ECE 2100   Lecture notes   Fri, 1/10/03

A. Stolp
1/9/03

Stuff

HW # 2 due F, 1/17 by 5:00 pm in a yet-to-be-determined locker

Ch 1: 11,13, 14, 18, 19, Exercises: Ex1.4, Ex1.15   **Answers:** 13) 24mw   14) 0.092V   18 last part) 0.5W
19) 0.826, 0.0098, A, 75.13

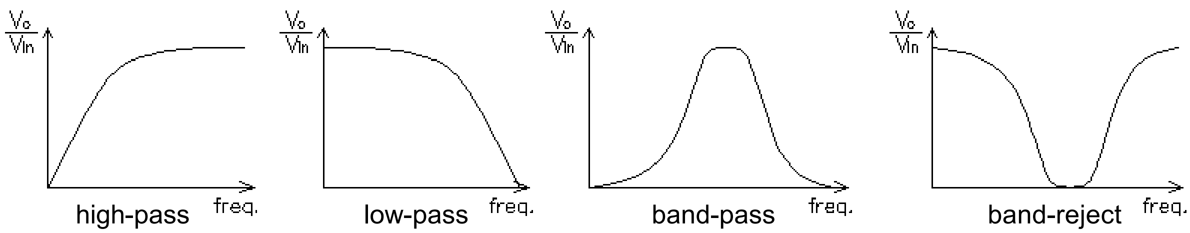
If you're re-taking this class, come talk to me.

Graduate students who are here to meet their proficiency requirement (Proficiency Students) MUST talk to me, please come up after class.

Signal Processing

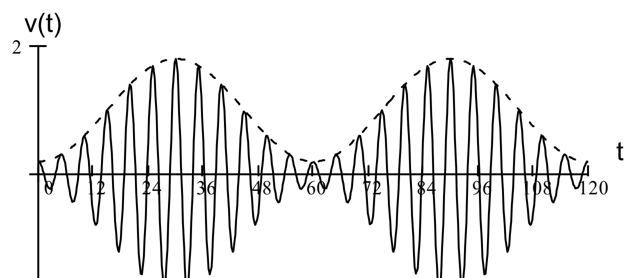
ADC, DAC

Filtering



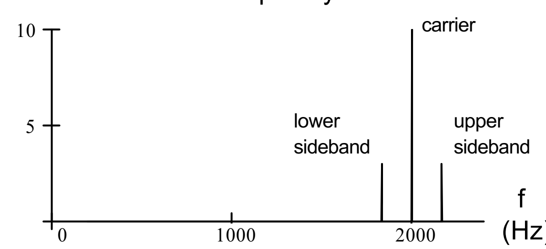
high-pass   low-pass   band-pass   band-reject (notch if very narrow) etc..

Modulation, demodulation

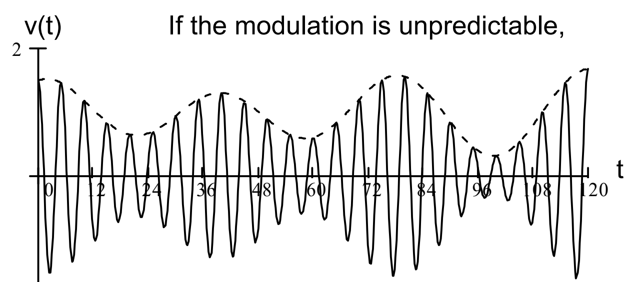


AM

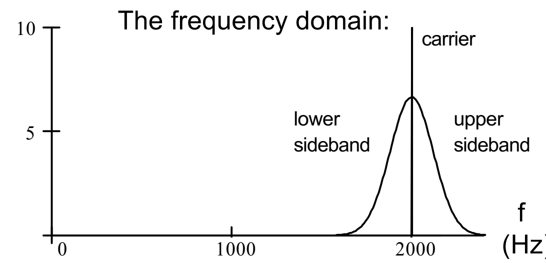
The frequency domain:

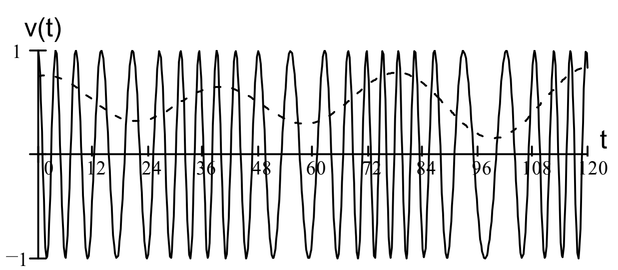


If the modulation is unpredictable,   then the spectrum blurs out

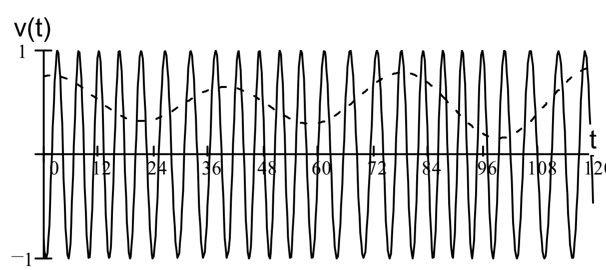


AM





FM



phase

Frequency multiplexing (Like radio stations which each use a different carrier frequency)

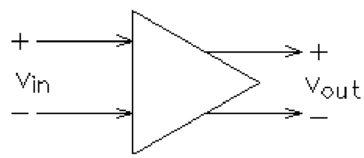
Time multiplexing (Used with digital signals, the bits of one signal are sent for a short time, then the bits of another, then another, and so forth.)

Etc...

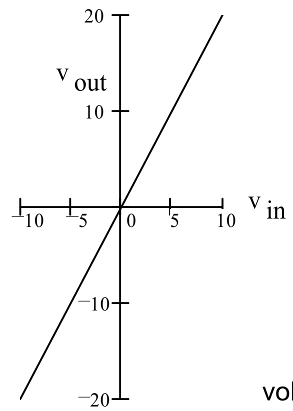
And.. the most important for us in this class... **Amplification**, creating a duplicate of a signal which has more power than the original.

Amplification

General symbol:



Transfer Characteristic:

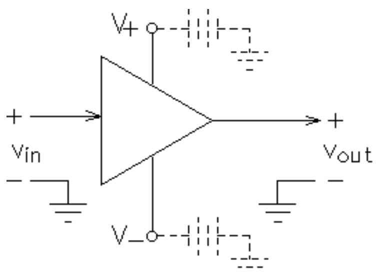


Amplifiers don't make a signal bigger, they actually make a bigger copy of the original. If the copy is exact, then there is no "distortion". All real amplifiers have some distortion.

voltage "gain" = 2 = $\frac{v_{out}}{v_{in}}$

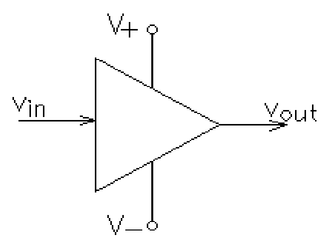
gain = slope

We can talk about voltage gain, current gain, and power gain.
All amplifiers must have the potential for power gain (will depend on the "load"). Transformers are not amplifiers.
Of course this means that all amplifiers must be connected to a power supply!



Batteries or power supplies are rarely shown on the schematic.

Signal voltages are assumed to be referenced to ground even if the grounds aren't shown.

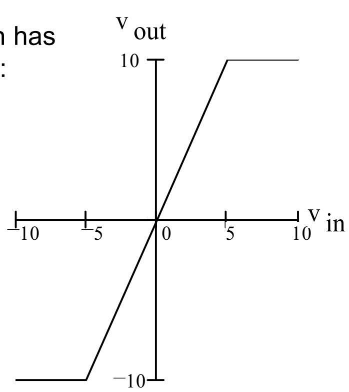


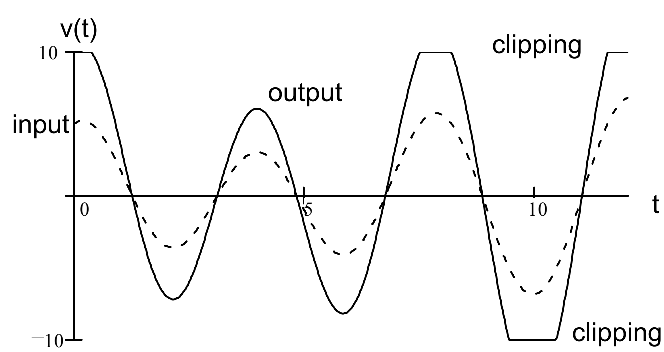
The output of all amplifiers are limited by the power supplies. Usually the limits are less than the power voltages.

Output limits, $L+ \leq V+$, $L- \geq V-$ (usually)

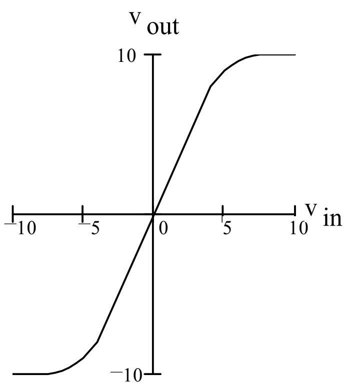
The output can't go beyond these limits no matter what the input does. If you want to avoid the "clipping" distortion in the output, you have to limit the input (make sure it's within an acceptable range).

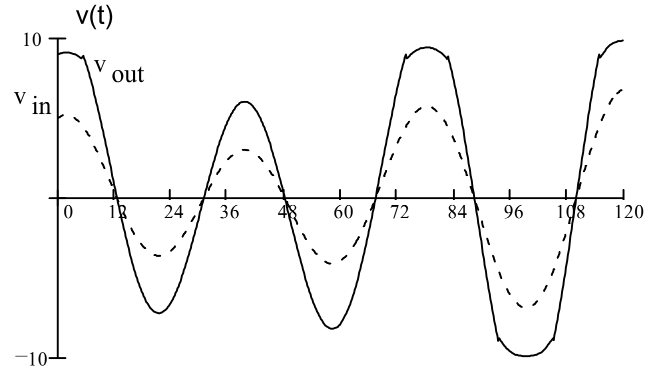
The transfer function has some non-linearities:



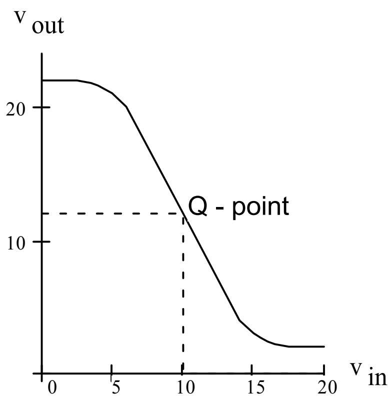


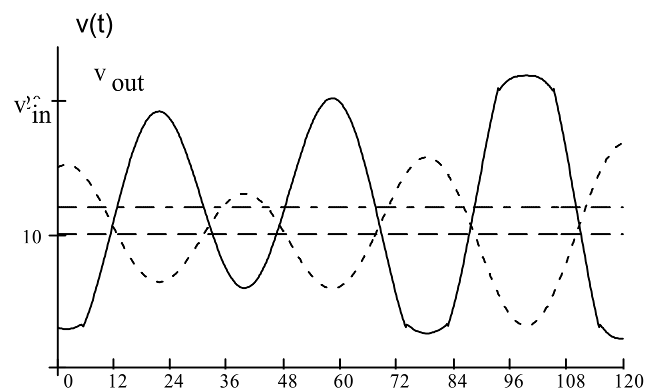
Often the clipping levels are not so well defined





Many of the transistor amplifier circuits that we'll see this semester will have DC offsets and will invert the signal.





The signal is considered the AC (changing) part of the waveform and the DC is called "bias" or the "quiescent - point" (Q - point) of the circuit.

Gain

voltage gain = $A_v = \dfrac{v_{out}}{v_{in}}$

lower -case letters refer to signal values

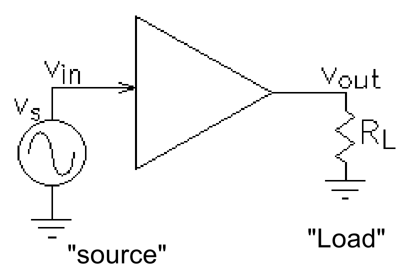
DC: $\dfrac{V_{OUT}}{V_{IN}}$ is rarely gain

Gains are dimensionless numbers

The two below require a load, otherwise there's no output current, & no output power.

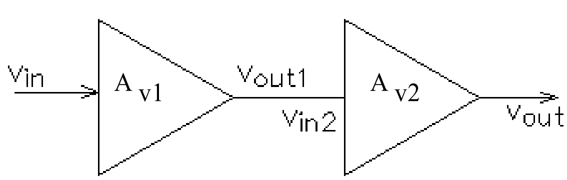
current gain = $\dfrac{i_{out}}{i_{in}} = \dfrac{i_L}{i_{in}}$

power gain = $\dfrac{P_{out}}{P_{in}} = \dfrac{P_L}{P_{in}}$



Gain is just an idealized transfer function.

Two stages



$v_{out} = v_{in2} \cdot A_{v2} = v_{out1} \cdot A_{v2} = v_{in} \cdot A_{v1} \cdot A_{v2}$

$A_{vtotal} = A_{v1} \cdot A_{v2}$

if $A_{v1} := 10$ & $A_{v2} := 4$ then $A_{vtotal} = A_{v1} \cdot A_{v2} = 40$ Same holds for multiple stages

Decibels

Your ears respond to sound logarithmically, both in frequency and in intensity.
Musical octaves are in ratios of two. "A" in the middle octave is 220 Hz, in the next, 440 Hz, then 880 Hz, etc...
It takes about ten times as much power for you to sense one sound as twice as loud as another.

10x power ~ 2x loudness

A bel is such a 10x ratio of power. Power ratio expressed in bels = $\log\left(\frac{P_2}{P_1}\right)$ bels. The bel is named for Alexander Graham Bell.

It is a logarithmic expression of a unitless ratio (like gain).

The bel unit is never actually used, instead we use the decibel (dB, 1/10th of a bel).

Power ratio expressed in dB = $10\cdot\log\left(\frac{P_2}{P_1}\right)$ dB

dB are also used to express voltage and current ratios, which related to power when squared. $P = \frac{V^2}{R} = I^2\cdot R$

Voltage ratio expressed in dB = $10\cdot\log\left(\frac{V_2^{\,2}}{V_1^{\,2}}\right)$ dB = $20\cdot\log\left(\frac{V_2}{V_1}\right)$ dB

Current ratio expressed in dB = $20\cdot\log\left(\frac{I_2}{I_1}\right)$ dB

These are the most common formulas used for dB

Some common ratios expressed as dB

$20\cdot\log\left(\frac{1}{\sqrt{2}}\right) = -3.01\cdot dB$ $\quad 10^{-\frac{3}{20}} = 0.708$ $\quad 20\cdot\log\left(\sqrt{2}\right) = 3.01\cdot dB$ $\quad 10^{\frac{3\cdot dB}{20}} = 1.413$

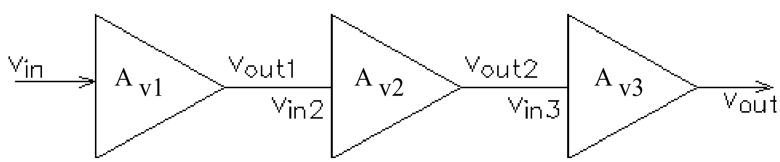
$20\cdot\log\left(\frac{1}{2}\right) = -6.021\cdot dB$ $\quad 10^{-\frac{6}{20}} = 0.501$ $\quad 20\cdot\log(2) = 6.021\cdot dB$ $\quad 10^{\frac{6\cdot dB}{20}} = 1.995$

$20\cdot\log\left(\frac{1}{10}\right) = -20\cdot dB$ $\quad 10^{-\frac{20}{20}} = 0.1$ $\quad 20\cdot\log(10) = 20\cdot dB$ $\quad 10^{\frac{20\cdot dB}{20}} = 10$

$20\cdot\log\left(\frac{1}{100}\right) = -40\cdot dB$ $\quad 10^{-\frac{40}{20}} = 0.01$ $\quad 20\cdot\log(100) = 40\cdot dB$ $\quad 10^{\frac{40\cdot dB}{20}} = 100$

We will use dB fairly commonly in this class, especially when talking about frequency response curves. In fact, we already have.

Multiple amplifier stages



Gain expressed as ratios: $A_{vtotal} = A_{v1}\cdot A_{v2}\cdot A_{v3}$

Gain expressed as dB: $A_{vtotal\_dB} = A_{v1\_dB} + A_{v2\_dB} + A_{v3\_dB}$

If $A_{v1} := 20$, $A_{v2} := 8$ & $A_{v3} := 4$ then $A_{vtotal} = A_{v1}\cdot A_{v2}\cdot A_{v3} = 640$

$A_{v1\_dB} := 20\cdot\log(20)$ $\quad A_{v2\_dB} := 20\cdot\log(8)$ $\quad A_{v3\_dB} := 20\cdot\log(4)$ $\quad 20\cdot\log(640) = 56.124\cdot dB$

$A_{v1\_dB} = 26.021\cdot dB$ $\quad A_{v2\_dB} = 18.062\cdot dB$ $\quad A_{v3\_dB} = 12.041\cdot dB$

$A_{vtotal\_dB} = A_{v1\_dB} + A_{v2\_dB} + A_{v3\_dB} = 56.124\cdot dB$

Other dB-based units

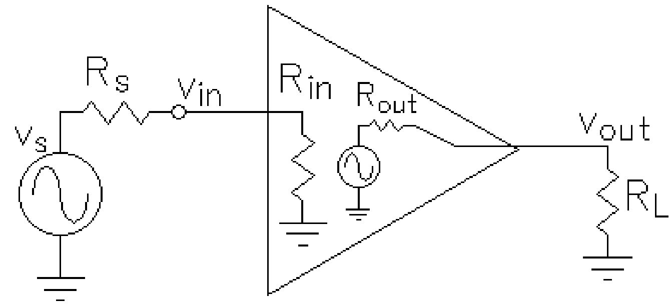
You may have encountered dB as an absolute measure of sound intensity (Sound Pressure Level or SPL). In that case the RMS sound pressure is compared as a ratio to a reference of 2 x 10^{-5} Pascals.

dBm is another absolute power scale expressed in dB. Powers are referenced to 1mW.

Volume Units (VU) are dBm with the added spec that the load resistor is 600Ω.

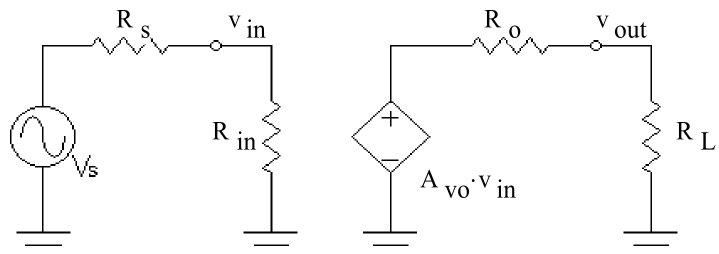
Amplifier Models

Up until now we haven't worried about the currents into and out-of our amplifiers. In reality, any source, including the amplifier, will have a source resistance (R_s or Z_s for the source and R_{out} or Z_{out} for the amp). Also any amplifier will let a little signal current flow in (modeled by an R_{in} or Z_{in}).



At this point, the triangle symbol gets to be a little cumbersome and is dropped.

Basic amplifier model:
Voltage amplifier
with source and load



\ ---------------- amplifier ------------- /

Notice the dependent source inside the amplifier

A_{vo} is the "unloaded" gain or "open-circuit" gain because

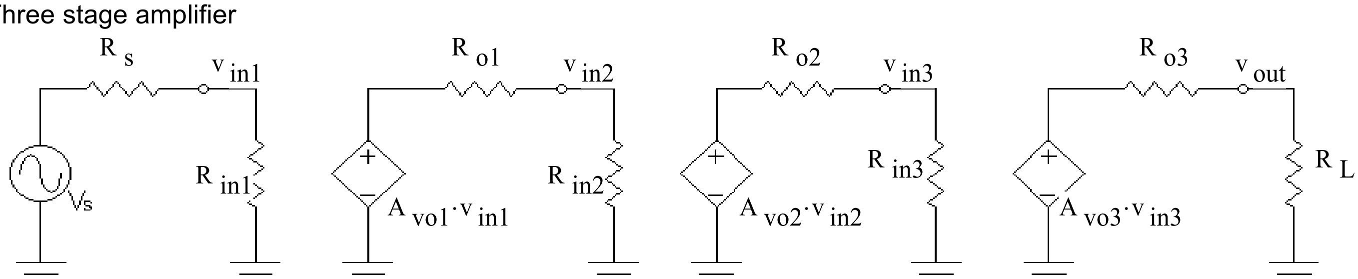
$A_{vo} \cdot v_{in}$ would be the output if there were no load resistor ($R_L = \infty$).

Overall gain: $$\frac{v_{out}}{v_s} = \frac{R_{in}}{R_s + R_{in}} \cdot A_{vo} \cdot \frac{R_L}{R_o + R_L}$$

or, in dB: $$20 \cdot \log\left(\frac{v_{out}}{v_s}\right) = 20 \cdot \log\left(\frac{R_{in}}{R_s + R_{in}}\right) + 20 \cdot \log\left(A_{vo}\right) + 20 \cdot \log\left(\frac{R_L}{R_o + R_L}\right)$$

- dB   + dB   - dB

Three stage amplifier



Overall gain: $$\frac{v_{out}}{v_s} = \frac{R_{in1}}{R_s + R_{in1}} \cdot A_{vo1} \cdot \frac{R_{in2}}{R_{o1} + R_{in2}} \cdot A_{vo2} \cdot \frac{R_{in3}}{R_{o2} + R_{in3}} \cdot A_{vo3} \cdot \frac{R_L}{R_{o3} + R_L}$$

Desirable characteristics

Want R_{in} --> ∞ High input resistance means the amplifier will not load down the source or previous stage.

Want R_o --> 0 Low output resistance means the amplifier supply lots of current to the load or next stage.

High R_{in} and low R_o means good current gain. In fact these terms are used much more often than "current gain".

At higher frequencies it may become more important to match impedances than to maximize R_{in}.& minimize R_o.