MAS836 – Sensor Technologies for Interactive Environments

Lecture 1 – Introduction and Analog Conditioning Electronics, Pt. 1

Expectations

- This ~~is not~~ *has become* a Lab class
  - …and does have an important lab component
- Class credit (12H) from:
  - Three or Four problem sets (30%)
    - Copying not allowed
    - Credit not available after solutions handed out
  - Final project (30%)
  - Lab Performance (30%)
  - Attendance/Participation/Reading (10%)

Projects

- "Project" should demonstrate skill integrating & applying sensors to make a meaningful and understood measurement
  - Final report required
    - Justify sensor & design choice, quantify performance
    - Class presentation in exam week
  - Short proposal needed
    - Proposals will be quickly covered in class
    - We plan these to be due about a month before project presentation

Goals

- Attain a broad familiarity with many different sensors useful in a broad definition of “HCI”
  - Develop judgment of what sensors and modalities are appropriate for different applications
  - Know how to electronically condition the sensor, hook it up to a microcomputer, and process the signal (at least basically)
  - Have some idea of how/where these sensors were used before
  - Have a reasonable idea of how different sensors work
  - Develop a sense for recognizing bad data and an intuition of how to resolve problems

Working Syllabus

- Session 1: Introduction, basic sensor-related electronics & signal conditioning
  - Op-Amps, biasing, active and passive filters, differential and bridge amplifiers, comparators
  - Lab 1 Out
- Session 2: Electronics continued
  - Nonlinear circuits, grounding, noise, synchronous detection, simple digital filtering & detection
  - PS1 Out
- Session 3: Electronics continued
  - (Lab 1 due) - PS1 Due
- Session 4: Microcontrollers, Digital Sensor Standards & Networks
  - Arduino, IEEE 1451, SensorML, ZigBee, wireless sensing, sensor fusion intro
- Session 5: Pressure & Force
  - Force-sensitive resistors , resistive bendy sensors, resistive strain gauges, silicon pressure sensors, load cells, pressure-through-displacement, fiber optic strain gauges & bend sensors

Note that most classes will involve application discussions

Working Syllabus (cont)

- Session 6: Piezoelectrics and electroactive materials
  - Intro to ferroelectrics, crystals, PZT, PVDF, electronics, and signal conditioning, electrostrictors and dielectric elastomers
  - Lab 2 due
- Session 7: Electric field and inductive sensing
  - Capacitive sensing modes and techniques, Hall sensors, magnetostrictive sensors, metal detectors, LVDT's, VR Trackers, Wireless tag sensors
  - PS2 Due / PS3 Out (Swap Lecture?)
- Session 8: Optical sensing
  - Devices (LDR's, solar cells, photodiodes, APD's, phototubes...), arrays, imagers, focal plane imaging/tracking, occultation, range by intensity of reflection, laser ranging (triangulation, phase slip, TOF)
  - Lab 3 Due
- Session 9: Inertial Systems
  - Orientation sensors (compasses, ball-cup, bubble levels), gyroscopes, accelerometers, MEMs devices, IMU's, analysis techniques
  - PS3 Due

Working Syllabus (cont)

- Session 10: Acoustics, thermal sensors
  - Temperature sensors (thermistors, integrated temperature sensors, thermocouples, RTD's, PIR, pyroelectric), acoustic pickups & techniques, sonar systems, beamformers
  - Lab 4 Due
- Session 11: MacroParticle, chemical, environmental sensors
  - Smoke detectors, optical scattering, smell, chemical and gas sensors and techniques, environment sensing systems (chemical, air, wind, humidity), remote techniques
  - Project Proposals Due
- Session 12: Medical and Radiation Sensing
  - Basic sensors for medical monitoring (heart rate, ECG, EKG, blood pressure, etc.), radiation detection (Geiger counters, scintillators, drift & proportional chambers, silicon strip detectors, calorimetery)
  - RF and Microwave Systems
  - Radar principles, chirped rangefinders, UWB radars, RF location systems, Doppler systems

Working Syllabus (cont)

- May X – Final Project Presentation

Reference Sources

Covers of "AIP Handbook of Modern Sensors," Jacob Fraden, "Sensors and Signal Conditioning," Ramon Pallas-Areny and John G. Webster, and "The Alarm, Sensor, & Security Cookbook," Thomas Petruzzellis, removed due to copyright restrictions.

- Jacob Fraden
  - AIP Handbook of Modern Sensors, >2'nd Edition
- Ramon Pallas-Areny and John G. Webster
  - Sensors and Signal Conditioning, 2'nd Edition
- Thomas Petruzzellis *(getting old…)*
  - The Alarm, Sensor, & Security Cookbook

Auxilary References (signals)

- Ramon Pallas-Areny & John G. Webster
  - Analog Signal Processing
- Paul Horowitz & Winifield Hill
  - The Art of Electronics
- Don Lancaster
  - Active Filter Cookbook

Auxilary References

Covers of "The OpAmp Cookbook," Walt Jung, "Intelligent Sensor Systems," John Brignell and Neil White, and "Sensors for Mobile Robots: Theory and Application," H.R. Everett, removed due to copyright restrictions.

- Walt Jung
  - The OpAmp Cookbook
- John Brignell & Neil White
  - Intelligent Sensor Systems
- H.R. Everett
  - Sensors for Mobile Robots

Good Niche References

Covers of "Capacitive Sensors: Design and Application," Larry Baxter, "Piezoelectric Ceramics: Principles and Applications," APC International, "Modern Inertial Technology: Navigation, Guidance, and Control," Anthony Lawrence, and "Electronic Distance Measurement: An Introduction," J.M. Rueger, removed due to copyright restrictions.

- Larry Baxter
  - Capacitive Sensors
- APC International
  - Piezoelectric Ceramics: Principles & Applications
- Anthony Lawrence
  - Modern Inertial Technology
- J.M. Rueger
  - Electronic Distance Measurement

Magazines

Covers of *Sensors Magazine*, *Circuit Cellar*, *NASA Tech Briefs*, *Test and Measurement*, and *IEEE Sensors Journal* removed due to copyright restrictions.

- Sensors Magazine - Free!
- Circuit Cellar - Best EE-hacker magazine out
- NASA Tech Briefs - Free!
- Test and Measurement - Free!
- IEEE Sensors Journal

Conferences

- Sensors Expo
  - Big trade show with tutorials and proceedings
- IEEE Sensors Conference
  - Very large new state-of-the-art sensors conference
- SPIE
  - Old standby conference for sensors & applications
- Transducers
  - Emphasizes MEMs, but like IEEE Sensors
- UIST
  - ACM conference on user interface technology
- Sensys, IPSN/SPOTS, etc.
  - Sensor net conferences - not sensors…

Websites

- http://www.sensorsportal.com/
  - References, hints, sources
- http://www.sensorsmag.com/
  - Sensors Magazine site
    - Buyers guide, Archive articles

Screenshot of "SensorsPortal" removed due to copyright restrictions.

- http://www.cs.cmu.edu/~chuck/robotpg/robofaq/10.html
  - Robotics sites often list sensor vendors, hints
- http://www.billbuxton.com/InputSources.html
  - Bill Buxton's encyclopedia on input devices

Hacker Websites

The following websites offer useful hacking gear, techniques, and ideas:

- instructables.com
- hackaday.com
- diylive.net
- diyaudioprojects.com
- bunniestudios.com/blog
- epanorama.net
- hackedgadgets.com
- evilmadscientist.com

Some Classic Sensor Module Sources

- http://www.parallax.com/
- http://www.sparkfun.com/
- http://www.ramseyelectronics.com/
- http://www.adafruit.com/

Basic Sources for Electronics

Digikey - www.digikey.com

Mouser - www.mouser.com

Newark

Allied

Hosfelt Electronics

JameCo

Mat Electronics

JDR

All Electronics

Radio Shack (mainly online now)

Today's Assignment

Reading Assignment #1 (electronics)

- Read Fraden, Chapters 1&2 and Chapter 4
  - His introduction & signal conditioning sections
- If you have Horowitz and Hill, go through Chapters 4 and 7
  - Op Amps
- If you have Pallas-Areny, glance through Chapter 3
  - Signal conditioning for resistive sensors

The Age of the Sensor...

- Interaction revolution underway - possibilities exploding
  - Small, low-cost sensors easily available to measure nearly everything…
  - Moore's Law makes processors capable of meaningfully exploiting the data in real time.
  - Low barriers to entry - easy to try things
    - Deaf and blind computers...
    - We don't really know what will really come after keyboard and mouse…
    - You can't realize your vision for the future of interactivity by buying a card and plugging it in...
  - Sensors are permeating everything - interactivity everywhere
    - From toys to automobiles to smart homes
  - From Burglar alarms to Ubiquitous Computing

Sensing as Commodity

- Sensors are now becoming a commodity, and soon can easily be designed into most any device.
  - Rather than omitting them from a cost/complexity viewpoint, it begins to make more sense to just include them if there's any suspicion that they could be needed.
  - This causes a shift in how sensors are used – rather than rely on only 1 or 2 sensors made a priori to measure particular quantities, many sensors will be used that don't necessarily exactly measure the quantity of interest (especially as applications will become more general and evolve over time).

Sensor Networks as Extension of the Nervous System

Sensors are becoming ubiquitous and networked – how do they connect to people?

Origins

- This class is a proper expansion of the pair of lectures on electronics and sensors that I give in MAS863, “How to Make (Almost) Anything”
  - Even so, “sensors” is a vast and general field
  - Any one lecture here can become least an entire course elsewhere at MIT
  - You won’t become an expert
    - Although you will be able to wander into a restaurant in sensorland and order a meal from the menu

Trading Modality

- Sensor modes are intrinsically synaesthetic
- Use physics and constraints to couple a measured quantity into an unknown
  - Temperature can infer wind velocity (heat loss)
  - Displacement can infer:
    - Pressure (with an elastomer or spring: $F = kx$)
    - Volume of fluid in a tank ($V = Ah$)
    - Velocity (2 measurements at different times: $v = dx/dt$)
    - Temperature (thermometer level)
    - Angle from vertical (displacement of a bubble)
  - Measurements are used with a mathematical model to derive other parameters
    - Estimation and Kalman Filtering, etc.
      - Not covered here...

Active and Passive Sensing

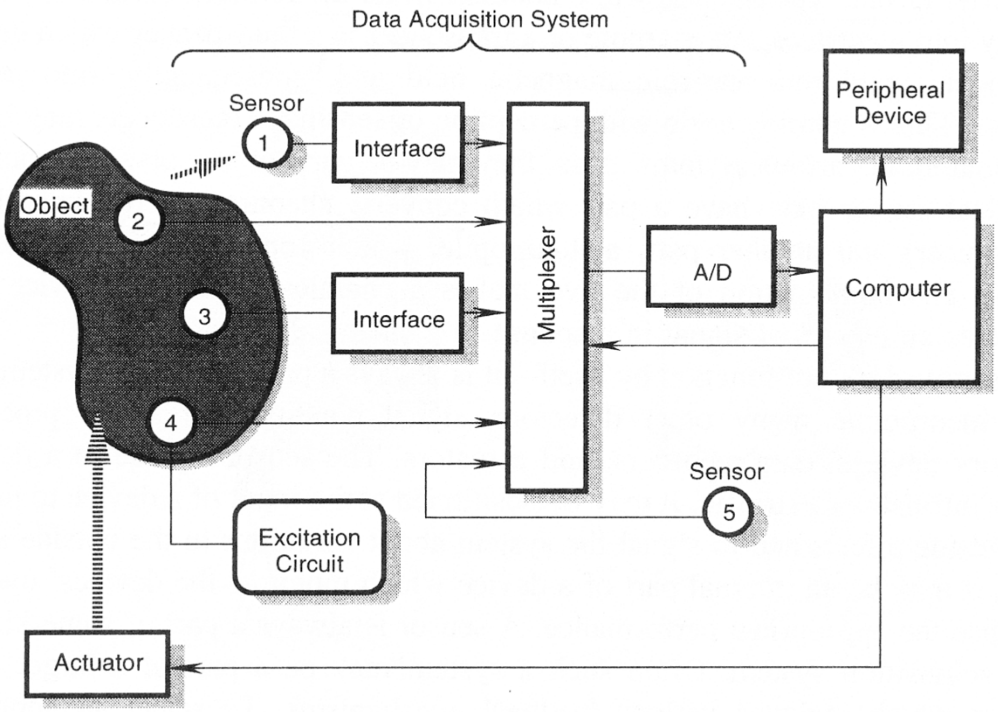


FIGURE 1.2. Positions of sensors in a data acquisition system. Sensor 1 is noncontact, sensors 2 and 3 are passive, sensor 4 is active, and sensor 5 is internal to a data acquisition system.

- Contact (2,3,4), noncontact (1), and internal (calibration) sensing (5)
- An active sensor (4) requires power, & may stimulate environment for a response
  - Thermistor, FSR, sonar
- A passive sensor (1,2,3,5) generates a response directly from the received energy
  - Photodiode, electrodynamic or piezo microphone
- Actuation to aid/enable sensing

Ohm's Law

- Electronics control the flow of electrons
- "Voltage" is the potential the electrons drop across the circuit
  - Measured between 2 points, typically a test point and ground
  - Equivalent to the "pressure" in a pipe
- "Current" is the flux of electrons per unit time (Amperes)
  - Current is defined as flowing from "+" to "-"
    - Opposite real electron motion!
  - Equivalent to the dynamic amount of fluid through the pipe
- "Resistance" relates voltage to current
  - E.g., the width of the pipe

$$I = \frac{V}{R}$$

Voltage (Volts) (V)

Current (Amperes) (I)

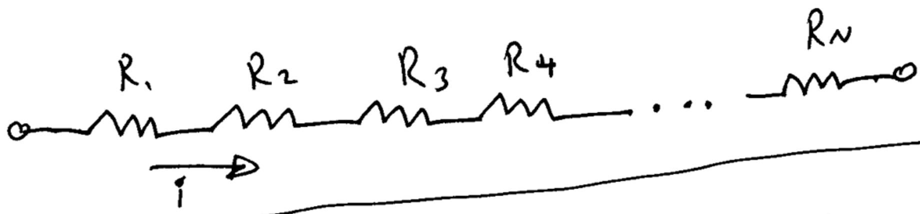
Resistance (Ohms) (R)

$$V = IR$$

Resistance turns current into voltage

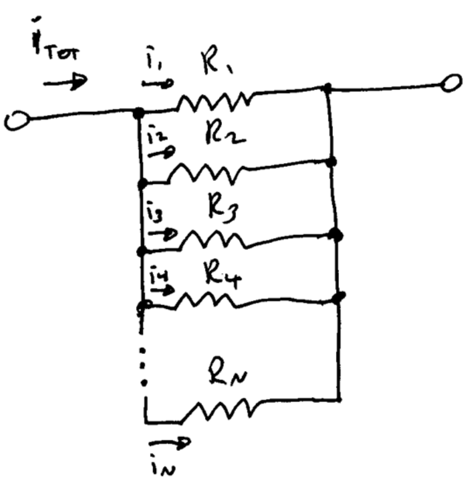
Combining Resistors

Resistors in Series just add



$$R_{TOT} = R_1 + R_2 + R_3 + R_4 + \dots R_N = \sum_{i=1}^{N} R_i$$

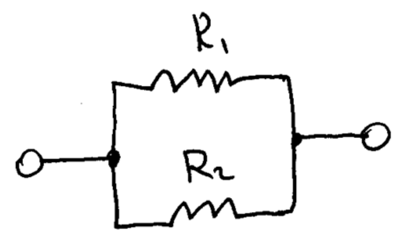
Resistors in Parallel are weighted by their inverse



Current Splits

$$i_{TOT} = i_1 + i_2 + i_3 + i_4 + \dots i_N$$

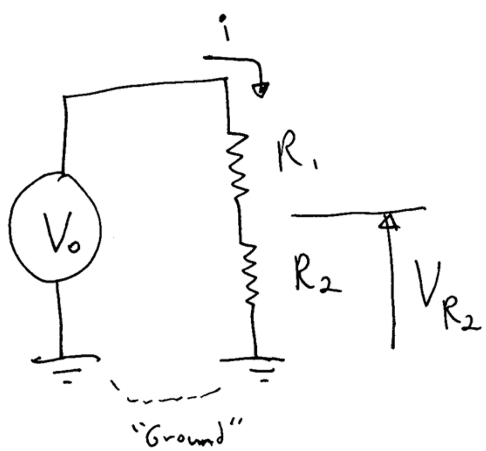
$$R_{TOT} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \dots \frac{1}{R_N}}$$



$$R_{TOT} = \frac{R_1 R_2}{R_1 + R_2}$$

Power and Voltage Dividers

- The power dissipated in a circuit is:
  - $P = IV = I^2R = V^2/R$
    - amps • volts = Watts = 1 Joule/second
  - Keep below ratings
    - Don't burn a resistor, blow a transistor, distort a sensor reading
- Voltage Divider:



$R_{TOT} = R_1 + R_2$

⟹ Resistors in series add

$i = \frac{V_0}{R_{TOT}} = \frac{V_0}{R_1 + R_2}$

$V_{R_2} = i R_2 = V_0 \frac{R_2}{R_1 + R_2}$

Potentiometer

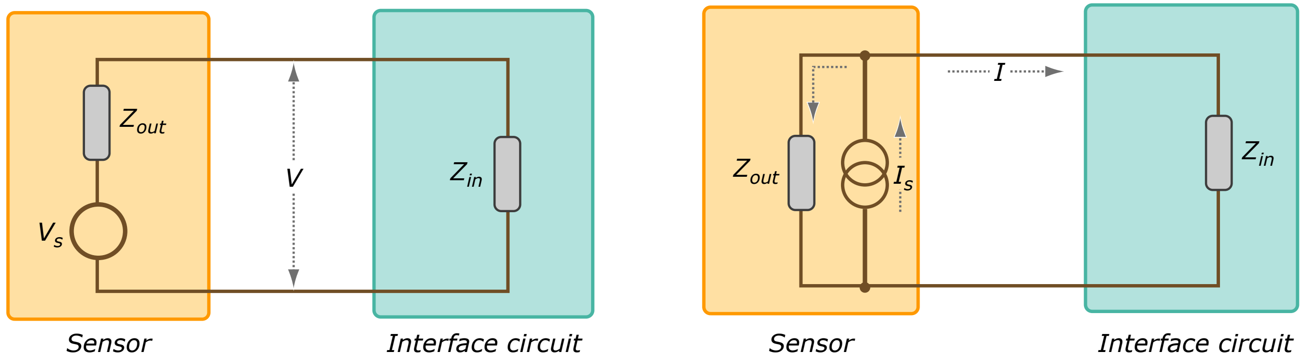
Potentiometer

Signal Conditioning

$$V_i = V_o \frac{Z_i}{Z_i + Z_o}$$

$$I_i = I_o \frac{Z_o}{Z_i + Z_o}$$

Wants High Z_i



Wants Low Z_i

Image by MIT OpenCourseWare.

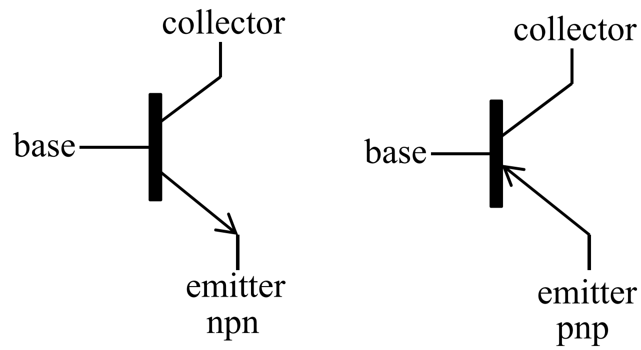
The connection between a sensor and an interface circuit. In the image on the left, the sensor has voltage output. In the image on the right, the sensor has current output.

- Sensors produce different kinds of signals
  - Voltage output or current output
  - Can't necessarily take sensor output and put right into microprocessor ADC or logic input
  - Signal may need:
    - High-to-low impedance buffer, current-to-voltage conversion, gain, detection, filtering, discrimination...

Transistors

Drawing of "Transistor Man" from *The Art of Electronics* (page 64) removed due to copyright restrictions.

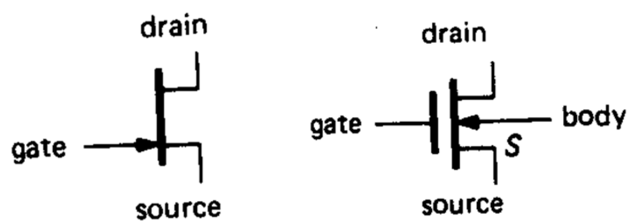
Bipolar transistors



Transistor symbols.

Images of TO-5, TO-18, and TO-92 transistor packages, and an ohmmeter's view of a transistor's terminals h removed due to copyright restrictions. See: Google Books

$$I_C = h_{fe}\, i_B = \beta i_B$$



JFET *MOSFET*

Thank You, Transistor Man!

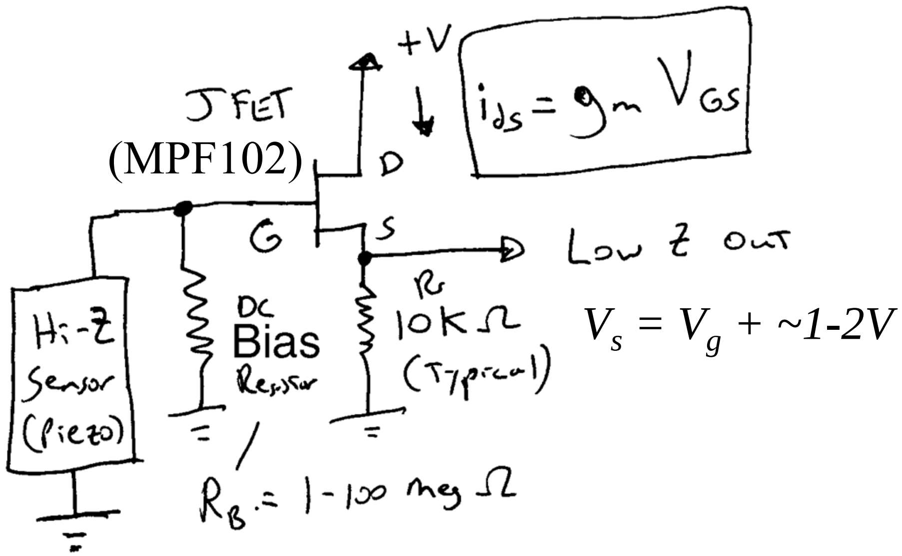
A low base current (gate voltage) controls a much larger collector (drain) current

$$I_s = g_m V_{gs}$$

Transconductance → g_m

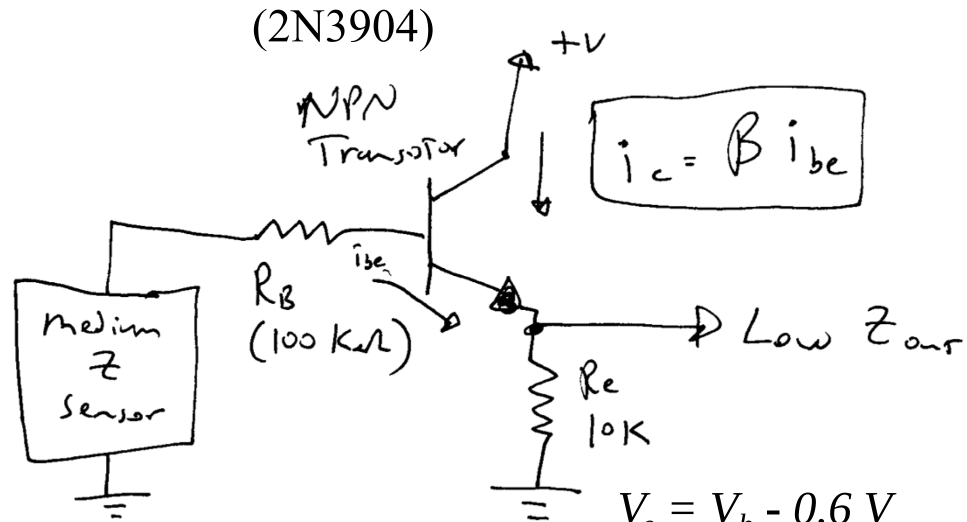
Simple Source and Emitter Followers

Source Follower



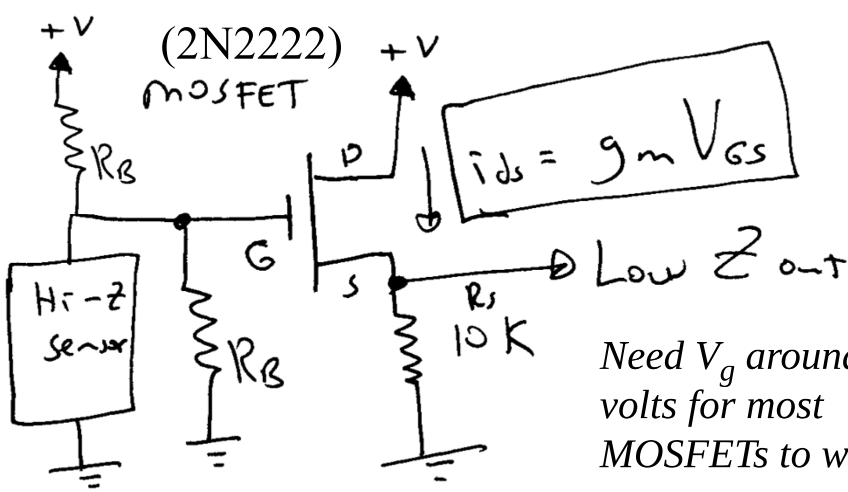
$V_s = V_g$ + ~1-2V

Emitter Follower



$V_e = V_b$ - 0.6 V

Sensor output > 0.6 V (or need biasing)



Need V_g around 2 volts for most MOSFETs to work

EF Voltage Gain = $R_L/(r_e + R_L)$ ~1

EF Output $Z_{EF} = R_s/h_{fe} + r_e$

SF Voltage Gain = $R_L g_m/(1 + R_L g_m)$ ~1

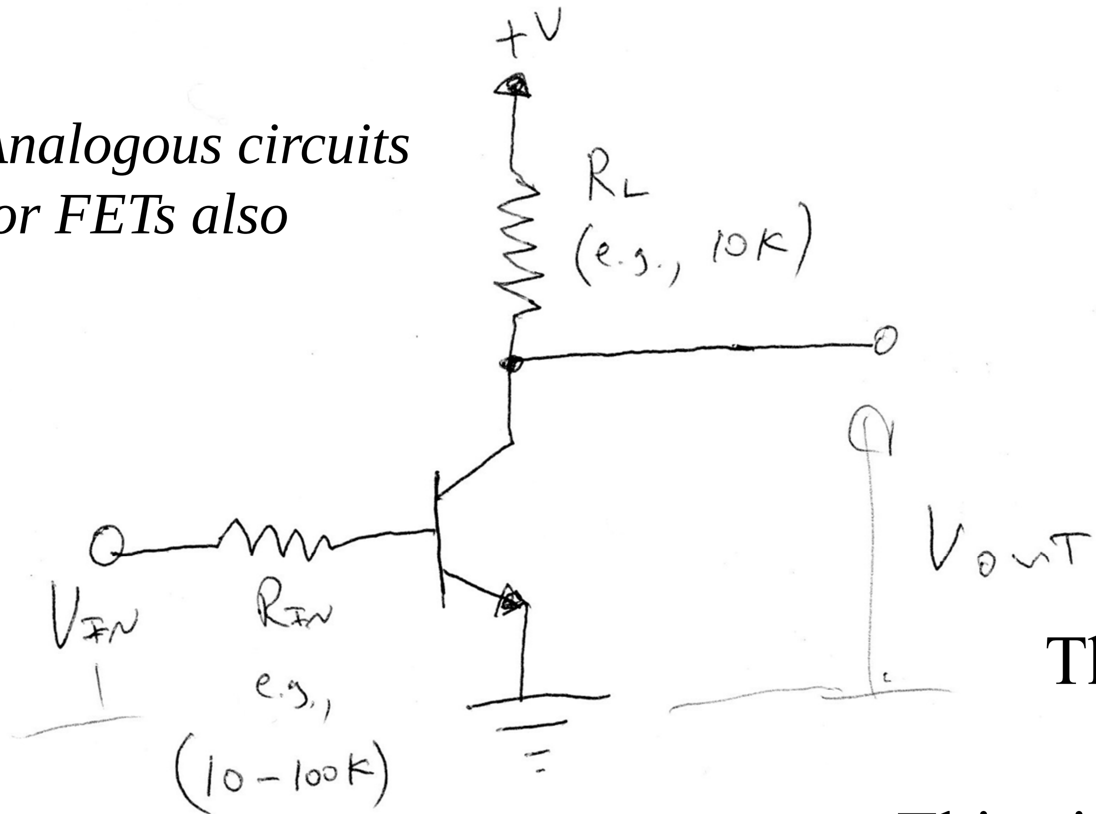
SF Output $Z_{SF} = 1/g_m$

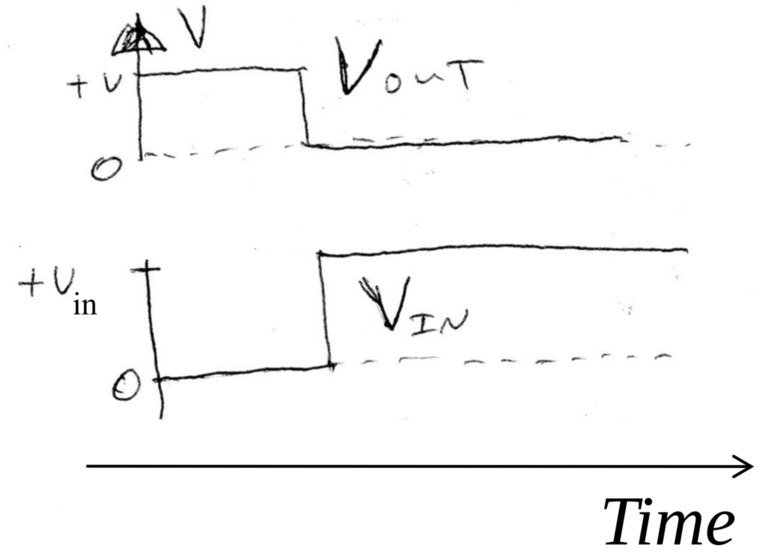
(Z_{SF} ~1/10 of Z_{EF} for R_s < 50K)

+ *Grounded Emitter Switch*

The Grounded Emitter Switch

Analogous circuits for FETs also





This circuit inverts V_{out} vs. V_{in}

V_{out} can be larger than V_{in}

-> This circuit can shift logic levels!

R_L can be a device

- Then the device turns on when V_{in} goes high

"Open Collector" gates have this output, without R_L

-They pull V_{out} to ground when V_{in} is high

Transistor can give linear gain when an emitter resistor added

- Must be properly biased!

The “Ideal” OpAmp Model

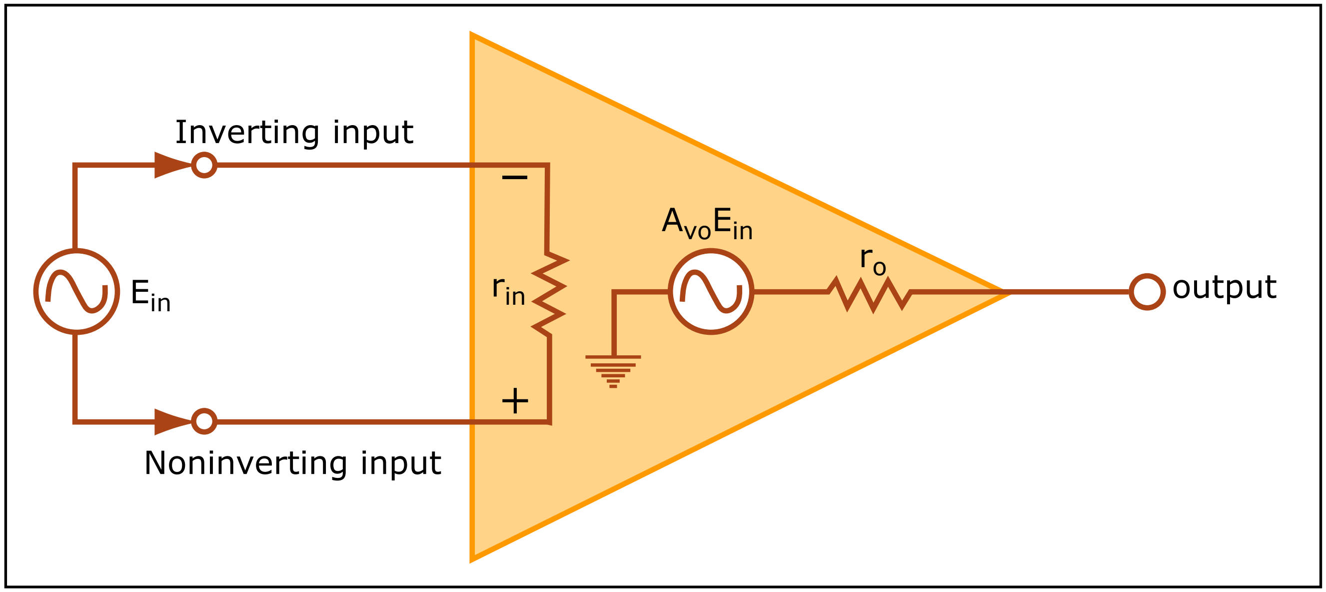


Image by MIT OpenCourseWare.

$E_o = A_{vo}\,E_{in}$
$A_{vo} = \infty$
$r_{in} = \infty$
$r_o = 0$
$BW = \infty$
$E_o = 0$ if $E_{in} = 0$

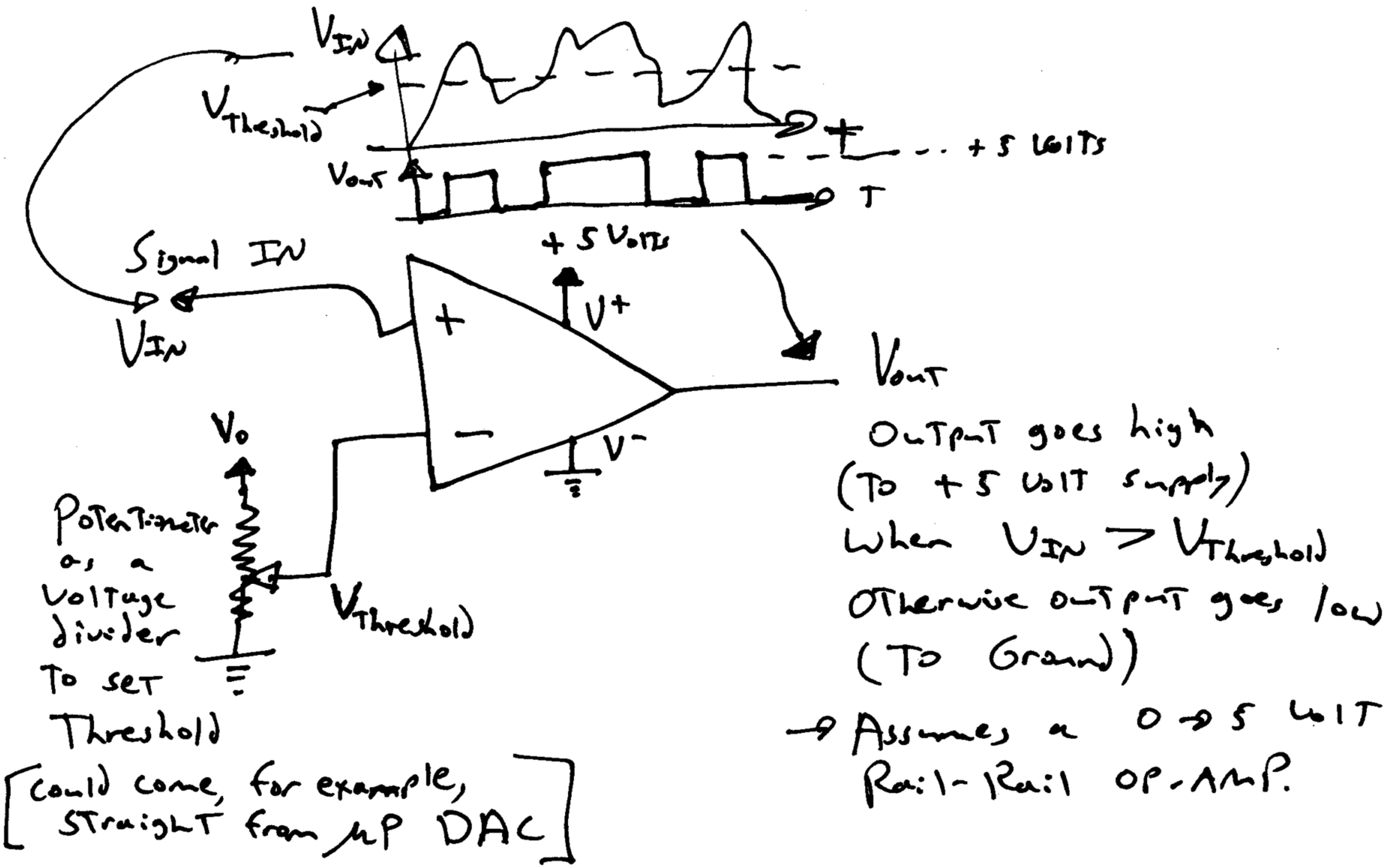
Circuit for an ideal OpAmp (operational amplifier.)

1. The voltage gain is infinite – $A_{vo} = \infty$.
2. The input resistance is infinite – $r_{in} = \infty$.
3. The output resistance is zero – $r_o = 0$.
4. The bandwith is infinite – $BW = \infty$.
5. There is zero input offset voltage – $E_o = 0$ if $E_{in} = 0$.

Ideal OpAmp Possibilities

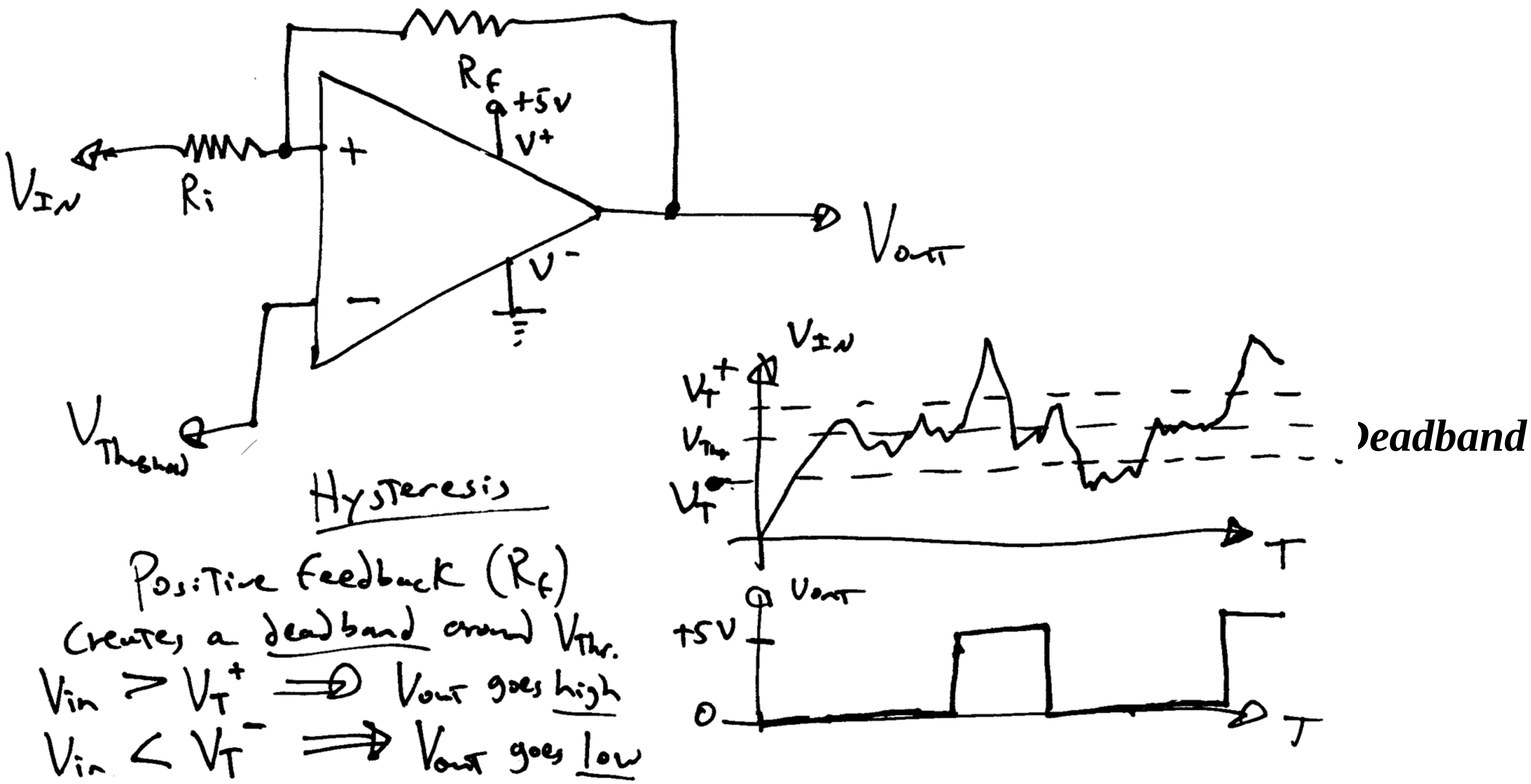
- No current flows into the input pins
  - Ideal behavior dictated by external components and signal sources
  - Comparator
    - Get a 1-bit digital trigger from an analog signal
  - Comparator with Hysteresis
    - Build in deadband for noise
- With negative feedback, current flows through feedback resistor to make V+ equal to V-
  - Ignores stability issues, bandwidth, and parasitics...

The Comparator



- Makes an analog signal into a 1-bit digital signal
  - Directly drives logic pin on microprocessor
    - Detects when signal is above threshold

The Schmidt Trigger

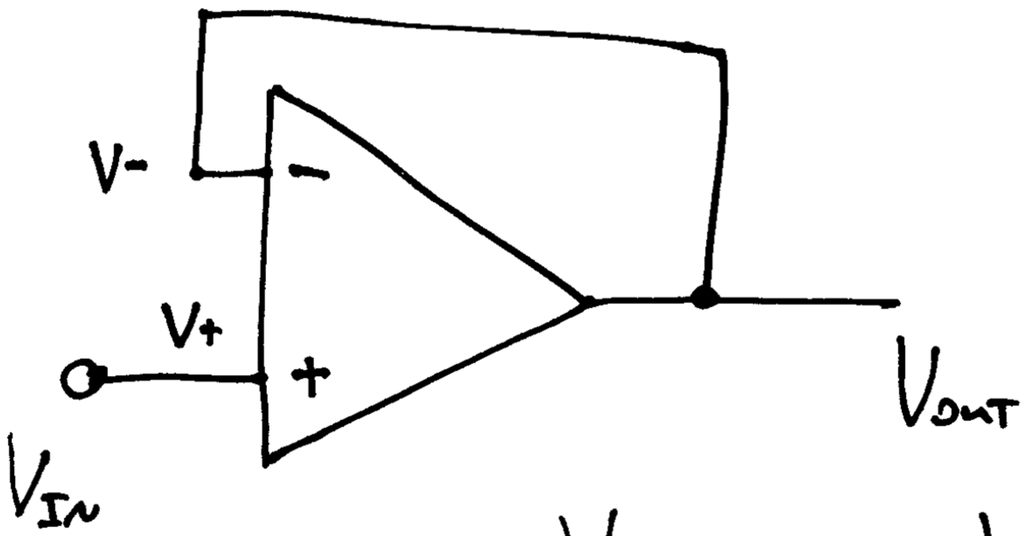


- *Suppresses jitter and spurious triggering from noisy signals*
- Deadband thresholds, V^+ and V^-, can be calculated via superposition
  - Ground V_{IN}, and with R_f and R_i as a voltage divider on V_{out}, calculate the voltage at the OpAmp's noninverting pin
  - Note that this assumes a low-impedance V_{IN} (source impedance sums with R_i)

Negative Feedback

- Transimpedance Amplifier
- Voltage Follower
- Non-Inverting Amplifier
- Inverting Amplifier
- Inverting Summer

The Voltage Follower



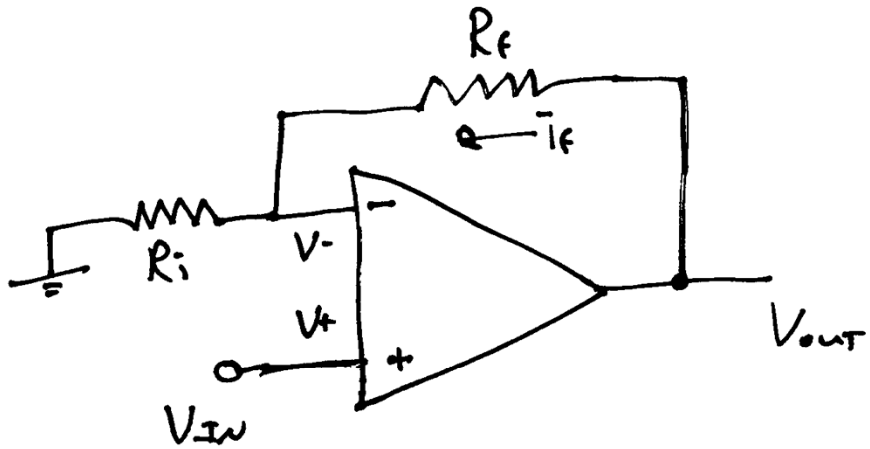
Negative Feedback forces $V_- = V_+$

$\Rightarrow V_{OUT} = V_{IN}$

V_{OUT} gives low impedance drive from potentially very high impedance V_{IN} sources

- A unity-gain buffer to enable high-impedance sources to drive low-impedance loads

The Non-Inverting Amplifier



Again, negative feedback means V- = V+ when the Op Amp is working.

$$V_- = V_{OUT}\left(\frac{R_i}{R_f + R_i}\right) = V_+ = V_{IN}$$

Voltage Divider!

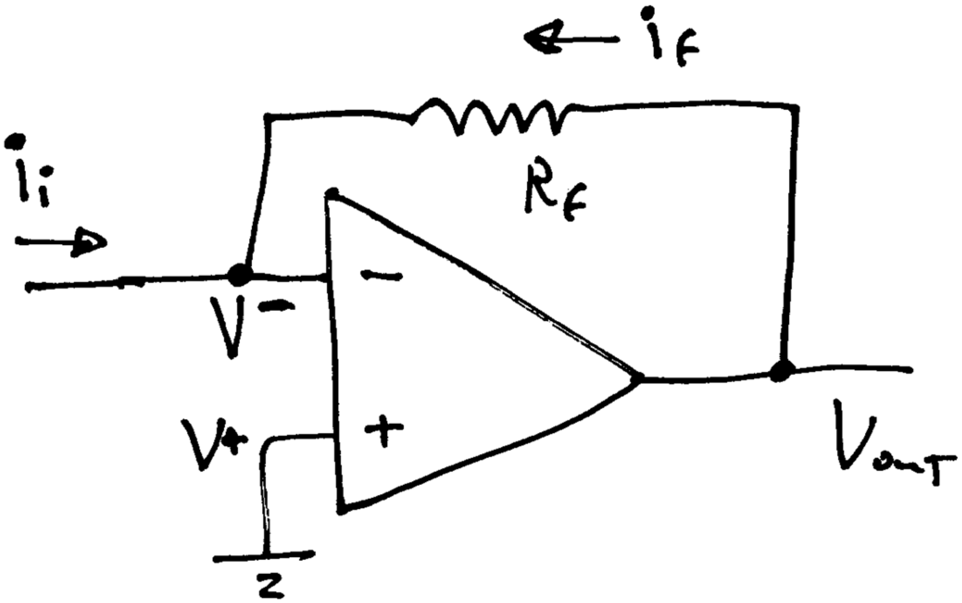
$$\therefore V_{OUT} = V_{IN}\left(\frac{R_f + R_i}{R_i}\right) = V_{IN}\left(1 + R_f/R_i\right)$$

Gain

Non-inverting OP-Amp gives Low-Z V_{OUT} from very high-Z V_{IN}, but also offers voltage gain ⇒ $1 + R_f/R_i$

- Like voltage follower, but gives voltage gain
  - Gain can be adjusted from unity upward via resistor ratio
  - High-Z input is good for conditioning High-Z sensors

The Transimpedance Amplifier



V_{OUT} Gives good low-Z drive (low impedance)

$Z_{in} \to \infty$ means

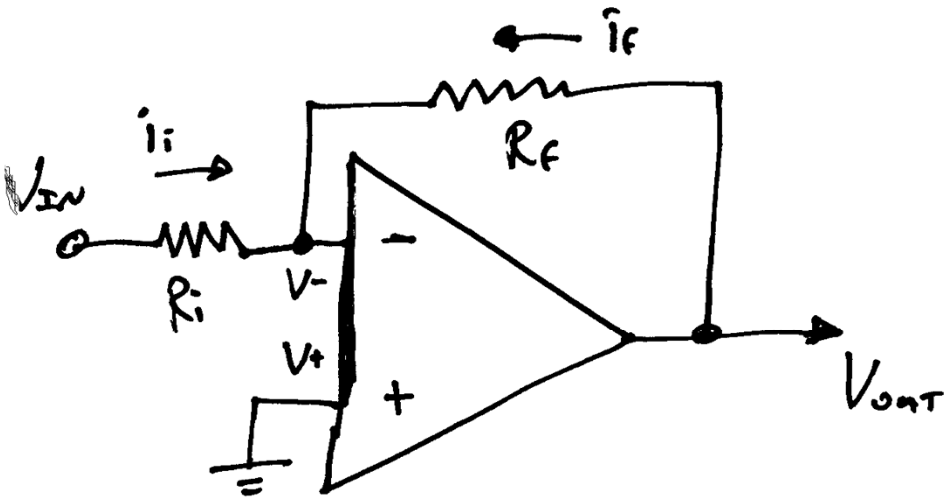
$$i_i = -i_f = -\frac{V_{OUT}}{R_f}$$

Negative Feedback forces $V^- = V^+$

$$\therefore \quad V_{OUT} = -i_i R_f$$

- Converts a current into a voltage
  - Generates a proportional (w. R_f) voltage from an input current
  - Produces a low-impedance output that can drive a microcomputer’s A-D converter, for example

The Inverting Amplifier



$i_f = -i_i$, since $Z_{in} \to \infty$

$V_+ = V_- = 0$, because of negative feedback and grounded V_+

$$\Rightarrow i_f = \frac{V_{OUT}}{R_f} = -i_i = \frac{V_{IN}}{R_i}$$

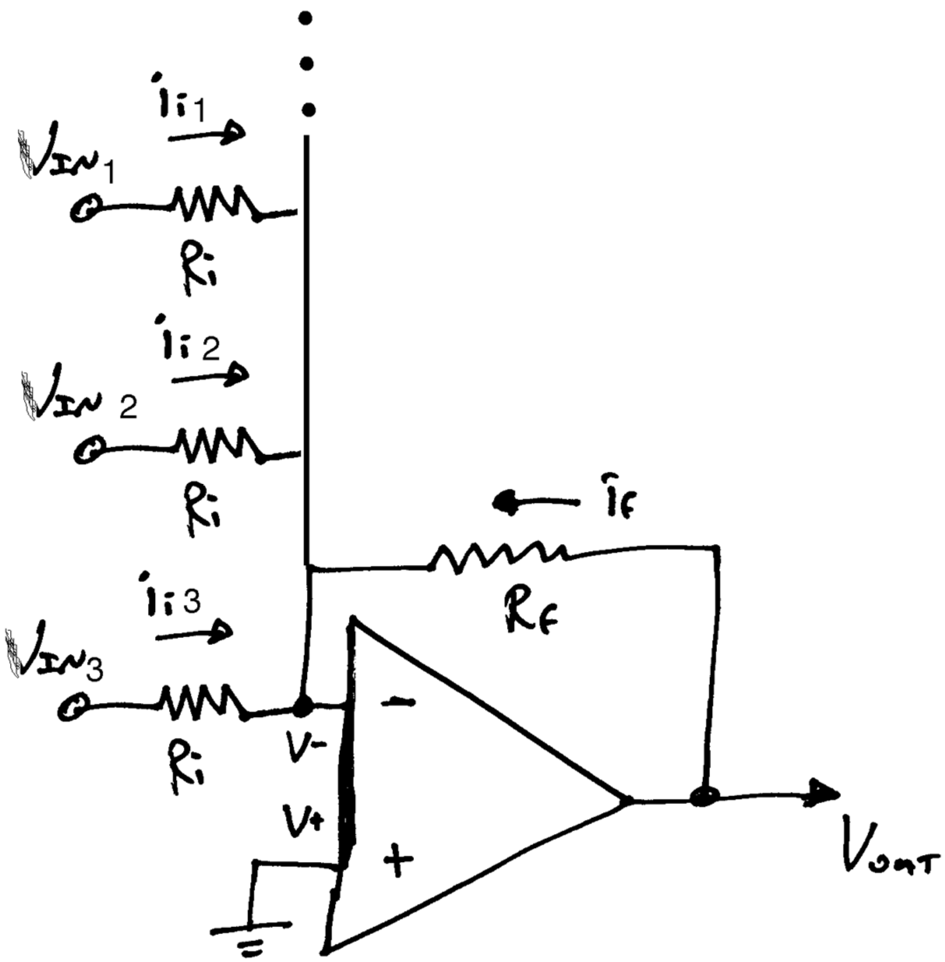
$$V_{OUT} = V_{IN}\underbrace{\left(-\frac{R_f}{R_i}\right)}_{\text{Gain}}$$

Inverting Op Amp produces negative voltage gain: $-R_f/R_i$

Input Impedance $= R_i$
(not huge, as with inverting Op Amp)

- Inverts signal, voltage gain varies from zero upward with the ratio of two resistors
  - Extension to summer is trivial with additional R_i's
  - Input impedance is not infinite: $Z_{in} = R_i$

The Summing Amplifier

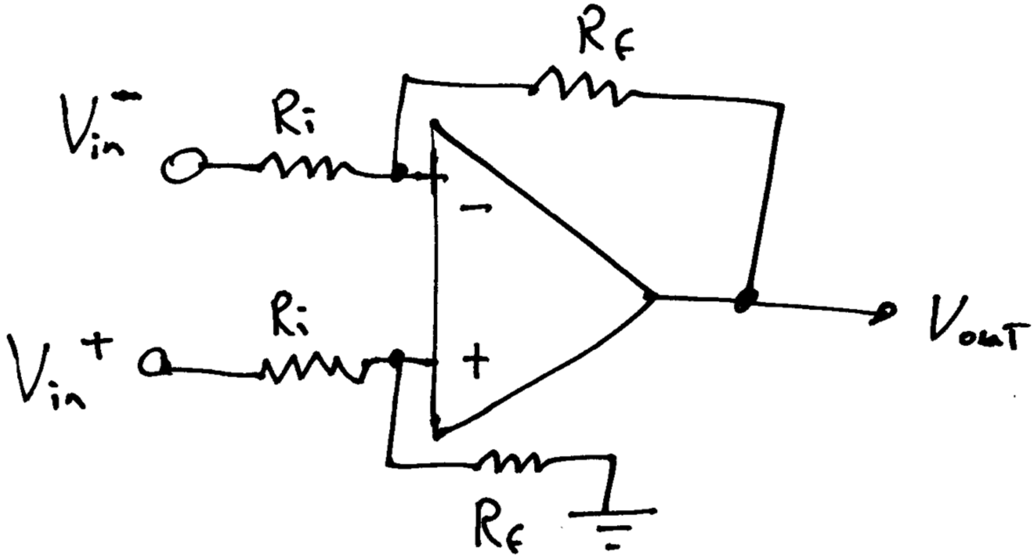


- No crosstalk between inputs because of virtual ground

Differential Amplifiers

- Intro to differential sensors
  - Pickup coil, piezoelectric, etc.
  - Comparison to reference (null drift, etc.)
    - Bend with strain gauges
- Simple differential amplifier
  - Intrinsic impedance imbalance
- Brute-force instrumentation amplifier
- 3-OpAmp differential amplifier w. gain
- 2-OpAmp differential amplifier

The Simple Differential Amplifier



Voltage Gain → R_f/R_i

$$V_{OUT} = (V_{in}^+ - V_{in}^-)\, R_f/R_i$$

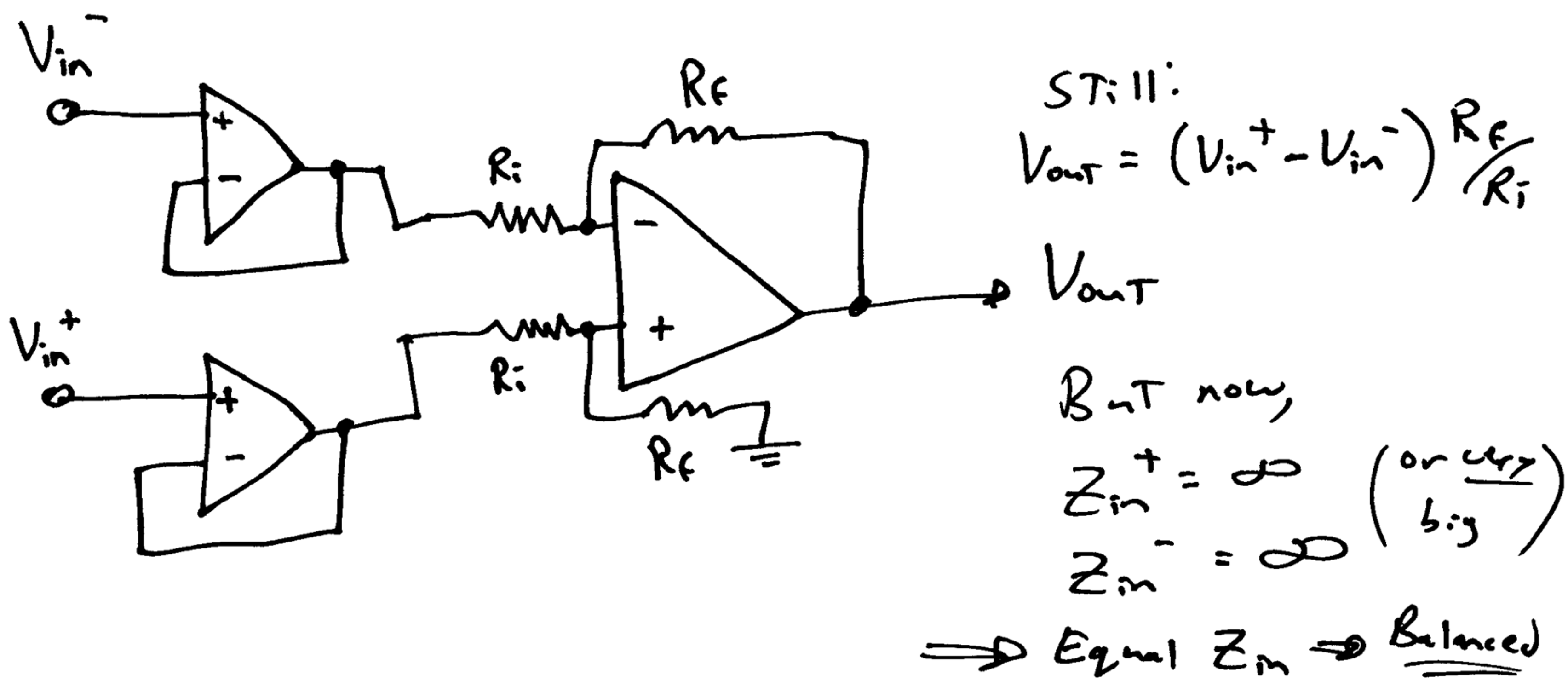
$$Z_{in}^- = R_i$$

$$Z_{in}^+ = R_i + R_f$$

$\Rightarrow$ Unequal Z_{in} → Unbalanced

- Subtracts two input signals
  - Input resistors must be equal, feedback and shunt resistors must be equal
  - Provides voltage gain
- The input impedances aren't equal, however
  - The amplifier is *unbalanced!*
    - A high-impedance sensor will produce common-mode errors (e.g., the system will be sensitive to the common voltage)
    - Differential sensors will be more sensitive to induced pickup signals (which tend to be high impedance)

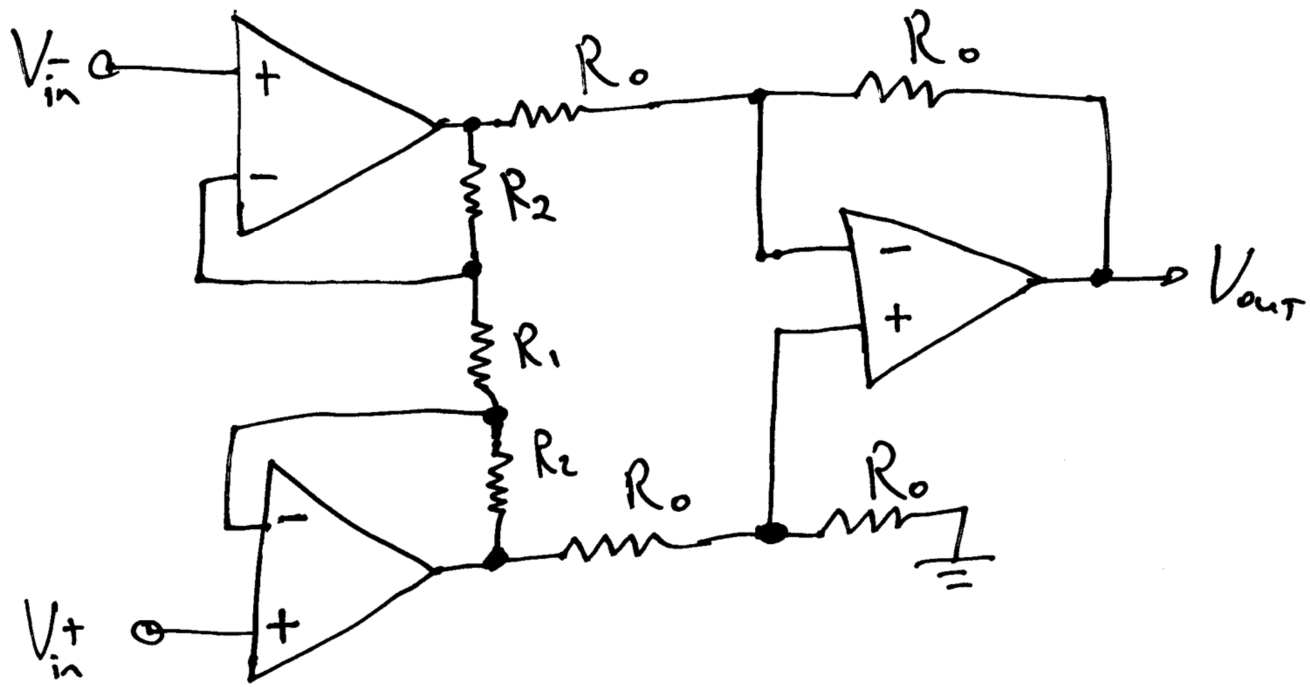
The Basic Instrumentation Amplifier



- Buffer each leg of the differential amplifier by a voltage follower
  - Impedance is now extremely high at both inputs
  - Impedance can be set by a shunt resistor across inputs
  - This is a *balanced* “instrumentation” amplifier

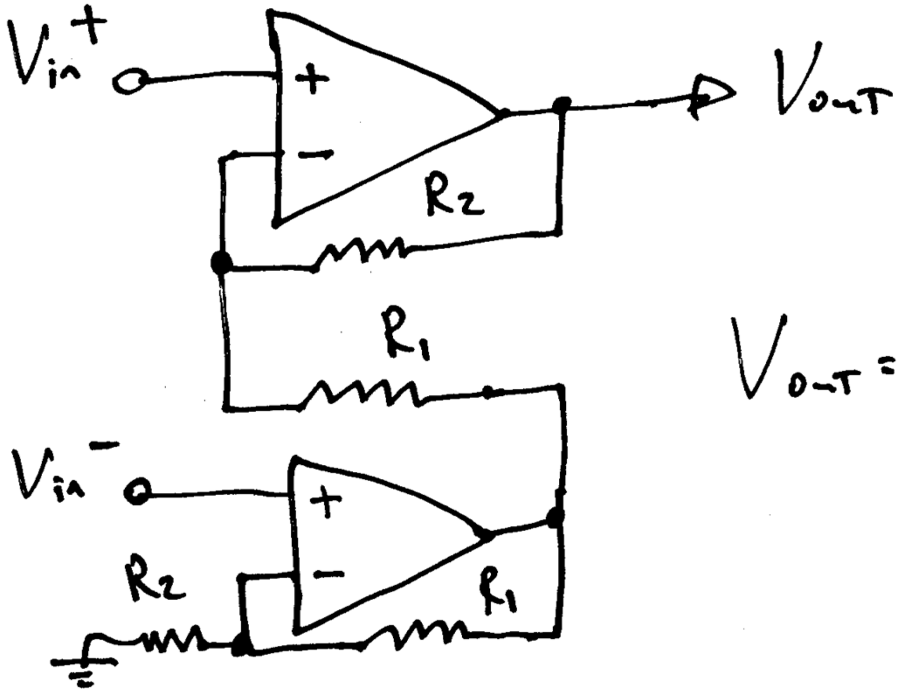
The Three-OpAmp Instrumentation Amplifier

$$V_{out} = \left(V_{in}^{+} - V_{in}^{-}\right)\overbrace{\left(1 + \frac{2R_2}{R_1}\right)}^{\text{Gain}}$$



- Gain is varied by changing only one resistor, R_1
  - No need to re-trim other components for a gain change
  - Gain at first stages is better for signal/noise
  - This is the instrumentation amplifier of choice

An Instrumentation Amplifier with Two OpAmps



$$V_{OUT} = \left(V_{in}^+ - V_{in}^-\right)\overbrace{\left(\frac{R_2}{R_1} + 1\right)}^{\text{Gain}}$$

- Can use when you only have space for a dual OpAmp
  - Gain change requires two resistors to be adjusted
  - Common mode sensitivity increases at higher frequency

Commercial Instrumentation Amplifiers

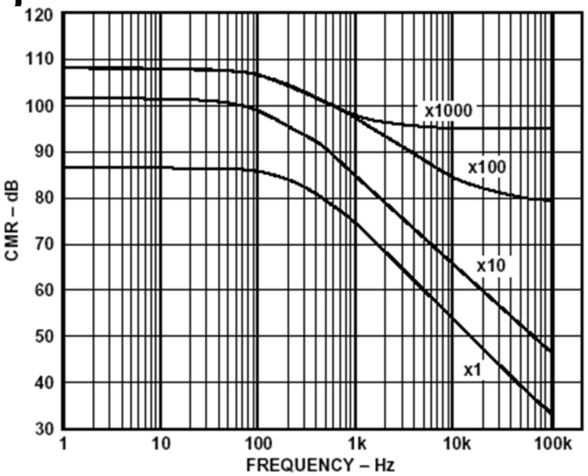
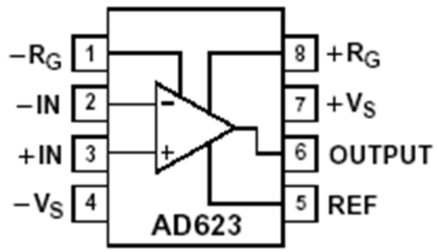
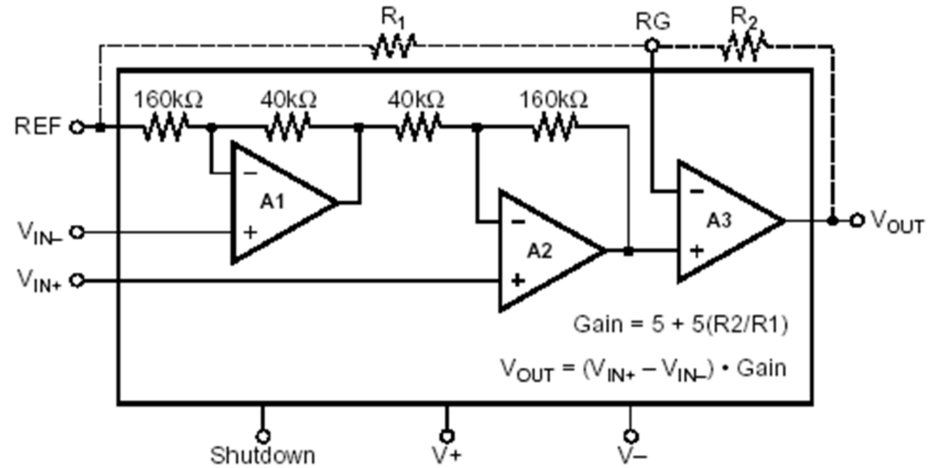


Figure 1. CMR vs. Frequency, +5 V_S, 0 V_S



Courtesy of Analog Devices. Used with permission.



Courtesy of Texas Instruments. Used with permission.

INA2321
500 kHz, 94 dB CMRR, R-R, μA sleep

- Analog Devices AD623
- Analog Devices AD AMP01
- BurrBrown (TI) INA series (INA2321)
- TI TLC271

Can be fairly slow, but precise DC properties, low drift, high gain, well matched

The Wheatstone Bridge

Differential readout of a resistive sensor

Graph of the sensitivity of a disbalanced bridge as a function of impedance ratio from *Handbook of Modern Sensors* removed due to copyright restrictions. See: page 217 on Google Books.

R3 = Resistive Sensor

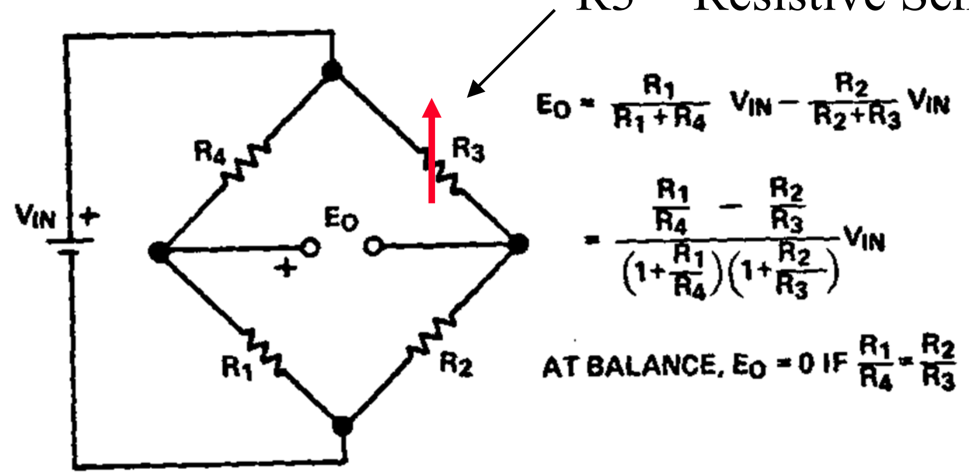
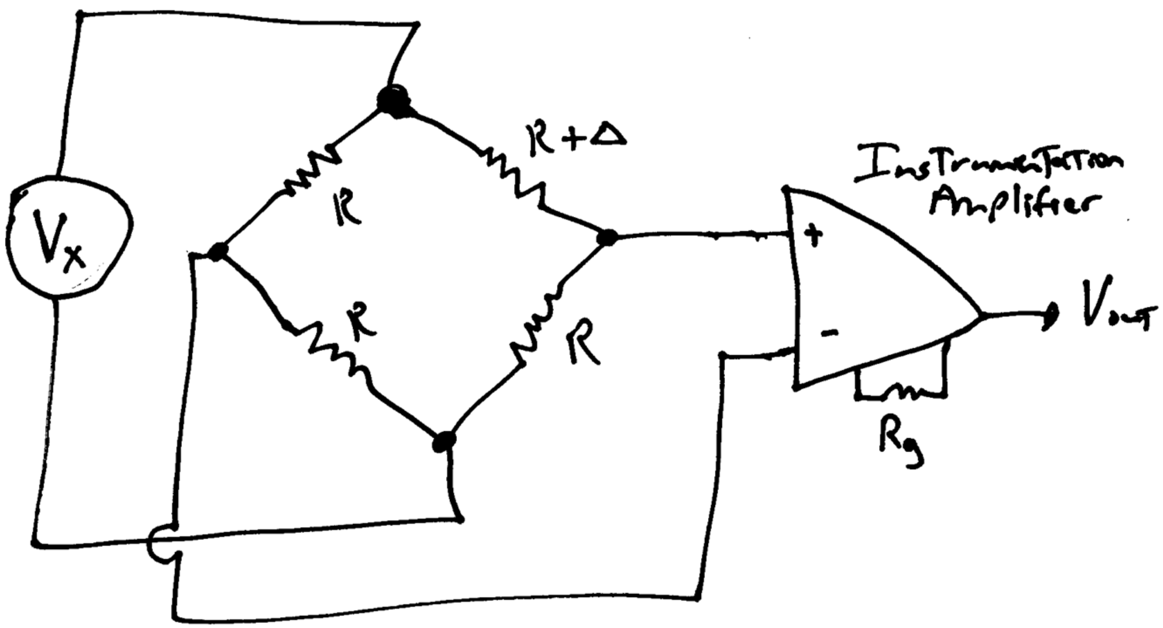


Figure 2-1. Basic bridge circuit — voltage excitation and voltage readout

$\kappa = R_4/R_1$

- Bridge Conditioning
- Active Bridge Servo'ing to keep null

Basic Bridge Conditioning with a Diff. Amp

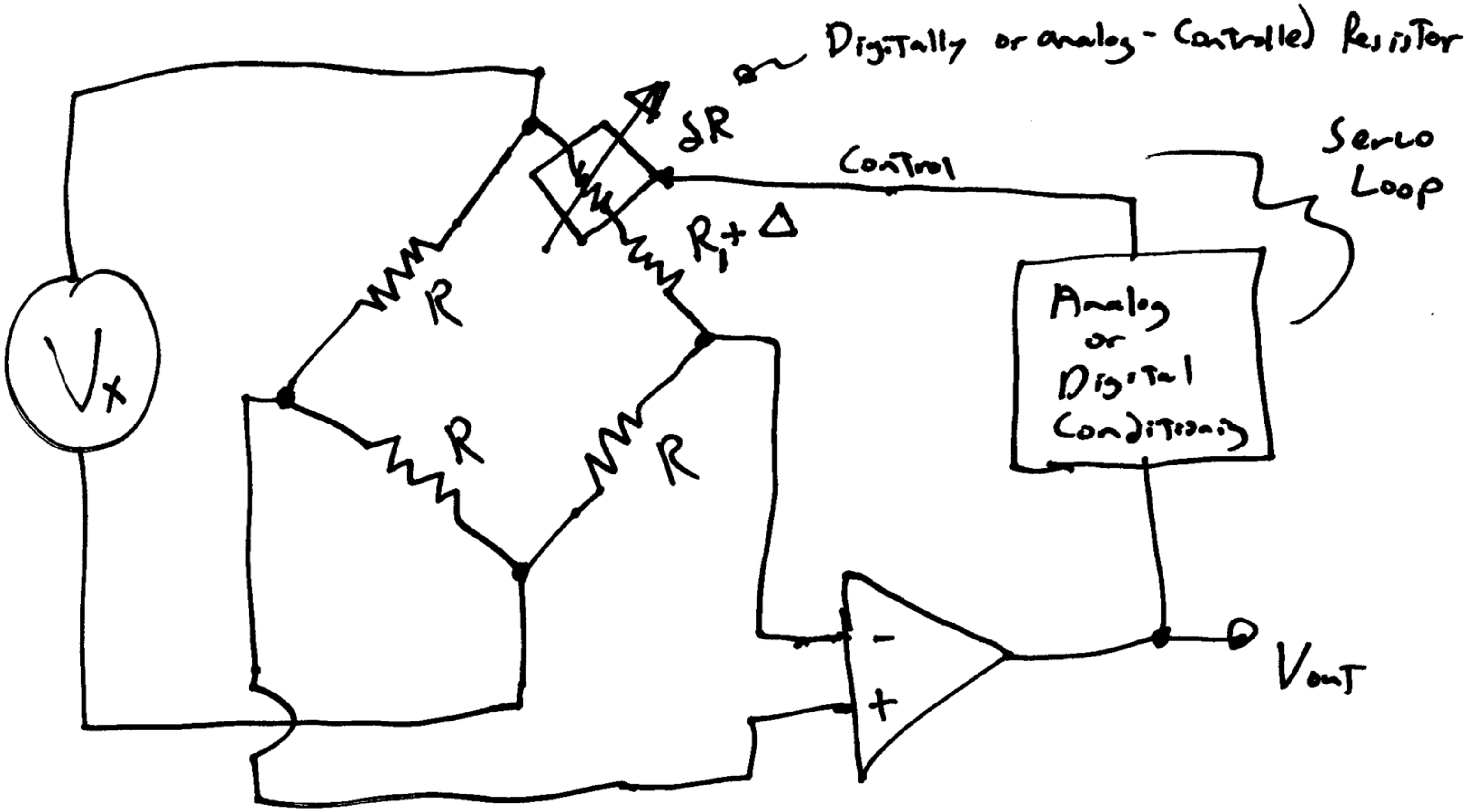


$$V_{OUT} = G_I \, V_x \, \frac{\Delta}{2(2+\Delta)}$$

$$\simeq G_I \, V_x \, \frac{\Delta}{4} \quad (\text{small } \Delta,\ \Delta << .05)$$

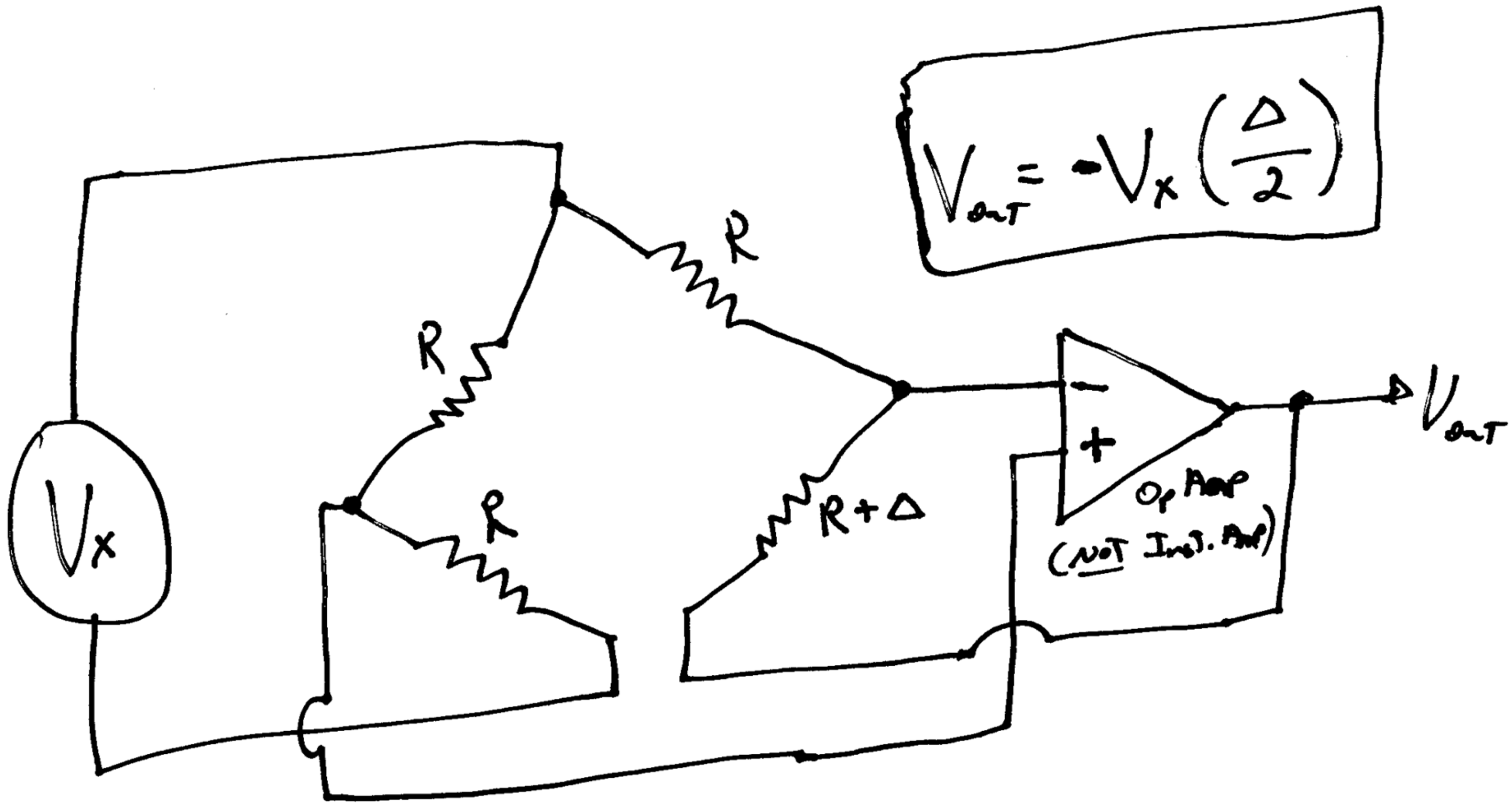
- G_I is the gain of the instrumentation amplifier (set by R_g)
- As the sensor readings increase (Δ grows in magnitude), the bridge becomes less sensitive and nonlinear

Servo'ed Resistor Balance



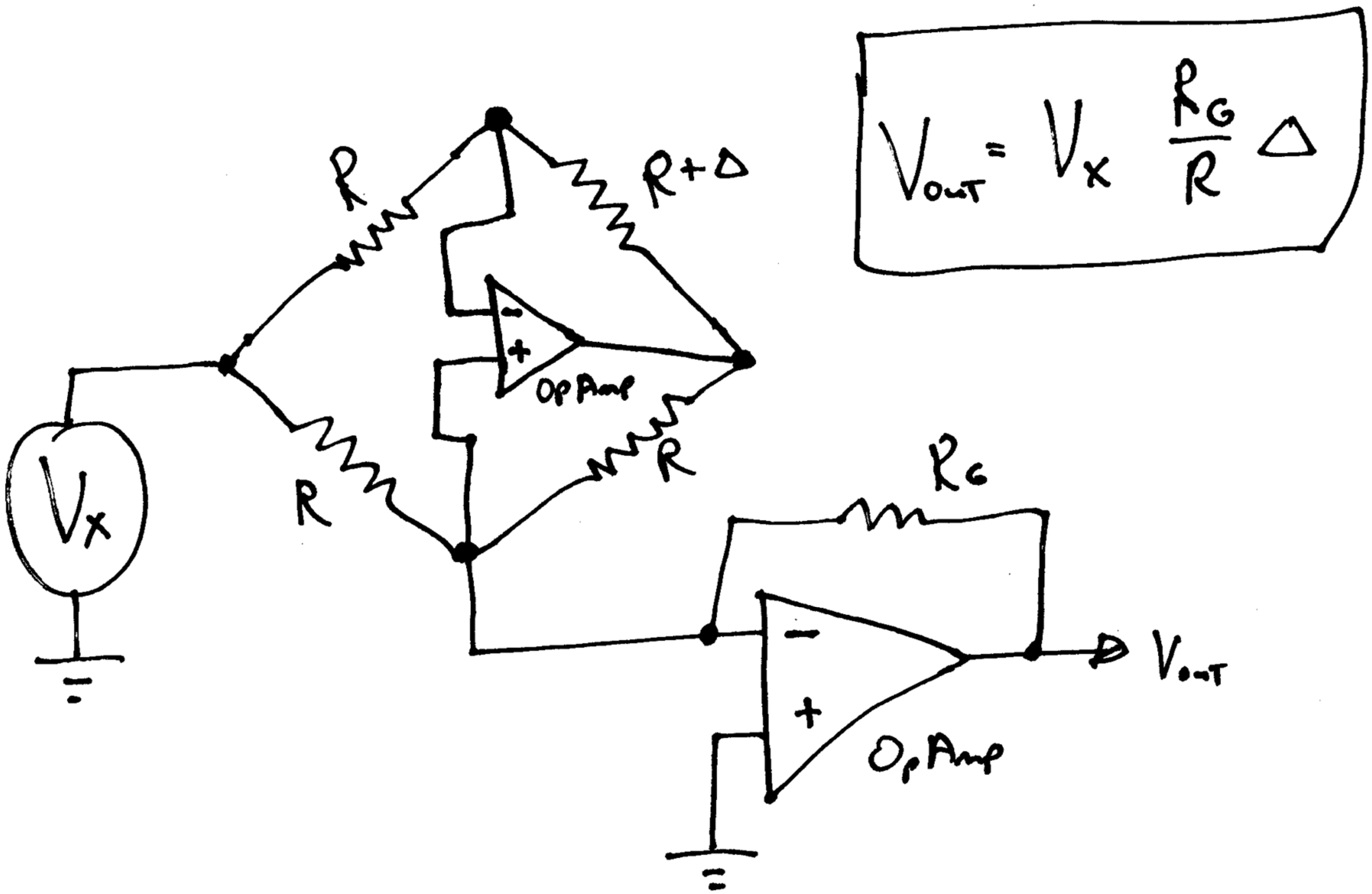
- A voltage (or digitally) variable resistor is adjusted in the negative feedback loop of an OpAmp to maintain the bridge's null
  - Feedback works to make $R_1 + \Delta + \delta R = R$

Servo’ed Drive of a Split Bridge



- Drives a split bridge in feedback to maintain null
  - Possible when one has full access to the bridge legs

Servo'ed Drive of a Full Bridge



- Bridge Servo'ed to ground opposite legs
  - Maintain balance, gain set by R_G

Packaged Bridge Amplifiers

BurrBrown (TI) XTR106

4-20mA CURRENT TRANSMITTER
with Bridge Excitation and Linearization

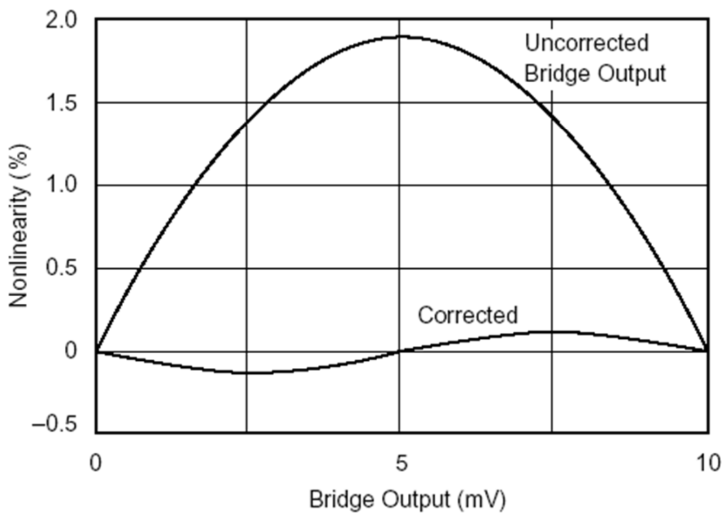
FEATURES

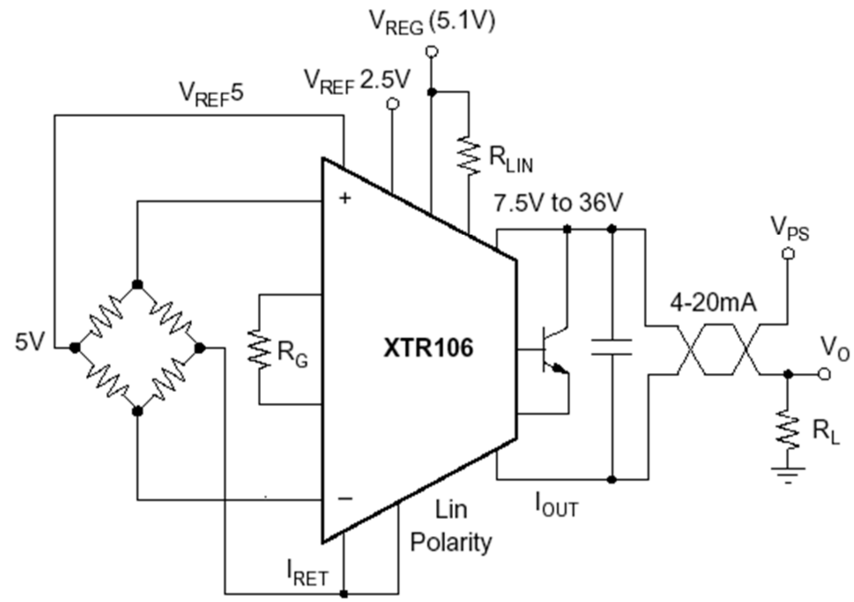
- LOW TOTAL UNADJUSTED ERROR
- 2.5V, 5V BRIDGE EXCITATION REFERENCE
- 5.1V REGULATOR OUTPUT
- LOW SPAN DRIFT: ±25ppm/°C max
- LOW OFFSET DRIFT: 0.25μV/°C
- HIGH PSR: 110dB min
- HIGH CMR: 86dB min
- WIDE SUPPLY RANGE: 7.5V to 36V
- 14-PIN DIP AND SO-14 SURFACE-MOUNT

APPLICATIONS

- PRESSURE BRIDGE TRANSMITTERS
- STRAIN GAGE TRANSMITTERS
- TEMPERATURE BRIDGE TRANSMITTERS
- INDUSTRIAL PROCESS CONTROL
- SCADA REMOTE DATA ACQUISITION
- REMOTE TRANSDUCERS
- WEIGHING SYSTEMS
- ACCELEROMETERS

BRIDGE NONLINEARITY CORRECTION USING XTR106





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