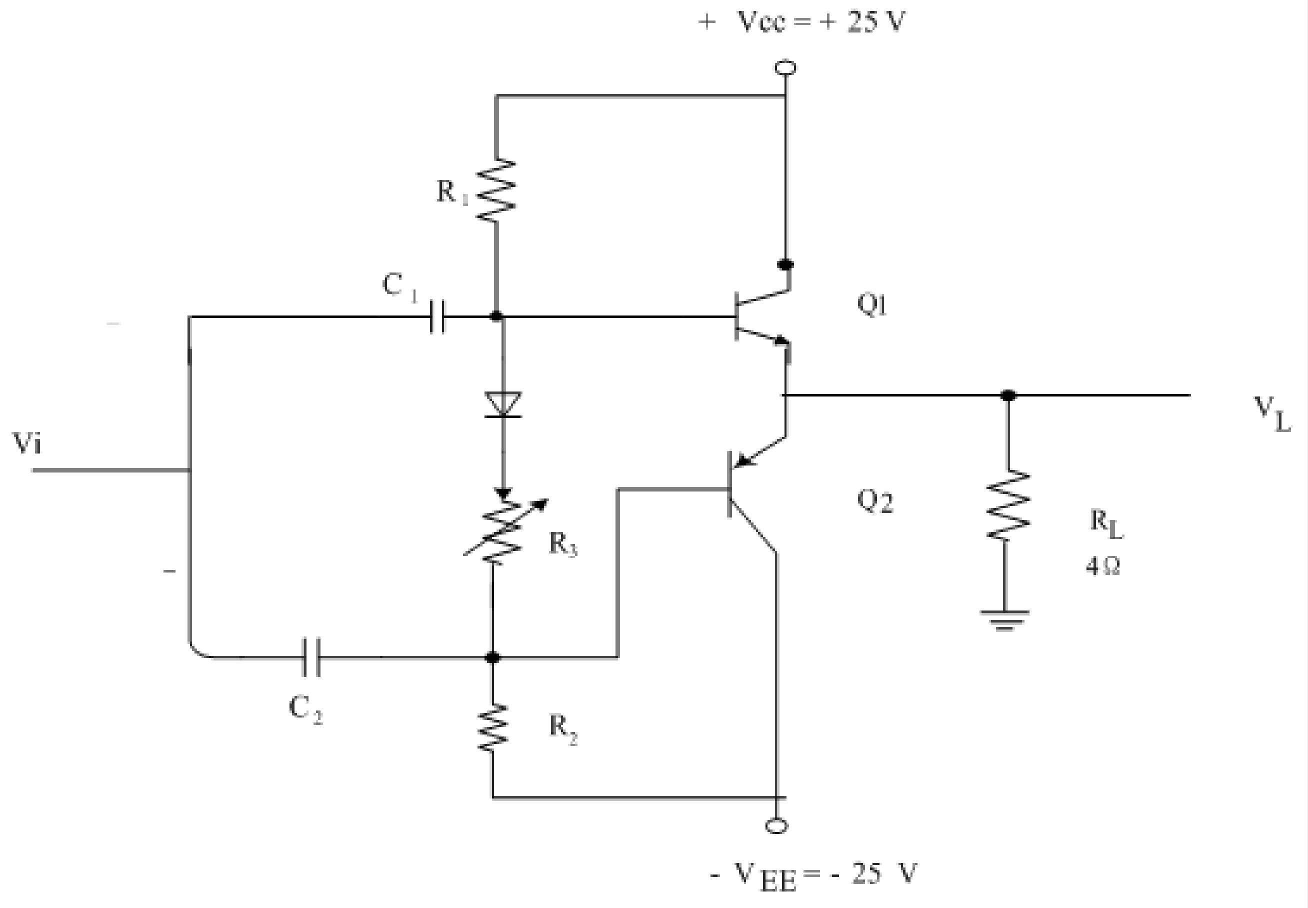
The amplifier does not provide exact switching of one transistor off and the other on at the zero voltage condition.

Solution:

Biasing the transistors in class AB improves this operation by biasing both transistors to be on for more than half a cycle.

Example 7.4

For the Fig.7.6, calculate the input power, output power, power dissipated by each output transistor and circuit efficiency for an input of 12V rms.



Example 7.4

Solution:

Ideally, the power amplifier has a voltage gain of unity, the peak input and output voltage is

$$V_L(p) = V_i(p) = \sqrt{2}V_i = \sqrt{2}(12V) \approx 17V$$

The output across the load is

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

The peak load current is

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

Example 7.4

The dc current from the supplies is

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

The power supplies to the circuit is

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

The power dissipated by each output transistor is

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

The circuit efficiency is

$$\eta\% = \frac{P_o(ac)}{P_i(dc)} \times 100\% = \frac{36.125W}{67.75W} \times 100\% = 53.3\%$$

7.5 Summary

1. Amplifier classes:

   Class A : the output signal varies for a full 360° of the cycle.

   Class B: the output varying over one-half the input signal cycle or 180° of signal.

   Class AB: the output signal swing occurs between 180° and 360°

   Class C: the output conducts for less than 180°

   Class D: has operation using pulse/digital signal

2. Amplifier efficiency:

   Class A: maximum efficiency of 25%(without transformer) and 50%(transformer)

   Class B: maximum efficiency of 78.5%

3. Power considerations:

   Input power: provided by the dc power supply

   Output power: delivered to the load

   Dissipated power: the difference between input and output powers.