Overview

Resistors and capacitors
PCB layout of analog circuits
Simple rules for using op amps

11.1. Resistors and capacitors

11.1.1. Resistors

The resistor or capacitor type is defined by
- the manufacturing process,
- the materials used, and
- the testing performed.

carbon composition
- hot-pressed carbon granules
- used in digital circuits as +5V pullups.

1% metal film resistors
- analog amplifier circuits
- analog filter circuits

11.1.2. Capacitors

Polarized capacitors
- only positive voltages are applied
- DC power supply filters

Nonpolarized or bipolar capacitors
- operate for both positive and negative voltages
- analog filters

Capacitor Comparison Chart

Reference, "Analog Dialogue", Analog Device Corporation

TYPE	TYPICAL DIELECTRIC ABSORPTION	ADVANTAGES	DISADVANTAGES
NPO ceramic	<0.1%	Small case size Inexpensive Good stability Wide range of values Many vendors Low inductance	DA generally low, but may not be specified Limited to small values (10 nF)
Polystyrene	0.001% to 0.02%	Inexpensive Low DA available Wide range of values Good stability	Damaged by temperature > +85°C Large case size High inductance
Polypropylene	0.001% to 0.02%	Inexpensive Low DA available Wide range of values	Damaged by temperature > +105°C Large case size High inductance
Teflon	0.003% to 0.02%	Low DA available Good stability Operational above +125°C Wide range of values	Relatively expensive Large size High inductance
MOS	0.01%	Good DA Small Operational above +125°C Low inductance	Limited availability Available only in small capacitance values
Polycarbonate	0.1%	Good stability Low cost Wide temperature range	Large size DA limits to 8-bit applications High inductance
Polyester	0.3% to 0.5%	Moderate stability Low cost Wide temperature range Low inductance (stacked film)	Large size DA limits to 8-bit applications High inductance

Monolithic ceramic (High K)	>0.2%	Low inductance Wide range of values	Poor stability Poor DA High voltage coefficient
Mica	>0.003%	Low loss at HF Low inductance Very stable Available in 1% values or better	Quite large Low values (<10 nF) Expensive
Aluminum electrolytic	High	Large values High currents High voltages Small size	High leakage Usually polarized Poor stability Poor accuracy Inductive
Tantalum electrolytic	High	Small size Large values Medium inductance	Quite high leakage Usually polarized Expensive Poor stability Poor accuracy

Either all digital or all analog ***Mixed Digital ----------Analog***

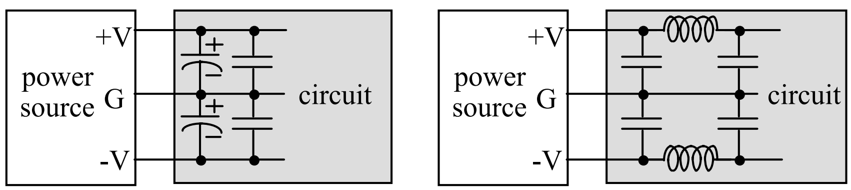
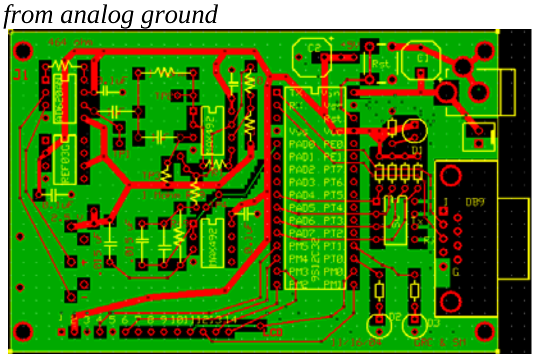


Figure 11.1. DC supply filters.

PC board layout considerations

Position the bypass capacitors as close to the chip as possible
Place a ground plane under sensitive analog circuits
Separate digital ground from analog ground



Notice in this EKG system

Digital circuits on the right, analog circuits on the left
Ground plane under analog circuits
Each chip has a 0.1 uF bypass capacitor close to the power pin

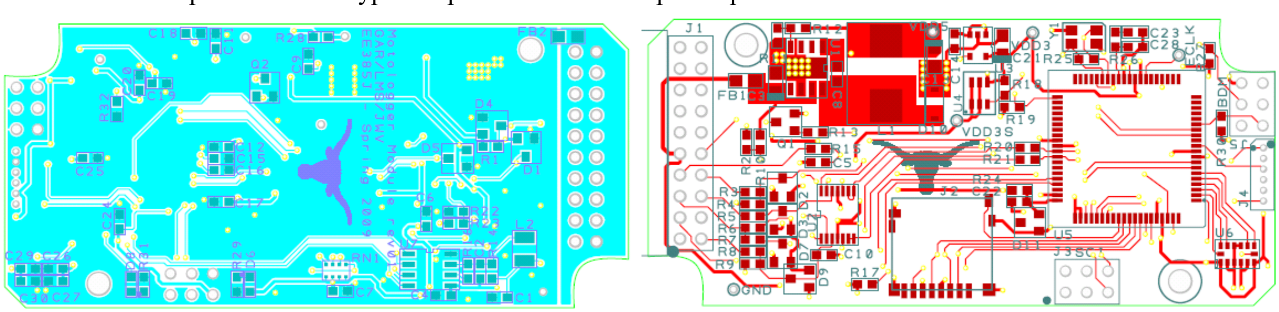


Figure 6.3. Bottom and top PCB layout for a 9S12 system.

11.2. Op Amps

11.2.2. Ideal Op amps

We will begin our discussion of op amps with the ideal op amp.

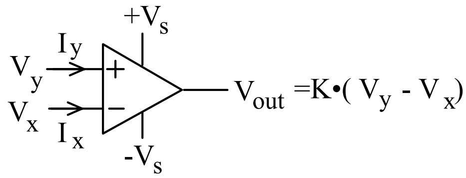


Figure 11.3. Ideal op amp.

	OPA350	AD8031	TLC2272	MAX495
Single op amp	OPA350	AD8031		MAX495
Double op amp	OPA2350	AD8032	TLC2272	MAX492
Quad op amp	OPA4350		TLC2274	MAX494
Description			Rail-to-Rail	Rail-to-Rail
K, open loop gain			104 dB	108 dB
R_{cm}, input impedance			10^{12} Ω || 8pF	
R_{diff}, input impedance			10^{12} Ω || 8pF	2 MΩ
V_{os}, offset voltage			3 mV	0.5 mV
I_{os}, offset current			100 pA	6 nA
I_b, bias current			100 pA	60 nA
e_n, noise density			50 nV/√Hz	25 nV/√Hz
f_1, gain*bandwidth product			2.18 MHz	500 kHz
dV/dt, slew rate			3.6 V/µs	0.2 V/µs
$\pm V_s$, Voltage supply			0 to 5 or ±5 V	2.7 to 6 V
$\pm I_s$, Supply current			3 mA	170 µA

Table 11.3. Parameters for various op amps used in this chapter.

Open data sheet for OPA2350 and enter this data

Rule 1. Voltage ranges are bounded by the supply voltages

A "rail-to-rail" op amp operates in its linear mode all the way from $-V_s$ to $+V_s$.

Rule 2. Input currents are zero

Rule 3. Negative feedback drives V_x to equal V_y

Rule 4. Positive feedback or no feedback drives V_{out} to equal $-V_s$ or $+V_s$

11.2.3. Realistic Op Amp Models

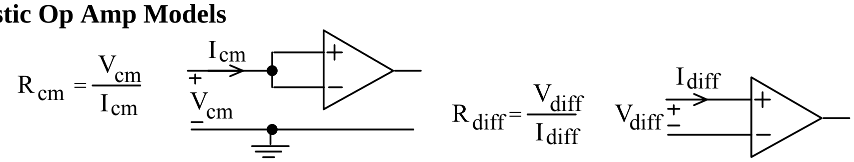
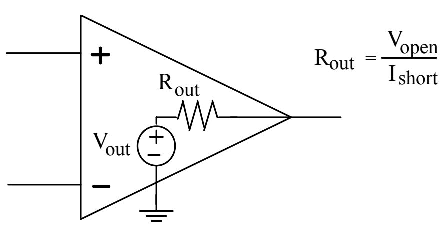


Figure 11.4. Definition of op amp differential input impedance.



> ***Observation:*** *The input and output impedance's of the op amp are not necessarily the same as the input and output impedance's of the entire analog circuit.*

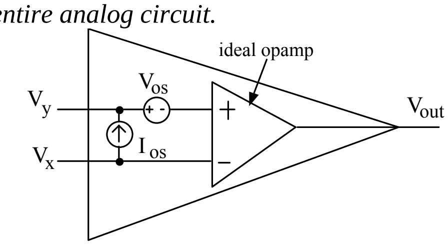


Figure 11.5. Definition of op amp offset voltage and offset current.

> ***Observation:*** *The use of a null offset pot increases manufacturing costs and incurs a labor cost to adjust it periodically. Therefore, the overall system cost may be reduced by using more expensive op amps that does not require a null offset pot.*

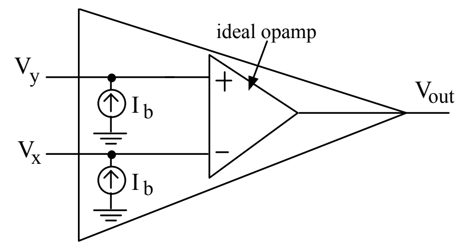
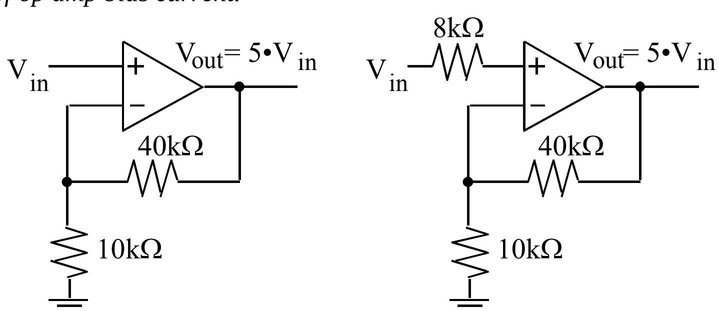


Figure 11.5. Definition of op amp bias current.



$$Z_{in} = \frac{V_{in}}{I_{in}}$$

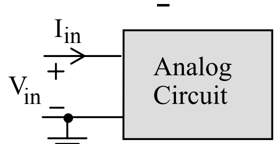
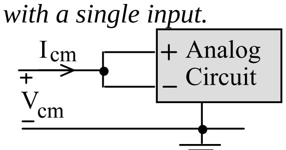


Figure 11.7. Input impedance for an analog circuit with a single input.

$$Z_{cm} = \frac{V_{cm}}{I_{cm}}$$



$$Z_{diff} = \frac{V_{diff}}{I_{diff}}$$

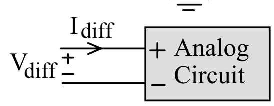
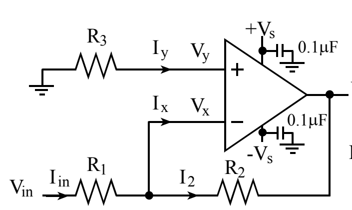


Figure 11.8. Input impedance for an analog circuit with two inputs.



$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

$$R_3 = \frac{R_1 * R_2}{R_1 + R_2}$$

Figure 11.11. Inverting amplifier.

Get the LM4041CILPR adjustable shunt reference from TI
The REF03 2.50V is a reference from Analog Devices

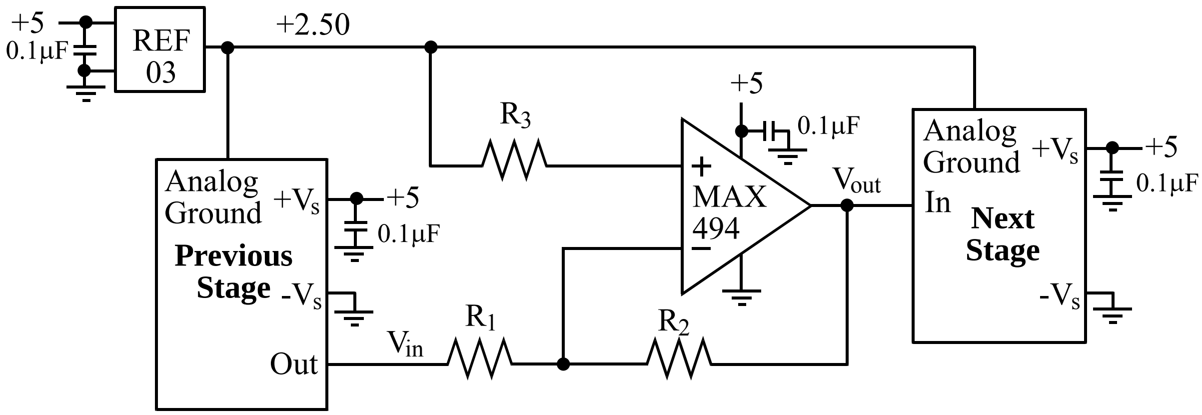


Figure 11.12. Inverting amplifier with an effective -2.5 V to +2.5 V analog signal range.

11.2.7. Linear Mode Op Amp Circuits

This design example works with any analog circuit in the form

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

designed with one op amp as shown in the following figure.

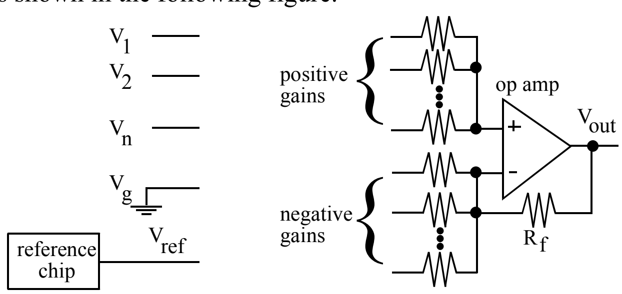


Figure 11.14. Boiler plate circuit model for linear circuit design.

The **first step** is to choose a reference voltage

Common Error: *If you use resistor divider from the +12V supply to create a voltage constant, then the power supply ripple will be added directly to your analog signal.*

Part	Voltage (V)	±Accuracy (mV)
AD1580, AD589, REF1004, MAX6120, LT1034, LM385	1.2	1 to 15
ADR420, ADR520, REF191, MAX6191, LT1790, LM4120	2.048	1 to 10
AD580, REF03, REF43, REF1004, MAX6192, MAX6225, LT1389, LM336	2.5	1 to 75
AD1583, ADR530, ADR423, REF193, MAX6163, LT1461, LM4120	3	1.5 to 10
ADR366, REF196, MAX6331, LT1461, LM3411, LM4120	3.3	4 to 10
AD1584, ADR540, ADR292, REF198, MAX6241, LT1790, LM4040	4.096	2 to 8
ADR425, AD586, REF02, REF195, MAX6250, LT1027, LT1236, LM336	5.0	2 to 20
AD581, AD587, AD633, REF01, LT1236, LM4040, LM4050	10.0	5 to 30

Table 11.4. Parameters of various precision reference voltage chips.

The **second step** is to rewrite the design equation in terms of the reference voltage, V_{ref}.

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

The **third step** is to add a ground input to the equation. Ground is zero volts (V_g=0), but it is necessary to add this ground so that the sum of all the gains is equal to one.

$V_{out} = A_1V_1 + A_2V_2 + \ldots + A_nV_n + A_{ref}V_{ref} + A_gV_g$

Choose A_g such that

$A_1 + A_2 + \ldots + A_n + A_{ref} + A_g = 1$

In other words, let

$A_g = 1 - (A_1 + A_2 + \ldots + A_n + A_{ref})$

The **fourth step** is to choose a feedback resistor, R_f, in the range of 10 kΩ to 1MΩ. The larger the gains, the larger the value of R_f must be. Then calculate input resistors to create the desired gains. In particular,

$|A_1| = R_f/R_1$ so $R_1 = R_f/|A_1|$
$|A_2| = R_f/R_2$ so $R_2 = R_f/|A_2|$
$|A_n| = R_f/R_n$ so $R_n = R_f/|A_n|$
$|A_{ref}| = R_f/R_{ref}$ so $R_{ref} = R_f/|A_{ref}|$
$|A_g| = R_f/R_g$ so $R_g = R_f/|A_g|$

The **last step** is to build the circuit. If the gain is positive, then the input resistor is connected to the positive terminal of the op amp. Conversely, if the gain is negative, then the input resistor is connected to the negative terminal of the op amp.

For example, we will design the following analog circuit

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

The **first step** is to choose a reference voltage. The REF02 +5.00V voltage reference will be used.

The **second step** is to rewrite the design equation in terms of the reference voltage.

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

The **third step** is to add a ground input to the equation so that the sum of all the gains is equal to one.

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

The **fourth step** is to choose a feedback resistor, R_f =150 kΩ. The value is a multiple of the least common multiple of the gains: 5,3,2,1. Then calculate input resistors to create the desired gains.

$R_1 = R_f/|A_1| = 150$ kΩ/5 = 30 kΩ
$R_2 = R_f/|A_2| = 150$ kΩ/3 = 50 kΩ
$R_3 = R_f/|A_3| = 150$ kΩ/2 = 75 kΩ
$R_{ref} = R_f/|A_{ref}| = 150$ kΩ/2 = 75 kΩ
$R_g = R_f/|A_g| = 150$ kΩ/1 = 150 kΩ

The **last step** is to build the circuit.

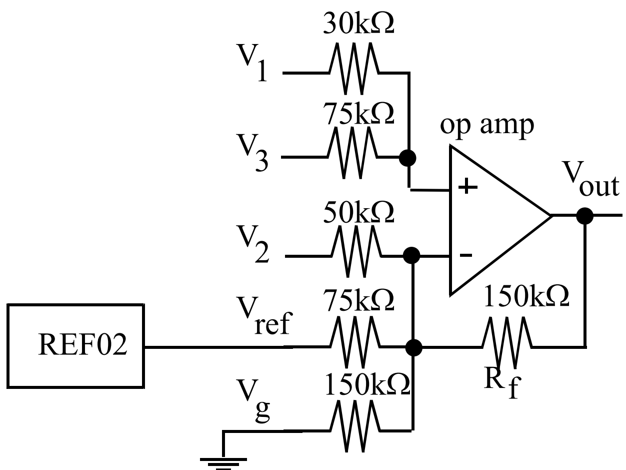


Figure 11.15. A linear op amp circuit.

The bottom line

Quality analog circuits require quality parts
Two approaches to analog circuit design
- **Use simple rules to develop circuits**
- **Start with existing circuit and modify it**

A design problem like Figure 11.15 will be on Quiz2