ECE/CS 5780/6780: Embedded System Design

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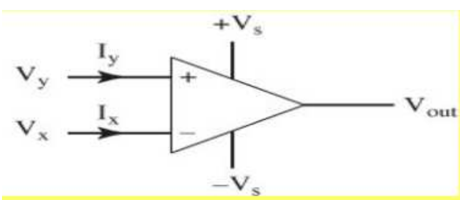
Lecture 17: Operational Amplifiers

Introduction to Analog Interfacing

- Most embedded systems include components that measure and/or control real-world parameters.
- These include position, speed, temperature, etc.
- Usually exist in a continuous, or analog, form.
- Often need to amplify, filter, and convert these signals to digital form.
- This chapter develops analog circuit building blocks for data acquisition and control systems.

Ideal Op Amps



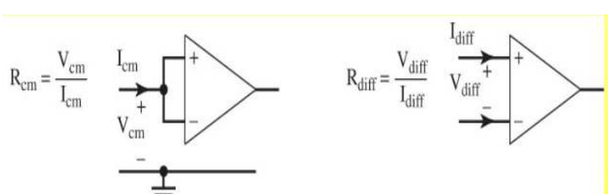
$$V_{out} = K(V_y - V_x)$$

1. Voltage ranges are bounded by the supply voltages, $\pm V_s$.
2. Input currents, I_x and I_y, are zero.
3. Negative feedback drives V_x to equal V_y.
4. Positive feedback or no feedback drives V_{out} to equal $-V_s$ or $+V_s$.

Various Op Amps

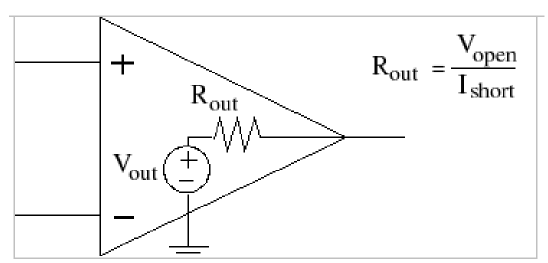
Op amp	Description	Open loop gain	$\pm V_s$	$\pm I_s$
OPA4227	High Precision	160 dB	$\pm$5 to $\pm$15 V	$\pm$3.8 mA
OPA4132	High-Speed FET	130 dB	$\pm$2.5 to $\pm$18 V	$\pm$4.8 mA
TLC2274	Rail-to-Rail	104 dB	0 to 5 or $\pm$5 V	3 mA

Input Impedance

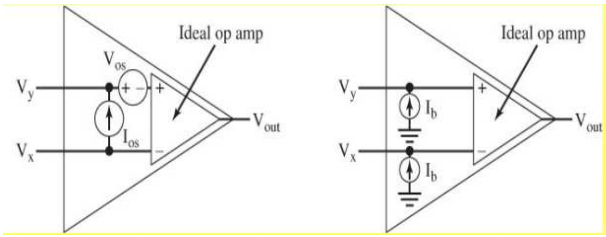


Op amp	R_{cm}	R_{diff}
OPA4227	1 GΩ	10 MΩ
OPA4132	10^{13} Ω	10^{13} Ω
TLC2274	10^{12} Ω	10^{12} Ω

Output Impedance

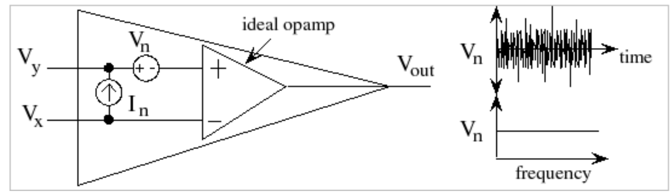


Offset Voltage, Offset Current, and Bias Current



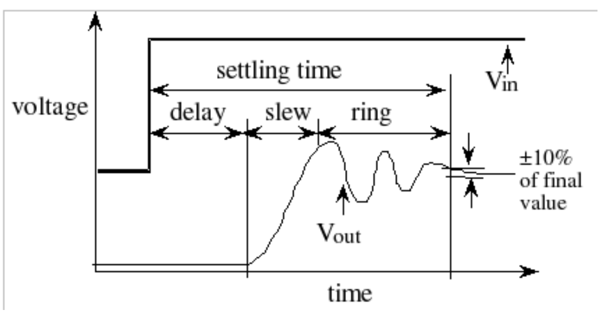
Op amp	V_{os}	I_{os}	I_b
OPA4227	0.075 mV	10 nA	10 nA
OPA4132	0.5 mV	50 pA	50 pA
TLC2274	3 mV	100 pA	100 pA

Noise Density



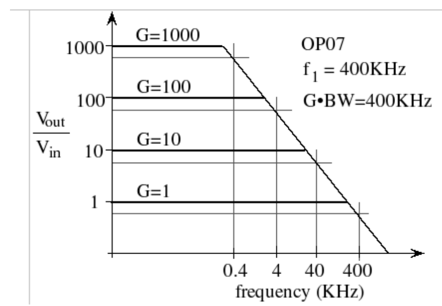
Op amp	e_n
OPA4227	3 nV/$\sqrt{Hz}$
OPA4132	23 nV/$\sqrt{Hz}$
TLC2274	50 nV/$\sqrt{Hz}$

Transient Response



Op amp	dV/dt, Slew rate
OPA4227	2.3 V/μs
OPA4132	20 V/μs
TLC2274	3.6 V/μs

Frequency Response



Op amp	f_1
OPA4227	8 MHz
OPA4132	8 kHz
TLC2274	2.18 MHz

Power Gain (A_{db})

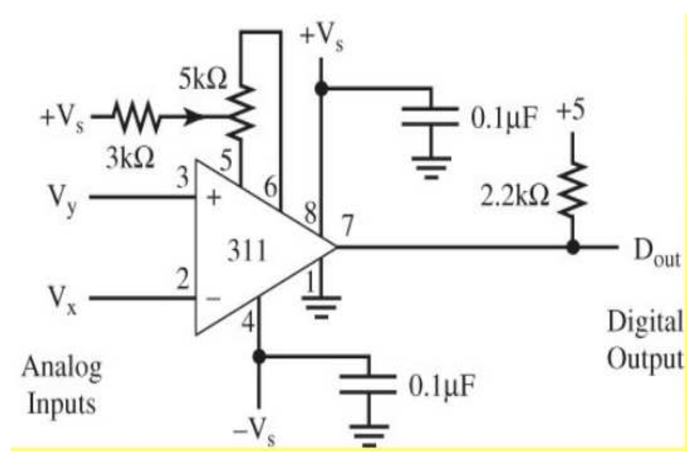
- Combines voltage gain, input impedance, and output impedance.

$$P_{in} = \frac{V_{in}^2}{R_{in}}$$

$$P_{out} = \frac{V_{out}^2}{R_{out}}$$

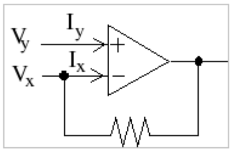
$$A_{db} = 10log_{10}\frac{P_{out}}{P_{in}} = 20log_{10}\frac{V_{out}}{V_{in}} + 10log_{10}\frac{R_{in}}{R_{out}}$$

Threshold Detector



Simple Rules for Linear Op Amp Circuits

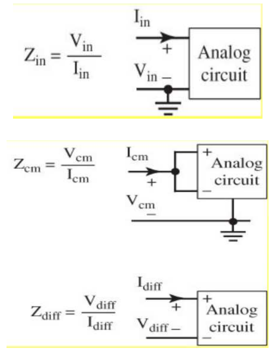
- Choose quality components.
- Negative feedback required to create linear mode circuit.



- Assume no current flows into the op amp inputs.
- Assume negative feedback equalizes input voltages.
- Choose resistor values in the 1kΩ to 1MΩ range.
- BW depends on the gain and the op amp performance.

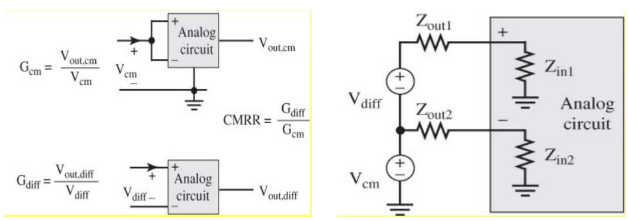
Simple Rules for Linear Op Amp Circuits (cont)

- Equalize the effective resistance to ground at the two op amp inputs.
- Input impedance is input voltage / input current.

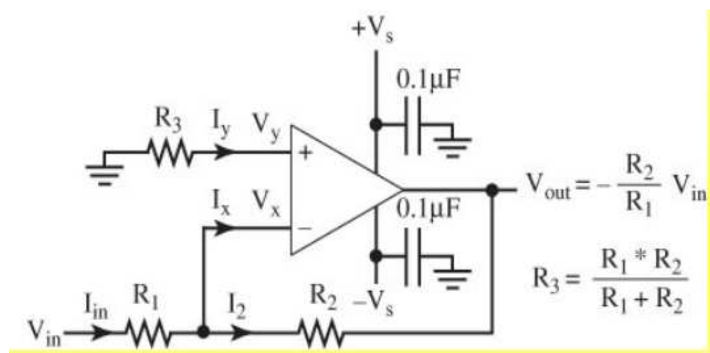


Simple Rules for Linear Op Amp Circuits (cont)

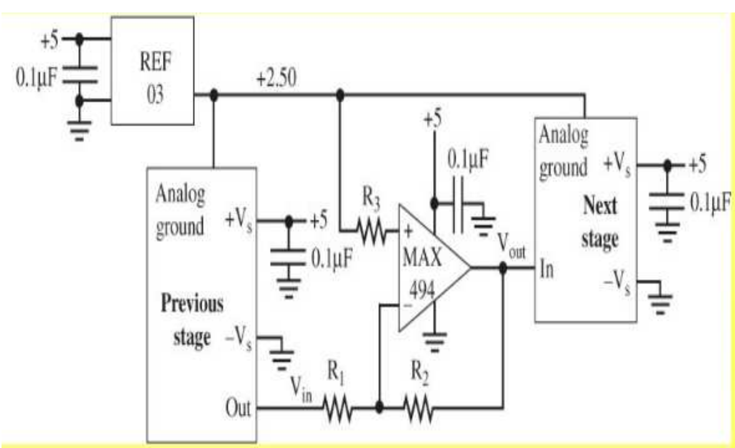
- Match input impedances to improve common-mode rejection ratio (CMRR).



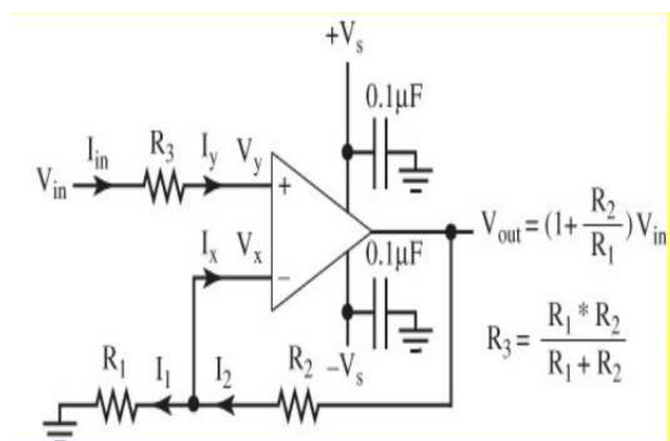
Inverting Amplifier



Inverting Amplifier with -2.5V to 2.5V Range

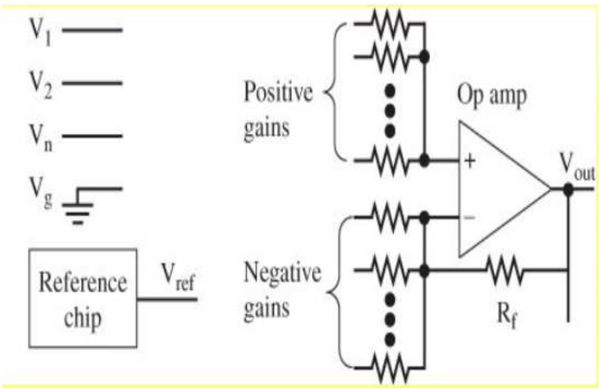


Noninverting Amplifier



Model for Linear Circuit Design

$$V_{out} = A_1V_1 + A_2V_2 + \ldots + A_nV_n + B$$



Linear Circuit Design

$$V_{out} = 5V_1 - 3V_2 + 2V_3 - 10$$

- Choose a reference voltage from available reference voltage chips.

$$V_{ref} = 5V$$

- Rewrite the design equation in terms of the reference voltage, V_{ref}.

$$V_{out} = 5V_1 - 3V_2 + 2V_3 - 2V_{ref}$$

- Add a ground input to the equation such that the sum of the gains is 1.

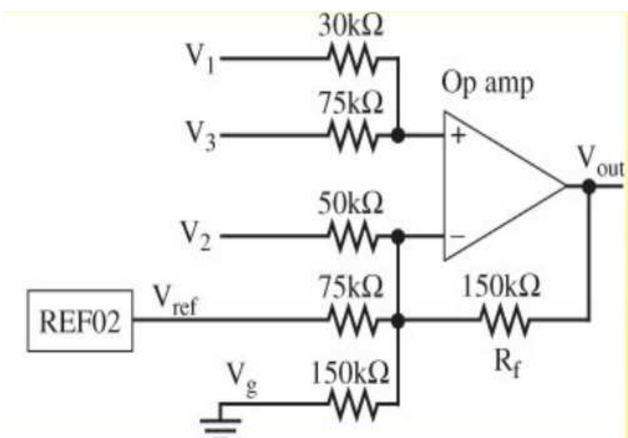
$$V_{out} = 5V_1 - 3V_2 + 2V_3 - 2V_{ref} - V_g$$

- Choose a feedback resistor, R_f, in range of 10 kΩ to 1 MΩ.

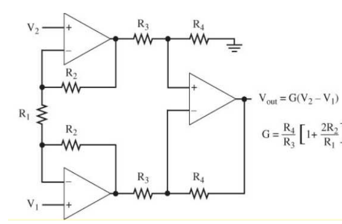
$$R_f = 150k\Omega \quad R_1 = 30k\Omega \quad R_2 = 50k\Omega$$
$$R_3 = 75k\Omega \quad R_{ref} = 75k\Omega \quad R_g = 150k\Omega$$

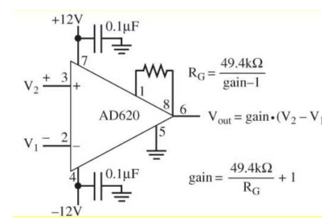
- Build the circuit: connect positive gain inputs to positive terminal and negative gain inputs to the negative terminal.

Linear Op Amp Circuit

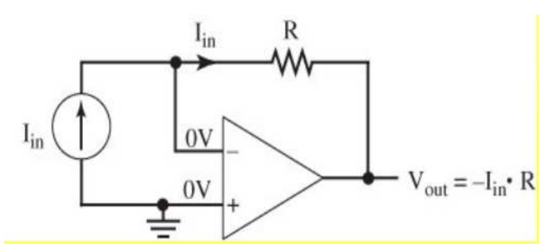


Instrumentation Amplifier

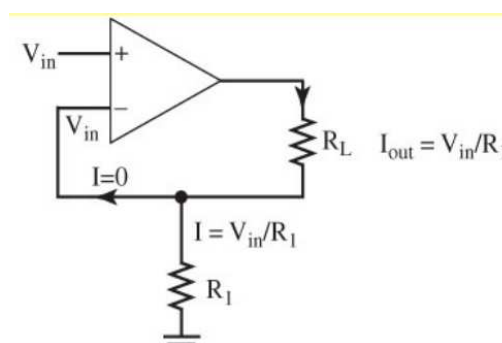




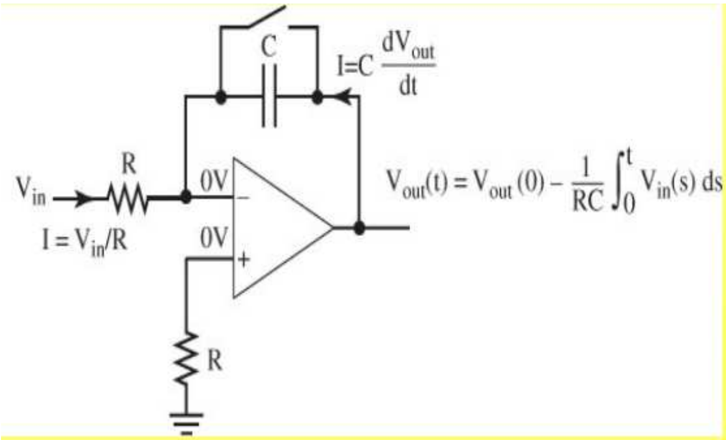
Current-to-Voltage Circuit



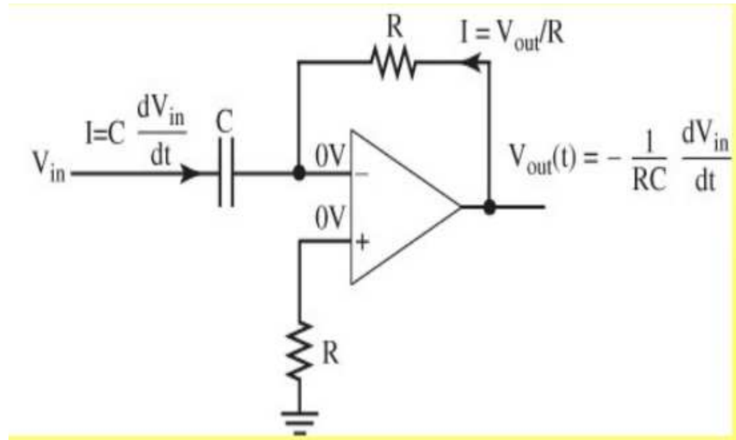
Voltage-to-Current Circuit



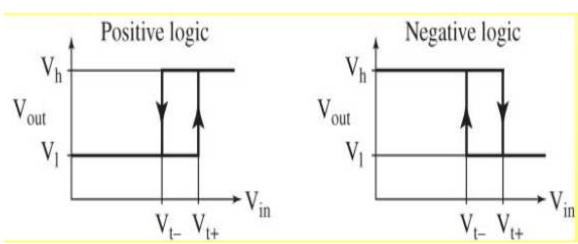
Integrator Circuit



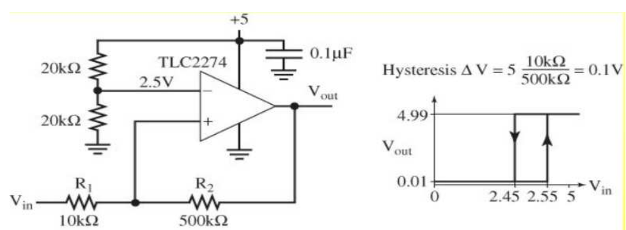
Derivative Circuit

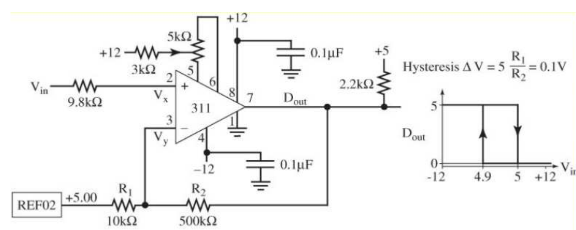


Hysteresis



Voltage Comparators with Hysteresis





Analog Isolation