ENEE4304
Instrumentation and Measurements

L8
Signal Conditioning

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Signal Conditioning Functions

- Isolation
- Filtering
- Amplification
- Linearization (bias removal)
- Excitation
- Other Functions

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What is Electrical Isolation?

- Electrical isolation is a protective design feature of many data loggers and data acquisition systems.
- Isolation is implemented to separate measurement signals from each other in order to keep them from interacting and causing electrical issues.
- Isolation, separates different sections in the system to cut off the flow of current among them. This protects the system's electrical components while still allowing for communication and data exchange as usual between electric circuits.
- For example, you can use Hall effect sensors which incorporate magnetism to transfer data across isolated system components.
- By allowing no DC paths, isolation keeps unintended current from flowing between the system segments.

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Why Isolate Your Systems?

- Isolation is often required in real-time data acquisition applications such as:
- Medical Devices
- Automotive manufacturing
- Machine monitoring (turbines, motors, etc.)
- Food processing operations
- Many other heavy industrial uses

- One excellent reason to use isolated data acquisition systems is to protect yourself or your personnel from electrical accidents.
- In particular, galvanically-isolated systems protect operators from being exposed to unsafe currents and high voltage.
- Otherwise, current flowing between the system's units can cause serious harm.
- Electrical isolation also ensures that your system's circuits are safe from damage from excessive current and voltage levels.
- Isolated measurement systems ensure that your measurements are free (as much as possible) from signal noise.

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- While it's true that all measurements have a certain amount of inaccuracy, if you're working in a high-accuracy application then you'll need to reduce this inaccuracy as much as possible.
- An isolated design helps to prevent signal noise by likewise preventing ground loop feedback. Galvanic isolation offers an additional benefit in the form of common-mode voltage rejection, which reduces signal noise by ignoring those signals (voltages) which are common to both inputs.
- This is especially useful if you're trying to record accurate measurements in areas with high levels of electromagnetic interference.

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- For the average user of a data acquisition system, the most likely risk is that the analog/digital signals will be corrupted or that the system will be damaged as a result of unintended ground current flow.
- Ground loops pose one of the greatest threats, both to measurement signals and to users themselves:
- • Data Loss: Networked data systems lacking isolation are at great risk of losing data through signal degradation.
- Isolation safeguards data from signal degradation while also helping to protect your initial investment in your data acquisition system.

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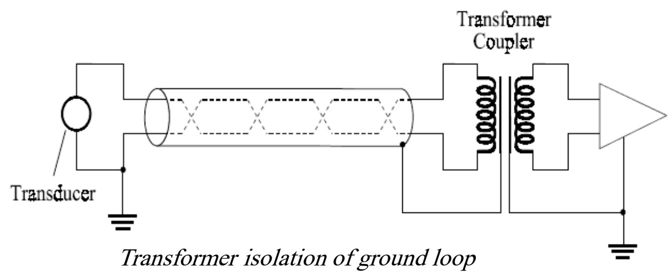
- Physical harm: Users of non-isolated systems face a real risk of harm caused by high current or voltage. Isolation prevents these ground loops from forming, thereby protecting the system and measurement signals.
- If you need to take additional precaution, galvanic isolation prevents ground loops by preventing the current paths which cause current to flow between units in the first place (i.e. by breaking the loop).

Signal circuit isolation

- Where a signal conductor is required to be earthed/grounded at both ends and additional noise immunity is required, the ground loop should be broken by isolating the signal source from the measuring equipment.
- Isolation by the use of transformers, opto-couplers and common mode chokes, is shown next



Transformer isolation of ground loop

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Transformer isolation of ground loop

- When a transformer is used to isolate the signal source from the measurement system the common mode voltage appears between the windings of the transformer and not at the input to the measurement circuit.
- Noise coupling between the circuits is very small and dependent on any stray capacitance between the transformer windings.
- Disadvantages with using transformers are that they are quite large and costly, especially where several signal circuits have to be isolated.
- In addition, transformers have limited frequency response and provide no DC continuity from the signal source to the measurement system.

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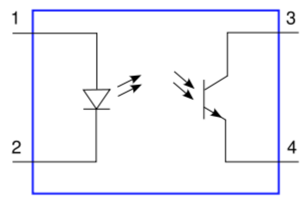
Optocouplers

It consists of a light emitting diode and photo transistor pair



The opto-coupler are typically used more for digital signals because of their non-linearity to analog signals.

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Optocouplers

- LED for emitter
- Air as barrier for isolation
- Phototransistor for detector

- Transformer is similar, but only for AC
- Optocoupler can be used for DC

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When to Use?

- There are many situations where signals and data need to be transferred from one subsystem to another within a piece of electronics equipment, or from one piece of equipment to another, without making a direct electrical connection.
- Often this is because the source and destination are at very different voltage levels, like a microprocessor which is operating from 5V DC but being used to control a triac which is switching 240V AC.
- In such situations the link between the two must be an isolated one, to protect the microprocessor from overvoltage damage.
- Where small size, higher speed and greater reliability are important, it is much better to use an opto-coupler.
- These use a beam of light to transmit the signals or data across an electrical barrier, and achieve excellent isolation

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Parameters

- The most important parameter for optocouplers is their **isolation.**
- The second most important parameter is **transfer efficiency**, measured as the current transfer ratio or CTR.
- CTR is simply the ratio between a current change in the output transistor and the current change in the input LED which produced it.
- Typical values for CTR range from 10% to 50% for devices with an output phototransistor and up to 2000% or so for those with a Darlington transistor pair in the output.

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Parameters

- **Optocoupler's bandwidth** - determines the highest signal frequency that can be transferred through it
- Typical opto-couplers with a single output phototransistor may have a bandwidth of 200 - 300kHz, while those with a Darlington pair are usually about 10 times lower, at around 20 - 30kHz.

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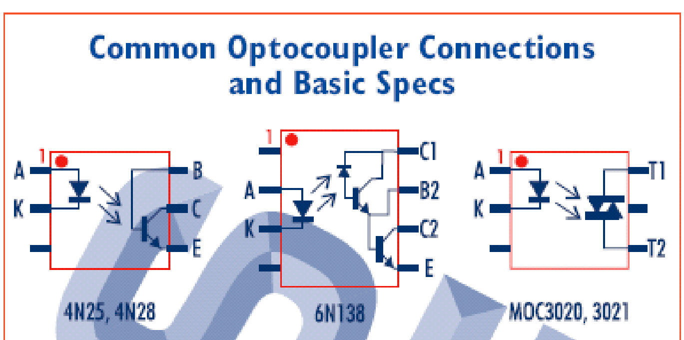

Darlington Pair

TYPE	ISOLATION (V_{ISO})	INPUT LED $I_{F(max)}$	OUTPUT $V_{CE(max)}$	CTRmin (@ I_F)	BANDWIDTH (kHz)
4N25	5300Vrms	80mA	7V	20% (10mA)	300
4N28	5300Vrms	80mA	7V	10% (10mA)	300
6N138	2500Vrms	20mA	7V	300% (1.6mA)	~20
MOC3020	7500Vpk	50mA	Voff = 400V	(Trig. @ 30mA)	—
MOC3021	7500Vpk	50mA	Voff = 400V	(Trig. @ 15mA)	—

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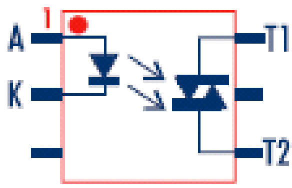

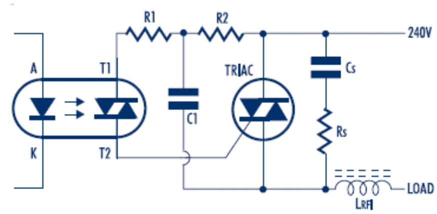

- The other main type of optocoupler is the type having an output Diac or bilateral switch, and intended for use in driving a Triac or SCR.

- Examples of these are the MOC3020 and MOC3021.
- Here the output side of the opto-coupler is designed to be connected directly into the triggering circuit of the Triac where it's operating from and floating at full 120/240 VAC

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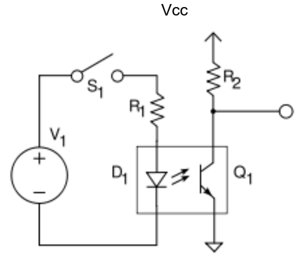

- A simple circuit with an opto-isolator.
- When switch S1 is open, LED D1 is off, so Q1 is off and no current flows through R2, so Vout = Vcc.
- When switch S1 is closed, LED D1 lights.
- Phototransistor Q1 is now triggered, so current flows through R2
- Vout is then pulled down to low state.
- This circuit, thus, acts as a NOT gate.

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Mechanical Relays

- Mechanical Relays can also provide isolation, but even small relays tend to be fairly bulky compared with ICs.
- Because relays are electro-mechanical, they are not as reliable and are only capable of relatively low speed operation.

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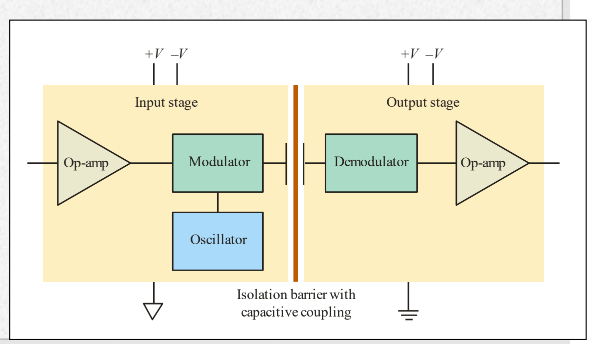
An **isolation amplifier** is designed to provide an electrical barrier between the input and output in order to provide protection in applications where hazardous conditions exist.

A typical isolation amplifier uses a high frequency modulated carrier frequency to pass a lower frequency signal through the barrier.



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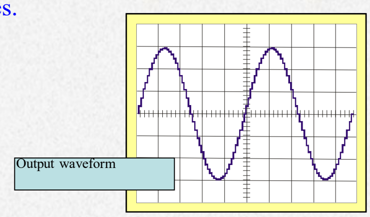
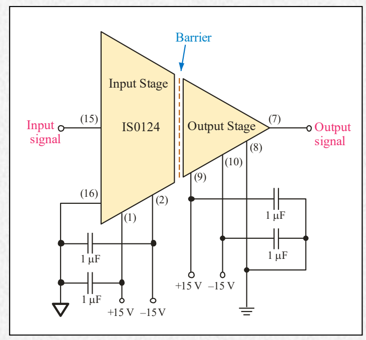
Isolation Amplifiers

The ISO124 is a capacitively-coupled isolation amplifier that uses pulse width modulation to transmit data across the barrier.

The ISO124 has fixed unity gain and is rated to 1500 Vrms of isolation.
The frequency response is specified to 50 kHz, but high-frequency ripple due to the PW modulation may be observed on the output at higher frequencies.





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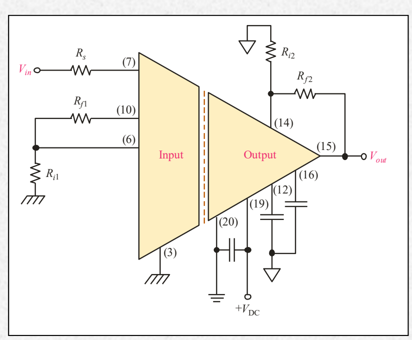
Isolation Amplifiers

The 3656KG is a transformer coupled isolation amplifier that uses pulse width modulation to transmit data across the barrier.

The 3656KG can have gain for both the input and output stages. The 3656KG is suited for patient monitoring applications, such as an ECG amplifier. The manufacture’s data sheet shows detailed connection diagrams for various applications1.

http://focus.ti.com/lit/ds/symlink/3656.pdf



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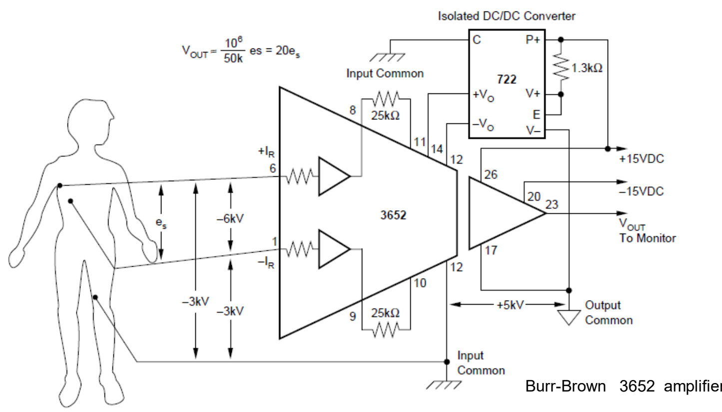
Isolation Amplifier

- Mandatory for use in medical equipment to isolate patients body connected electrodes from the equipment grounds

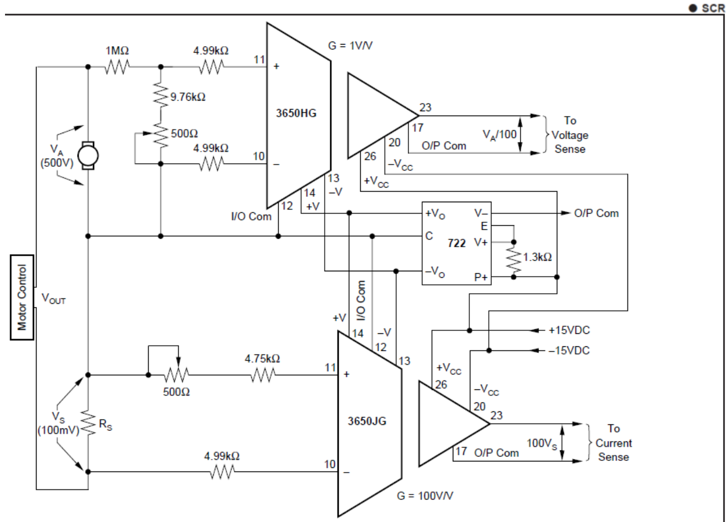


Burr-Brown 3652 amplifier

Isolation Amplifier

- Isolated current & voltage sensor

APPLICATIONS
- INDUSTRIAL PROCESS CONTROL
- DATA ACQUISITION
- INTERFACE ELEMENT
- BIOMEDICAL MEASUREMENTS
- PATIENT MONITORING
- TEST EQUIPMENT
- CURRENT SHUNT MEASUREMENT
- GROUND-LOOP ELIMINATION
- SCR CONTROLS



. Isolated Armature Current and Voltage Sensor.

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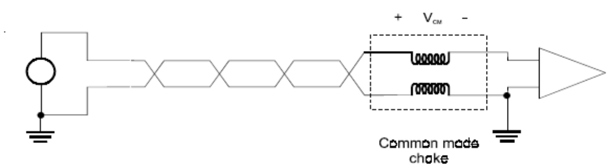
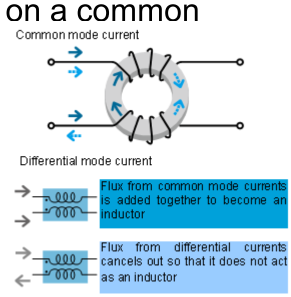
Common Mode Choke

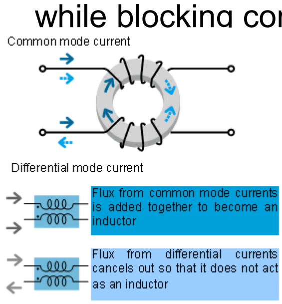
- When a transformer is connected as a common mode choke, as shown below
- DC and differential analog signals are transmitted while common mode AC signals are rejected.
- The common mode noise voltage appears across the windings of the choke.
- One big advantage with this type of isolation circuit is that multiple signal circuits can be wound on a common core without coupling.

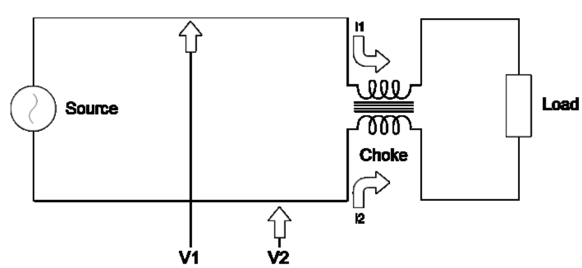




Common-mode choke

- Common-mode chokes, where two coils are wound on a single core, are useful for prevention of electromagnetic interference (EMI) and radio frequency interference (RFI) from power supply lines and for prevention of malfunctioning of electronic equipment.
- They pass differential currents (equal but opposite), while blocking common-mode currents.





A typical common-mode choke configuration. The common mode currents, I1 and I2, flowing in the same direction through each of the choke windings, creates equal and in-phase magnetic fields which add together. This results in the choke presenting a high impedance to the common mode signal.

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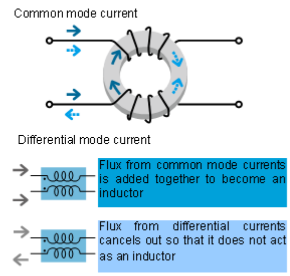
- Magnetic fields produced by differential-mode currents in the windings tend to cancel each other out; thus the choke presents little inductance or impedance to differential-mode currents.
- This also means the core will not saturate even for large differential-mode currents, and the maximum current rating is instead determined by the heating effect of the winding resistance.
- Common-mode currents, however, see a high impedance due to the combined inductance of the windings.



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Filtering

- Processing of signal to remove certain band of frequencies from it
- Filters can be classified as : low pass (LPF), high pass (HPF), band-pass (BPF) , band stop (BSF)
- Also filters can be classifiesd as:
  - passive (contain R,L, C)
  - Active (opamp , R,C)

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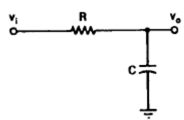
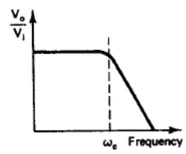
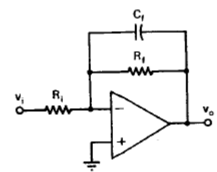
Reminder

- 1st order LPF







$\tau = RC$

$\omega_c = 1/\tau$

$\dfrac{V_o}{V_i} = \dfrac{1}{1 + j\omega\tau}$

$\phi = \tan^{-1}(-\omega\tau)$

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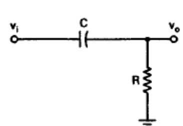
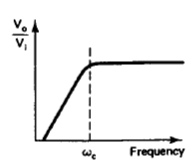
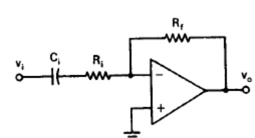
- 1st order HPF







$$\frac{V_o}{V_i} = \frac{j\omega\tau}{1 + j\omega\tau}$$

$$\phi = \tan^{-1}(1/\omega\tau)$$

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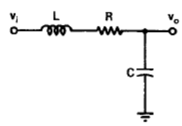
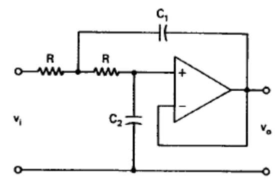
- 2nd order LPF

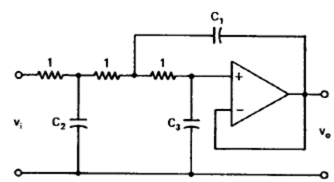


$$\frac{V_o}{V_i} = \frac{1}{(j\omega/\omega_c)^2 + (2\,\zeta\, j\omega/\omega_c) + 1}$$

$$\zeta = (R/2)(C/L)^{1/2}$$

$$Q = 1/(2\zeta) = \omega_c/\Delta\omega,$$





Normalized third order LPF filter

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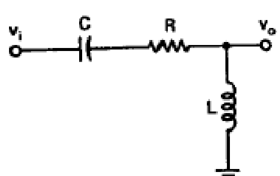
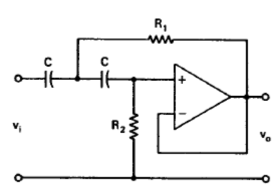
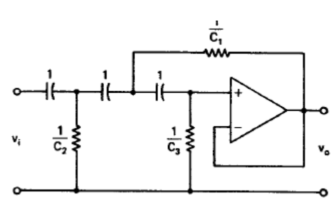
- 2nd order HPF





Second order HPF filter



Normalized third order HPF filter

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Op-amp Considerations for active filters

- In most cases we have assumed **<u>an ideal op-amp</u>**, now we consider some non-ideal characteristics:
- The Gain Bandwidth Product
- Input Offset Voltage
- Slew Rate

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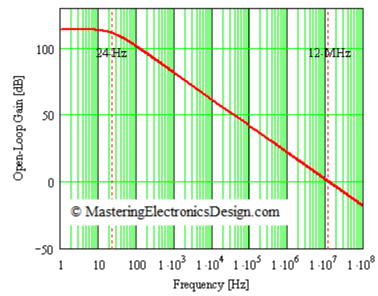
Op-amp Considerations

- The Gain Bandwidth Product describes the op amp gain behavior with frequency.
- Manufacturers insert a dominant pole in the op amp frequency response, so that the output voltage versus frequency is predictable.
- Why do they do that?
- Because the operational amplifier, which is grown on a silicon die, has many active components, each one with its own cutoff frequency and frequency response.
- Because of that, the operational amplifier frequency response would be random, with poles and zeros which would differ from op amp to op amp even in the same family.
- As a consequence, manufacturers thought of introducing a dominant pole in the schematic, so that the op amp response becomes more predictable.
- It is a way of "standardizing" the op amp frequency response. At the same time, it makes the op amp more user friendly, because its stability in a schematic becomes more predictable.

Gain Bandwidth Product (GBW)

- GBW product of an opamp is equal to the product of gain and bandwidth at a particular frequency.
- **The gain bandwidth product is constant** , thus for a non-inverting amplifier circuit, we obtain the bandwidth by dividing the GBW product by the amplifier circuit gain

$$\text{Bandwidth [Hz]} = \frac{\text{Gain Bandwidth Product [Hz]}}{\text{Closed Loop Gain}}$$



- The dominant pole will make the op amp behave like a single-pole system, which has a **drop of 20 dB** for every decade of frequency, starting with the cutoff frequency

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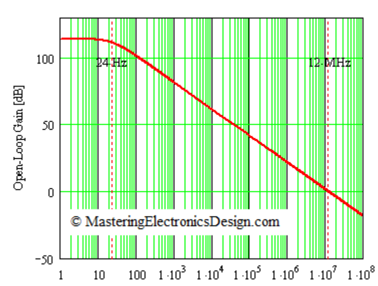
Gain Bandwidth Product (GBW)

- In the case of ADA4004, the gain bandwidth product is 12 MHz.
- This means that, at a gain of one, the bandwidth is 12 MHz, and at the maximum open-loop gain of 500000 (114 dB), the bandwidth is 12 MHz divided by 500000, which is 24 Hz. This is the op amp open-loop cutoff frequency.

$$\text{Bandwidth [Hz]} = \frac{\text{Gain Bandwidth Product [Hz]}}{\text{Closed Loop Gain}}$$



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Input Offset Voltage

- Ideal opamp has the property of zero output voltage when the input voltage is zero
- Practical opamps exhibit this feature; they have an input offset voltage.
- **The input offset voltage is the voltage that must be applied between the input terminals to get zero output**
- The offset voltage is not important when dealing with voltages above 1 V
- The offset voltage is nulled by introducing an opposing voltage at one of the opamp terminals according to data sheet of particular opamp.

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Input Bias Current

- In practical opamps, the current flowing into the terminals is not zero
- In order to keep the input transistor of the opamp on, a base or gate current called input bias current is required all the time
- When this current flows through the feedback network it causes errors
- To minimize these errors, feedback resistors should be kept low such as below 10K
- **The effect of bias currents is reduced or eliminated by making the impedances seen by each input of the opamp almost equal**

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Slew Rate

- **Slew Rate (SR) is the maximum rate of change of amplifier output voltage**
- When rapid changes are demanded in the output, the current available to charge and discharge the compensation cap is limited and slew rate limiting occurs, for example a 741 opamp has SR of 0.5V/uS
- Thus the output cannot change from -5V to +5V in less than 20 us

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Slew Rate (SR)

Slew rate (SR) is the maximum rate at which an op-amp can change output without distortion.

$$SR = \frac{\Delta V_o}{\Delta t} \quad \text{(in V/}\mu\text{s)}$$

The SR rating is given in the specification sheets as V/µs rating.

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Maximum Signal Frequency

The slew rate determines the highest frequency of the op-amp without distortion. assume input and output are sinusoidal

Vo=Vop sinωt

$$f \leq \frac{SR}{2\pi V_p}$$

where V_{op} is the peak output voltage

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Power Supply

Power Supply

The usual supply voltages are ±15 V. When v_o is allowed to exceed the op-amp biasing voltages the op amp will saturate and is said to be out of the amplifier's linear range (typically ±13 V). We may reduce the power-supply voltage, but this also reduces the linear range. When the power supply goes below approximately 4 V the internal biasing voltages of the device are not satisfied.

It would be convenient always to have dual-polarity power supplies available in equipment or circuits using op amps. Unfortunately, this is not possible. There are, however, certain circuitry tactics for using the operational amplifier in single-polarity configurations. One solution is to ground the minus supply terminal, while the positive is connected to V_{cc} in the usual way. Figure 1.17 shows this circuit. The noninverting input is connected to a junction on a voltage-divider network. This effectively raises the operating point above ground.

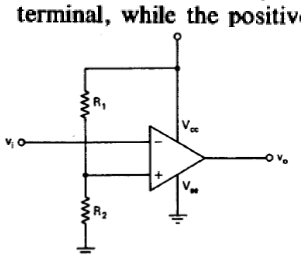

Figure 1.17 Single power-supply circuit.

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Different Op Amps

Op amps are bipolar or FET types. The bipolar op amps have a pair of bipolar input transistors. They have good input offset voltage stability but moderate input bias currents and input resistances. FET-input op amps with a pair of input FETs offer very low input bias currents and very high input resistances but have poor input offset voltage stability (Dostal, 1981).

Programmable Op Amps

A programmable op amp such as the UC4250 permits setting the power consumption and dynamic properties of the op amp. By adding the proper external resistor, we can adjust the quiescent supply current [the operating current flowing in a circuit during zero-signal (idle) intervals]. Lower quiescent currents yield lower frequency responses and lower output current capabilities (Dostal, 1981).

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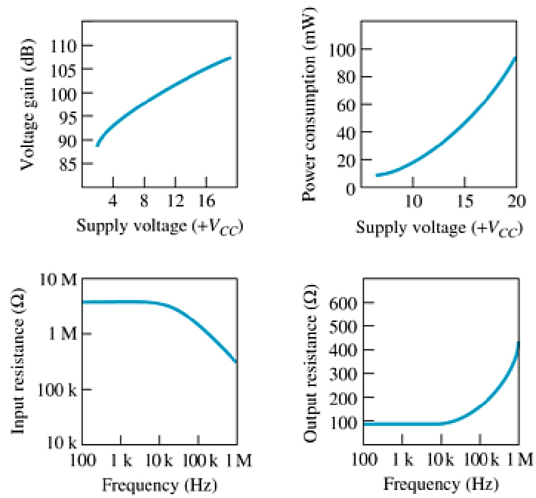
Common opamps

Type	Feature	Input bias current	Offset voltage	GBW	Price
741	Low cost	80 nA	2 mV	1 MHz	$0.35
308	Low bias current	3 nA	2 mV	1 MHz	0.69
ICL8007	FET input	50 pA	50 mV	1 MHz	5.00
CA3130	FET input	6 pA	20 mV	4 MHz	0.89
OP-07	Low offset	1 nA	30 μV	800 kHz	1.99
LH0052	Low offset	0.5 pA	0.1 μV	1 MHz	5.00
LF351	High GBW	50 pA	5 mV	4 MHz	0.62
LM312	Low bias current	3 nA	0.7 mV	1 MHz	2.49
UC4250	Programmable	7.5 nA	4 mV	800 kHz	1.84

	Iomax	funity	slew rate (V/uS)
	mA	MHz	(V/uS)
LF353	20	4	13
LF356	20	5	12
LM318	21	15	70
LM739	1.5	6	1
NE531	20	1	35
TL072	10	3	13
LM741	25	1	0.5
TL074	17	4	13

Op-Amp Performance

The specification sheets will also include graphs that indicate the performance of the op-amp over a wide range of conditions.



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Example

- Design a 1st order LPF for the audio frequency (< 20 kHz) and a dc gain =11 using a LM741C opamp with GBW=1Mhz, SR=0.5 V/us , input impedance 3 Mohm
- What is peak value of output the voltage that can be obtained considering the SR? assume input is sinusoidal.

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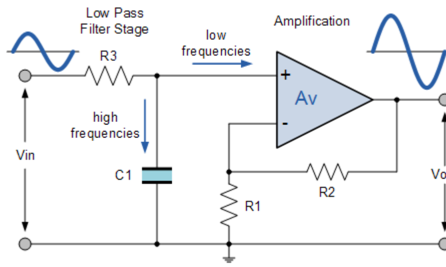
Example solution

- Dc gain k= 1+R2/R1=11 ==> R2/R1=10
- Choose R1=5kΩ, ==> R2=50 kΩ
- For balance of resistance at both opamp terminals choose R3=R1//R2
- R3=5k//50k=4.55kΩ
- fc=20 kHz=1/(2πR3C1)
- ==> C1=1.75 nF



- Now assuming Vo=Vp sinωt
- And we can find the ΔV/Δt= ωVp cosωt or slow rate as the max value of ΔV/Δt which is equal to : SR= ωVp =2πf Vp
- and the max allowable values of Vi and Vo are

$$V_{op} \le \frac{SR}{2\pi f}$$

$$V_{op} \le \frac{0.5\ V/\mu sec}{2\pi(20000)Hz} = 3.98\ V$$

$$Vi(peak) \le \frac{3.98}{11} = 0.362\ V$$

Amplification & other Functions

- Non Inverting amplifier
- Inverting amplifier
- Difference amplifier
- Instrumentation amplifier
- Integrator
- Differentiator
- Log amplifier
- Anti-log amplifier
- Trans-conductance Amplifier
- Rectifiers

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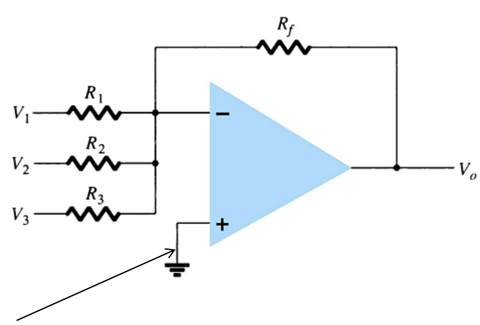
Voltage Summing

The output is the sum of individual signals times the gain:

$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$



Add resistance of equal
=R1//R2//R3//Rf

[Formula 14.3]

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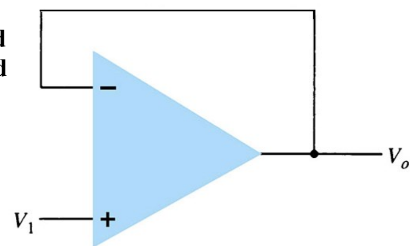
Voltage Buffer

Any amplifier with no gain or loss is called a unity gain amplifier.
The advantages of using a unity gain amplifier:

- **Very high input impedance**
- **Very low output impedance**

Realistically these circuits are designed using equal resistors ($R_1 = R_f$) to avoid problems with offset voltages.



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Difference Amplifier

$$V_{out} = aV_1 - bV_2$$

$$a = \left(1 + \frac{R_4}{R_2}\right) * \frac{R_3}{R_3 + R_1} = \left(\frac{R_2 + R_4}{R_2}\right) * \frac{R_3}{R_3 + R_1}$$

$$b = \frac{R_4}{R_2}$$

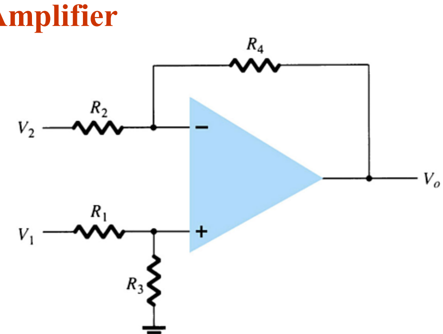
for

$$R4 = R3 = mR$$

$$R1 = R2 = R$$

$$\& \, a = b = m$$

$$V_{out} = m(V_1 - V_2)$$



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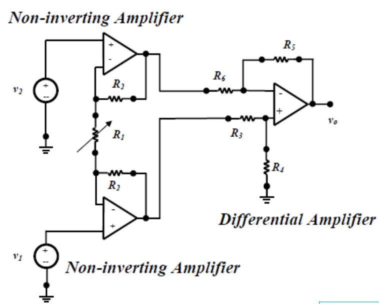
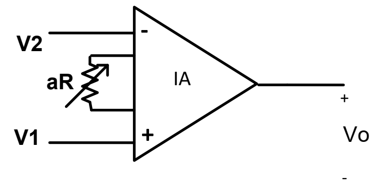
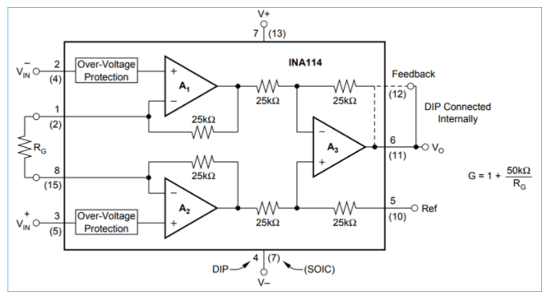
IA





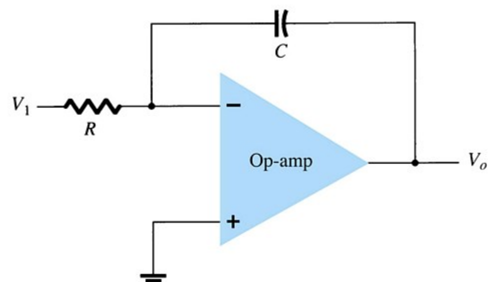
$$= \left(1 + \frac{2}{a}\right)(V_1 - V_2)$$



Integrator

The output is the integral of the input. Integration is the operation of summing the area under a waveform or curve over a period of time. This circuit is useful in low-pass filter circuits and sensor conditioning circuits.

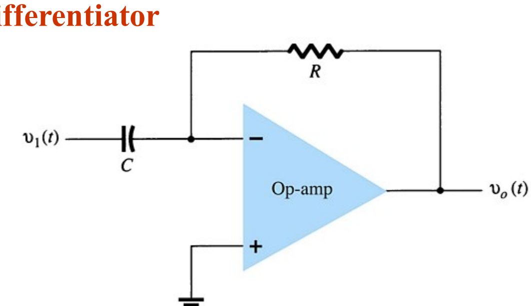
$$v_o(t) = -\frac{1}{RC}\int v_1(t)dt$$



Differentiator

The differentiator takes the derivative of the input. This circuit is useful in high-pass filter circuits.

$$v_o(t) = -RC\frac{dv_1(t)}{dt}$$



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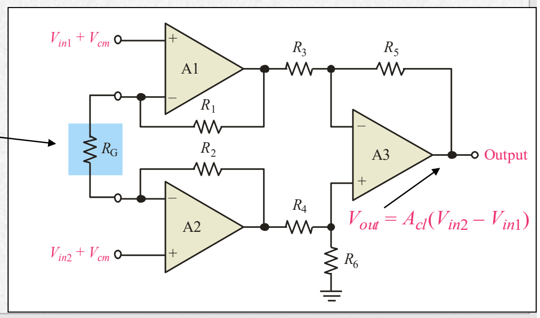
Signal Conditioning

Practical Example of an Instrumentation Amplifiers

An **instrumentation amplifier** (IA) amplifies the voltage difference between its terminals. It is optimized for small differential signals that may be riding on a large common mode voltages.

The gain is set by a single resistor that is supplied by the user.

The output voltage is the closed loop gain set by R_G multiplied by the voltage difference in the inputs.



Signal Conditioning

Instrumentation Amplifiers

An IA that is based on the three op-amp design is the AD622. The formula for choosing R_G is:

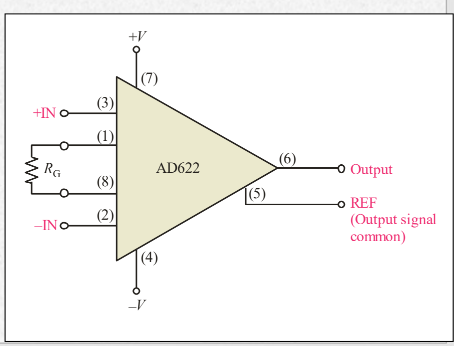
$$R_G = \frac{50.5\ \text{k}\Omega}{A_v - 1}$$

Example: What value of R_G will set the gain to 35?

Solution:

$$R_G = \frac{50.5\ \text{k}\Omega}{A_v - 1} = \frac{50.5\ \text{k}\Omega}{35 - 1}$$

$= 1.5\ \text{k}\Omega$



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Signal Conditioning

Instrumentation Amplifiers

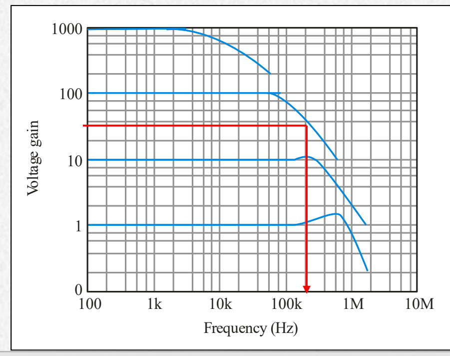
The bandwidth of any IA (or op-amp for that matter) is lower for higher gain. The graph shows the BW for various gains for the AD622.

Question:

What is the BW for a gain of 35?

Answer:

Reading the graph, the BW is approximately 200 kHz.



Summary

The Operational Transconductance Amplifier

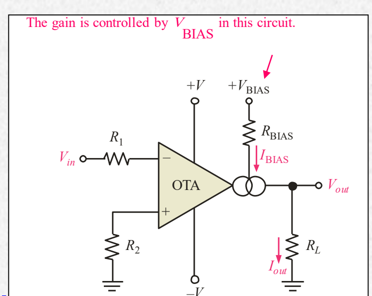
The **operational transconductance amplifier** (OTA) is a voltage-to-current amplifier. As in the case of FETs, the conductance is output current divided by input voltage. Thus,

$$g_m = \frac{I_{out}}{V_{in}}$$

Like FETs, the gain of an amplifier is written in terms of g_m: $A_v = g_m R_L$

Unlike FETs, the OTA has a g_m that can be "programmed" by the amount of bias current.

Thus gain can be changed electronically by varying a dc voltage.



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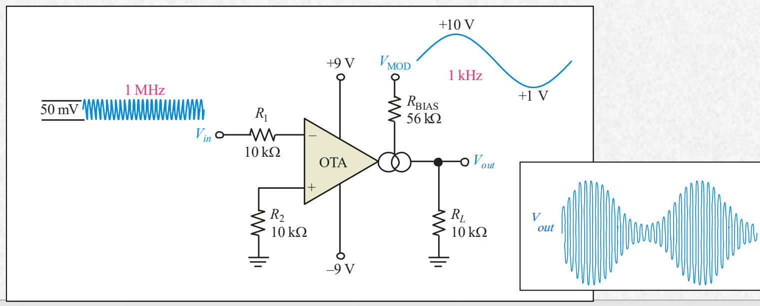
Summary

The Operational Transconductance Amplifier

The OTA adds a measure of control to circuits commonly implemented with conventional op-amps. Applications for OTAs include voltage controlled low-pass or high-pass filters, voltage controlled waveform generators and amplifiers, modulators, comparators, and Schmitt triggers.

In this example, an amplitude modulator is shown.



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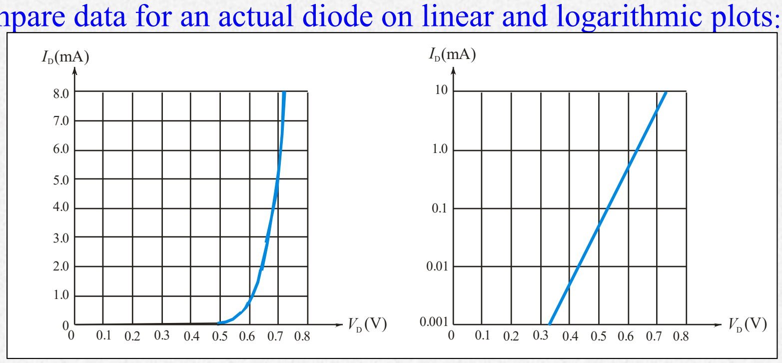
Summary

The Logarithmic Amplifier

A diode has the characteristic in which voltage across the diode is proportional to the log of the current in the diode.

Compare data for an actual diode on linear and logarithmic plots:



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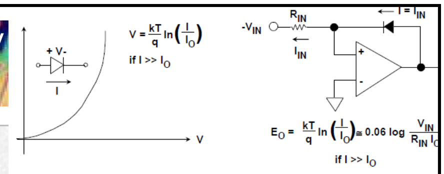
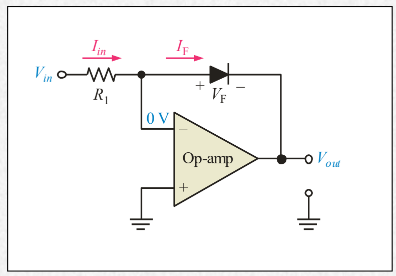


The Logarithmic Amplifier

When a diode is placed in the feedback path of an inverting op-amp, the output voltage is proportional to the log of the input voltage. The gain decreases with increasing input voltage; therefore the amplifier is said to compress signals.

Many sensors, particularly photo-sensors, have a very large dynamic range outputs.

Current from photodiodes can range over 5 decades. A log amp will amplify the small current more than the larger current to effectively compress the data for further processing.



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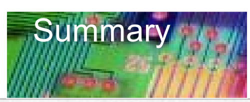


The Logarithmic Amplifier

For the circuit shown, the equation for V_{out} is

$$V_{out} \cong -(0.025\ \text{V})\ln\frac{V_{in}}{I_R R_1}$$

(I_R is a constant for a given diode.)

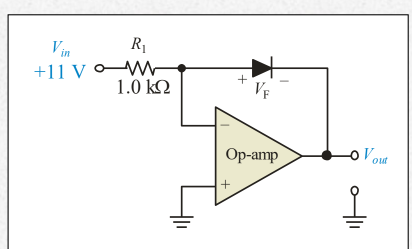
Example:

What is V_{out}? (Assume I_R = 50 nA.)

Solution:

$$V_{out} \cong -(0.025\ \text{V})\ln\frac{11\ \text{V}}{(50\ \text{nA})(1.0\ \text{k}\Omega)}$$

$= -307$ mV



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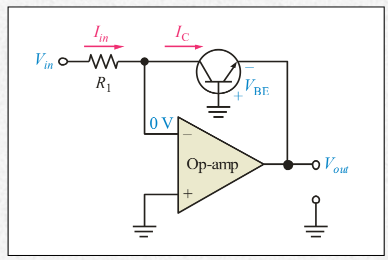
The Logarithmic Amplifier

When a BJT is used in the feedback path, the output is referred to the ground of the base connection rather than the virtual ground. This eliminates offset and bias current errors. For the BJT, I_{EBO} replaces I_R in the equation for V_{out}:

$$V_{out} = -(0.025\ \text{V})\ln\frac{V_{in}}{I_{\text{EBO}}R_1}$$

Log amplifiers are available in IC form with even better performance than the basic log amps shown here.

For example, the MAX4206 operates over 5 decades and can measure current from 10 nA to 1 mA.



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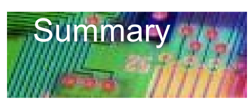


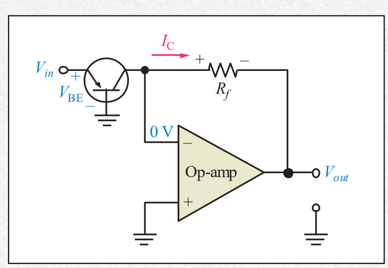
The Antilog Amplifier

An antilog amplifier produces an output proportional to the input raised to a power. In effect, it is the reverse of the log amp. The equation for V_{out} for the basic BJT antilog amp is:

$$V_{out} = -R_f I_{\text{EBO}}\,\text{antilog}\frac{V_{in}}{25\ \text{mV}}$$

IC antilog amps are also available. For example, the Datel LA-8048 is a log amp and the Datel LA-8049 is its counterpart antilog amp.

These ICs are specified for a six decade range.



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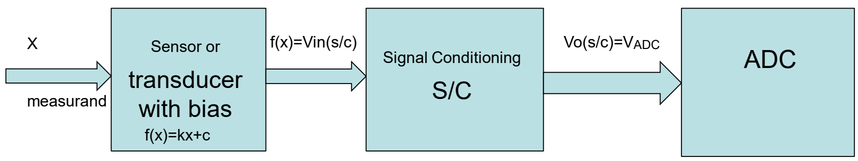
Bias Removal

- The signal conditioning block have two functions in this case:



- First is to remove the bias
- Second is to make the output range of s/c block match or equal the input range of the ADC block for best system resolution

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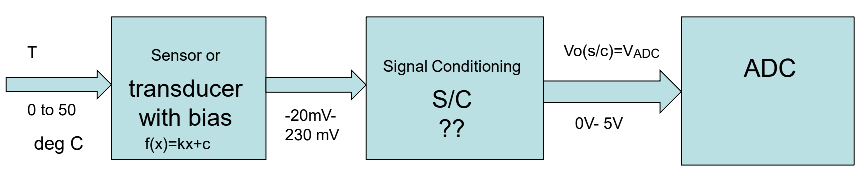
Linearization (Bias Removal)



- Example : a sensor output changes from -20mV to +230mV as the temperature changes from 0 to 50 deg C
- Design and implement a s/c circuit such that its output matches the input range of the ADC 0-5V

x =T [C]	f(x)=Vin(sc)	Vo(sc)
0	-20mV	0
50	230mV	5

- Assuming that the sensor output is linearly dependant on the input
- Vo(sc) = a Vi(sc)+ b
- 0 = a (-20mV)+b ➔ b=0.02 a (1)
- 5V= a (230 mV)+ b (2)
- Substitute (1) in (2) and pay attention to units yields
- 5000mV =250mV x a ➔ a=20; b =0.4
- Vo(sc) =20 Vi(sc)+0.4

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- Vo(sc) =20 Vi(sc)+0.4
- =20(Vi(sc)-(-0.02))

- The above function can be implemented in different ways such as instrumentation amplifier, difference amplifier and others

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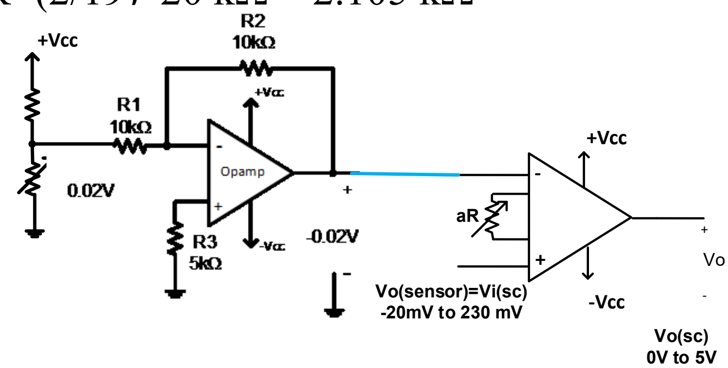
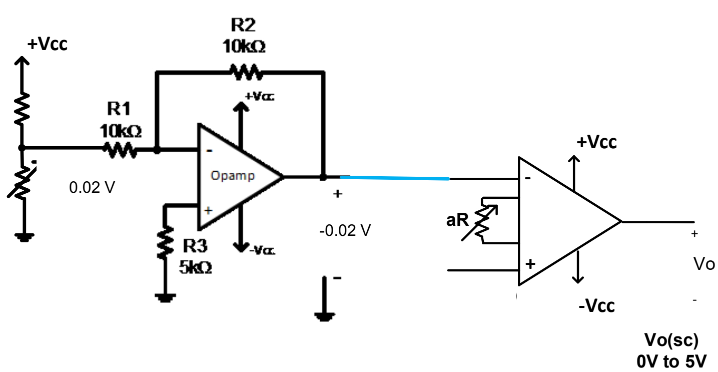
Implementation using IA

- 1+2/a=20 ==> a=2/19
- Assume Internal resistance of IA=20kΩ

then aR=(2/19)*20 kΩ = 2.105 kΩ





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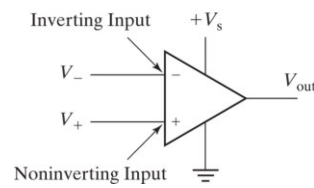
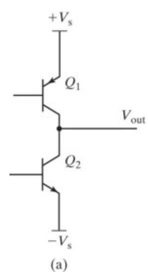
The Comparator

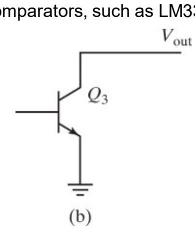


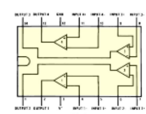
- A specially designed op-amp, optimized to switch V_{out} *fast*
  - If V+ > V-, then $V_{out} \approx$ Vs
  - If V- > V+, then $V_{out} \approx 0$ V
- But usually output is '*open collector*'
  - Can pull *low*, but…
  - Needs external resistor (pull-up) to go high

Typical op-amp output stage and *some* comparators (Push-Pull (Totem Pole))



<u>Open collector</u> output stage (typical of most comparators, such as LM339)





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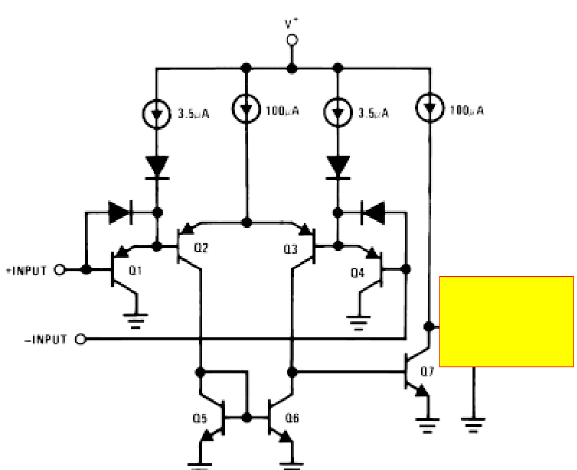
Inside the LM339 comparator



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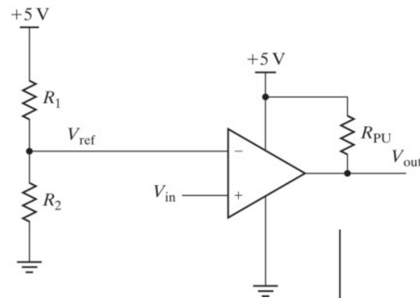
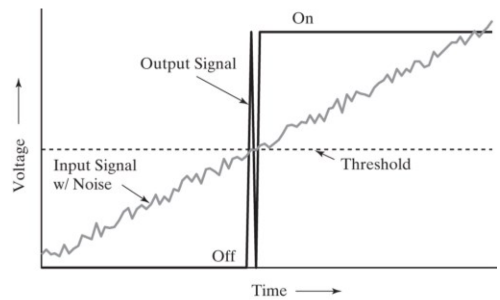
Simple Non-inverting Comparator

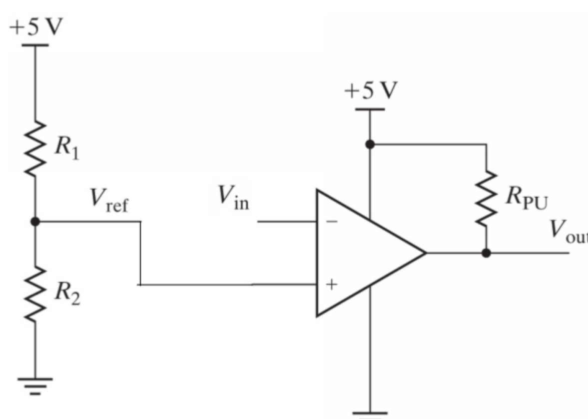


Intro to Mechatronic Design, Fig. 11.19, p. 246



Intro to Mechatronic Design, Fig. 11.20, p. 247

Inverting Comparator



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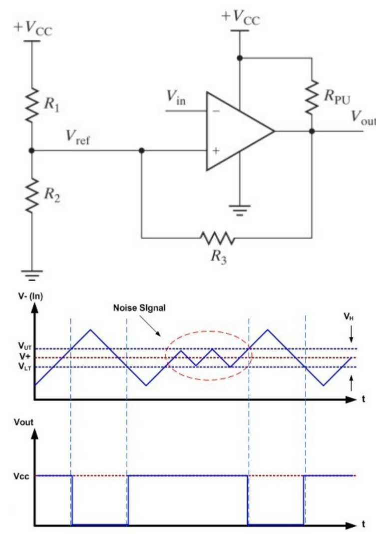
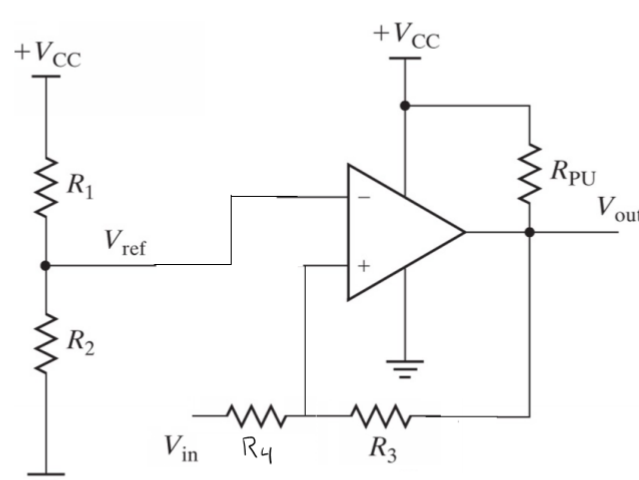
Inverting Comparator with Hysteresis

- Add hysteresis (i.e., a *change* in V_{ref} that depends on V_{out} by feeding back to the *non-inverting* terminal
  - When the input voltage *rises* to the threshold, the threshold *drops* to a *lower* value
  - When the input voltage *drops* to the threshold, the threshold is *raised* to a *higher* value



http://www.ermicro.com/blog/wp-content/uploads/2010/03/comp_10.jpg

Non-inverting comparator with hysteresis



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