Course Overview

We will cover the following topics.

AMPLIFIERS : Basic concepts concerning signals; circuit models; frequency response; characteristics of simple amplifiers.

OPERATIONAL AMPLIFIERS: Terminal characteristics of the ideal op amp; op amp analysis and useful configurations

DIODES : Diode properties and modeling; non-linear circuits and power supplies.

BIPOLAR JUNCTION TRANSISTOR: Properties and operation of the BJT; dc and ac modeling; BJT amplifiers.

We will cover in less detail the following topics.

FIELD EFFECT TRANSISTOR : Operation and modeling

DIGITAL ELECTRONICS: Basic concepts; inverters

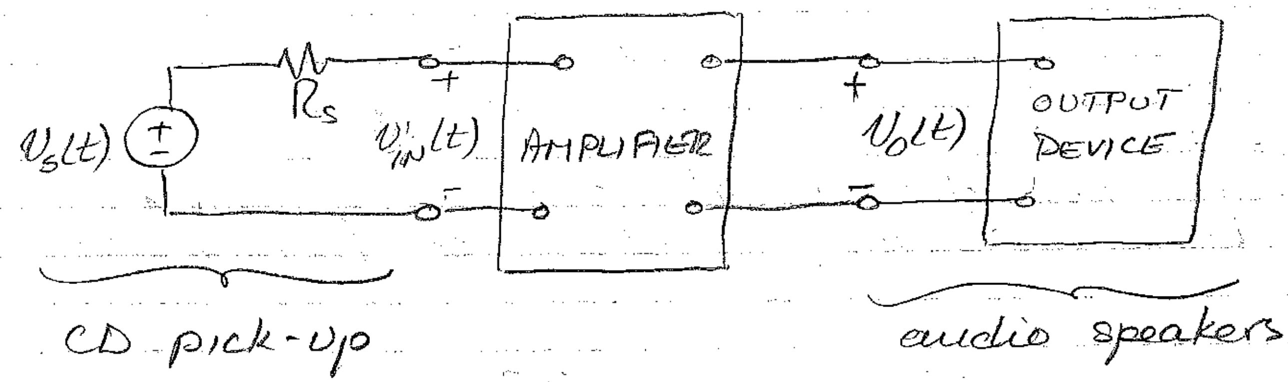
SIGNALS

A SIGNAL is a time-dependent quantity that can be used to convey information.

Typical signals for electronics: time-dependent voltage $v(t)$ or current $i(t)$.

Representation: We can use a Thevenin or Norton equivalent to represent a signal. The actual signal source can be of many types, usually some kind of TRANSDUCER:

- CD optical pick-up (audio CD)
- transmitted EM wave (radio)
- electrocardiogram transducer (ECG)



FREQUENCY SPECTRUM and FOURIER ANALYSIS

FOURIER THEOREM: A signal that is a periodic function of time can be decomposed into a (generally) infinite number of sinusoids of certain frequencies and amplitudes.

Example: Square wave $V_{SQ}(t)$ can be represented as ...

$$V_{SQ}(t) = \frac{4V}{\pi}\left[\sin\omega_0 t + \frac{1}{3}\sin 3\omega_0 t + \frac{1}{5}\sin 5\omega_0 t + \dots\right]$$

$$V \equiv \text{amplitude} \qquad \omega_0 = \frac{2\pi}{T}$$

SEDRA FIGS 1.5, 1.6

Non-periodic signals can be represented by a continuous spectrum of frequencies:

SEDRA FIG 1-7

ANALOG AND DIGITAL SIGNALS

ANALOG: A signal that is directly analogous to the physical quantity it represents.

Analog signals are CONTINUOUS -

- sound (continuous variation in air pressure)
- seismograph output

DIGITAL: A signal that is sampled (DISCRETIZED) and DIGITIZED by representing the discrete components using a number with finite precision

SEDRA FIGS 1.8, 1.9

BINARY REPRESENTATION uses a series of ONE's (1) and ZERO's (0) to represent the value of a discrete signal. For example:

$$v(t_0) = 7 \; |V| \Rightarrow 0111$$

$$v(t_0) = 11 \; |V| \Rightarrow 1011$$

In DIGITAL ELECTRONICS, we use analog devices, particularly FET and BJT circuits, to generate digital representations of signals and information.

AMPLIFIERS

We can arrange for a...

VOLTAGE AMPLIFIER : $v_O = A_V v_I$

CURRENT AMPLIFIER : $i_O = A_i i_I$

POWER AMPLIFIER : $P_O = A_P P_I$

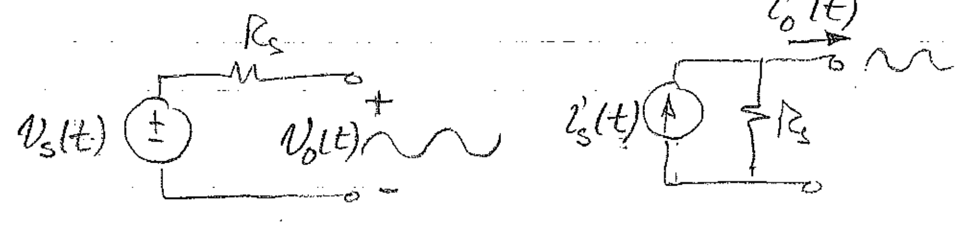
where A_V, A_i, A_P is the GAIN (which is not necessarily greater than 1).

Another important signal processing function is FILTERING which involves extraction of information from NOISE, or more generally, recovering the useful part of a signal.

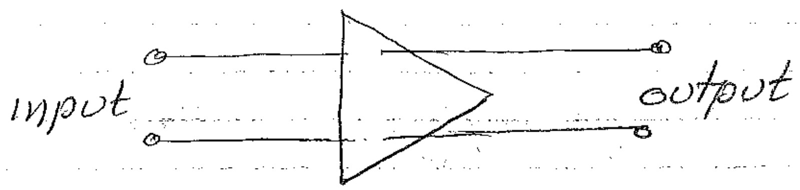
COURSE PERSPECTIVE We will assume that signals taken, for example, from some physical system, exist as electrical signals. This will have been done by a TRANSDUCER.

We will represent signal sources as either Thevenin or Norton equivalents. Frequently, we will assume that such sources produce sine waves or, from a Fourier Series point of view, a sum of sine waves.

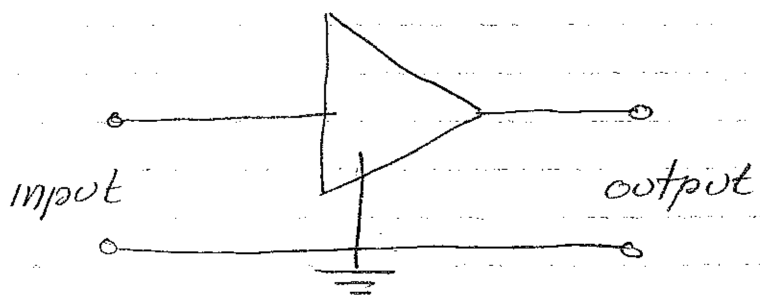
SOURCES:



General Amplifier Circuit Symbol

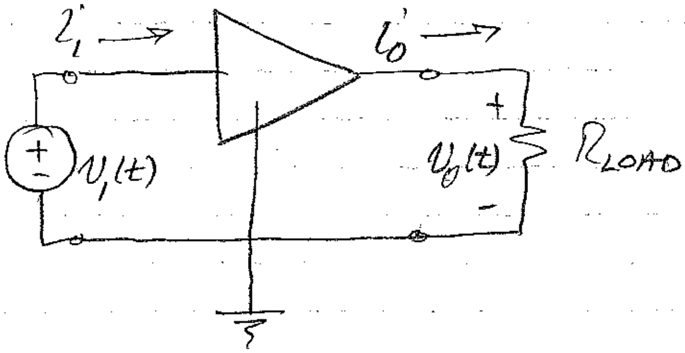


- or -



common ground

VOLTAGE GAIN



$$v_o(t) = A_v \cdot v_i(t)$$

$$\text{GAIN: } A_v = \frac{v_o}{v_i}$$

A plot of the output voltage as a function of the input voltage is called the TRANSFER CHARACTERISTIC.

If the v_O vs. v_I plot is a straight line, the amplifier is LINEAR. The slope of the line is the GAIN.

SEDRA FIG 1.12

POWER GAIN

$$A_p \equiv \frac{\text{load power}}{\text{input power}} = \frac{v_O i_O}{v_I i_I}$$

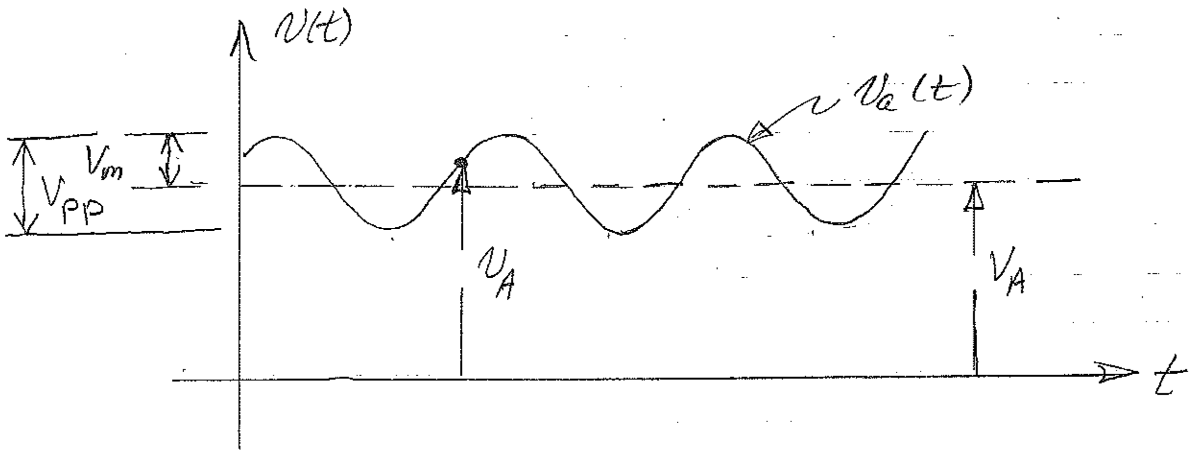
CURRENT GAIN

$$A_i = \frac{i_O}{i_I}$$

Note that $A_p = A_v \cdot A_i$

NOTATION

In general, a signal will have an ac component and a dc component. Assuming the ac component is a sinusoid, we have:



AC COMPONENT: $v_a(t) = V_m \sin(\omega t + \varphi)$

$V_m \equiv$ amplitude $\quad V_{pp} \equiv$ peak-peak amplitude

rms amplitude: V_a

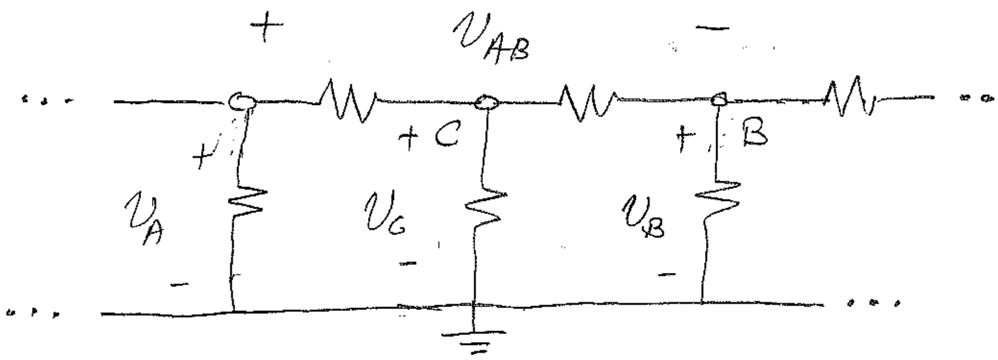
phasor : $\overline{V_a}$

DC COMPONENT: V_A

TOTAL INSTANTANEOUS VALUE: $v_A = v_a + V_A$

SEDRA/SMITH FIG. 6.6 illustrates the same concepts with current as the signal source.

Some other notation follows:



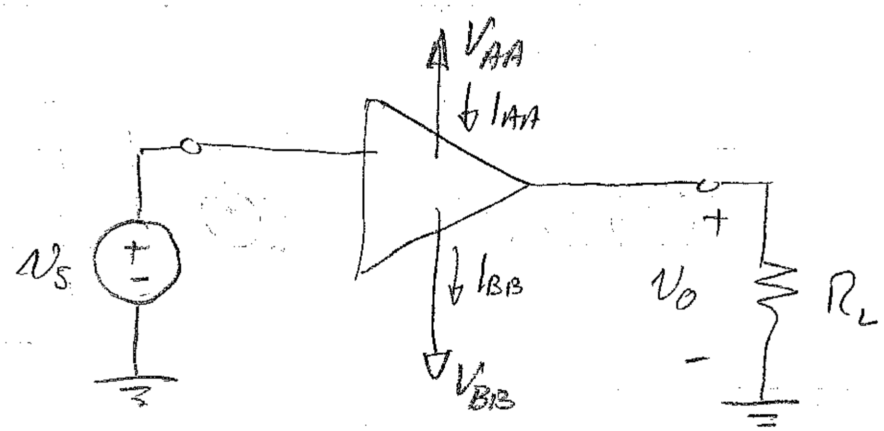
$$v_{AB} \equiv v_A - v_B$$

$v_A, v_B, v_C \equiv$ voltage relative to ground

POWER SUPPLY: V_{CC}

EXAMPLE

Let's look at a simple example. In addition to reviewing some simple calculations, this problem illustrates the kind of circuit diagrams we will be drawing.



CIRCUIT DIAGRAM

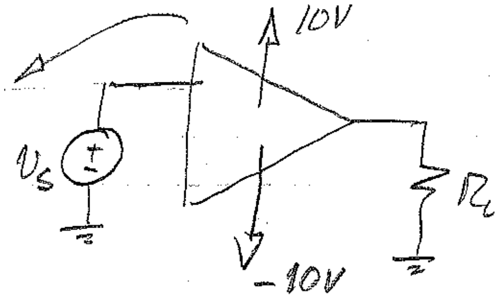
V_{AA} and V_{BB} are power supplies (you can't operate an amplifier without power!). I_{AA} and I_{BB} are currents flowing between the power supplies and the amplifier.

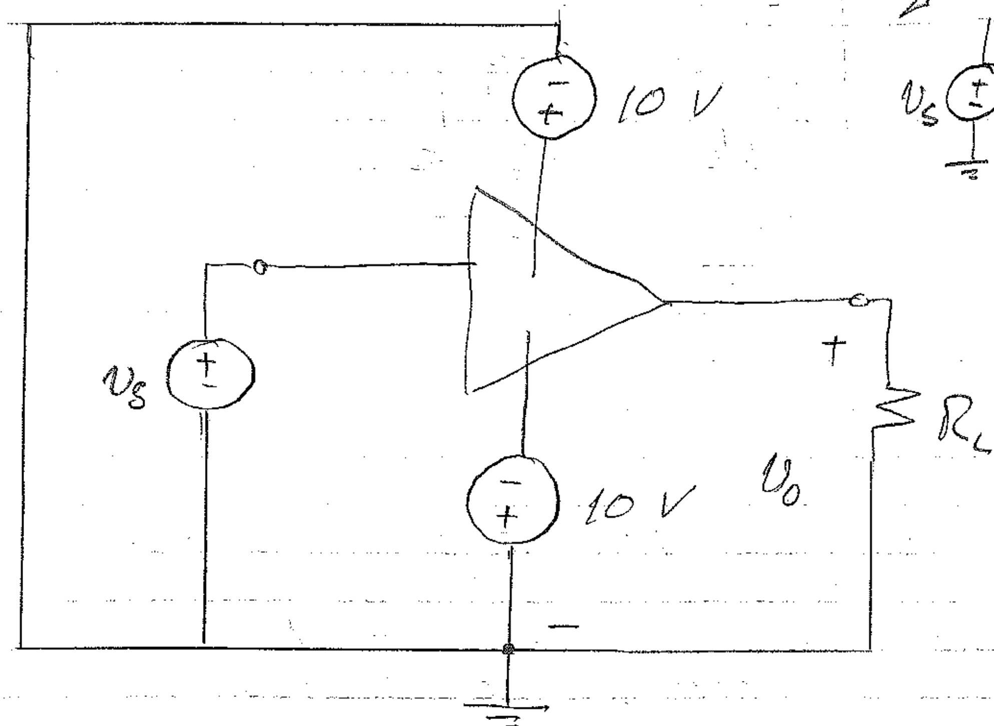
NOTE: Unless we are interested in a power analysis (which we do below), we often will not draw the power supplies on the diagram. But they are still understood to be there.

The source is v_S (R_s is assumed to be negligible). The load is R_L.

To illustrate more explicitly what is going on here, we re-draw the circuit below using more familiar notation.

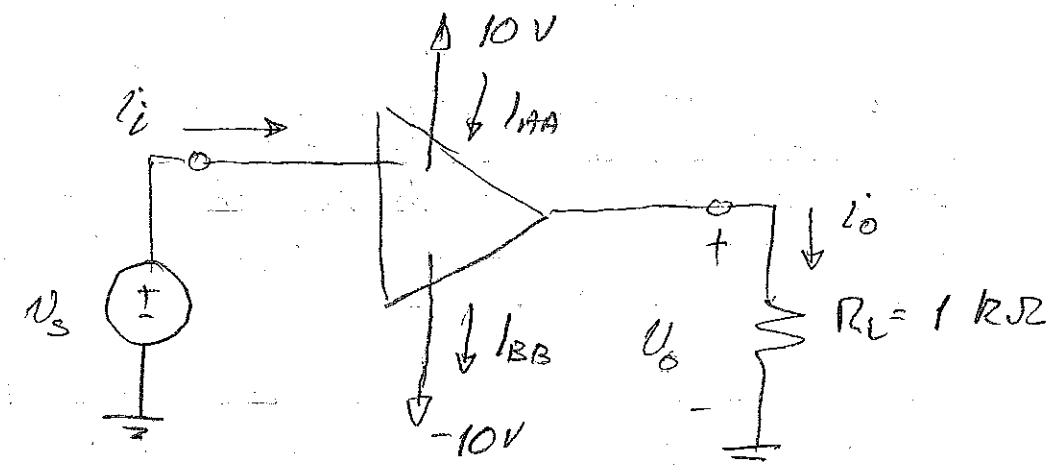
Suppose $V_{AA} = 10$ V, $V_{BB} = -10$ V. Then the circuit above is ...





Surely the notation in the previous drawing is more convenient.

Some simple calculations:



GIVEN: $I_{AA} = 1\ mA \quad I_{BB} = 0.5\ mA$

$v_s = 1\ \sin(\omega t)\ V$

$v_o = 5\ \sin(\omega t)\ V$

$i_i = 0.1\ \sin(\omega t)\ mA$

FIND: Voltage, current, power gain.

Note that only ac quantities have been specified here for v_s, v_o, i_i.

Voltage gain: $A_V \equiv \dfrac{v_o}{v_s} = \dfrac{5}{1} = 5\ \dfrac{V}{V}$

Current gain: $A_i \equiv \dfrac{i_o}{i_i}$

$i_o = v_o/R_L = 5\ \sin(\omega t)\ mA$

$$\Rightarrow \quad A_i = \frac{5\times10^{-3}}{0.1\times10^{-3}} = 50\ \frac{A}{A}$$

Power: Since we are dealing with ac quantities, we calculate power using rms values. Also, to be consistent, we will calculate power ABSORBED in each case here.

$$P_o = V_o I_o \qquad (V_o, I_o \text{ are rms values})$$

$$V_o = 5/\sqrt{2}\ \text{V (rms)}$$

$$I_o = 5/\sqrt{2}\ \text{mA (rms)}$$

$$\Rightarrow \quad P_o = 12.5\ \text{mW}$$

$$P_i = V_i I_i$$

$$V_i = 1/\sqrt{2}\ \text{V (rms)}$$

$$I_i = 0.1/\sqrt{2}\ \text{mA (rms)}$$

$$\Rightarrow \quad P_i = 0.05\ \text{mW}$$

$$\therefore \quad A_p \equiv \frac{P_o}{P_i} = 250\ \frac{W}{W}$$

Note that in taking the ratio in A_p, our factors of $\sqrt{2}$ divide out. However, they were necessary for the calculation of individual values.

POWER ANALYSIS

We can look at power into and out of the amplifier. Lets calculate power delivered by and absorbed by the amplifier.

Power supplies: The amp is absorbing power from both supplies:

$$P_{\text{abs from supplies}} \equiv P_{dc} = V_{AA} I_{AA} - V_{BB} I_{BB}$$

$$P_{dc} = 10(1\times10^{-3}) - (-10)(0.5\times10^{-3})$$

$$= 15 \text{ mW}$$

Source: The amp is absorbing power from the source. We calculated this above.

$$P_{\text{abs from source}} \equiv P_S = 0.05 \text{ mW}$$

Load: The amp is delivering power to the load. We calculated this above.

$$P_{\text{del to load}} \equiv P_L = 12.5 \text{ mW}$$

Note that power absorbed and delivered are not equal, This is because the amp is also dissipating power, that is, its getting hot and delivering heat energy to the surroundings. In general, we have...

$$P_L + P_{diss} = P_{dc} + P_s$$

$$\therefore \quad P_{diss} = P_{dc} + P_s - P_L$$

$$= 15 + 0.05 - 12.5$$

$$= 2.55 \text{ mW}$$

P_{diss} (dissipated power) is power delivered to circuit elements inside the amplifier.

Finally, we can define a POWER EFFICIENCY:

$$\eta \equiv P_L / P_{dc} = 83.3\%$$

So this is the power delivered to the load as a fraction of the power needed to run the amp.

DECIBELS & LOG SCALES

Gain is usually expressed on a log scale. Specifically, we define the DECIBEL:

$$A_v(dB) \equiv 20 \log_{10}(A_v) \quad dB$$

$$A_i(dB) \equiv 20 \log_{10}(A_i) \quad dB$$

$$A_p(dB) = 10 \log_{10}(A_p) \quad dB$$

NOTE:

if $A_v = A_i$ then

$$A_p(dB) = 10 \log(A_v^2) = 20 \log A_v$$

so then $A_v(dB) = A_i(dB) = A_p(dB)$

WHY LOGS?

We are frequently concerned with ratios rather than additions. For example we may want to know what happens when a signal frequency is doubled.

A fixed increment on a linear scale represents addition, e.g. 1cm. represents 20 ms.

A fixed increment on a log scale represents multiplication, e.g. 1cm. represents ×2 (a factor of 2).

From previous example:

$A_v = 5 \; |V/V|$

$A_v(dB) = 20 \log 5 = 14 \; dB$

$A_i = 50 \; |A/A|$

$A_i(dB) = 20 \log 50 = 34 \; dB$

$A_p = P_L / P_1 = \frac{12.5}{0.05} = 250 \; |W/W|$

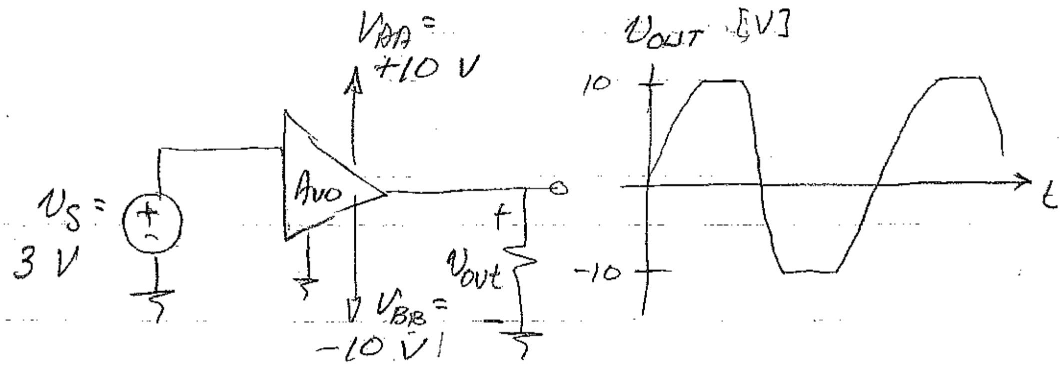
$A_p(dB) = 10 \log 250 = 24 \; dB$

AMPLIFIER SATURATION

The amplifier output voltage cannot exceed the power supply values. Therefore, if

$$v_{OUT} = A_v v_{IN} > V_{AA} \text{ or } < -V_{BB}$$

where V_{AA} and $-V_{BB}$ are the power supply limits, the output will be limited to V_{AA} or $-V_{BB}$ and "clipping" or "saturation" occurs.



Suppose $A_{vo} = 5 \Rightarrow v_o = \pm 15$ V! This will be clipped to ± 10 V.

SEDRA FIG 1.14

BIASING

In general, a transfer characteristic will have a region that is non-linear as well as a region that is linear.

If we try to amplify a signal

$$v_i(t) = V_m \cos(\omega t)$$

our output will not be $v_o = A_v v_i$ as can be seen from FIG 1.14.

However, if we add a dc component V_I to the signal, we will "move" the signal to a linear region of the transfer characteristic. This procedure is called BIASING.

The output is now

$$v_O = V_O + v_o(t)$$

We can then identify an "ac" or "signal" gain

$$A_v = \frac{v_o}{v_i}$$

v_o = ac component of output

v_i = ac component of input