Introduction To Amplifiers

ET 210 Discrete Semiconductors

Introduction

- The amplifier is probably the most common circuit used in electronics
- Most systems have many amplifiers not just one and these circuits are implemented in many ways
- However all amplifiers share some common characteristics

Amplifier Properties

- Amplifiers have three basic properties
  - gain
  - input impedance
  - output impedance

Gain

- Gain is the multiplier between the amplifier input and output
- There are three types of gain
  - voltage gain (A_V)
  - current gain(A_I)
  - power gain(A_P)
- All amplifiers have all three types of gain - but usually only one is "of interest"

Gain

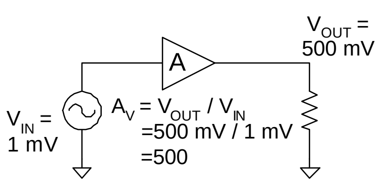
- Gain is defined as the ratio of the output value in relation to the input value

$$A_V = \frac{V_{OUT}}{V_{IN}} \qquad A_I = \frac{I_{OUT}}{I_{IN}} \qquad A_P = \frac{P_{OUT}}{P_{IN}}$$

Voltage Gain Current Gain Power Gain

Amplifier Gain

- An Example



Amplifier Gain

- The gain equation can be manipulated depending on what we need to solve for
  - Voltage gain is used but the same manipulations can be used for current and power

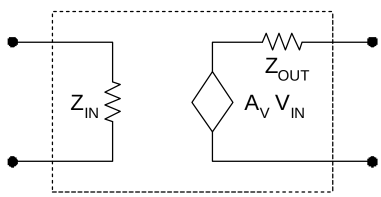
$$A_V = \frac{V_{OUT}}{V_{IN}}$$

$$\Rightarrow V_{OUT} = A_V V_{IN}$$

$$\Rightarrow V_{IN} = \frac{V_{OUT}}{A_V}$$

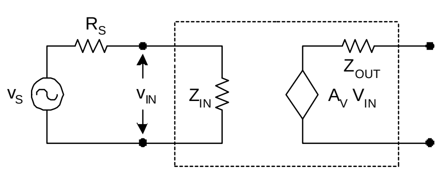
The General Amplifier Model

- Schematic



The General Amplifier Model

- Input Voltage



$$v_{IN} = \frac{Z_{IN}}{R_S + Z_{IN}} v_S$$

The General Amplifier Model

- Input Voltage – An Example

$$A_V = 10, v_S = 100mV, R_S = 500\Omega, Z_{IN} = 1k\Omega$$

$$ideally\ \ v_{OUT} = A_V v_S = 10 \times 100mV = 1V$$

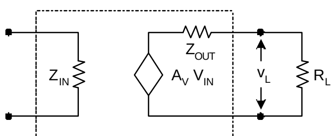
$$but\ \ v_{IN} = \frac{Z_{IN}}{R_S + Z_{IN}} v_S$$

$$v_{OUT} = A_V v_{IN} = A_V \left(\frac{Z_{IN}}{R_S + Z_{IN}} \right) v_S$$

$$= 10 \left(\frac{1k\Omega}{500\Omega + 1k\Omega} \right) 100mV = 667mV$$

The General Amplifier Model

- Effect of Output Impedance



$$v_{OUT} = A_V v_{in}$$

$$v_L = \frac{R_L}{Z_{OUT} + R_L} v_{OUT}$$

The General Amplifier Model

- The Effect of Output Impedance – An Example

$$v_{OUT} = 1V,\ \ Z_{OUT} = 100\Omega,\ R_L = 500\Omega$$

$$\text{ideally}\ \ v_L = v_{OUT} = 1V$$

$$\text{but}\quad v_L = \frac{R_L}{Z_{OUT} + R_L} v_{OUT}$$

$$= \frac{500\Omega}{100\Omega + 500\Omega} 1V = 833mV$$

The General Amplifier Model

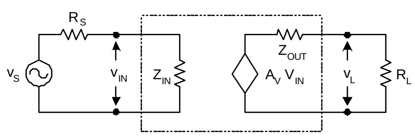
- Effective Voltage Gain
  - When we combine the effects of the source resistance, amplifier input and output impedance and load resistance the actual gain will be considerably less than the ideal gain (A_V)
  - This reduced gain is called the *effective gain* ($A_{V(eff)}$)

$$A_{V(eff)} = \frac{v_L}{v_S}$$

The General Amplifier Model

- Effective Gain – An Example

$$v_S = 10mV, R_S = 150\Omega.$$
$$A_V = 100, Z_{IN} = 1k\Omega, Z_{OUT} = 200\Omega$$
$$R_L = 1.5k\Omega$$
$$\text{quick and dirty - } v_L = A_V v_S = 100 \times 10mV = 1V$$



The General Amplifier Model

- Effective Gain – An Example

$$v_S = 10mV, R_S = 150\Omega.$$
$$A_V = 100, Z_{IN} = 1k\Omega, Z_{OUT} = 200\Omega$$
$$R_L = 1.5k\Omega$$
$$v_{IN} = \frac{Z_{IN}}{R_S + Z_{IN}} v_S = \frac{1k\Omega}{150\Omega + 1k\Omega} 10mV = 8.70mV$$
$$v_{OUT} = A_V v_{IN} = 100 \times 8.70mV = 870mV$$
$$v_L = \frac{R_L}{Z_{OUT} + R_L} v_{OUT} = \frac{1.5k\Omega}{200\Omega + 1.5k\Omega} 870mV = 768mV$$
$$A_{V(eff)} = \frac{v_L}{v_S} = \frac{768mV}{10mV} = 76.8$$

The Ideal Voltage Amplifier

- Characteristics
  - The ideal voltage amplifier has the characteristics:
    - Infinite Gain
    - Infinite input impedance ($v_{IN} = v_S$)
    - Zero output impedance ($v_L = v_{OUT}$)
  - While no amplifier is truly ideal - we will find the op amp comes close enough to "effectively" have these characteristics

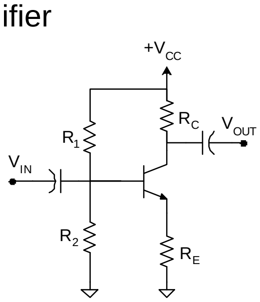
BJT Amplifier Configurations

- Amplifier Properties

Property	Low	Midrange	High
Gain	< 100	100-1000	➢1000
Impedance	< 1k	1k – 10k	> 10k

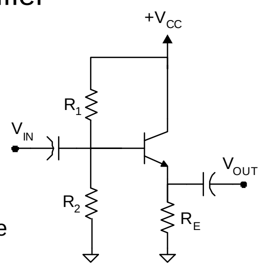
The Common-Emitter (CE) Amplifier

- The most widely used of all BJT amplifiers
  - Midrange voltage and current gain
  - High power gain
  - Midrange input and output impedance



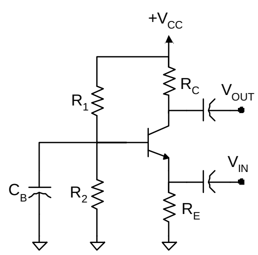
The Common-Collector (CC) Amplifier

- Used for its current gain and impedance characteristics
  - – Midrange current gain
  - – Low voltage gain
  - – High input impedance
  - – Low output impedance



The Common-Base (CB) Amplifier

- Rarely used except in high frequency circuits
  - – Midrange voltage gain
  - – Low current gain
  - – Low input impedance
  - – High output impedance



Amplifier Characteristics

- Comparison of CE, CC & CB Characteristics

	A_V	A_I	A_P	Z_{IN}	Z_{OUT}
CE	Midrange	Midrange	High	Midrange	Midrange
CC	<1	Midrange	Midrange	High	Low
CB	Midrange	<1	Midrange	Low	High

BJT Amplifiers

- Determining The Configuration
  - To determine what configuration amplifier one terminal of the transistor will not have in input or output - this is the “common” terminal
    - Common Emitter (CE)
    - Common Collector (CC)
    - Common Base (CB)

Amplifier Classifications

- Class A amplifiers
  - a single transistor that conducts during the entire period of the input
- Class B amplifier
  - two transistors each of which conduct during one-half of the input period
- Class C amplifier
  - a single transistor that conducts for less than one-half the input period

Amplifier Efficiency

- Transistor amplifiers increase the power of the ac input signal by drawing power from the dc supply
- An ideal amplifier would have an efficiency of 100%
  - real world amplifier efficiencies are always less than 100 %

Amplifier Efficiency

- When calculating amplifier efficiency we usually disregard the input signal power
- Efficiency is represented by the Greek letter ?

$$h = \frac{P_L}{P_{dc}} \times 100$$

General Amplifier Characteristics

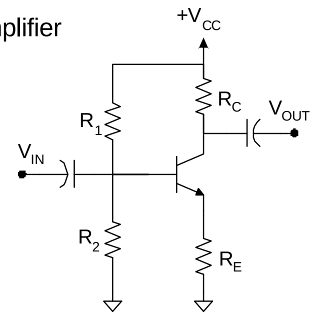
- Distortion
  - An ideal amplifier produces an exact replica of the input signal
  - Distortion is any deviation of the output signal from the exact wave shape of the input signal

General Amplifier Characteristics

- **Class A amplifiers** have the following characteristics
  - an active device that conducts during the entire input period
  - an output that contains very little distortion
  - a maximum theoretical efficiency of 25%
- Generally used as “small signal” amplifiers

General Amplifier Characteristics

- Class A Amplifier

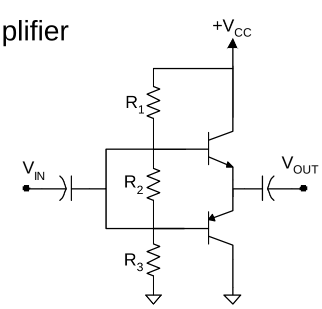


General Amplifier Characteristics

- **Class B amplifiers** have the following characteristics
  - two transistors biased at cutoff - each conducts during one-half the input signal period
  - an output that contains little distortion
  - a maximum theoretical efficiency of 78.5%
- Primarily used as a power amplifier

General Amplifier Characteristics

- Class B Amplifier

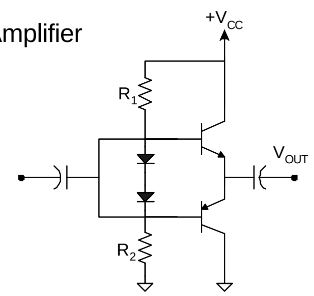


General Amplifier Characteristics

- The **class AB amplifier** is a variation of the class B amplifier that uses diodes to bias the transistors so they conduct over slightly more than one-half the input period
- Class AB amplifiers are used to avoid *crossover distortion* which is often a problem in class B amplifiers

General Amplifier Characteristics

- Class AB Amplifier

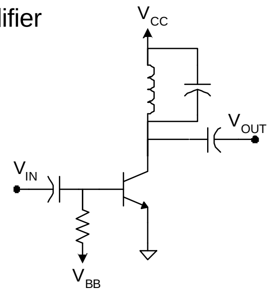


General Amplifier Characteristics

- Class C amplifiers have the following characteristics
  - a single transistor that conducts for less than one-half the input period
  - an output that probably has some distortion
  - a maximum theoretical efficiency of 99%
- A *tuned amplifier* that finds limited use due to its distortion characteristics

General Amplifier Characteristics

- Class C Amplifier



Decibels

- Gains - power, voltage or current are often given in decibels (dB)
- The decibel is a power ratio measurement used to simplify the recording of very large (or very small) numbers

Decibels

- Definition
  - A decibel (dB) is 10 times the common logarithm of the ratio of output power divided by the input power or:

$$A_{P(dB)} = 10\log A_P = 10\log \frac{P_{OUT}}{P_{IN}}$$

Decibels

- Definition
  - To "reverse" the process or find the straight power gain from the power gain in dB we simply:

$$A_P = \log^{-1}\frac{A_{P(dB)}}{10} = 10^{\frac{A_{P(dB)}}{10}}$$

Decibels

- An Example

$$A_P = 2500$$
$$A_{P(dB)} = 10\log A_P = 10\log(2500) = 34dB$$
convert back to straight power gain
$$A_P = \log^{-1}\left(\frac{A_{P(dB)}}{10}\right) = 10^{\left(\frac{A_{P(dB)}}{10}\right)} = 10^{\left(\frac{34}{10}\right)} = 2512$$

Decibels

Gain	dB value	Gain	dB value
2	3	½	-3
4	6	¼	-6
16	12	1/16	-12
100	20	1/100	-20
1,000	30	1/1,000	-30
10,000	40	1/10,000	-40

The dBm Reference

- Definition
  - Power values are sometimes expressed as a ratio to a power level – in this case 1 mW

$$P_{dBm} = 10\log\frac{P}{1mW}$$

The dBm Reference

- Definition
  - Of course we may need to transform a power in dBm back to watts

$$P = \log^{-1}\left(\frac{P_{dBm}}{10}\right)mW = 10^{\left(\frac{P_{dBm}}{10}\right)}mW$$

dB Voltage Gain

- Definition
  - Often we are interested in voltage gain instead of power gain – but we must remember dB is a power ratio

$$A_{V(dB)} = 20\log(A_V) = 20\log\frac{V_{OUT}}{V_{IN}}$$

dB Voltage Gain

- Definition
  - Of course there will be times we have the voltage gain in dB and want straight voltage gain

$$A_V = \log^{-1}\left(\frac{A_{V(dB)}}{20}\right)$$

The dBV Reference

- Definition
  - You may also run into dBV or decibel referenced to one volt
  - This is calculated exactly the same as dBm except you must remember the extra factor of two required working with dB and volts

$$V_{dBV} = 20\log\frac{V_V}{1V}$$

$$V_V = \log^{-1}\frac{V_{dBV}}{20} = 10^{\frac{V_{dBV}}{20}}$$

Working With dB

- Changes in dB Gain
  - If the voltage gain of an amplifier (or system) changes by X dB then the power gain has also changed by the same X dB
    this assumes the load the amplifier is driving doesn't change
  - note this does not mean the power gain will be the same value as the voltage gain - just that if they change they will change by the same amount

Working With dB

- Review
  - dB are logarithmic forms of the power or voltage gain
  - Power gain in db is found by - 10 log A_P
  - Voltage gain in db is found by - 20 log A_V
  - Never multiply dB values - see 1st bullet
  - Do not mix values in dB and normal format - use only one or the other