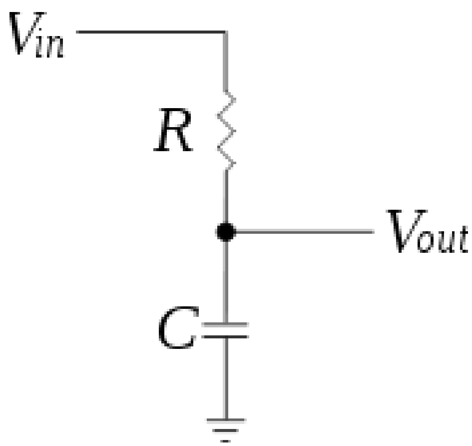
MAS836 – Sensor Technologies for Interactive Environments

Lecture 3 – Analog Conditioning Electronics, Pt. 3

Passive RC Filters

- Passive LP Filter: RC network: $f_c = 1/(2\pi RC)$



-3dB = 0.707

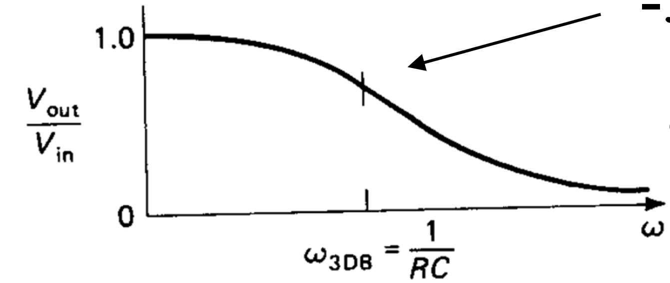
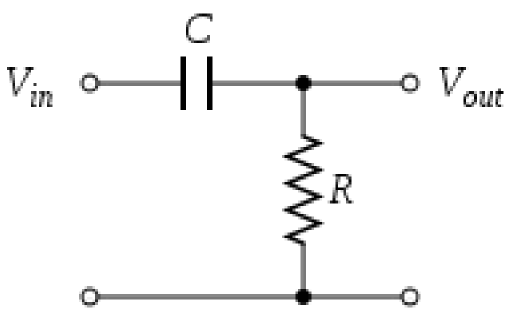
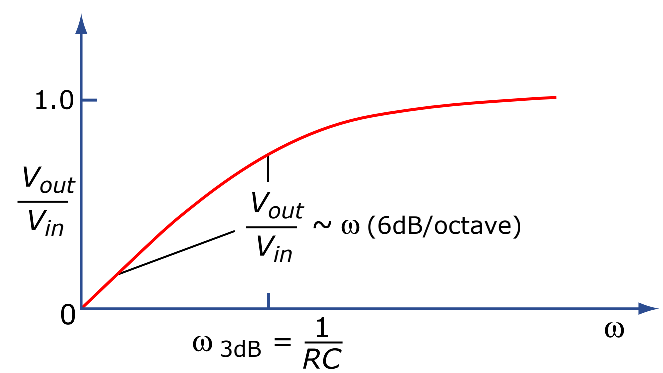


Figure 1.59. Frequency response of low-pass filter.

- Passive HP filter: RC network: $f_c = 1/(2\pi RC)$





Frequency response of a high-pass filter.

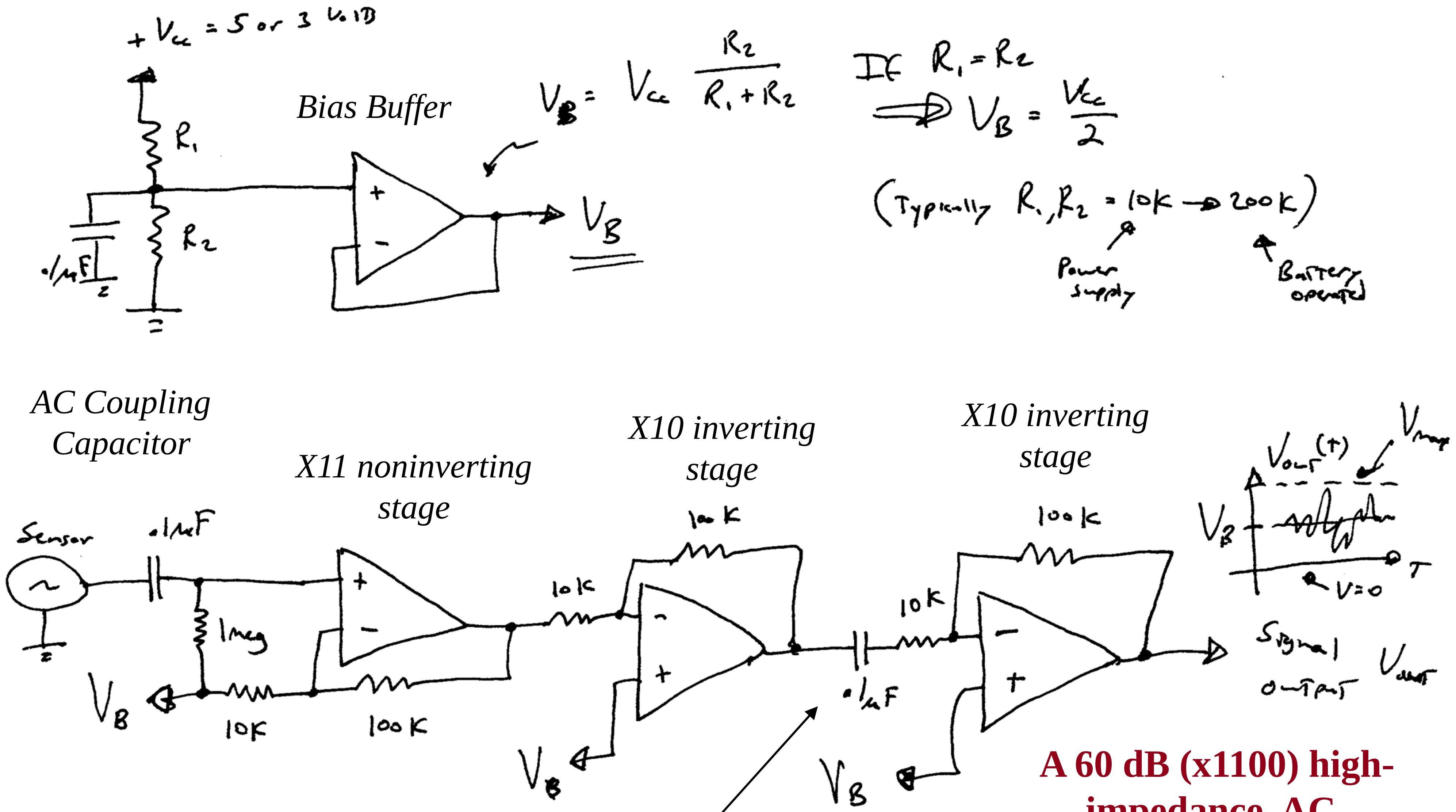
Correction - To take the magnitude of a complex impedance, add the real and imaginary parts in *quadrature*

Biasing

- AC Coupling
- Biasing noninverting input
- Biasing at inverting input

Buffer the voltage divider’s output and use it everywhere...

Biasing an entire circuit with a Buffered Voltage



AC Coupling Capacitor (decouple accumulated offset errors)

A 60 dB (x1100) high-impedance, AC-Coupled amplifier with bias made from a quad OpAmp

Sampling

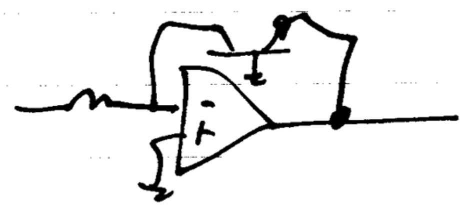
- Nyquist: $f_{in} < f_s/2$
- Bandlimited (demodulation) sampling
  - $\Delta f_{in} < f_s/2$
  - Loose absolute phase information
    - Don’t know whether phase moves forward or backward
  - Quadrature sampling
    - Bandlimited sampling at t and a quarter-period later
    - Form the “Analytic Signal”
      - I.E., the Quadrature (complex) Amplitude
    - Can also do this with multipliers and quadrature demodulation
  - Synchronous undersampling for periodic signals

Nonlinear Signal Shaping

Amplitude Compression

- Diode Shapers
- Log Amps
- Companders
- Analog Multipliers
  - Squaring and square-rooting

$$V_{BE} = \frac{KT}{q} \log_e \left(\frac{I_c}{I_o} \right)$$



$V_o =$

Transdiode

Log Amplifiers

Burr-Brown Products from Texas Instruments

LOG101

SBOS242A – MAY 2002 – REVISED APRIL 2003

Precision LOGARITHMIC AND LOG RATIO AMPLIFIER

FEATURES

- EASY-TO-USE COMPLETE CORE FUNCTION
- HIGH ACCURACY: 0.01% FSO Over 5 Decades
- WIDE INPUT DYNAMIC RANGE: 7.5 Decades, 100pA to 3.5mA
- LOW QUIESCENT CURRENT: 1mA
- WIDE SUPPLY RANGE: ±4.5V to ±18V

APPLICATIONS

- LOG, LOG RATIO, ANTI-LOG COMPUTATION: Communication, Analytical, Medical, Industrial, Test, and General Instrumentation
- PHOTODIODE SIGNAL COMPRESSION AMPS
- ANALOG SIGNAL COMPRESSION IN FRONT OF ANALOG-TO-DIGITAL (A/D) CONVERTERS

DESCRIPTION

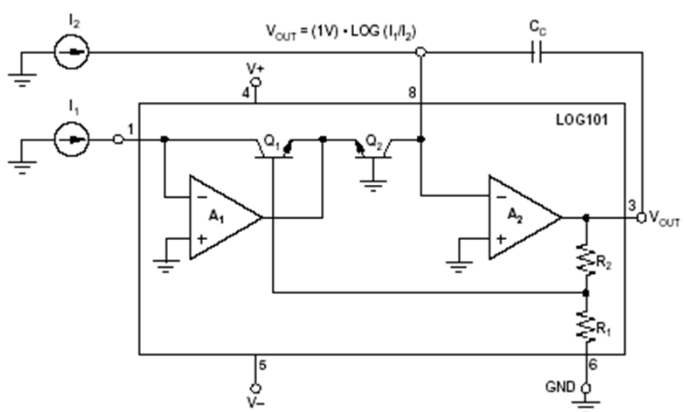
The LOG101 is a versatile integrated circuit that computes the logarithm or log ratio of an input current relative to a reference current.

The LOG101 is tested over a wide dynamic range of input signals. In log ratio applications, a signal current can come from a photodiode, and a reference current from a resistor in series with a precision external reference.

The output signal at V_{OUT} is trimmed to 1V per decade of input current allowing seven decades of input current dynamic range.

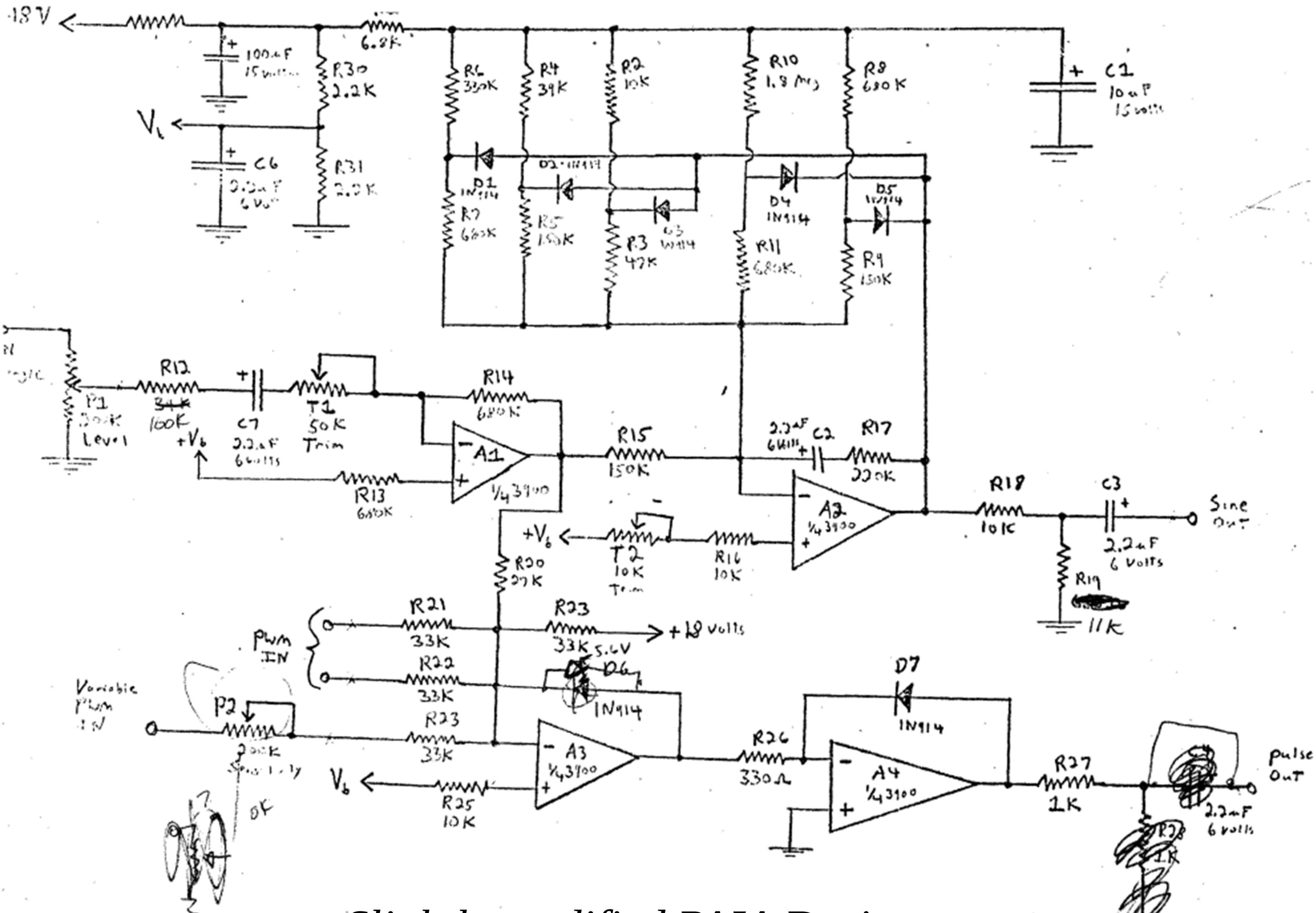
Low DC offset voltage and temperature drift allow accurate measurement of low-level signals over a wide environmental temperature range. The LOG101 is specified over the temperature range –5°C to +75°C, with operation over –40°C to +85°C.

Note: US Patent Pending



Smoothly limit (compress) he amplitude of a signal

Diode Triangle-to-Sine Waveshaper

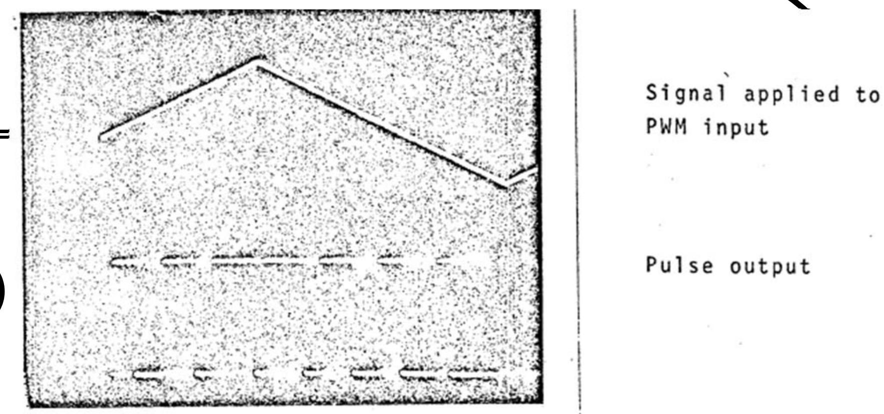


Slightly modified PAIA Design

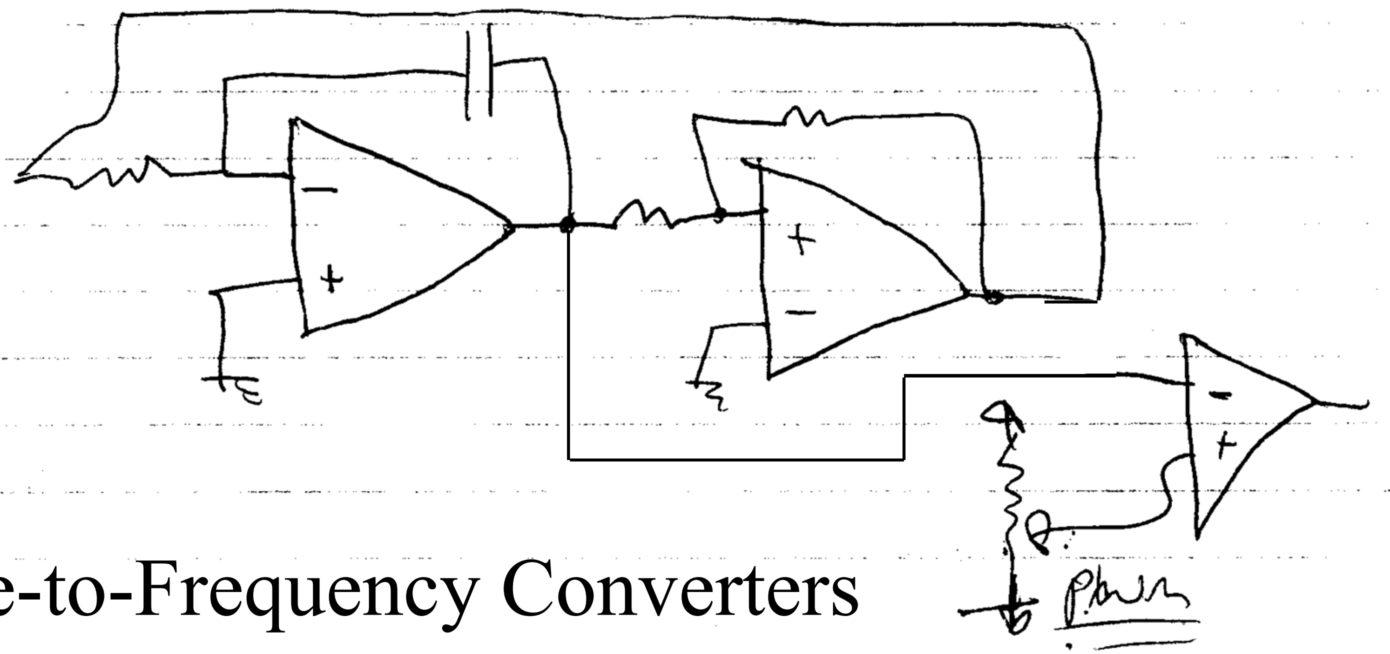
Digitization

- Can use an analog-digital converter (ADC)
  - 8-12 bit converters commonly on µComputers
    - Sometimes 16 or 24 bit (µConverter from Analog)
  - For special applications, one can use an ADC chip
    - Typically talk SPI, I^2C, etc.
  - Many kinds of ADC
    - Pipeline, Successive Approximation, Flash, ΣΔ…
    - Ari will tell you lots about how these work and their characteristics
- For just 1 or 2 bits, you can use comparators
  - Comparitors often on µC chip too
- You can also convert an amplitude into a time signal
  - Only need a logic pin and a timing routine (or internal µC timer)
  - Voltage to pulse-width, voltage to frequency
    - Can do current too!

Pulse Encoding



- The astable multivibrator
  - VCO (voltage controlled oscillator)
  - PWM (pulse-width modulation)

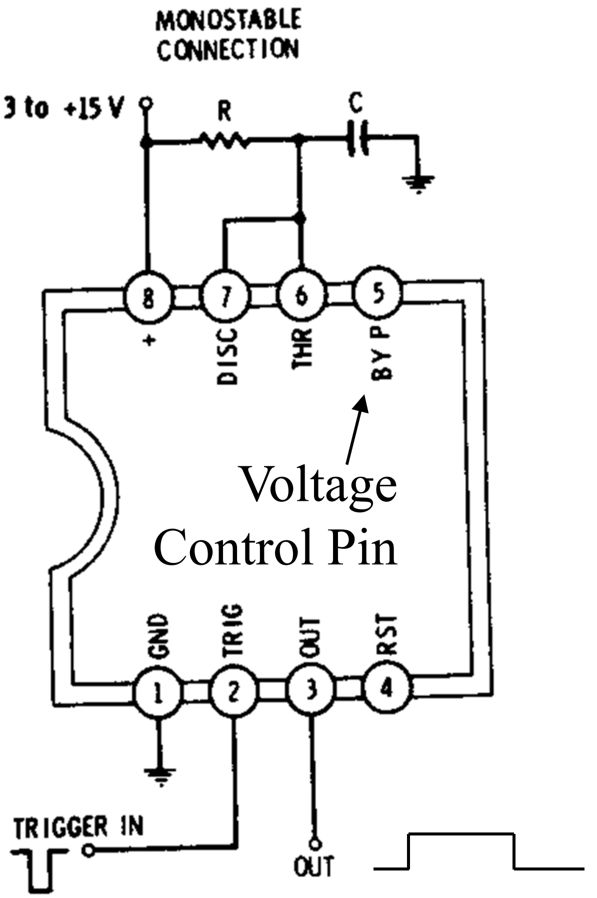


- Voltage-to-Frequency Converters
- Using the 555 as a Voltage-to-PW converter

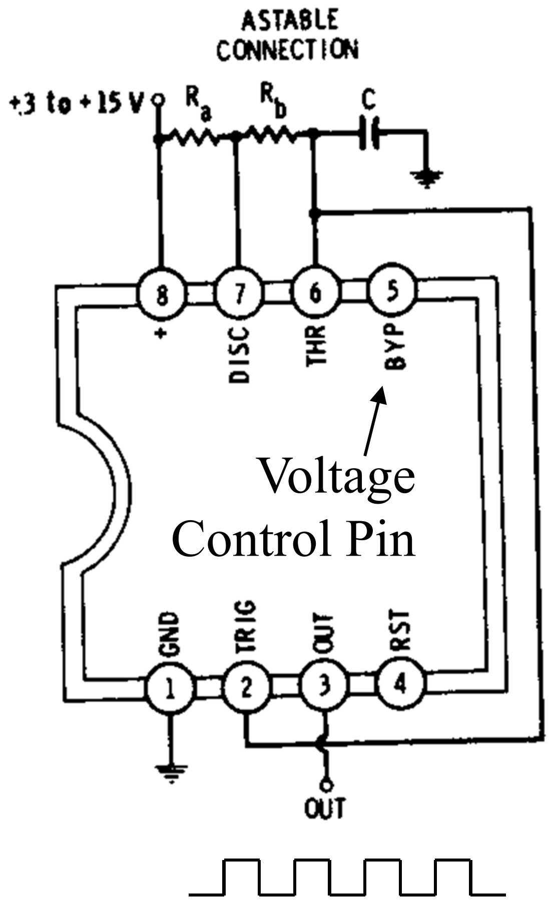
How do I make this into a VCO?

What kind of waveform(s) does this produce?

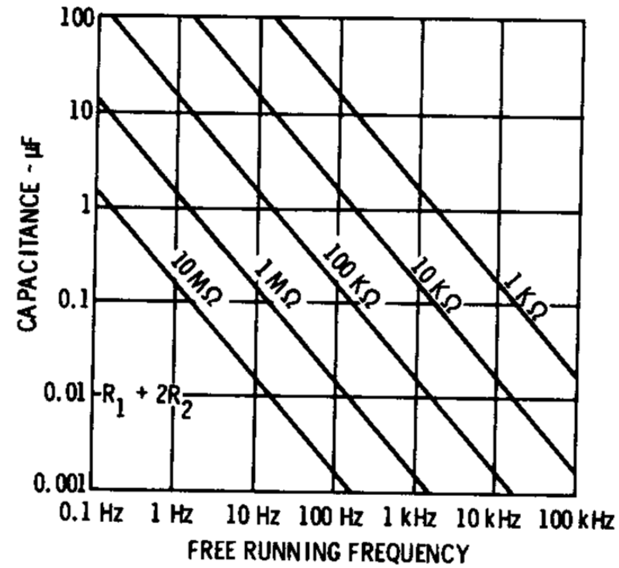
The 555 Timer (556 is dual version)



"One Shot"



"Astable"



(A) Graph of R1, R2, C, and operating frequency.

CHARGE TIME (OUTPUT HIGH):	$0.693\,(R_1 + R_2)\,C$
DISCHARGE TIME (OUTPUT LOW):	$0.693\,(R_2)\,C$
PERIOD:	$0.693\,(R_1 + 2R_2)\,C$
FREQUENCY:	$\frac{1.44}{(R_1 + 2R_2)\,C}$

LIMITS: MAX $R_1 + R_2$ -- 3.3 meg
MIN R_1 OR R_2 -- 1 K
MIN RECOMMENDED CAPACITANCE: 500 pF
MAX CAPACITANCE -- LIMITED BY C LEAKAGE

DUTY CYCLE: $= \frac{\text{TIME HIGH}}{\text{TIME LOW}} = \frac{R_1 + R_2}{R_2}$

(B) Design equations.

Extremely versatile and cheap (and old!) module
Low power version (L555 or 555L)
Normal version does hours - 1 microsec
Can voltage-control the pulse period (nonlinear)
Triggering a monostable from a clock provides a voltage-variable periodic pulse (that can be timed in a microprocessor)

Analog Multipliers (4-Quadrant)

ANALOG DEVICES

Low Cost Analog Multiplier

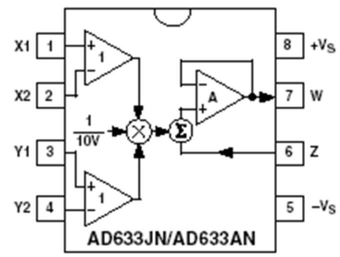
AD633

FEATURES
- 4-Quadrant Multiplication
- Low Cost 8-Lead Package
- Complete—No External Components Required
- Laser-Trimmed Accuracy and Stability
- Total Error within 2% of FS
- Differential High Impedance X and Y Inputs
- High Impedance Unity-Gain Summing Input
- Laser-Trimmed 10 V Scaling Reference

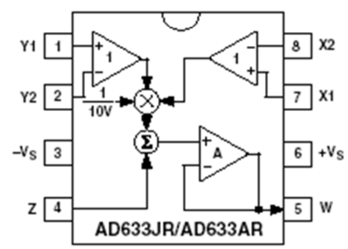
APPLICATIONS
- Multiplication, Division, Squaring
- Modulation/Demodulation, Phase Detection
- Voltage Controlled Amplifiers/Attenuators/Filters

CONNECTION DIAGRAMS

8-Lead Plastic DIP (N) Package



8-Lead Plastic SOIC (RN-8) Package



$$W = \frac{(X_1 - X_2)(Y_1 - Y_2)}{10V} + Z$$

PRODUCT DESCRIPTION

The AD633 is a functionally complete, four-quadrant, analog multiplier. It includes high impedance, differential X and Y inputs and a high impedance summing input (Z). The low impedance output voltage is a nominal 10 V full scale provided by a buried Zener. The AD633 is the first product to offer these features in modestly priced 8-lead plastic DIP and SOIC packages.

The AD633 is laser calibrated to a guaranteed total accuracy of 2% of full scale. Nonlinearity for the Y input is typically less than 0.1% and noise referred to the output is typically less than 100 µV rms in a 10 Hz to 10 kHz bandwidth. A 1 MHz bandwidth, 20 V/µs slew rate, and the ability to drive capacitive loads make the AD633 useful in a wide variety of applications where simplicity and cost are key concerns.

The AD633's versatility is not compromised by its simplicity. The Z-input provides access to the output buffer amplifier, enabling the user to sum the outputs of two or more multipliers, increase the multiplier gain, convert the output voltage to a current, and configure a variety of applications.

The AD633 is available in an 8-lead plastic DIP package (N) and 8-lead SOIC (R). It is specified to operate over the 0°C to 70°C commercial temperature range (J Grade) or the –40°C to +85°C industrial temperature range (A Grade).

PRODUCT HIGHLIGHTS

1. The AD633 is a complete four-quadrant multiplier offered in low cost 8-lead plastic packages. The result is a product that is cost effective and easy to apply.
2. No external components or expensive user calibration are required to apply the AD633.
3. Monolithic construction and laser calibration make the device stable and reliable.
4. High (10 MΩ) input resistances make signal source loading negligible.
5. Power supply voltages can range from ±8 V to ±18 V. The internal scaling voltage is generated by a stable Zener diode; multiplier accuracy is essentially supply insensitive.

This is a cheap one
$5 or so apiece

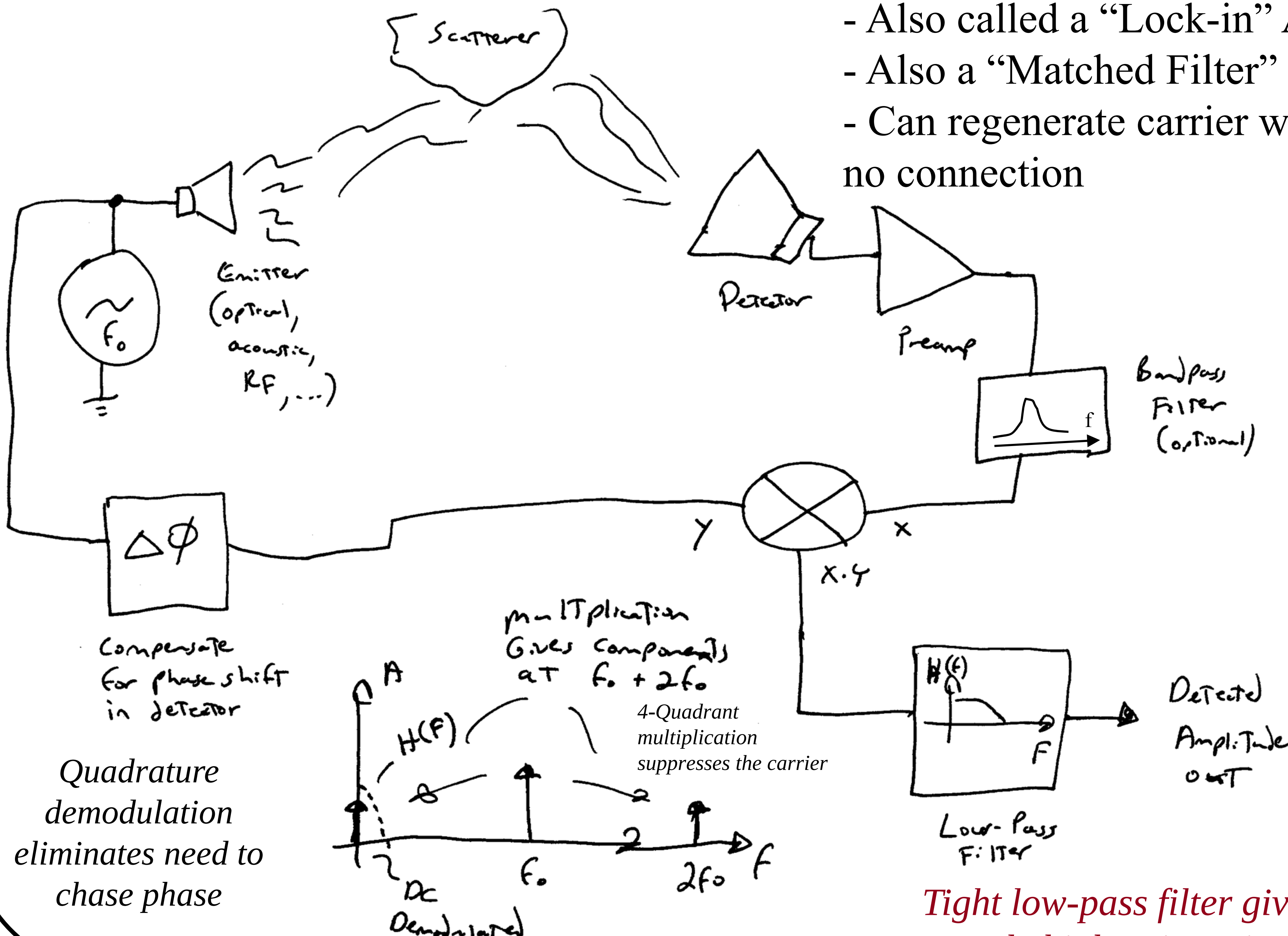
They get much more expensive with more bandwidth and accuracy

4-Quadrant flips phase w. sign

2-Quadrant multiplies |X|•Y only changes gain

Synchronous Detection

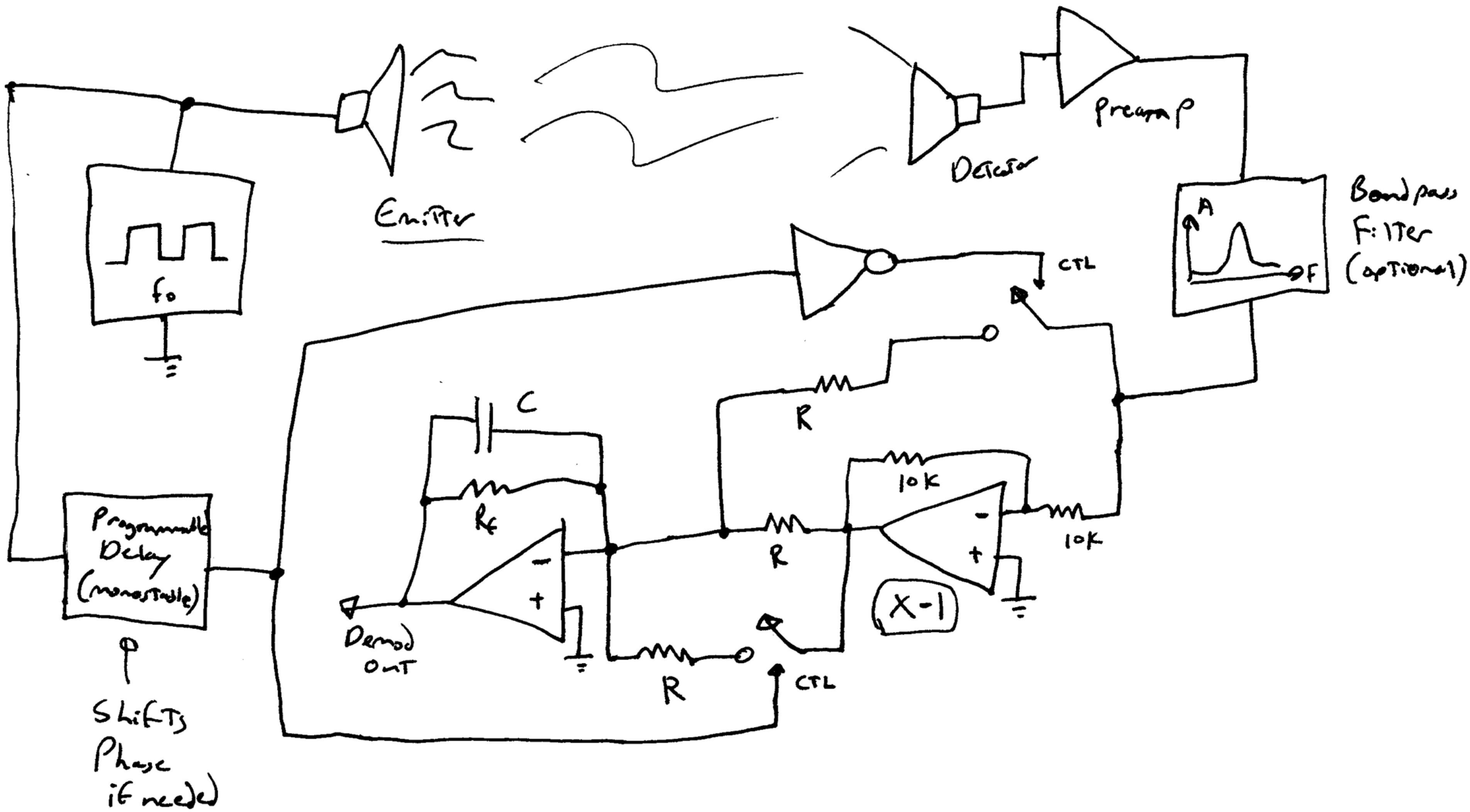
- Also called a "Lock-in" Amplifier
- Also a "Matched Filter" of sorts
- Can regenerate carrier with PLL if no connection



Quadrature demodulation eliminates need to chase phase

Tight low-pass filter gives extremely high noise rejection!

Demodulating with a switch (Walsh Waves)



Cheaper, and sometimes more accurate than using a multiplier
Some analog switches have the built-in inverter
Can use instrumentation amplifier (w. passive filters on inputs) to subtract on from off
If µP is fast enough, this can be done digitally (dynamic range in sum?)

Buy it as the AD630

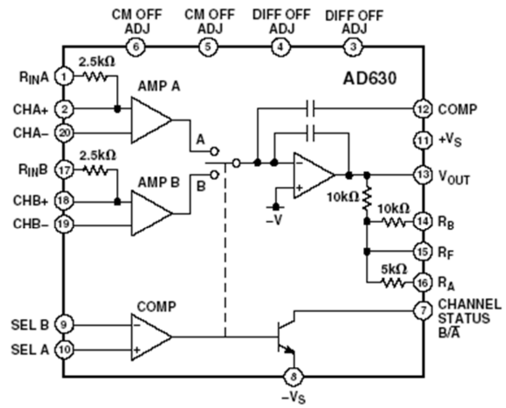
ANALOG DEVICES

Balanced Modulator/Demodulator

AD630

FEATURES
Recovers Signal from +100 dB Noise
2 MHz Channel Bandwidth
45 V/µs Slew Rate
–120 dB Crosstalk @ 1 kHz
Pin Programmable Closed Loop Gains of ±1 and ±2
0.05% Closed Loop Gain Accuracy and Match
100 µV Channel Offset Voltage (AD630BD)
350 kHz Full Power Bandwidth
Chips Available

FUNCTIONAL BLOCK DIAGRAM



PRODUCT DESCRIPTION

The AD630 is a high precision balanced modulator which combines a flexible commutating architecture with the accuracy and temperature stability afforded by laser wafer trimmed thin-film resistors. Its signal processing applications include balanced modulation and demodulation, synchronous detection, phase detection, quadrature detection, phase sensitive detection, lock-in amplification and square wave multiplication. A network of on-board applications resistors provides precision closed loop gains of ±1 and ±2 with 0.05% accuracy (AD630B). These resistors may also be used to accurately configure multiplexer gains of +1, +2, +3 or +4. Alternatively, external feedback may be employed allowing the designer to implement his own high gain or complex switched feedback topologies.

The AD630 may be thought of as a precision op amp with two independent differential input stages and a precision comparator which is used to select the active front end. The rapid response time of this comparator coupled with the high slew rate and fast settling of the linear amplifiers minimize switching distortion. In addition, the AD630 has extremely low crosstalk between channels of –100 dB @ 10 kHz.

The AD630 is intended for use in precision signal processing and instrumentation applications requiring wide dynamic range. When used as a synchronous demodulator in a lock-in amplifier configuration, it can recover a small signal from 100 dB of interfering noise (see lock-in amplifier application). Although optimized for operation up to 1 kHz, the circuit is useful at frequencies up to several hundred kilohertz.

Other features of the AD630 include pin programmable frequency compensation, optional input bias current compensation resistors, common-mode and differential-offset voltage adjustment, and a channel status output which indicates which of the two differential inputs is active. This device is now available to Standard Military Drawing (DESC) numbers 5962-8980701RA and 5962-89807012A.

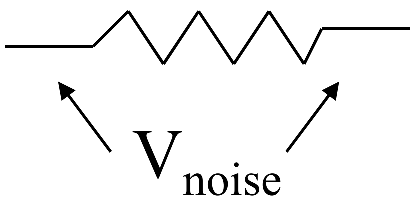
PRODUCT HIGHLIGHTS

1. The configuration of the AD630 makes it ideal for signal processing applications such as: balanced modulation and demodulation, lock-in amplification, phase detection, and square wave multiplication.
2. The application flexibility of the AD630 makes it the best choice for many applications requiring precisely fixed gain, switched gain, multiplexing, integrating-switching functions, and high-speed precision amplification.
3. The 100 dB dynamic range of the AD630 exceeds that of any hybrid or IC balanced modulator/demodulator and is comparable to that of costly signal processing instruments.
4. The op-amp format of the AD630 ensures easy implementation of high gain or complex switched feedback functions. The application resistors facilitate the implementation of most common applications with no additional parts.
5. The AD630 can be used as a two channel multiplexer with gains of +1, +2, +3, or +4. The channel separation of 100 dB @ 10 kHz approaches the limit which is achievable with an empty IC package.
6. The AD630 has pin-strappable frequency compensation (no external capacitor required) for stable operation at unity gain without sacrificing dynamic performance at higher gains.
7. Laser trimming of comparator and amplifying channel offsets eliminates the need for external nulling in most cases.

Sources of Noise in Electronics

- Johnson (or Nyquist) Noise
  - Flat spectrum
  - $V_{noise} = \sqrt{4kTR[\Delta f]}$
    - Independent of current
    - Comes from the fluxuation-dissipation theorem

10K resistor @ room temp develops 1.3 µV over decade in frequency



- Flicker Noise
  - 1/f spectrum (equal power per decade of frequency)
  - Increases with current through element
  - Due to nonidealities (or “granularity) in component

Flicker noise in different kinds of resistors:

rms microvolts per volt applied across the resistor, measured over one decade of frequency:

Carbon-composition	0.10µV to 3.0µV
Carbon-film	0.05µV to 0.3µV
Metal-film	0.2µV to 0.2µV
Wire-wound	0.01µV to 0.2µV

Shot Noise

- Shot (or Quantization) noise
  - "Rain on the Roof" - when each electron does something different
  - Prevalent where electrons cross a barrier
    - Diodes, transistors
  - Not in wires, less in resistors
  - $I_{noise} = \sqrt{2qI_{dc}\Delta f}$ (charges acting independently)
  - *Proportionally* worse with small current
  - Flat spectrum
- Popcorn noise
  - Periodic spikes in signal
    - These days, typically a bad component...

Noise Parameters

- Sensor impedance will produce Johnson noise
  - Current and voltage modes
- Signal-to-noise (dB) = $10 \log_{10}(V_s^2/V_n^2)$
- Noise figure is ratio (in dB) of the output noise of the real amplifier to the output noise of a zero-noise amplifier (only gain) with a given resistor R_s at the input.
  - Insensitive parameter for high R_s
  - Useful for a fixed, given impedance
    - RF device at 50 Ω or a particular sensor
  - Equivalent to noise temperature (T of R_s to give noise in ideal amplifier)
- Noise adds in quadrature (if sources are uncorrelated!)

Noise in Inverting and Noninverting Amplifiers

Images from “The Art of Electronics” (page 447) describing noise in non-inverting and inverting amplifiers removed due to copyright restrictions. See: Google Books.

Noise gain = noninverting gain via Thevenin

Noise gain, and the problem with capacitive loads at the inverting input

Short answer for noise - for high impedance sources, use low i_n OpAmps

- for low impedance sources, use low v_n OpAmps

The Non-Ideal OpAmp

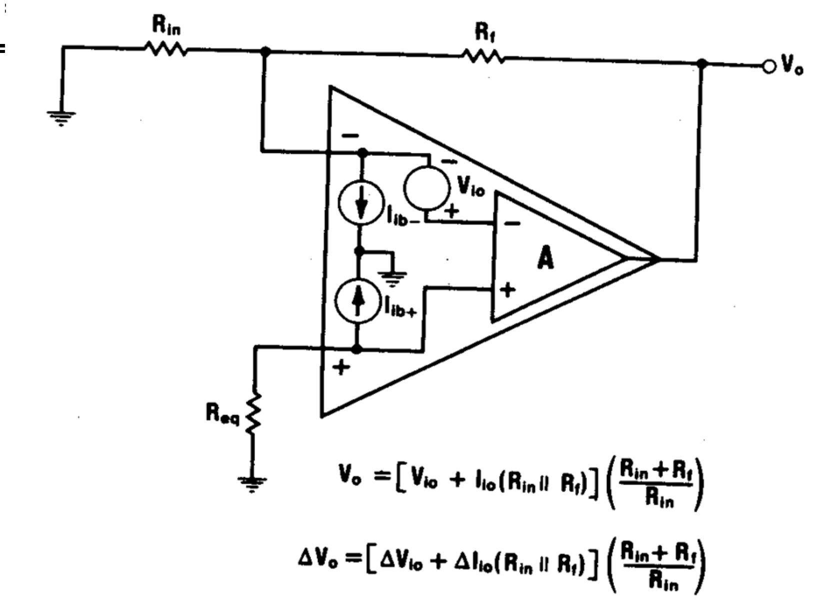
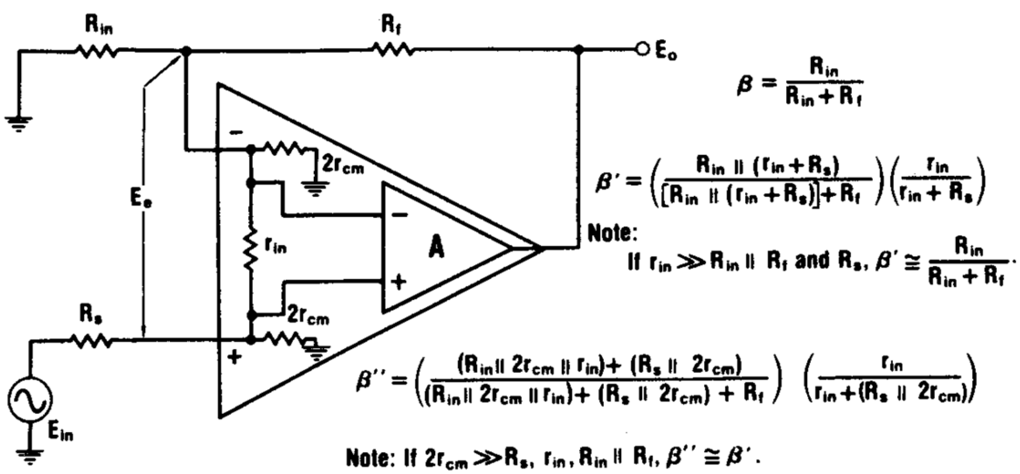


Fig. 1-18. Composite input offset-voltage and -current errors.

Offset voltage and Current

- Important for precision DC applications
- Can drift with temperature and general mood
- High impedance source
  - Use low offset current amp
    (also make + and - impedance identical)
- Low impedance source
  - Use low offset voltage amp



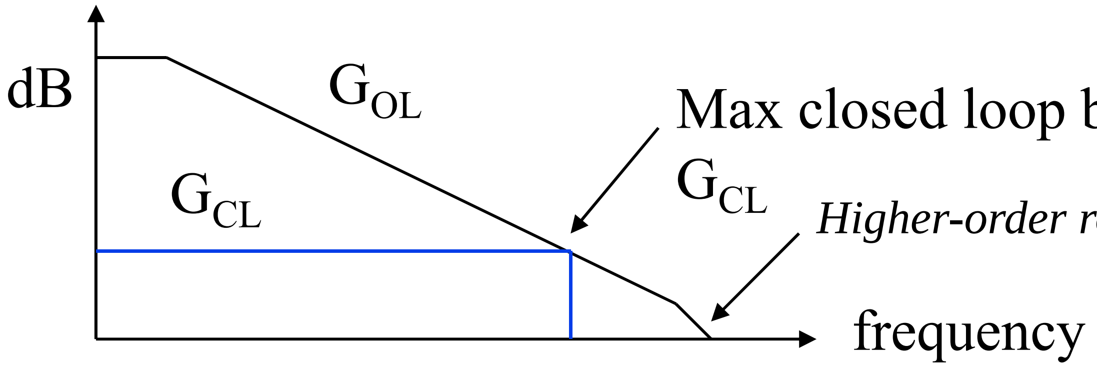
(B) Noninverting configuration.

Fig. 1-14. Effects of finite input resistance.

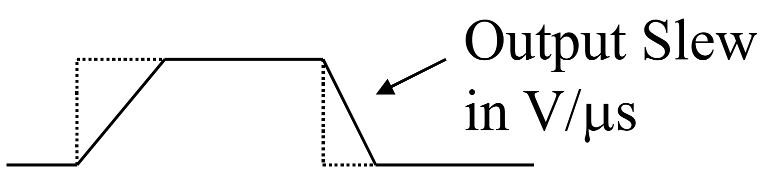
Finite input resistance (and CM resistance)

-Use high-Z (FET or MOSFET) amplifier where this is critical (e.g., high-Z sensor)

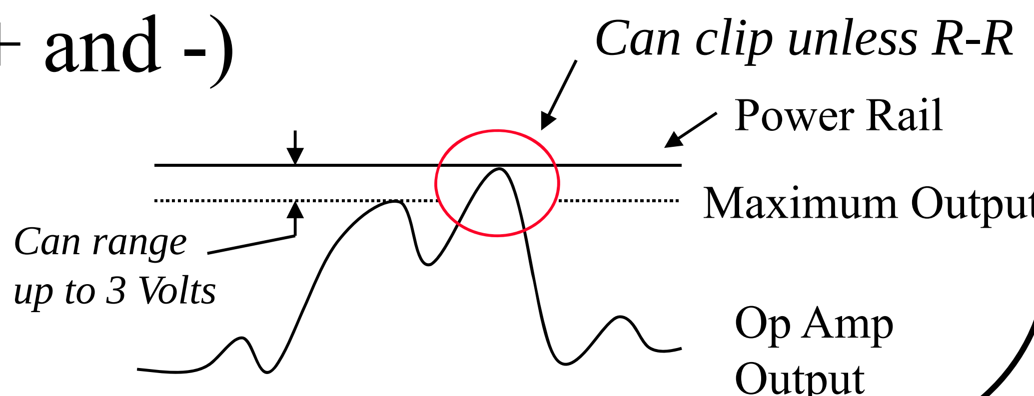
The Non-Ideal OpAmp (cont.)



- Gain-Bandwidth limitations
  - The more closed-loop gain your circuit needs, the more bandwidth you need in your OpAmp.
- Speed (slew rate)



- Maximum output current (typically 20 mA, less for µpwr)
- Maximum output voltage (+ and -)
  - Rail-Rail...
- Maximum input voltage
  - Rail-Rail...



Some of Joe's Old Favorites (needs updating!)

* Ancient: 741
* Garden variety, out to 200 Khz; not bad for audio either (LF351, TLO81/2/4, OP482/4
* A little better: AD711/712/713
* Generic, single supply (pulls to ground) LM324 (quad)
* Low Power: TLO6x, CMOS: TLC271 series (programmable power), CA3130, CA3140
* Low Power, low V, R-R (often CMOS): LPC661IN (National), MAX494 series, OP491, TLC2274 series
* Similar, but a bit faster: OP462 series
* Low voltage, R-R, moderate power, good speed: MAX474/475
* Good DC performance (low drift): LM308, OP297/497, OP27
* Low noise, Stiff drivers (600 Ohm audio lines), standard in audio: NE5532/5534, TLE2082 series
* Low voltage noise: AD743, AD745, AD797 (this one is touchy...)!
* Fast OpAmps: LM318, AD817 (video; nice and stable), AD829 (low noise video)
* Differential video amps/drivers (not really OpAmps): LM733, NE529 (stability woes... very fast and cheap)
* Comparators (not really OpAmps either...): LM311, LM339 (quad; single supply), CA3290 (CMOS)
* Instrumentation amplifiers (" "): Burr Brown INA series, AnalogD's AMP01 (low noise), AD623 (low V, R-R)

OPA340 3.3V supply, rail-to-rail input and output
LT1792 very low current and voltage noise
OPA129 lowest bias current (100fA), but low bandwidth
LTC1150 chopper stablized opamp, no ext. clock, pin for pin replacement for 8pin single package opamps

OpAmp Variants:

* Norton Amplifiers (CDA's): e.g., LM3900
* Current-Feedback Amplifiers: e.g., National Comlinear series
* Programmable Gain Amplifiers (PGA's): e.g., AD8320, OPA675, OPA676

Ari Benbasat on OpAmps

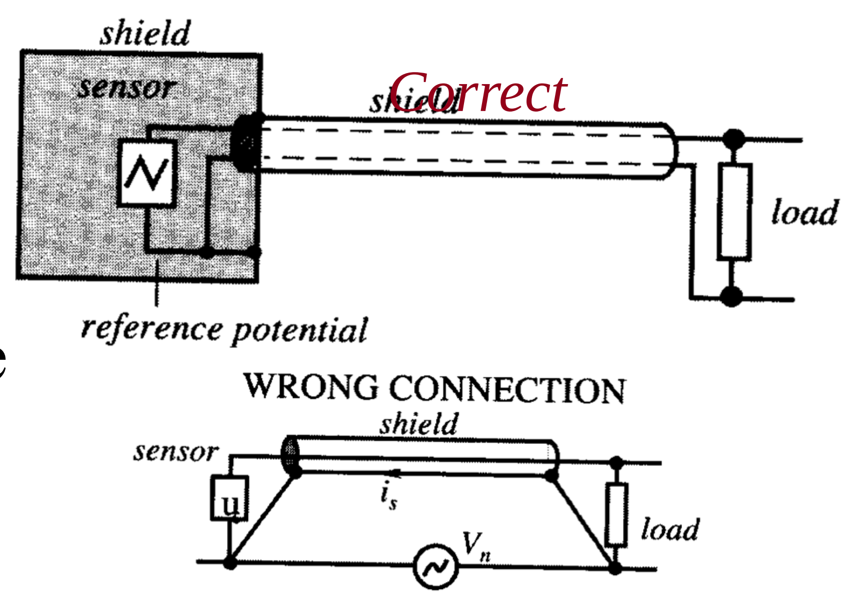
Here is the low-power op amp I spec'ed out for my thesis and/or future Stack work:

"...the Maxim MAX9911 is recommended. It is available in a single SC70 package (5mm2) with shutdown, and has a turn on time of 30 us. Typical current draw is 4 uA with a shutdown draw of 1 nA. The gain bandwidth product of 200 kHz is acceptable for most uses."

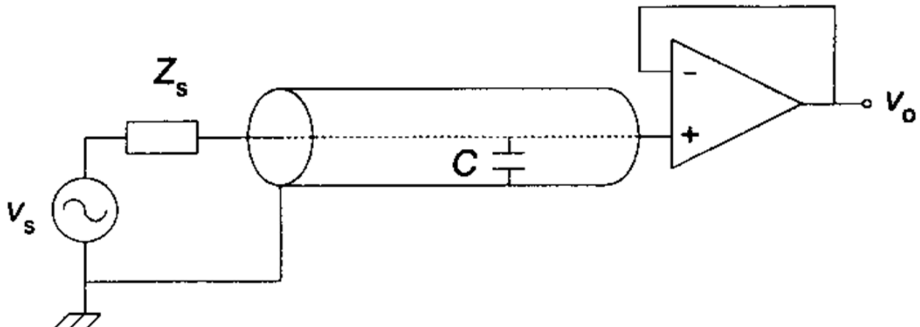
Other Sources of Noise

- Pickup!!!
  - Capacitive coupling (high-Z sensors)
    - Shield, use differential pair cable and perhaps differential front end
  - Inductive coupling (low-Z sensors)
    - Use differential pair, shield w. high-permiability material (iron or µ-metal), reorient components (vector coupling)
  - Shielded cable
  - Shielded pair
    - Ground shield at signal source

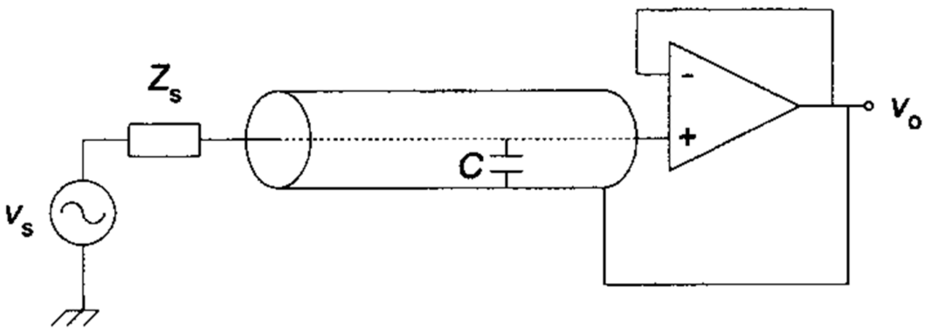
Black Magic!



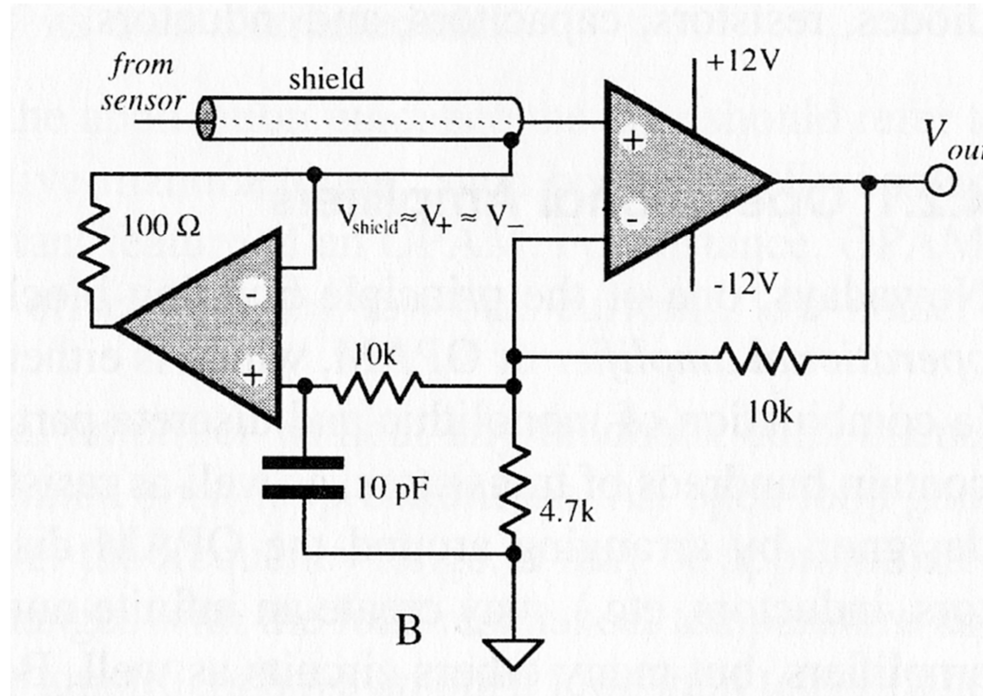
Driven Shields



(a)

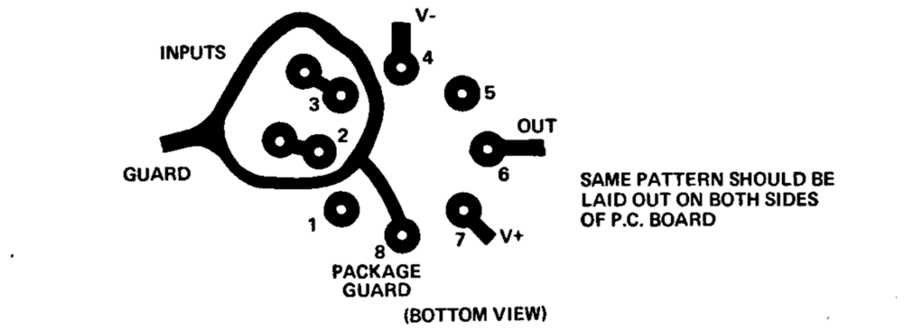


(b)

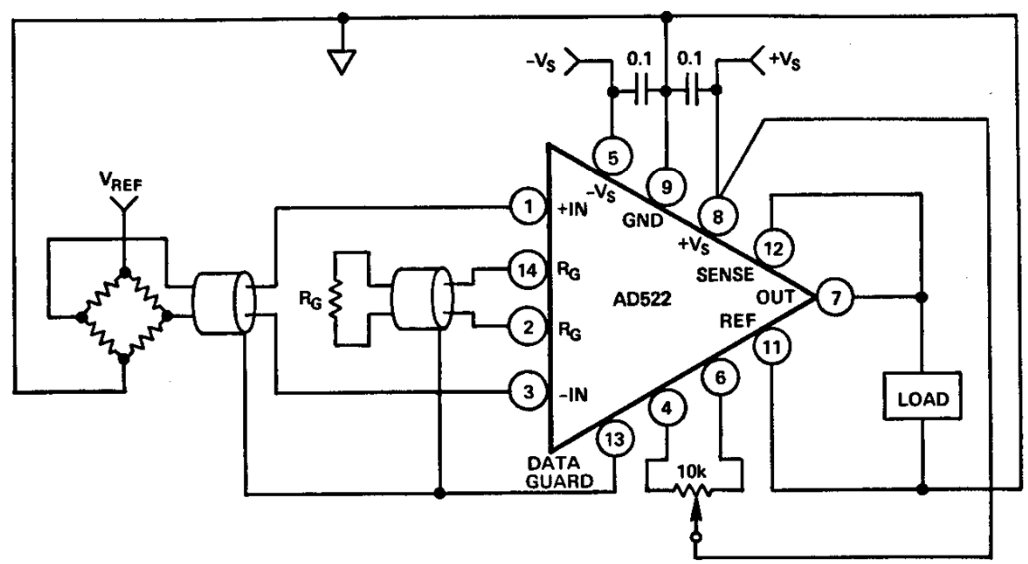


Guard Electrodes

- On-Board Driven Shields to prevent crosstalk and coupling
- Guards should be driven by a low-impedance source close to the voltage on the electrodes to be guarded
  - E.g., a driven shield, or a ground in an inverting op-amp configuration



b. Board layout for guarding inputs of AD515 with guarded TO-99 package



c. Use of the AD522 instrumentation amplifier's guard terminal to guard both the input connections and connections to a remote gain-setting resistor

Figure 3-6. Guarding

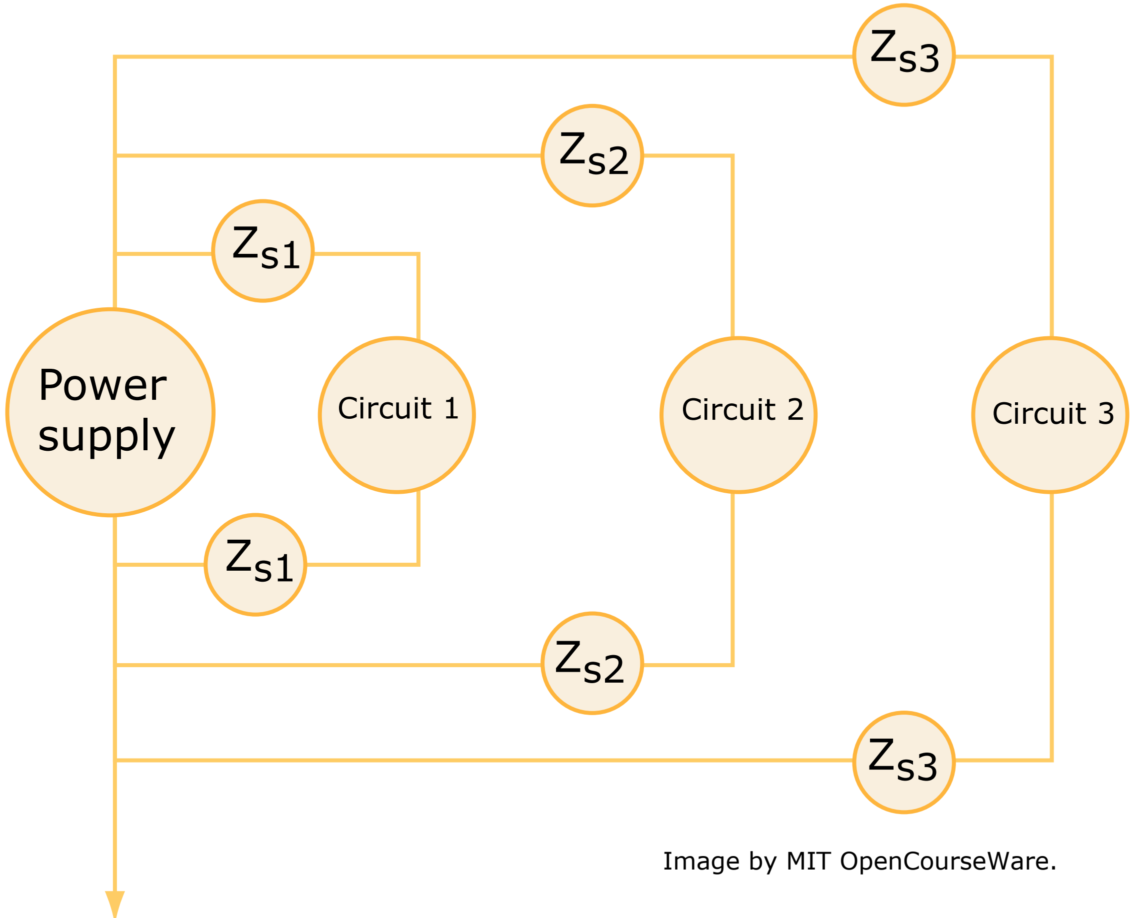
Other Types of Pickup

- Lack of **Bypass Capacitors**
  - Put them (.1 uF) at the power terminals of every component
  - Use a groundplane
- Microphonics
  - Jiggling things…
    - Lock it all down
  - RF detection with nonlinear junctions
    - Shield, shield, shield…
  - Ionizing radiation
    - Lead, etc.

Ground Loops

- Ground loops are caused by running (or daisy-chaining) the power supply past too many loads
  - Resistive and inductive components of the “wire” cause voltages to be dropped as current is pulled
  - Wire everything directly to the power supply!

More Ground Loops



Power distribution with separated supply lines for each circuit to reduce interface resulting from a common impedance

In order to reduce interference that results from a common impedance, power distribution can be done with separate supply lines for each circuit.

The Right Way...

Mixed Signal Systems

Diagram of power supply distribution and grounding in a system containing both digital and analog circuits, from *Analog Signal Processing* (page 480) removed due to copyright restrictions. See: page 480 of Analog signal processing on Google Books.

Where possible, pour ground and power planes (separate digital & analog ground except at junction), avoid running sensitive analog signals past noisy digital lines.

- Worship the Star...

Jason adds more here!

Many books on the subject…

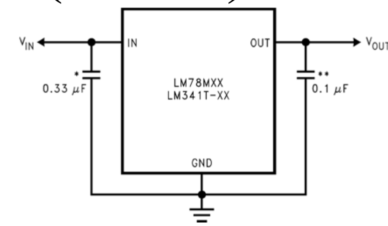
Cover for *Noise Reduction Techniques in Electronic Systems*, Henry W. Ott, removed due to copyright restrictions.

Cover for *Grounding and Shielding Techniques*, Ralph Morrison, removed due to copyright restrictions.

… But it's often a black art!

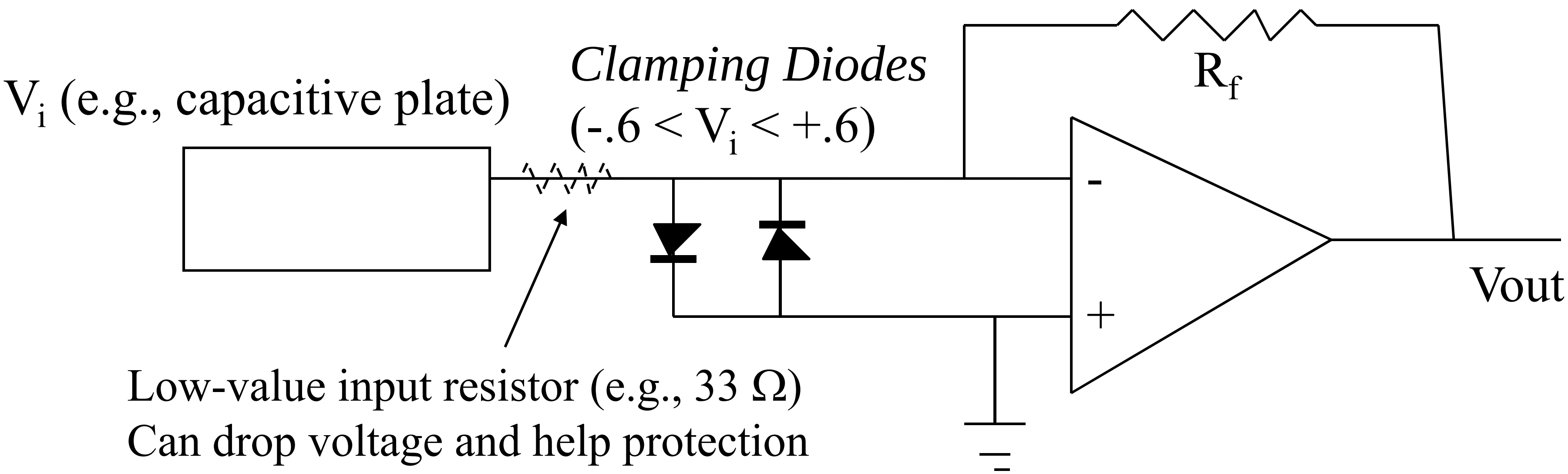
Voltage Regulators

- Series Regulators are simple often 3-terminal devices (in-gnd-out) that step an input voltage down to a lower (stable) reference voltage
  - Waste power dissipated = (ΔV)(I)
    - Keep within device limits to avoid overheating



  - Maximum ΔV ranges from approx. 100 mV to 3 V, depending on device, currents range from 100 mA to many Amperes
- Switched Capacitor Regulators provide limited current w. minimal components, and can boost voltage.
- Inductive switching regulators require external inductor and possibly other components, but can raise (boost) or lower (buck) voltage at very high (over 90%) efficiency. Some regulators can switch from boost to buck to keep running as the battery dies
  - These regulators transform impedance
- Many regulators of all types often include a “battery low” output

Isolation and Protection



- Diode Protection for inputs
  - e.g., from static electricity (ESD), actuator voltage, etc.
- Isolation Amplifiers
  - Inductive
  - Optical
  - Capacitive

Inductive(?) Isolation Amplifier

ANALOG DEVICES

Precision, Wide Bandwidth 3-Port Isolation Amplifier

AD210*

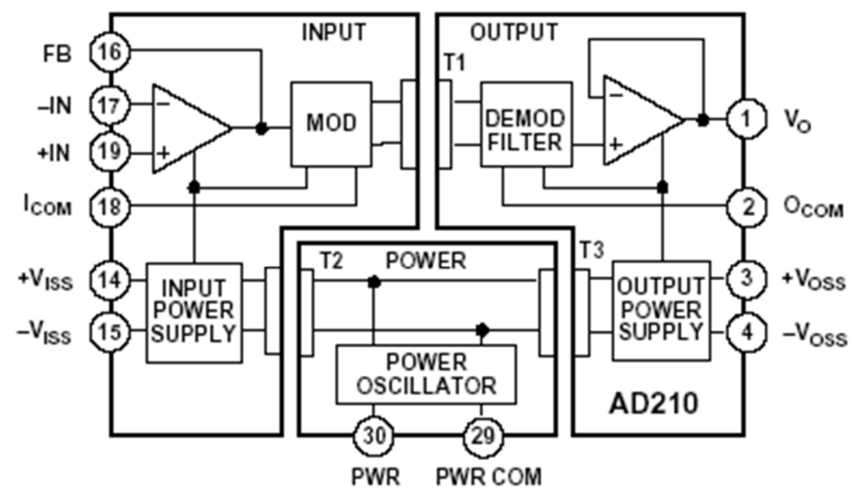
FEATURES

High CMV Isolation: 2500 V rms Continuous
±3500 V Peak Continuous
Small Size: 1.00" × 2.10" × 0.350"
Three-Port Isolation: Input, Output, and Power
Low Nonlinearity: ±0.012% max
Wide Bandwidth: 20 kHz Full-Power (–3 dB)
Low Gain Drift: ±25 ppm/°C max
High CMR: 120 dB (G = 100 V/V)
Isolated Power: ±15 V @ ±5 mA
Uncommitted Input Amplifier

APPLICATIONS

Multichannel Data Acquisition
High Voltage Instrumentation Amplifier
Current Shunt Measurements
Process Signal Isolation

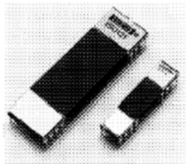
FUNCTIONAL BLOCK DIAGRAM



Courtesy of Analog Devices. Used with permission.

Other Isolation Amplifiers

BURR-BROWN®



ISO120
ISO121

Precision Low Cost ISOLATION AMPLIFIER

FEATURES

- 100% TESTED FOR PARTIAL DISCHARGE
- ISO120: Rated 1500Vrms
- ISO121: Rated 3500Vrms
- HIGH IMR: 115dB at 60Hz
- USER CONTROL OF CARRIER FREQUENCY
- LOW NONLINEARITY: ±0.01% max
- BIPOLAR OPERATION: $V_O = \pm 10V$
- 0.3"-WIDE 24-PIN HERMETIC DIP, ISO120
- SYNCHRONIZATION CAPABILITY
- WIDE TEMP RANGE: –55°C to +125°C (ISO120)

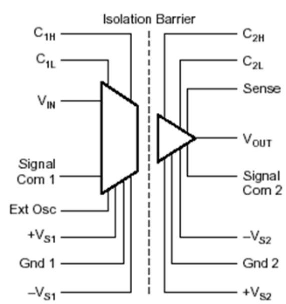
APPLICATIONS

- INDUSTRIAL PROCESS CONTROL: Transducer Isolator for Thermocouples, RTDs, Pressure Bridges, and Flow Meters, 4mA to 20mA Loop Isolation
- GROUND LOOP ELIMINATION
- MOTOR AND SCR CONTROL
- POWER MONITORING
- ANALYTICAL MEASUREMENTS
- BIOMEDICAL MEASUREMENTS
- DATA ACQUISITION
- TEST EQUIPMENT

DESCRIPTION

The ISO120 and ISO121 are precision isolation amplifiers incorporating a novel duty cycle modulation-demodulation technique. The signal is transmitted digitally across a 2pF differential capacitive barrier. With digital modulation the barrier characteristics do not affect signal integrity, which results in excellent reliability and good high frequency transient immunity across the barrier. Both the amplifier and barrier capacitors are housed in a hermetic DIP. The ISO120 and ISO121 differ only in package size and isolation voltage rating.

These amplifiers are easy to use. No external components are required for 60kHz bandwidth. With the addition of two external capacitors, precision specifications of 0.01% max nonlinearity and 150µV/°C max V_{OS} drift are guaranteed with 6kHz bandwidth. A power supply range of ±4.5V to ±18V and low quiescent current make these amplifiers ideal for a wide range of applications.

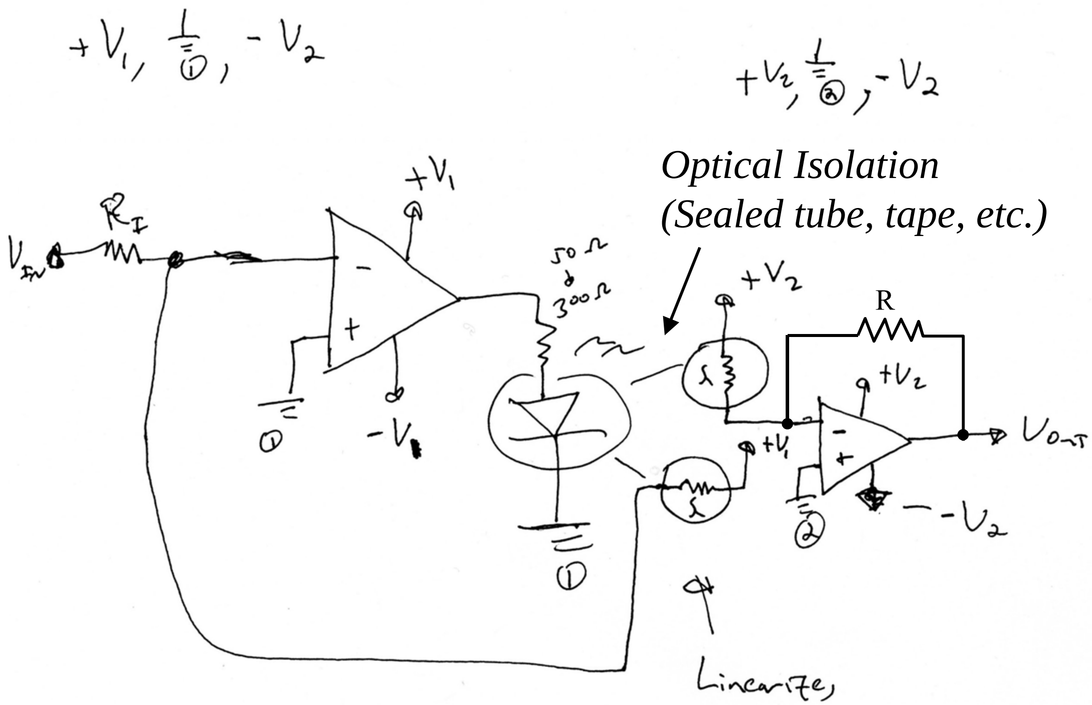


International Airport Industrial Park • Mailing Address: PO Box 11400 • Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd. • Tucson, AZ 85706
Tel: (520) 746-1111 • Twx: 910-952-1111 • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

Capacitive coupling

Optical analog isolation amps…

- Homebuilt around LDR's
- Feedback linearization..



Uses LDR's - can use photodiodes too.

Instead of dual receiver coupling, can drive 2 identical LEDs and couple each independently