Lecture #8

OUTLINE

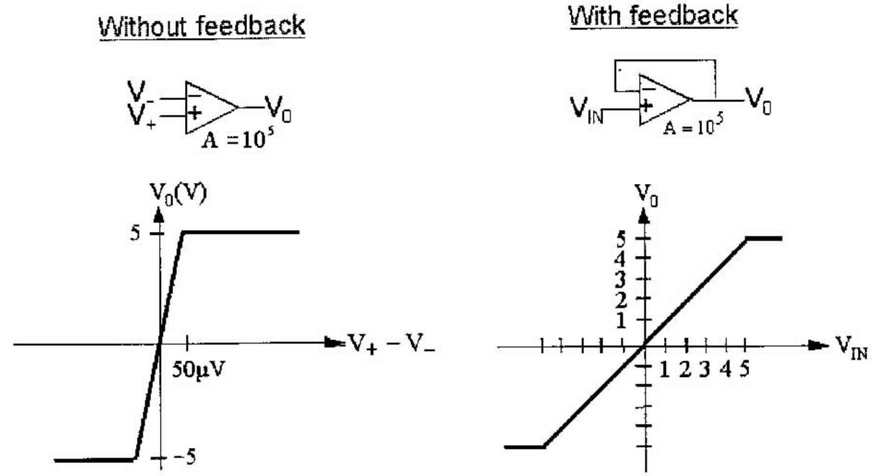
- Op-Amp ckts continued: examples
- Inverting amplifier circuit
- Summing amplifier circuit
- Noninverting amplifier circuit
- Differential amplifier circuit

Reading

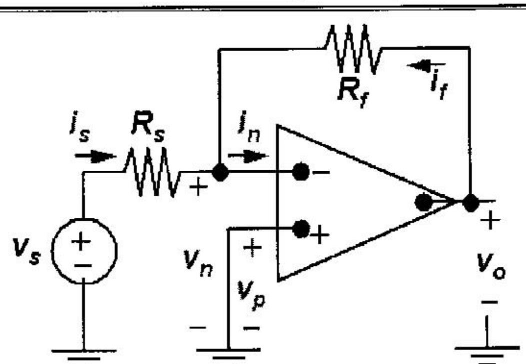
Chapter 14, also refer to Ch. 11

Review: Negative Feedback

- Negative feedback is used to "linearize" a high-gain differential amplifier.



Inverting Amplifier Circuit



$$v_o = -\frac{R_f}{R_s} v_s$$

$i_n = 0 \rightarrow i_s = -i_f$

$v_p = 0 \rightarrow v_n = 0$

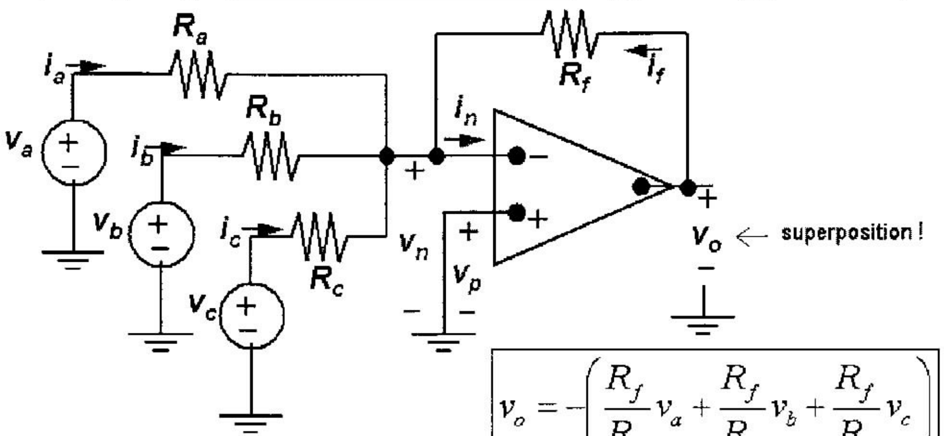
Analysis using Realistic Op Amp Model

- In the analysis on the previous slide, the op amp was assumed to be ideal, *i.e.*

$$\boldsymbol{R_i} = \infty;\ \boldsymbol{A} = \infty;\ \boldsymbol{R_o} = 0$$

- In reality, an op amp has finite $\boldsymbol{R_i}$, finite $\boldsymbol{A}$, non-zero $\boldsymbol{R_o}$, and usually is loaded at its output terminals with a load resistance $\boldsymbol{R_L}$.

Summing Amplifier Circuit



$$v_o = -\left(\frac{R_f}{R_a}v_a + \frac{R_f}{R_b}v_b + \frac{R_f}{R_c}v_c\right)$$

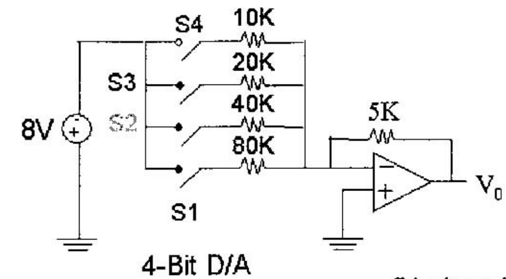
$i_n = 0 \rightarrow i_a + i_b + i_c = -i_f$

$v_p = 0 \rightarrow v_n = 0$

Application: Digital-to-Analog Conversion

A DAC can be used to convert the digital representation of an audio signal into an analog voltage that is then used to drive speakers -- so that you can hear it!

"Weighted-adder D/A converter"



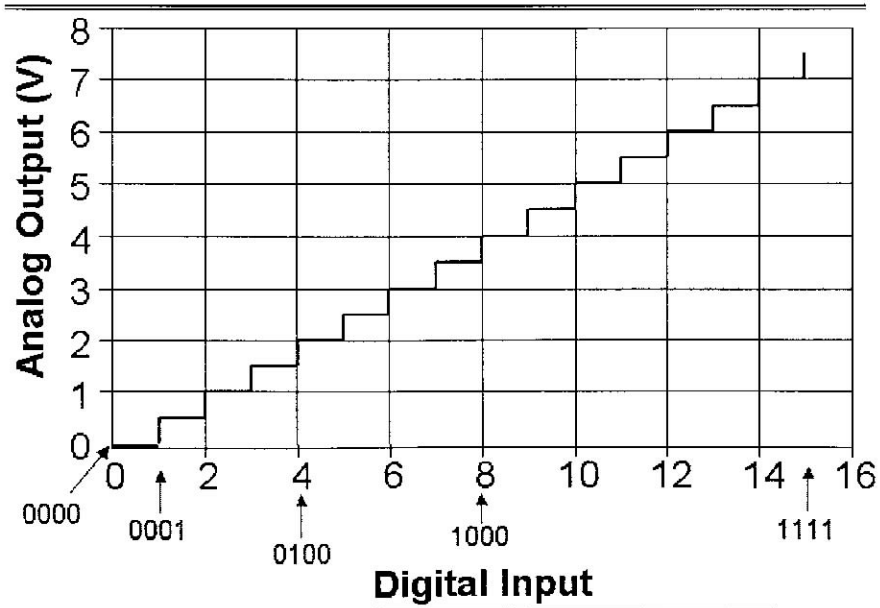
S1 closed if LSB =1
S2 " if next bit = 1
S3 " if " " = 1
S4 " if MSB = 1

(Transistors are used as electronic switches)

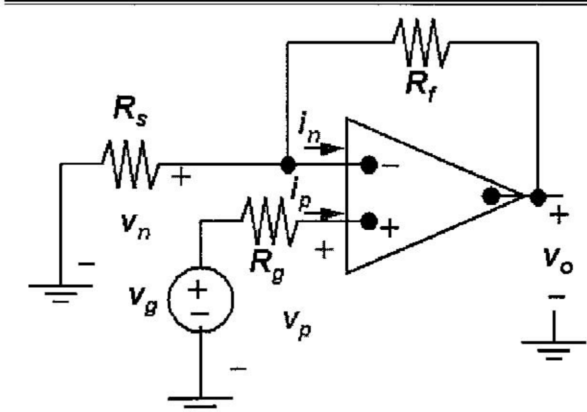
Binary number	Analog output (volts)
0 0 0 0	0
0 0 0 1	.5
0 0 1 0	1
0 0 1 1	1.5
0 1 0 0	2
0 1 0 1	2.5
0 1 1 0	3
0 1 1 1	3.5
1 0 0 0	4
1 0 0 1	4.5
1 0 1 0	5
1 0 1 1	5.5
1 1 0 0	6
1 1 0 1	6.5
1 1 1 0	7
1 1 1 1	7.5

MSB ↑ ↑ LSB

Characteristic of 4-Bit DAC



Noninverting Amplifier Circuit

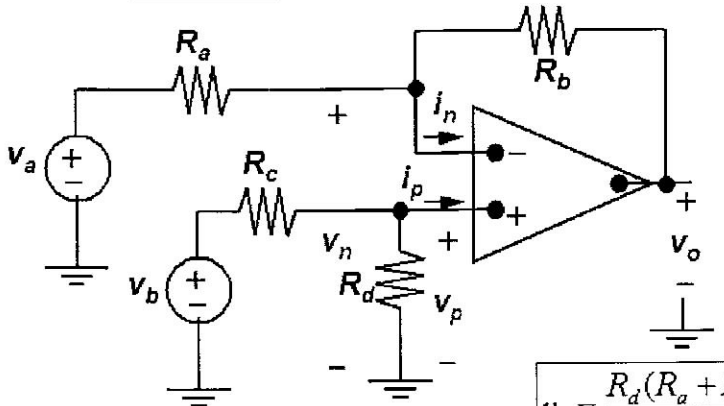


$$v_o = \frac{R_s + R_f}{R_s} v_g$$

$i_p = 0 \rightarrow v_p = v_g \rightarrow v_n = v_g$

$i_n = 0 \rightarrow R_s$ & R_f form a voltage divider

Differential Amplifier Circuit



$$v_o = \frac{R_d(R_a+R_b)}{R_a(R_c+R_d)}v_b - \frac{R_b}{R_a}v_a$$

$i_n = 0$ ➔ $\frac{v_n - v_a}{R_a} + \frac{v_n - v_o}{R_b} = 0$

$i_p = 0$ ➔ $v_p = \frac{R_d}{R_c + R_d} v_b = v_n$

If $\frac{R_a}{R_b} = \frac{R_c}{R_d}$, then $v_o = \frac{R_b}{R_a}(v_b - v_a)$

Differential Amplifier – Another Perspective

Redefine the inputs in terms of two other voltages:

1. *differential mode input* $v_{dm} \equiv v_b - v_a$

2. *common mode input* $v_{cm} \equiv (v_a + v_b)/2$

so that

$v_a = v_{cm} - (v_{dm}/2)$ and $v_b = v_{cm} + (v_{dm}/2)$

Then it can be shown that

$$v_o = A_{cm}v_{cm} + A_{dm}v_{dm}$$

where $A_{cm} = \frac{R_aR_d - R_bR_c}{R_a(R_c+R_d)}$ and $A_{dm} = \frac{R_d(R_a+R_b)+R_b(R_c+R_d)}{2R_a(R_c+R_d)}$

"common mode gain" **"differential mode gain"**

Differential Amplifier (cont'd)

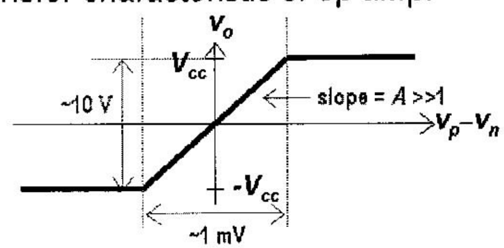
If $\frac{R_a}{R_b} = \frac{R_c}{R_d}$, then $v_{cm} = 0$ and $v_{dm} = \frac{R_b}{R_a}$

- **An ideal differential amplifier amplifies only the differential mode portion of the input voltage, and eliminates the common mode portion.**
  - provides immunity to noise (common to both inputs)
- If the resistors are not perfectly matched, the ***common mode rejection ratio*** (CMRR) is finite:

$$CMRR \equiv \left|\frac{A_{dm}}{A_{cm}}\right| \approx \frac{1 + R_b/R_a}{\varepsilon} \text{ if } \frac{R_a}{R_b} = (1-\varepsilon)\frac{R_c}{R_d}$$

Summary

- Voltage transfer characteristic of op amp:



- A feedback path between an op amp's output and its <u>inverting</u> input can force the op amp to operate in its linear region, where $v_o = A(v_p - v_n)$
- An **ideal op amp** has **infinite input resistance R_i**, **infinite open-loop gain A**, and **zero output resistance R_o**. As a result, the input voltages and currents are constrained:

$$v_p = v_n \text{ and } i_p = -i_n = 0$$