Data Conversion and Lab (17.368)

Fall 2013

Lecture Outline

Class # 01

September 05, 2013

Dohn Bowden

Today's Lecture Outline

- Course Admin
- General Course Overview
- Detailed Technical Discussions
  - Basic Analog
  - Quick Look at ADC
  - The Op Amp
  - The Comparator
- Lab
- Homework

Course Admin

Administrative

- Admin for tonight ...
  - Attendance/Introductions/Backgrounds
  - Syllabus
  - Textbook
  - 17.368 Web Site
  - Email List creation
  - Course Objectives

Attendance / Introductions / Backgrounds

- Attendance ...
  - When called ... please introduce yourself
    - Include the following
      - Education
      - Work Experience
      - Other notable work/engineering/hobbies
      - Future Plans

My Background

- Education
- Work Experience
- Other notable work/engineering/hobbies
- Future Plans

Syllabus

- Syllabus ...

  - Hard copies will be distributed
  - Electronic copy available on the class website
    - Web Address on syllabus

- Syllabus details ...

  - Next slide

Syllabus Review

Week	Date	Topics	Lab	Lab Report Due
1	09/05/13	Introduction/Basic Data Conversion, Course Overview, Op Amps in Data Conversion		
2	09/12/13	Op Amp Lab	1	
3	09/19/13	Sample and Hold Lecture and Lab	2	
4	09/26/13	A/D Conversion Fundamentals and Lab	3	1
5	10/03/13	A/D Conversion Lab Continuation	3 con't	
6	10/10/13	**Examination 1**		
7	10/17/13	D/A Conversion Fundamentals and Lab	4	2
8	10/24/13	D/A Conversion Lab Continuation		
9	10/31/13	Microcontroller and Sensors	4 con't	3
10	11/07/13	Microcontroller and Sensor Lab	5	
11	11/14/13	V/F and F/V Conversion Lecture	5 con't	4
12	11/21/13	**Examination 2**	Project	5
X	**11/28/13**	**No Class – Thanksgiving**		
13	12/05/13	Work on Course Project	Project	
14	12/12/13	Final Exam/Course Project Brief and Demonstration	Demo	

Grading Policy

- Located at the bottom of syllabus
- Exam # 1 (20%)   Exam #2 (20%)
- Laboratory ... including lab reports (30%)
- Final Exam/Course Project (30%)

A	93-100	A-	90-92		
B+	87-89	B	83-86	B-	80-82
C+	77-79	C	73-76	C-	70-72
D+	67-69	D	60-66		
F	Below 60				

Class Hours

- Thursdays evenings ... 6:30 – 9:20 PM
    - See syllabus for schedule of classes

- Please email me if you will not be in class ...

- I am available for extra help ***Before*** **/** ***After*** class
    - If possible ... please schedule in advance so I will ensure that I am available

- Labs – start to pick-up at approximately 9:05 PM

Textbook

- **Textbook is available on-line**
  - **The Data Conversion Handbook**, Analog Devices, Newnes 2005
    - The text is an Excellent Reference Source
  - We will also utilize other material to complement the class ...
    - Which will be available on-line

Course Web Site

- The Course Web site Homepage is at:

  http://faculty.uml.edu/dbowden

- This website will contain the following:

  - Syllabus
  - Lab material
    - Labs procedures
    - Datasheets
  - Reference documents
    - Such as the textbook material
    - Links
  - Class lectures (will be placed on the web site *AFTER* the lecture)
  - Homework

Email Distribution List

- I will be creating a class email list
- Email me at ...

  Dohn_Bowden@uml.edu

- This will ensure that your correct email address or addresses are included
- The email list will allow me to provide information to each of you

Course Objectives

- What do you want to get out of this class?

- My goals for the course ...

Course Evaluations

- How they are used

Questions?

General Course Overview

General Course Overview

- This is a lecture and a "Hands-on" (Lab) course ...
    - The best way to apply what you learn is by doing!
    - Similar to learning how to drive a car
    - Proficiency through experience

  – Experience with Data Conversion concepts by ...
    - Knowledge of components ... and
    - The identification and application of Data Conversion Techniques

General Course Overview

- Introduces the basic principles of data conversion
  - Along with the reasons we want to utilize them
  - And ...
  - When they should be used
- Covers the theory of operation for practical data conversion
- Theory is complemented with corresponding laboratory experiments

General Course Overview

- An understanding of analog signals
- The representation of an analog signal as a digital value
- Identification of the electronic components used in the conversion process
- Lab assignments
- Conclude with the design and building of a course project
  - Application of the techniques and information covered during the course

General Course Overview

- Typical Lecture/Class Structure
  - Detailed Technical Discussions
  - Lab
    - Overview
    - Lab Conduct
  - Homework

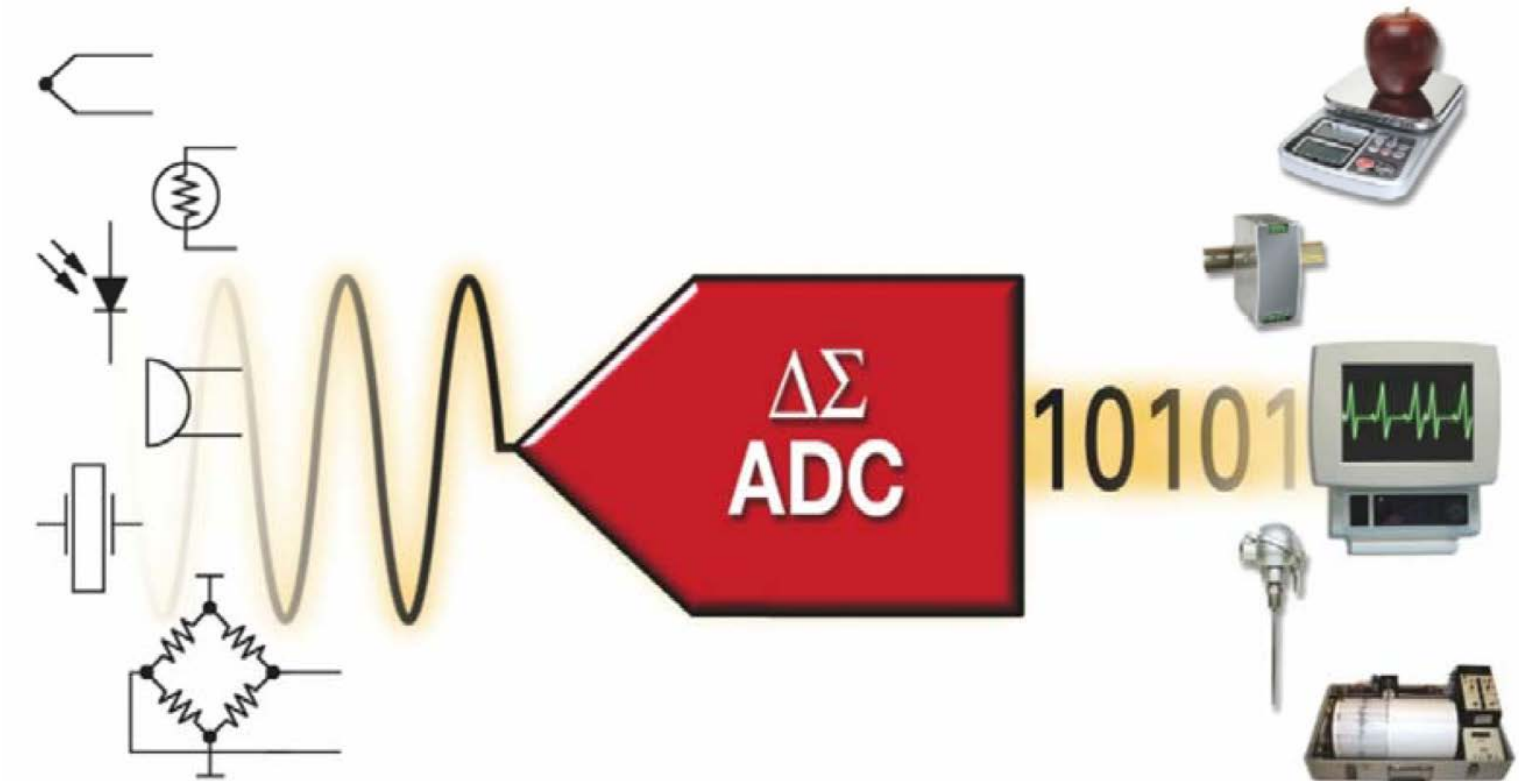
Detailed Technical Discussion

A Quick Look at …

Analog/Digital Signals and the ADC

Where are we headed?

Ultimately ... Signal Conversions from one form to another (I.E. ADC)



Analog Signals

- Real world signals are analog (naturally occurring)
  - For example ... sensors
- We need to be able to take these signals and convert them to a useful format (i.e. digital format) in order to be able to process them with the computer and/or digital logic circuits
- We can design circuits to do these conversions ... or ...
  - Utilize components designed to perform these conversions (for example ... the analog to digital converter)

Analog Fundamentals

- Before we get into the specifics of the Analog to Digital converter lets focus on some fundamentals:

- What is an ***analog*** signal?

  – An ***analog*** signal is **continuous** in amplitude & time within certain limits, i.e., it changes smoothly without interruptions

  – An example ...

    – a sinusoidal signal

Fundamentals

- What is a ***digital*** signal?
  - A ***digital*** signal is **discrete** in amplitude and time ...
    - i.e., it can only take certain specific values within certain limits at specific time intervals
    - When numbers are assigned to these steps (usually binary numbers) the result is a digital signal
    - An example ... a square wave is a 1-Bit digital signal with its high level being a binary ‘1’ and its low level being a binary ‘0’

Analog to Digital Converter

- **What is an *Analog-to-Digital converter*?**
  - An ***Analog-to-Digital converter*** (ADC) is an electronic circuit that changes or converts a continuous analog signal into a digital signal without altering its critical content

Analog to Digital Converter

- **How does an *Analog-to-Digital converter* work?**
  - In the simplest terms ... an *Analog-to-Digital converter* ...
    - *Samples* an analog waveform at uniform time intervals ...

    and ...

    - Assigns a digital value to each sample, which is called *Quantization*

The ADC Process

- Therefore, the ***Analog-to-Digital*** conversion carries out two processes ...

  – ***Sampling***

  and ...

  – ***Quantization***

Sampling

- ***Sampling*** is ...
  - The reduction of a continuous signal to a discrete signal
  - Specifically ... ***Sampling*** is the process of analyzing the continuous analog signal with measurements taken at discrete and standard intervals
    - An example ... the conversion of a sound wave (a continuous-time signal) to a sequence of samples (a discrete-time signal)

Quantization

- *Quantization* is ...
  - The procedure of constraining something from a continuous set of values (such as the real numbers) to a discrete set (such as the integers)

Quantization

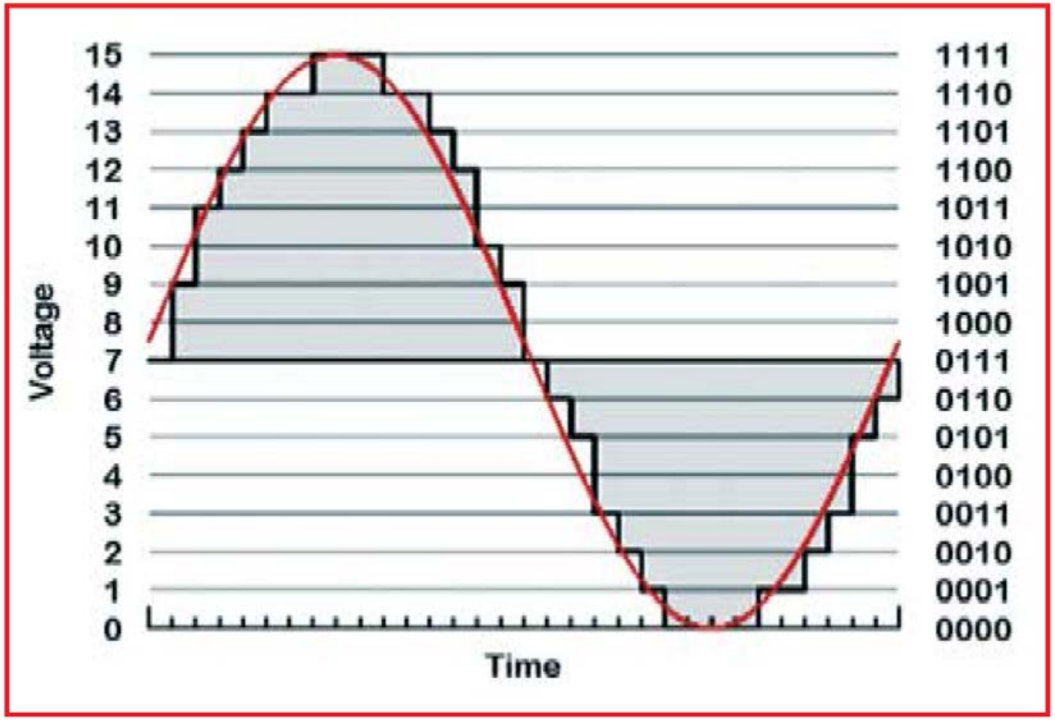
- The ADC represents an analog signal as a digital string of 1's and 0's with finite resolution

    - The ADC outputs a finite number of digital values for each sample taken ...

        – equal to 2^N

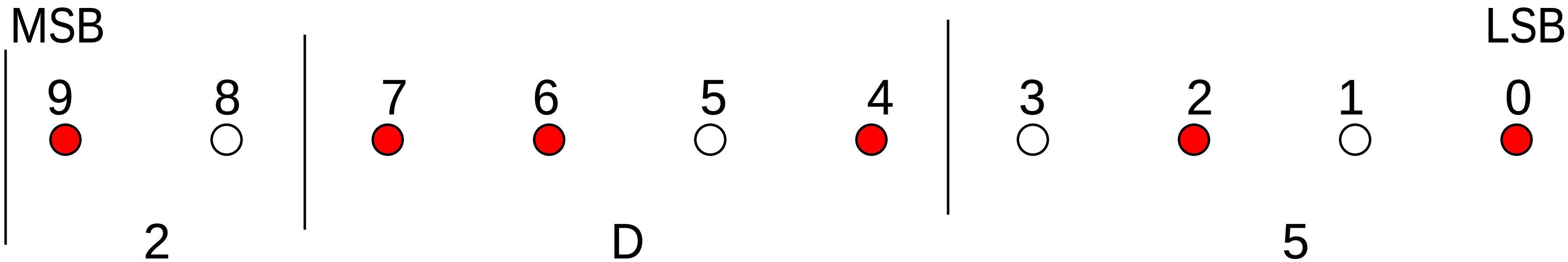
            (where N is the number of bits of the ADC)

We can represent an analog signal as a digital value



Digital Representation of an Analog Signal

- For example ... LEDs (Digital) representation of Analog voltage ...



(###h)*(Vmax/2^N) = voltage   2D5h = 725_{10}

(2D5h)*(5/2^{10}) = 3.54 volts

The Op Amp …

Our First Building Block

Operational Amplifiers (Op Amps)

- Components of the Data Conversion process will be introduced

- Starting with ... the Operational Amplifier

- Operation Amplifiers ... better known as Op-Amps

- As we shall see ...
  - Op amps can be configured in numerous ways (I like to look at an op amp as a "Programmable device")

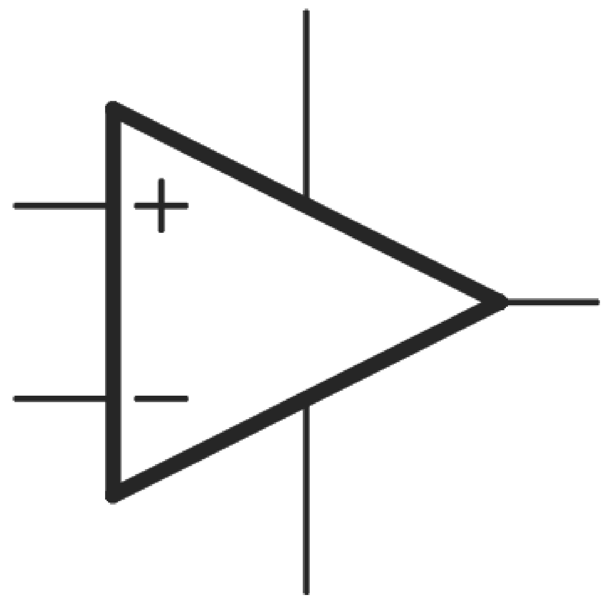
    - Programmable in that we utilizing external components to achieve the desired function, or ***operation***

- For example ... op amp circuits can restore original, weak signals which may be contaminated by "pick-up" and other miscellaneous noise

Operational Amplifiers (Op Amps)

- In this course, we will utilize op amps in ...
  - Sample and Hold circuits (we shall encounter them soon)
  - Conversions between analog and digital systems

The Op Amp ***Universal Symbol***



Op-Amp Attributes

- **Op-Amp** ... ***An analog electronic circuit element***
- First ... ***Ideal*** Op Amp Attributes:
  - Infinite differential gain (High voltage gain)
  - Zero Common Mode Gain
  - Zero Offset Voltage
  - Zero Bias Current

Op Amp *Input* Attributes

- * High input impedance
- Low Bias Current
- Responds to Differential Mode Voltages
- Ignores Common Mode Voltages

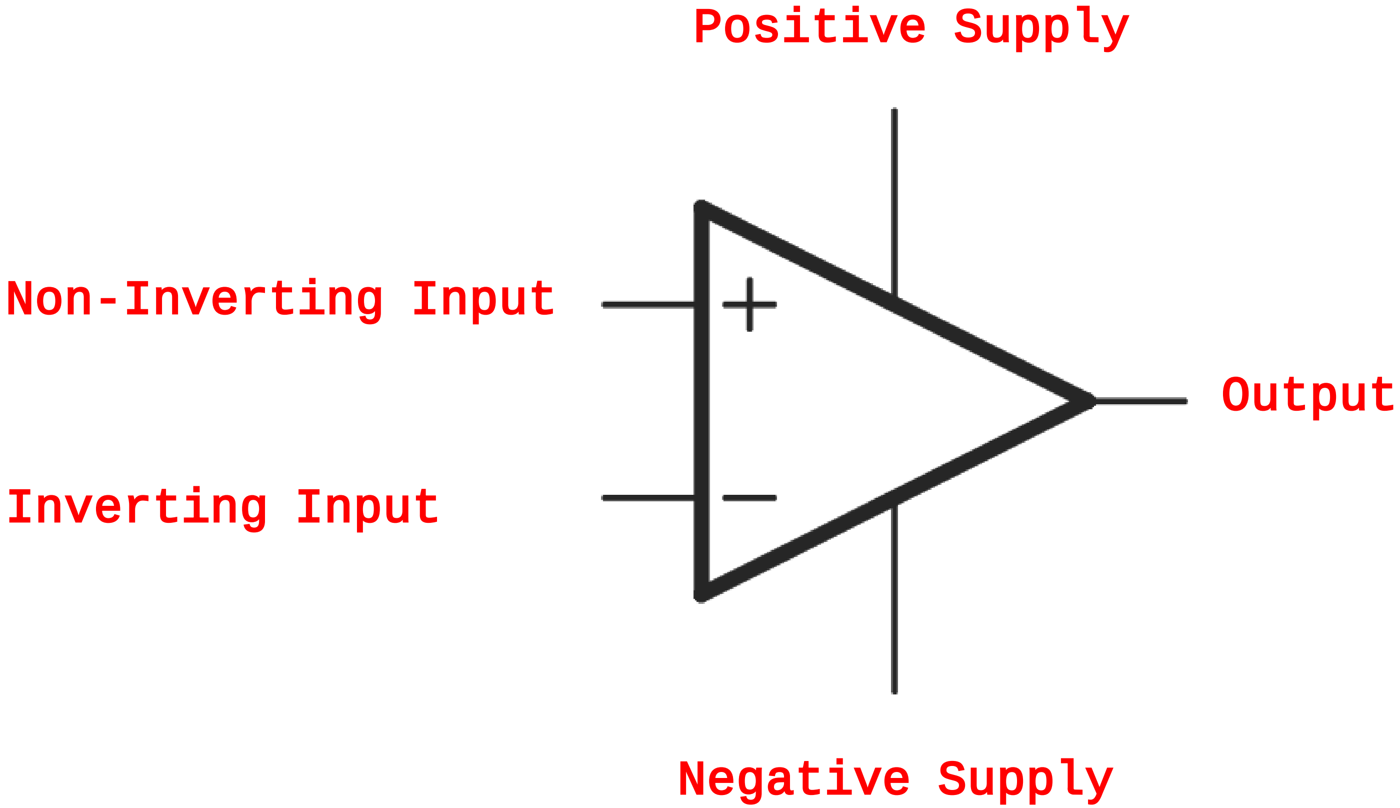
Op Amp *Output* Attributes

- * Low output (source) impedance

The Op-Amp

- An op amp is a ...
  - Differential input, ...
  - Single-ended output ... amplifier
- In other words ... an Op Amp processes
  - Small
  - Differential mode signals appearing between its two inputs
  - Developing a single-ended output signal referred to a power supply common terminal

Op Amp Symbol with Minimum Terminals Identified



Op-Amp Gain

- An *Ideal Op Amp* has **infinite gain** ...
  - For differential input signals
- *Real devices* have **high gain** ...
  - Called **open loop gain**

Open Loop / Closed Loop

- What is the difference between **Open Loop** and **Closed Loop**?
  - Open Loop ... no feedback used
  - Closed Loop ... feedback network used

Gain

- Gain is measured in terms of V_{OUT}/V_{IN}
  - Dimensionless ... Volt/Volt
- More often Gain is expressed in decibel
- What would the gain be in terms of decibels?

Gain in Decibels

$$dB = 20*\log\ (\text{numeric gain})$$

- **EXAMPLE** ...
  - Numeric gain of 1 million (10^6 V/V) is equivalent to 120 dB

- Open Loop Gains of 100 dB to 130 dB are common for precision op amps
- Open Loop Gains of 60 dB to 70 dB are common for high speed op amps
- Closed Loop Gain depends on the feedback network

Feedback

- Feedback consists of comparing the output of a system with the desired output and making corrections accordingly
- Feedback is an essential and salient point concerning op amp use
- With feedback, the net closed loop gain characteristics become primarily dependant on external components and less dependant on the relatively unstable amplifier open loop characteristics

Feedback Example

- Process of driving a car
  - The output ... position and velocity of the car
  - Output is sensed by the driver
  - The driver compares the output with expectations

    ... And makes corrections to the input (steering wheel, throttle, brake)
- In amplifier circuits the output should be a multiple of the input
  - So in a feedback amplifier the input is compared with the attenuated version of the output

Negative / Positive Feedback

- Feedback can be either **Negative** or **Positive**
  - **Negative Feedback** ... the process of coupling the output back in such a way as to cancel some of the input
    - Feedback loop is connected to the inverting input
  - **Positive Feedback** ... the process of coupling the output back in such a way as to add to the input
    - Feedback loop is connected to the non-inverting input

Negative Feedback

- Negative Feedback does lower the gain ...
  - but the benefits outweigh the loss of gain

- In fact, as more negative feedback is used, the resultant amplifier characteristics become ...

  - Less dependant on open loop characteristics

  - And ... Dependant on the properties of the feedback network itself

Negative Feedback

- Why would you want to apply Negative Feedback?
  - You may think that this would only have the effect of reducing the amplifier's gain and would be a pretty stupid thing to do.
- **Negative feedback ...**
  - Improves ...
    - Freedom from distortion and nonlinearity
    - Flatness of response (or conformity to some desired frequency response)
    - And ... predictability

Positive Feedback

- Feedback can also be ***Positive***
- Positive feedback is how you make an oscillator
- However ... positive feedback is not as important as negative feedback

Op-Amp Input Characteristics

- **Common Mode** (CM) signals are signals which are "common"/identical to one another at each input terminal
  - Ideal op amps ...
    - Will reject Common Mode signals
  - There is no gain for signals that are common to both inputs

Op-Amp Input Characteristics

- **Offset voltage V_{OS} ...** a small differential voltage must be applied to the inputs to force the output to zero

  – An ideal op amp has zero **Offset voltage V_{OS}**

    - Ideally if both inputs of an op amp are at the exactly the same voltage, the output should be at zero volts

    - In practice, a small differential voltage must be applied to the inputs to force the output to zero ... **Offset voltage V_{OS}**

- There is a wide range of actual values depending on the actual structure of the op amp

Op-Amp Input Characteristics

- **Bias current I_B …** the currents flowing into both op amp inputs
  - An ideal op amp draws **zero bias current I_B** at both inputs
- There is a wide range of actual values depending on the actual structure of the op amp

Signals Applied to Inputs

- *Inverting Input* ... Any DC or AC signal applied to the Inverting input is 180° out of phase at the output

- *Non-Inverting Input* ... Any DC or AC signal applied to the Non-Inverting input is in phase at the output

General Information

- Op amps have a positive and negative power supply terminals
- Op amps rarely, if ever, have a ground connection
  - Op amp output voltage becomes referred to a power supply common point
- Where is the op amp grounded?
  - Answer ... simply that it is indirectly grounded
    - Indirectly grounded by virtue of the commonality of its input, the feedback network, and the power supply
      - Hence we have a **virtual ground**

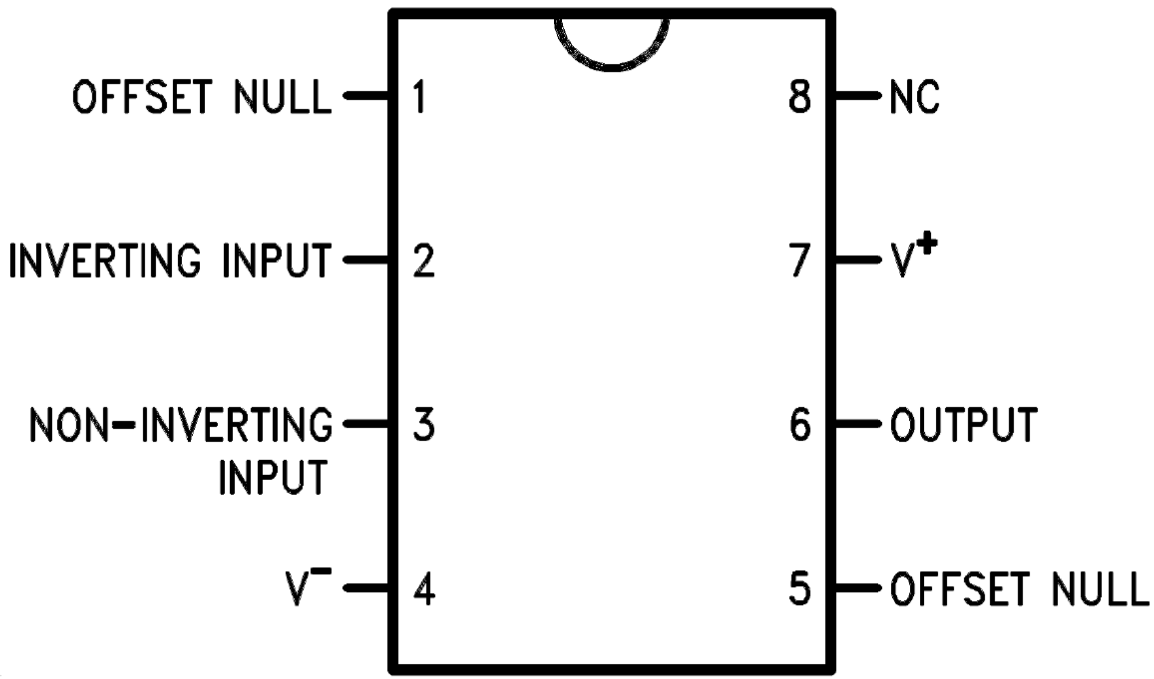
Virtual Ground

- Since an operational amplifier has very high open loop gain ...
  - The amplifier acts automatically to make the potential difference between its inputs tend to zero
  - The non-inverting (+) input of the operational amplifier is grounded ... then ...
    - Its inverting (-) input ... although not connected to ground
      - Will assume a similar potential ...
      - ... thus ... *Becoming a virtual ground*

The 741 Op-Amp

- There are many op-amps available today
- We will utilize the 741 for our class work
    - As the 741 is ...
        - Simple
        - Inexpensive ...
        - ... And ... it can be used to focus on our class topics

The 741 IC Schematic



Op-Amp Configurations

- We will utilize the following op amp configurations:
  - Inverting Amplifiers
  - Buffer
  - Summing Amplifiers
  - Comparators

- There are many other configurations ... but we will only focus on the above configurations

Op-Amp Circuit Analysis

- Before we get into the details for each of the op amp configuration we will provide some basic background information
- One may ask ... Where do the op amp equations come from for the various configurations?
  - We shall utilize simple DC circuit analysis ... and ...
  - Some basic "Ideal" op-amp assumptions

Assumptions

- The inputs to the op amps do not draw any current
    - The input impedance is so high that we can ignore the small currents that may leak into the amplifier
        - – Helps us apply Kirchhoff’s current law during the analysis

Assumptions

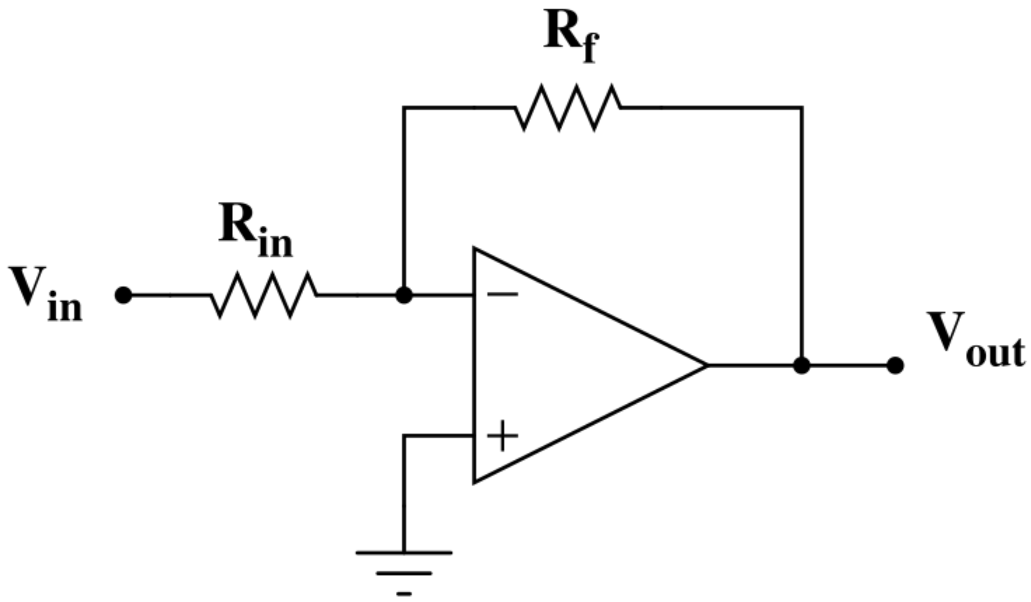
- The differential input voltage is zero when negative feedback is used
  - The op-amp will push or pull enough current (within reasonable conditions) through its output and feedback resistor to make the voltage at each input identical
    - This leads to the differential input voltage of zero
      - Another way of looking at it is to remember that the voltage on each input must be identical when there is negative feedback.

Assumptions

- The op amp voltage gain is so high that ...
  - A fraction of a millivolt between the input terminals will swing the output over its full range
    - Therefore we ignore that small voltage and state:
      - The output attempts to do whatever is necessary to make the voltage difference between the inputs zero

The Inverting Amplifier …

The *Inverting Amplifier*



$$V_{OUT} = -V_{in} * \left[\frac{R_f}{Rin} \right]$$

Inverting Amplifier

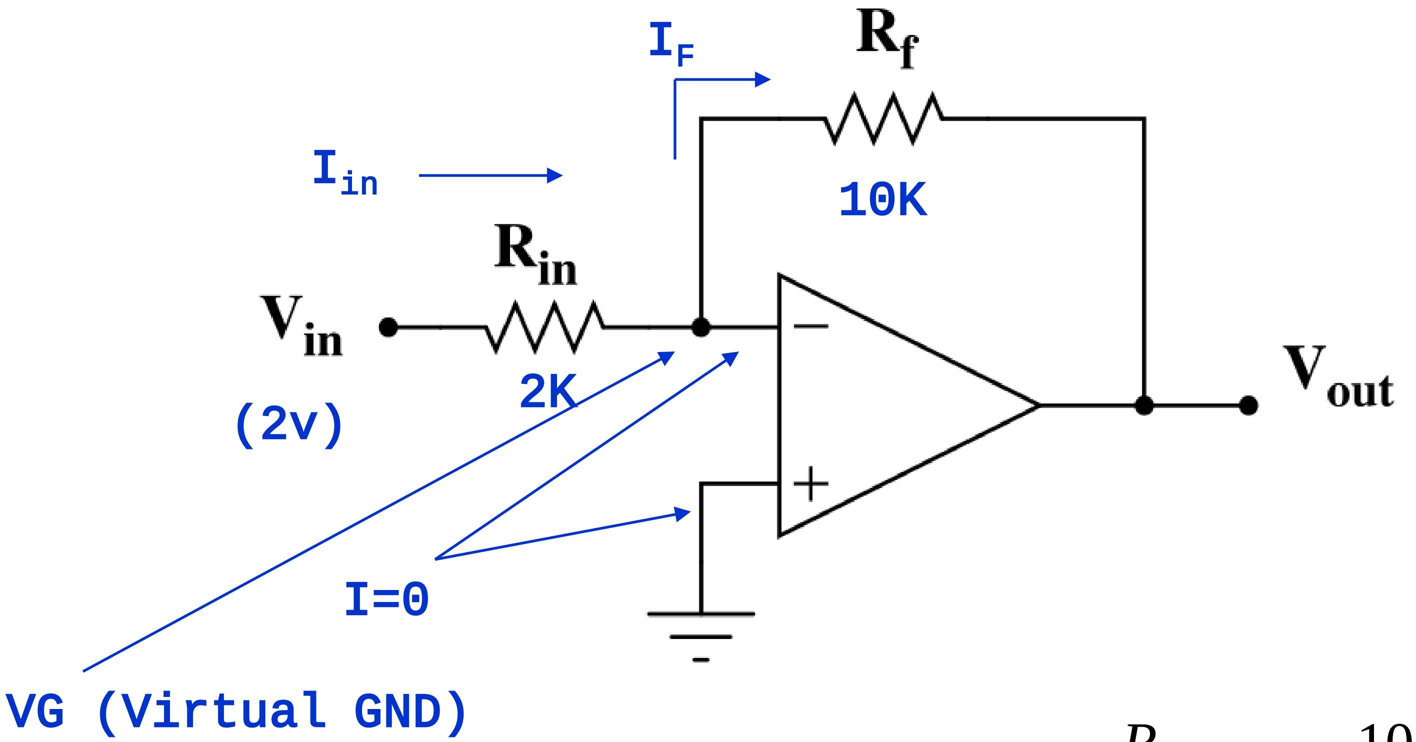
- The inverting amplifier uses negative feedback to control the very large open loop gain

- **Recall for open loop configuration** ... a 25 Microvolt (μV) input signal would result to the saturation voltage of +5V or –5V depending on the polarity of the input signal and which terminal it was applied

- The inverting configuration controls the gain

Inverting Amplifier

- Find V_{OUT} ...



$$V_{OUT} = -V_{IN} * \frac{R_F}{R_{IN}} = -2 * \frac{10K}{2K} = -10V$$

Inverting Amplifier

- In order to achieve the output from the previous example ...
  - We need to make sure that the op-amp is powered with at least

$$\pm\frac{10V}{80\%} = \pm 12.5V$$

  - Due to the fact that the 741 op amp has an output saturation of ~ 80% of the supplied voltages

Gain

$$V_{GAIN} = \left|\frac{V_{out}}{V_{in}}\right| = \frac{R_F}{R_{IN}} = \frac{10K}{2K} = 5$$

or

$$V_{GAIN} = \left|\frac{V_{out}}{V_{in}}\right| = \frac{10}{2} = 5$$

dB = 20*log (numeric gain) = 20*log (5) = 14 dB

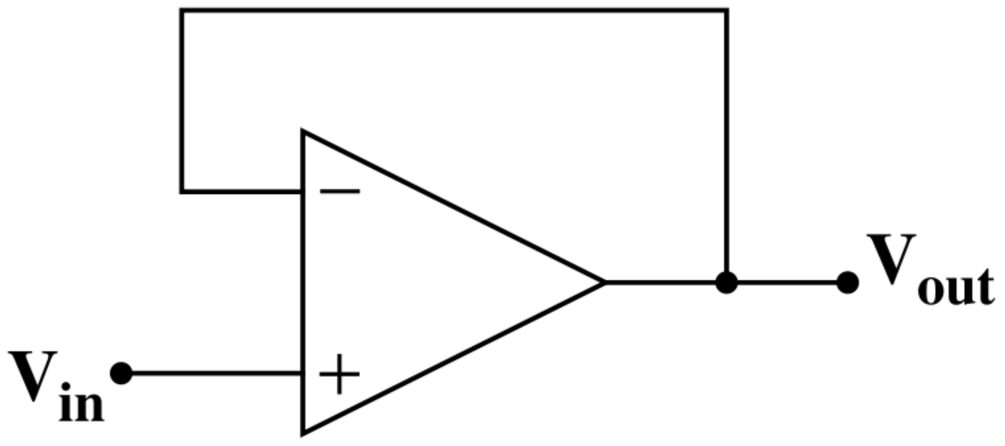
Gain

- Another Example ...
  - If ... V_{GAIN} = 10

V_{IN}		V_{OUT}
+0.2		-2
-0.4		+4
0		0
+0.32		-3.2

The Buffer …

The *Buffer*



$$V_{OUT} = V_{IN}$$

The *Buffer* ... also known as the Follower

- The Simplest amplifier configuration
  - As it requires no external components ...
    - Just a short between the output and inverting input

The *Buffer*

- The buffer is a Non-Inverting amplifier with ...
  - R_F set to zero ... and ...
  - R_{in} set to infinity

- Therefore ... using the non-inverting gain equation ...

$$GAIN = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{R_1} = 1 + \frac{0}{\infty} = 1$$

- We see that ...

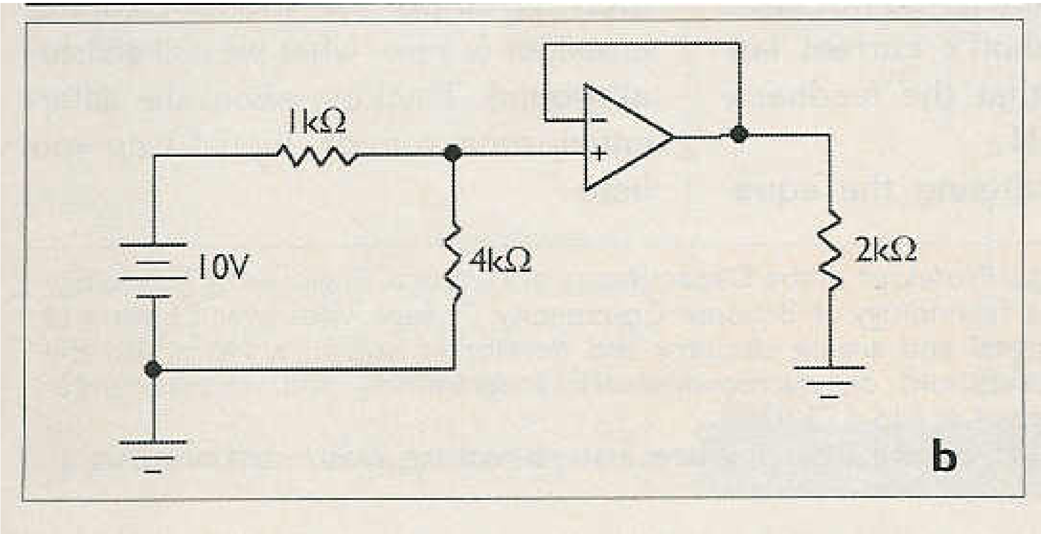
$$V_{OUT} = V_{IN}$$

The *Buffer*

- Why would we want an amplifier with a gain of 1?
  - Recall that ...
    - The op amp input sees a high impedance
    - Output of the op amp sees a low resistance (around 50 ohms)
  - Therefore ... impedance isolation (buffer) is useful when you want to eliminate the loading effect of one component or circuit on another
  - In other words it “Buffers” the input signal from the load

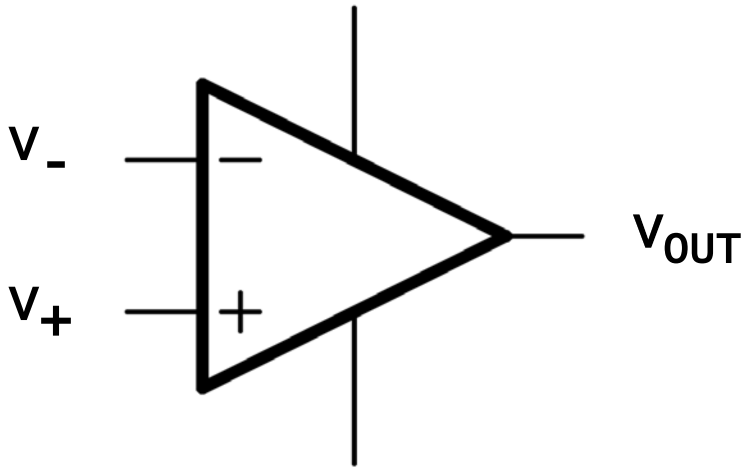
The *Buffer*

- Example ... using a buffer ...



The Comparator …

The *Comparator*



Comparator Fundamentals

- Compares the voltage level of two analog signals (inverting and non-inverting inputs) ... and ...
  - Identifies which signal is the largest
- Any minute difference between the applied voltages drives the output into saturation
- Because of its high gain and stable characteristics, the differential op amp is the main building block for the *comparator*

The *Comparator*

- The op amp is operating in the open loop mode when used in the comparator configuration
- There are devices made specifically for use as comparators ...
  - Why use devices specifically made as comparators?
    - Improved recovery times
    - Improved switching speeds
    - Improved output levels
- We will use the 741 op amp in open loop mode, vice specific comparator components

Why would we need a *Comparator*?

- Switching on lights and heaters
- Generating square waves from triangle waves
- Detecting when a level in a circuit exceeds some particular threshold
- Switching power supplies
- And so on ...

Comparators

- The output goes positive when the non-inverting input is more positive than the inverting input
- The output goes negative when the inverting input is more positive than the non-inverting input
- Therefore ...

IF V- $<$ V+ ... output is positive

IF V+ $<$ V- ... output is negative

IF V- $=$ V+ ... output is zero

The741 Op Amp Output Saturation

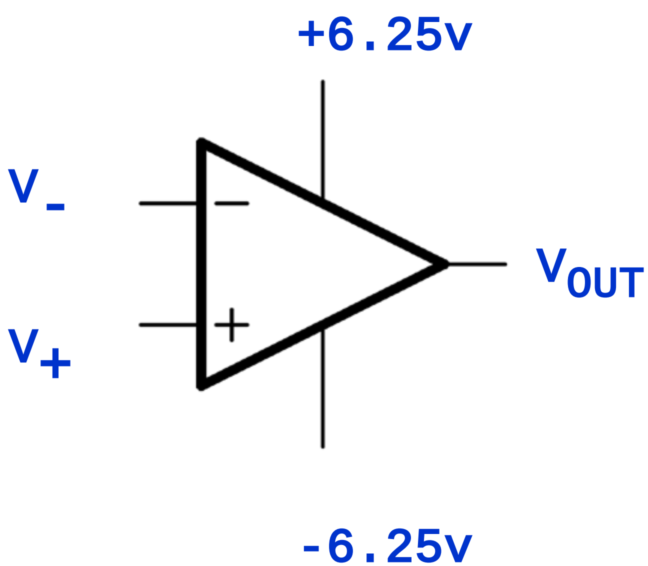
- The 741 op amp has an output saturation of ~ 80% of the supplied voltages
- Therefore, to obtain an output (saturation) voltage of +5v or –5v
  - We would need to supply +6.25v and -6.25v

80% of 6.25 = 5.0 volts

Comparator Example

Example 1: … we have a positive supply voltage of +5 and a negative supply voltage of -5. Assume a 741 op amp.

What is V_{OUT} for the values indicated in the table?

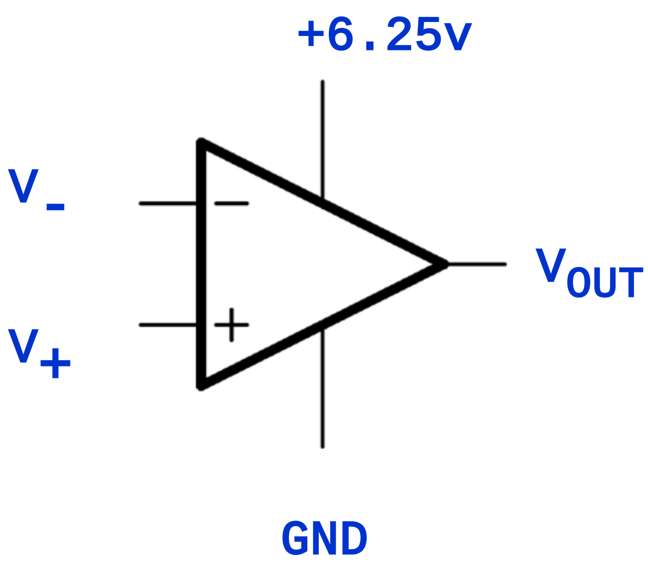


V_-	V_+	V_{OUT}
+1	-1	-5
+1	+2	+5
+2	+1	-5
0	0	0
-1	+1	+5
0	-1	-5
0	+1	+5
+3	+3	0

Comparator Example

Example 2 … we have a positive supply voltage of +5 and a negative supply voltage set to ground. Assume a 741 op amp.

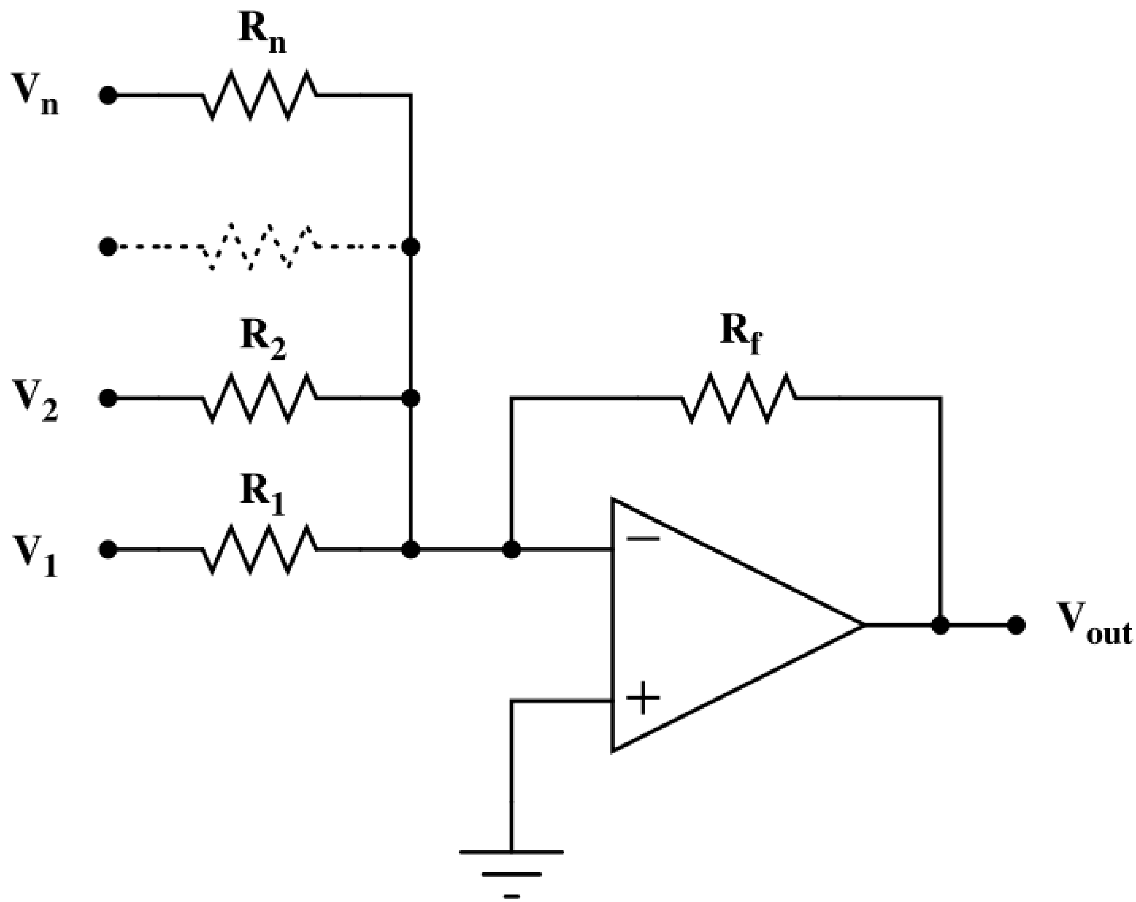
What is V_{OUT} for the values indicated in the table?



V_-	V_+	V_{OUT}
+2	-1	0
+1	+2	+5
+2	-2	0
0	-1	0
-2	-2	0
0	+1	+5

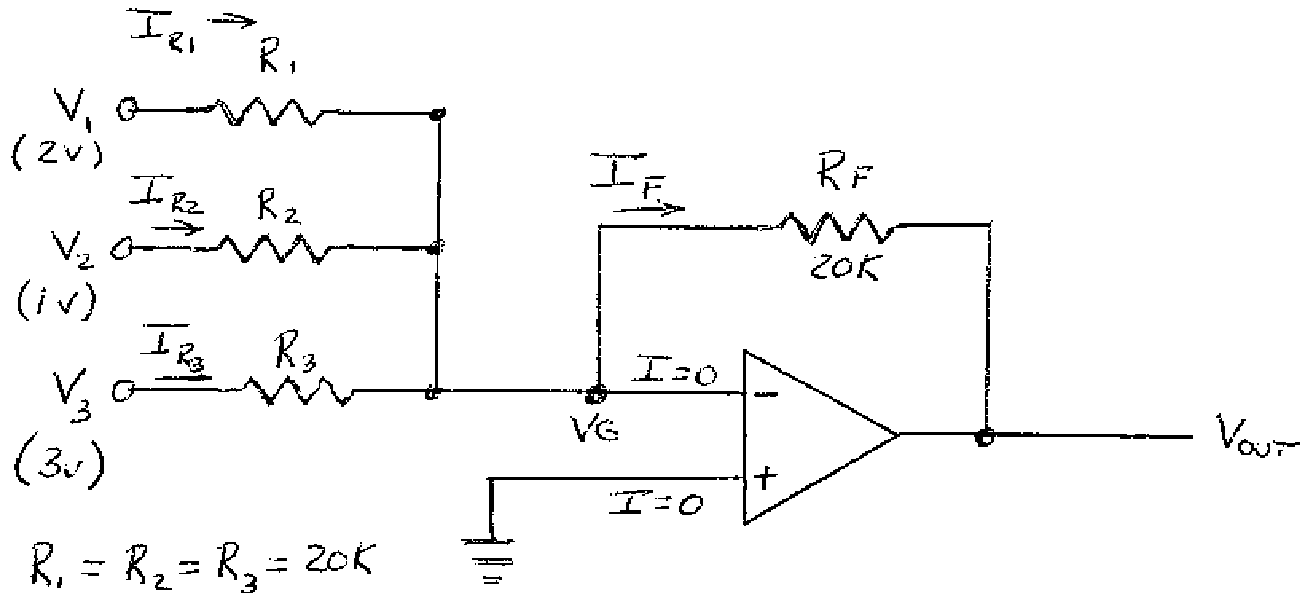
The Voltage Summing Amplifier …

The *Voltage Summing Amplifier*



The *Voltage Summing Amplifier*

- The voltage summing amplifier is capable of adding the algebraic sum of several applied voltages to one of it's input lines



The *Voltage Summing Amplifier*

- We have a virtual ground at the inverting input
- The input currents in each leg are ...

$$I_{R1} = \frac{V_1}{R_1} \qquad I_{R2} = \frac{V_2}{R_2} \qquad I_{R3} = \frac{V_3}{R_3}$$

$$I_{R_F} = I_{R1} + I_{R2} + I_{R3}$$

The *Voltage Summing Amplifier*

$$V_{OUT} = -I_{R_F} * R_F$$

- Or ...

$$V_{OUT} = -\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) * R_F = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right)$$

The *Voltage Summing Amplifier*

- And for ...

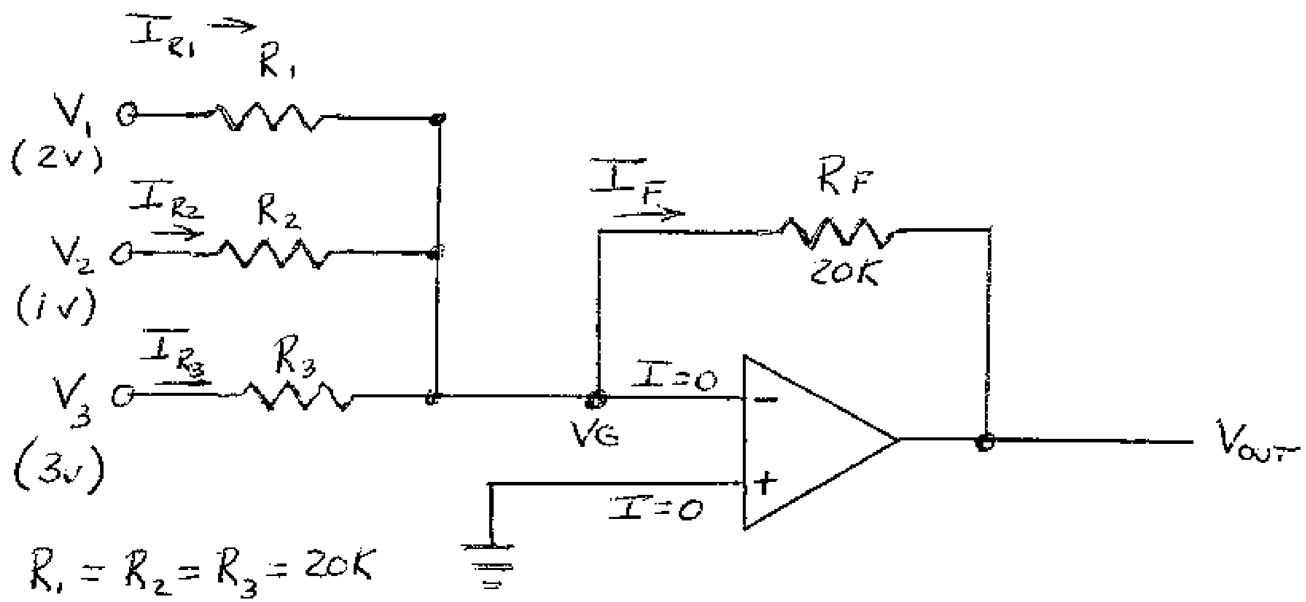
$$R_1 = R_2 = R_3 = R_F$$

- We have ...

$$V_{OUT} = -\left(V_1 + V_2 + V_3\right)$$

The *Voltage Summing Amplifier*

- Using the values shown on the initial drawing for the summing amplifier ...



The *Voltage Summing Amplifier*

$$I_{R1} = \frac{V_1}{R_1} = \frac{2}{20K} = 0.1mA$$

$$I_{R2} = \frac{V_2}{R_2} = \frac{1}{20K} = 0.05mA$$

$$I_{R3} = \frac{V_3}{R_3} = \frac{3}{20K} = 0.15mA$$

$$I_{RF} = I_{R1} + I_{R2} + I_{R3} = 0.1 + .05 + .015 = 0.3mA$$

$$V_{out} = -I_{RF} * R_F = -(0.3mA) * (20K) = -6volts$$

Example - *Voltage Summing Amplifier*

- For ...

$$R_1 = R_2 = R_3 = R_F$$

$$V_{OUT} = -\left(V_1 + V_2 + V_3\right)$$

V_1	V_2	V_3		V_{OUT}
+1	+1	+1		-3
+1	-1	-1		+1
+2	-1	-1		0
-3	-1	+3		+1
+1	+2	-1		+2

Summary …

Summary

- Op amps are our first data conversions building block
- Op amps can be configured in numerous ways utilizing external components in order to achieve the desired function, or ***operation***
- Major attributes of op-amps
    - High voltage gain
    - High input impedance
    - Low output impedance

Summary (continued)

- Open loop, closed loop, and negative feedback
- Gain is measured in terms of V_{OUT}/V_{IN}
- Discussed in detail the following op amp configurations:
  - Inverter
  - Buffer
  - Summing
  - Comparator
- And looked at their equations

Lab

Lab Overview …

LAB OVERVIEW

- Simulation using software is not an acceptable alternative to breadboarding

- Benefits of hands-on labs/breadboarding ...

  - Use of ...
    - Components
    - Test equipment
      - Knowledge of Test equipment is a foundation for hardware troubleshooting
  - ** Learn troubleshooting techniques
  - ** Will greatly enhance the class material
  - Solving Lab Problems will enforce the course material

LAB OVERVIEW

- Basic lab knowledge/techniques
  - Use of a breadboard
  - Learn the identification systems for components
    - Resistors
    - Capacitors
    - Integrated circuits
  - Application of data sheets

LAB OVERVIEW

- **Problems encountered during lab performance …**
  - Knowledge gained from troubleshooting

LAB OVERVIEW

- Lab grade ...
  - Lab proficiency 20 points
  - Lab Report Format 20 points
  - Lab Notebook 20 points
  - Technical adequacy 40 points
  - Late deductions as much as 30 points
- Explanation on why a lab could not be completed
- Lab preparation
  - Need to work through the lab prior to class
- Lab Results ...
  - Record in your lab notebook events/results
  - Write on what you did during the class ...
    - Not what you did after the lab

LAB OVERVIEW

- Things you should bring to the lab ...
  - A container for your board, parts, tools, etc.
  - Tools
    - Wire strippers
    - Wire cutters
    - Jeweler’s screwdrivers
    - Screwdriver
  - A copy of the lab (available on the web)

LAB OVERVIEW

- Lab Reports
  - Report form for each lab will be available on the web page
  - Electronic report submission is preferred over hard copies ...
    - PDF format preferred ... talk to me about other formats
    - Send via email NLT than 11:59 PM on the due date

- Lab results will usually be due 2 weeks after completion of the lab (as indicated on the syllabus)

- Labs will be available for downloading from the website NLT Wednesday evening

Lab #1 …

Lab

- Lab #1 will start next week
  - I will post it on the Course Web page by next Wednesday night

Lab #1 – Overview

- Build and test the following circuits ...
  - Comparator
  - Inverting Amplifier
  - Summing Amplifier

Next Class

Next Class Topics

- Perform Lab #1

Homework

Homework

1. Send me an email so I have your email address

2. Textbooks ... available on class webpage

    - Review Class Material

3. Prepare for Lab #1

    - Download the lab ... available NLT next Wednesday night
    - Bring your lab tools
    - Obtain a Lab notebook

Time to start the lab …

Lab

- No lab scheduled for this week ...

Questions?

References …

References

1. None