CHEM 524 –Course Outline – Signal Processing- (Part 9) –2013

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VI. Signal Processing (Read Text: Chapter 4.5)

A. Signal conditioning -- Detectors convert light to "electrons", next one must process that raw signal into something we can interpret and store – information above the noise

1. Preamplifiers -- goal to get signal level above interfering (external) sources of noise

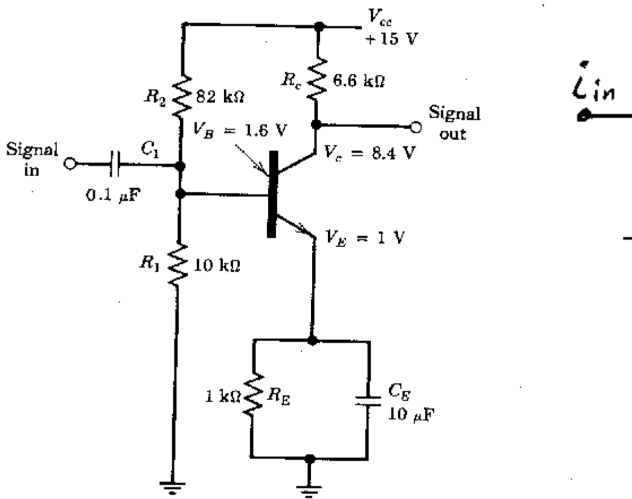
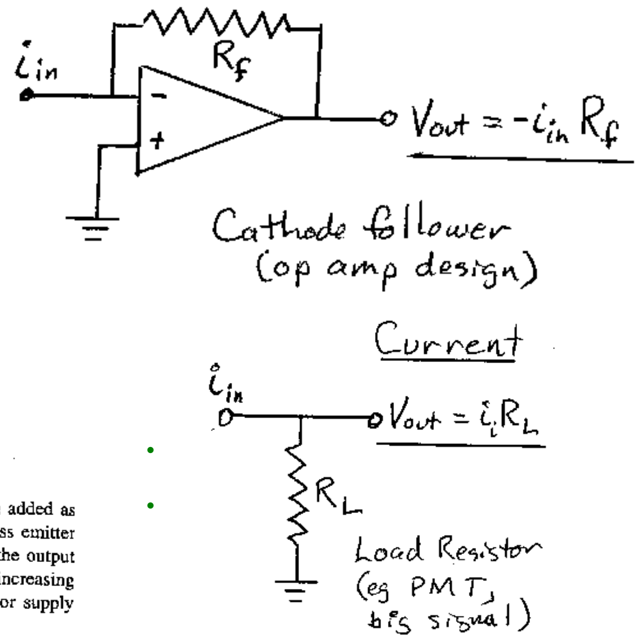


Fig. 3.21 An augmented version of Fig. 3.20. Calculated values of resistance have been added as well as an input lead with series capacitor C_1 to restrict input to ac; capacitor C_E to bypass emitter resistor R_E and improve signal gain; and an output lead (at the collector). In this circuit, the output signal is given by $V_o = V_{CC} - I_C R_C$. As the input signal to the base becomes more positive, increasing V_{BE} slightly, collector current I_C increases also. Since $I_C R_C$ is subtracted from the collector supply voltage V_{CC} to give output signal V_o, the output is 180° out of phase with the input.



- Current source, need an I to V convertor, could just use a resistor, R_L Where $V_o = i_d R_L$

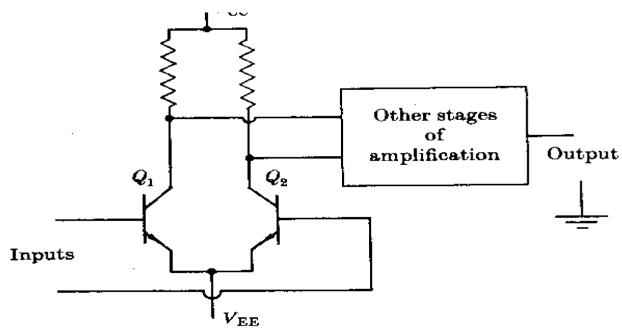


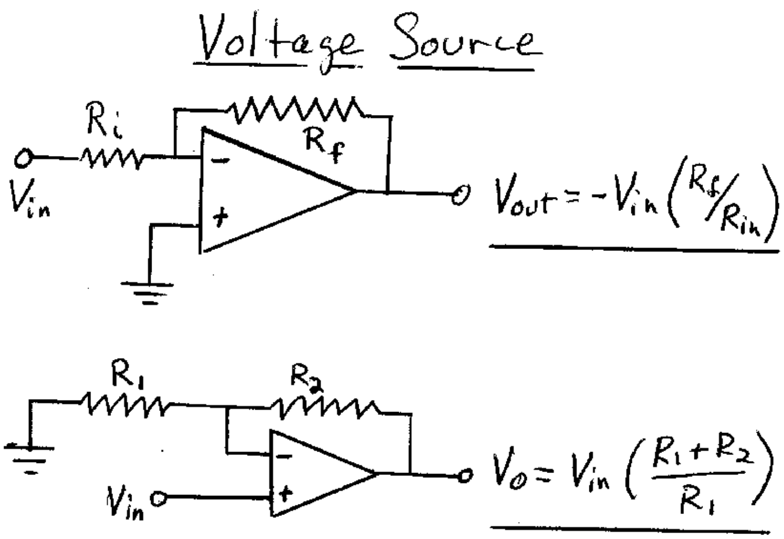
Fig. 4.3 Simplified diagram of a representative operational amplifier. Inputs are to the bases sistor pair Q_1 and Q_2, which comprise a differential input stage.

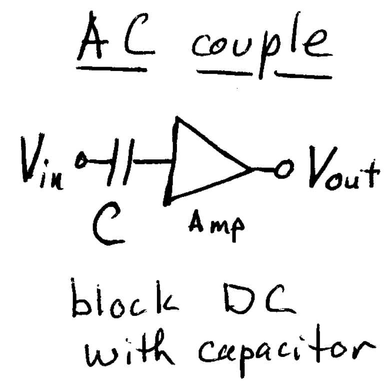
OP AMP –these are made of discrete components, but most of time we will use operational amplifiers as building blocks – symbol → triangle on side +/- V_{in} inputs, V_o output

- Idea is to have two inputs +/- at same potential but
- These have very high input impedance (no current draw)
- Output current is delivered to achieve balance in inputs through feedback loop
- This essentially operates by amplifying difference of two inputs

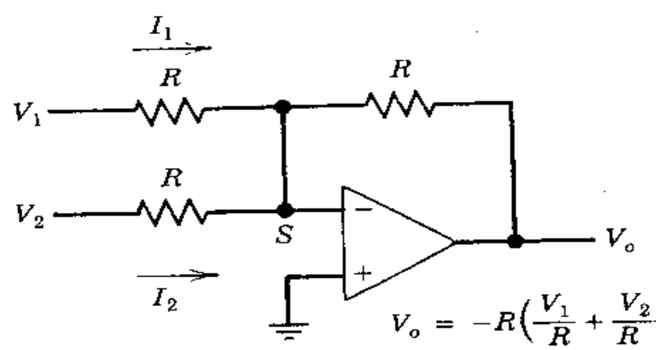
- Alternate I to V: (sometimes called Cathode follower, see above)
  - current-to-voltage convertor, op amp with R_f feedback: $V_o = - i_f R_f$
  - high input impedance, no current drain, $i_{in} = i_f$, op-amp drives i_f, low impedance out

- Voltage amplifiers can invert or not, and can sum two or more inputs
    - Recall, OPAMP drives the two inputs to same potential by current/voltage at output
    - Voltage invertor, op amp ratio feedback to input resistor, flip sign: $V_o = -V_{in}(R_f/R_{in})$
    - Non-inverting design, $V_o = V_{in}(R_1 + R_2/R_1)$
    - Summing amp, if balance resistors, no gain, $V_o = -R(V_1/R + V_2/R) = V_1 + V_2$





Voltage Follower ↑ **Summing Circuit** ↓ **AC Couple** ↑



$$V_o = -R\left(\frac{V_1}{R} + \frac{V_2}{R}\right) = -R(I_1 + I_2)$$
$$= -(V_1 + V_2)$$

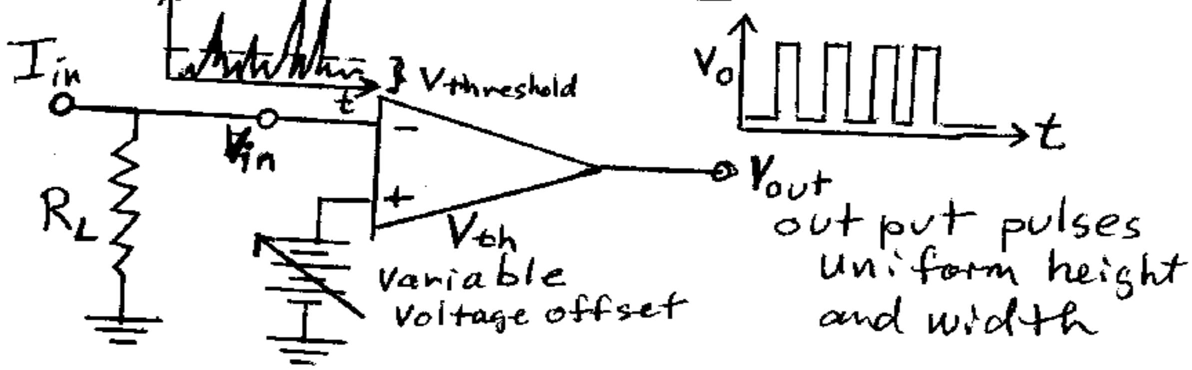
Fig. 4.8 Analog adder based on an operational amplifier circuit. All voltages, or currents, to be summed are taken in parallel leads to the inverting input. Often the point where such leads join is termed the summing point. For simple addition all resistances should be equal. If desired, a weighted sum may also be taken. In this case, one inserts appropriate values of input resistors R_i. Then one has an output equal to $V_o = -R_f[V_1/R_1 + V_2/R_2 + \cdots]$, where each signal V_i is weighted by $1/R_i$.

- AC couple (place capacitor in series) used to block DC, such as bias voltage, and avoids overloading the amplifier if high gain needed for small AC component

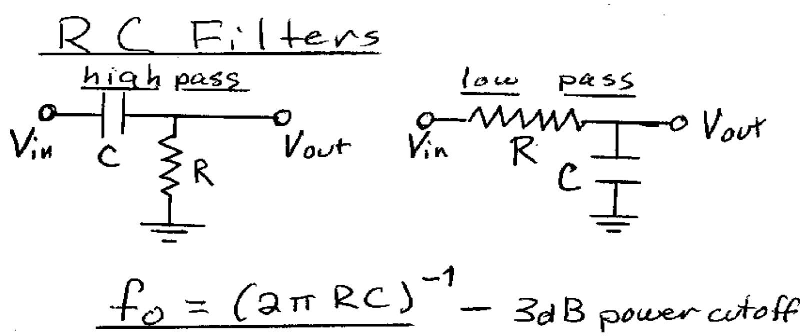
- PMT – use a current follower (I → V, as above) *or*
    - pulse count -- just amplify those pulses > threshold (to limit V) - count equiv. pulses
    - Variable offset on + input means – input must be above that voltage to drive current
    - With no feedback, output driven to V_{max} of OPAMP (power supply V) – uniform pulse

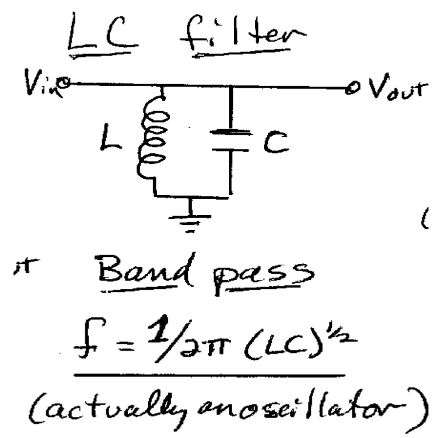
Photon Counting Discriminator

Pulse > Theshold



2a. Passive Filters -- low/high pass $f_c = 1/2\pi RC$

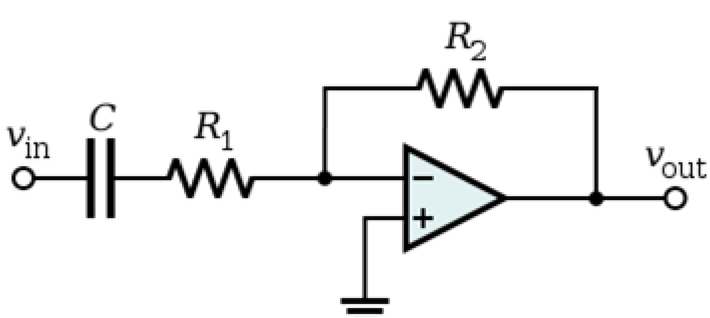




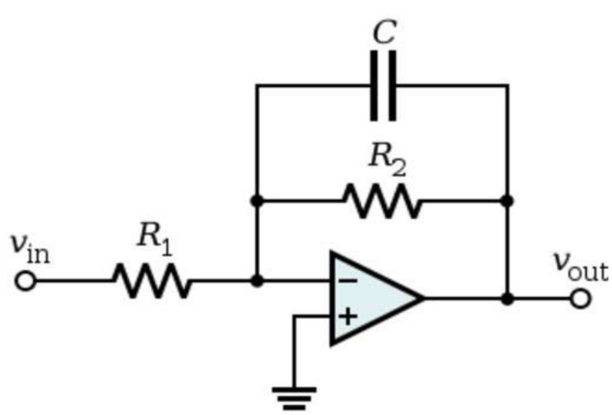
band pass $f_{bp} = (1/2\pi)(LC)^{-1/2}$

2b. Active filters, combine essential elements above

High pass:



Low pass:



corner frequency → $f_c = (1/2\pi\tau) = (1/2\pi R_1C)$

gain → $-R_1/R_2$ *or* $V_o = -V_i(R_1/R_2)$

$f_c = (1/2\pi\tau) = (1/2\pi R_2C)$

$V_o = -V_i(R_2/R_1)$

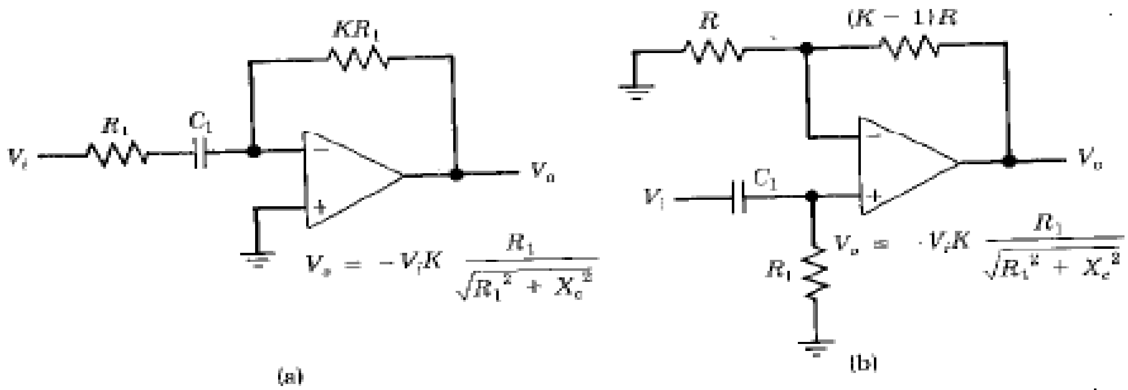


Fig. 4.24 Active first-order (one-pole) high-pass filters. Note the characteristic series input capacitor. These filters have typical 20 dB roll-off per decade of frequency at low frequencies. (a) Inverting type with gain. Since the input impedance is frequency-dependent, its gain is also. (b) Noninverting type coupling a regular *RC* high-pass filter to a voltage follower with gain.

For both: $f_o = 1/2\pi R_1 C_1$

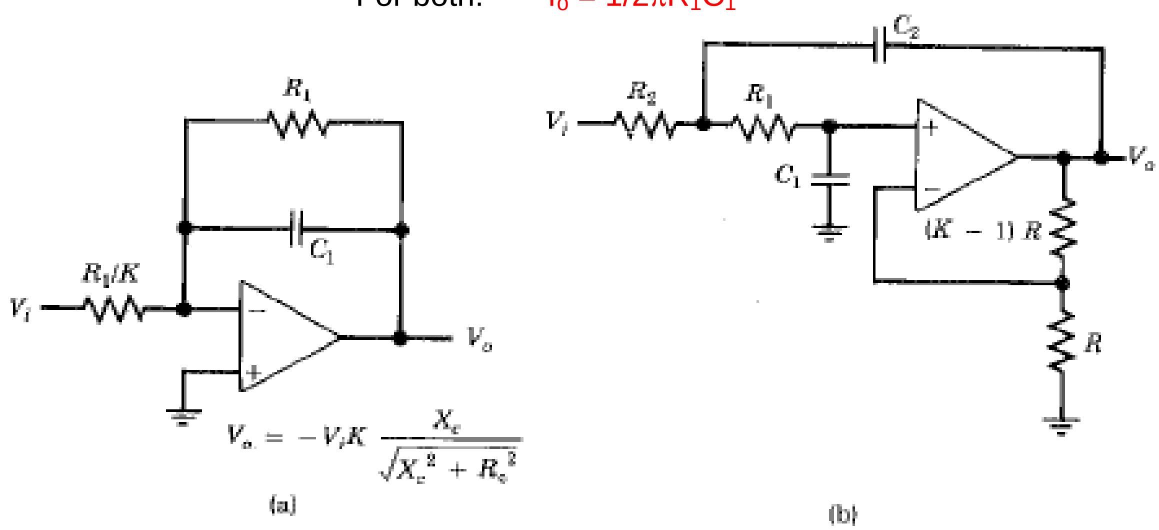


Fig. 4.25 Active low-pass filters of first and second order (one- and two-pole types). Note the characteristic resistive input. (a) Inverting first-order type. In this active filter the feedback impedance is frequency dependent. Roll-off at high frequencies is 20 dB per decade. (b) Noninverting second-order or two-pole low-pass filter. Note that if R_1 and C_1 were omitted, the filter would be the noninverting first-order counterpart of (a). When R_1 and C_1 are added, the roll-off with frequency doubles to 40 dB per decade. Further, the active filter becomes a voltage-controlled source voltage (VCVS).

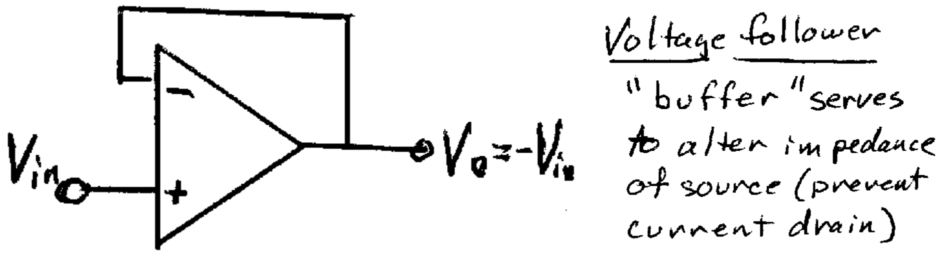
By using amplifiers to better shape filter characteristics, sharper cuton/cutoff, multipole one can select various characteristics in a single commercial package

Filter: 115 dB/octave rolloff, 1 Hz to 100 kHz range

Adjustable preamp (others fixed gain)

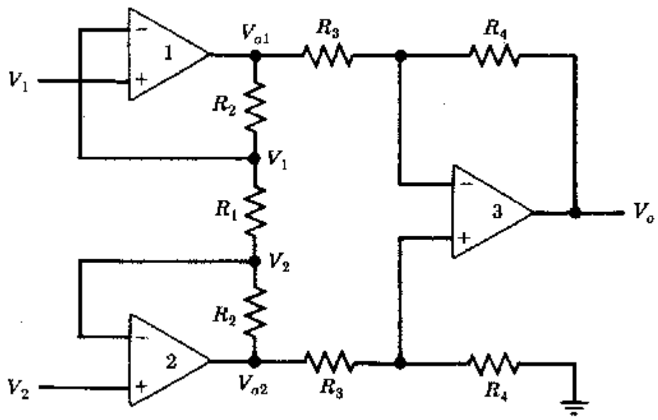
3. Other amplifiers –

buffer or voltage follower, matches impedance, protects source (equiv. to “wire”) –



Differential amp has output *amplifying difference* of two inputs.

Big thing is common mode rejection, stray signals on both are rejected.



$$V_o = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)(V_2 - V_1)$$

Fig. 4.17 The standard instrumentation amplifier. Two op-amps are used in follower amplifier configurations at the input. They are cross-coupled to ensure high input impedance, a differential gain given by $1 + 2R_2/R_1$, and a common-mode gain of unity. Note that the input pair of op-amps has a differential output V_{01} and V_{02}. This output drives the straight difference amplifier, based on op-amp 3. Its differential gain is small, R_4/R_3, but its common-mode gain is nearly zero. For the entire circuit, the differential gain is given by the expression $A_d = (1 + 2R_2/R_1)/(R_4/R_3)$. The overall common-mode rejection ratio (CMRR) is 10^5–10^6. A major advantage of this design is avoidance of the need for close matching of resistors with identical labels. The (differential) gain of the instrumentation amplifier can be adjusted by varying resistor R_1, which is attached externally when an integrated circuit form of the amplifier is used. Offset voltage can be compensated by trimming at the noninverting input of one of the input op-amps, for example op-amp 2.

Discriminator—only amplifies signals/pulses above a threshold, rejects low level noise (see p.3)

Circuits shown here are from: Strobel and Heineman, Chemical Instrumentation, A Systematic Approach, 3rd Ed. Wiley 1989

B. Voltage measurement

1. DVM and multimeters—high input impedance, variable functions, slow - electronic circuit that acts as an integrator many can also act as A/D convertors, give digital data often measure currents and impedance as well as voltage

2. Oscilloscopes—variable (fast) time response, gain —get wave form / transient (sketch)

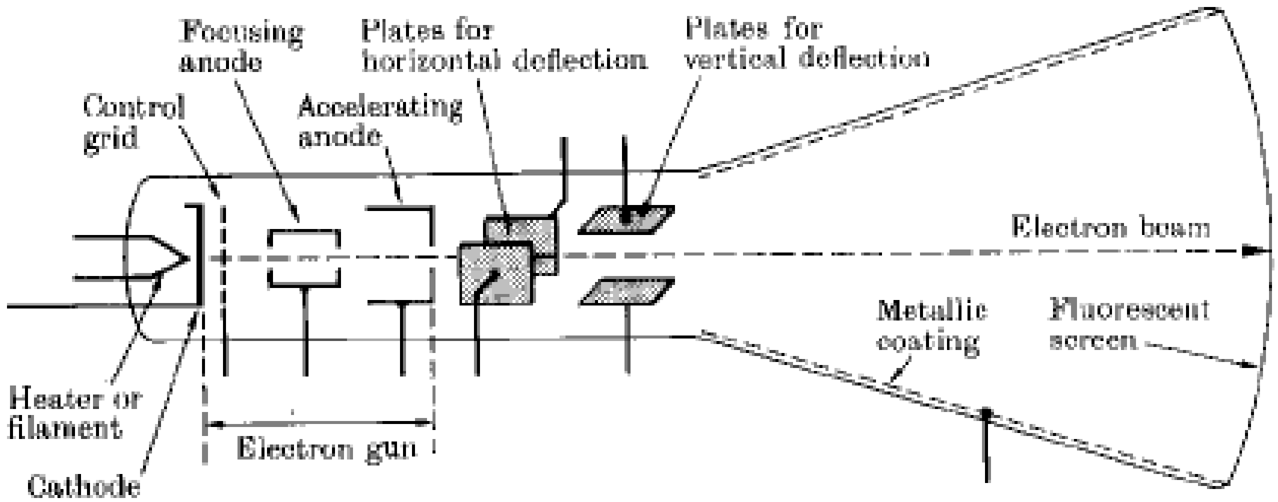


Fig. 3.8 Schematic diagram of a CRT with electrostatic focusing.

Type 465 Tektronix oscilloscope, popular analog oscilloscope, portable, and representative.

A digital storage oscilloscope manufactured by Agilent Technologies

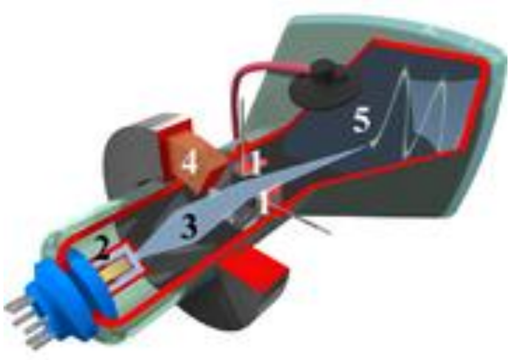


Illustration showing the interior of a cathode-ray tube for use in an oscilloscope. Numbers indicate: 1. Deflection voltage electrode; 2. Electron gun; 3. Electron beam; 4. Focusing coil; 5. Phosphor-coated inner side of the screen

Operation: time base (or voltage) sweeps beam horizontally

Signal at input moves beam vertically

Picture is time variation of repeat voltage (normal)

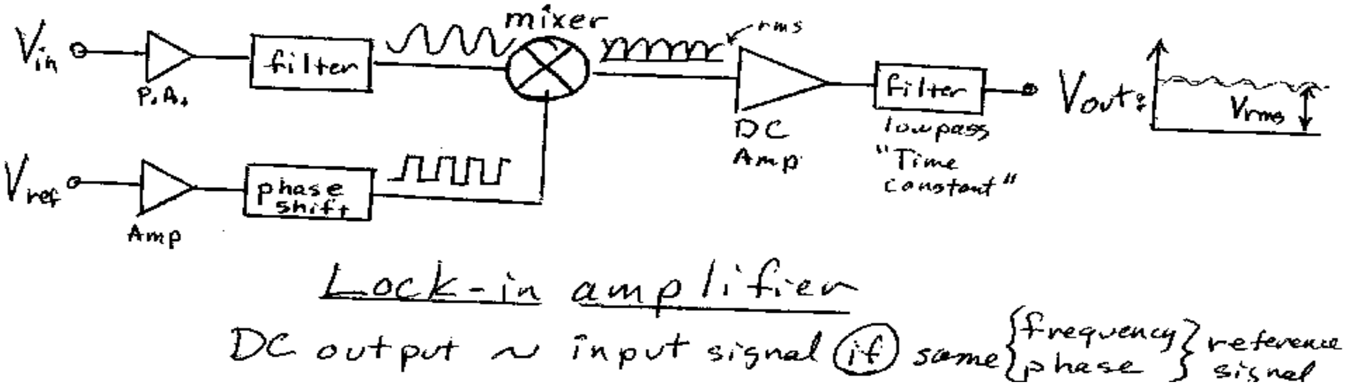
Storage scope, rewrite over fast trace wso you can see it

Modern, digitize signal and replay back (computer)

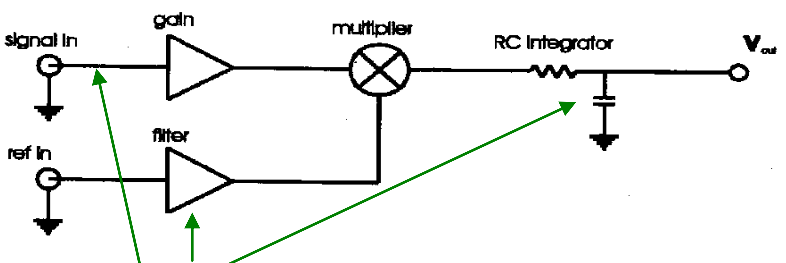
Transient recorder: e-beam write out transient waveform on chip, which can store that information, acts as way of slowing time, then another beam reads it out and electronics digitize the signal size capable of very fast (ns) data aquisition, for pulsed operation, can be a computer board

C. Demodulators—address time variation of signal, abstract out average signal size

1. Lock-in Amplifier – reference descriptive handout (SRS)- *linked on course site*



- detects components of input signal that have *same frequency and*
  - *are in-phase* with a *reference* signal (e.g. from a modulator) and
  - outputs a DC voltage proportional to rms of signal (applies gain to that signal)
  - synchronous demodulation (repeating signal *mixed* with reference)
  - -- phase has information – some lockins output that as well as RMS signal size
  - Can be dual channel, most have differential inputs, sense difference: A - B



  - filters are important part of commercial designs
    - AC couple signal in (optional low, high or band pass, adds *dynamic range*)
    - DC output (low pass, RC integrator--expressed as *time constant*)

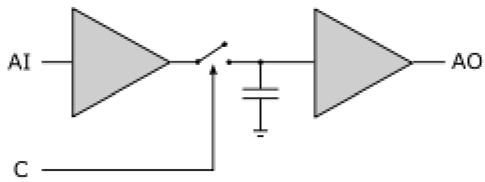
Stanford Research. SRS 830

- 1 mHz to 102.4 kHz frequency range
- >100 dB dynamic reserve
- 5 ppm/°C stability
- 0.01 degree phase resolution
- Time constants from 10 µs to 30 ks

- New models have *digital signal processing (DSP)* – digitizing waveform, filter and rectify in-phase signal digitally, as a computation, which gives enhanced dynamic range and a wide selection of filtering

- ***SIGNAL RECOVERY*** 7265 uses DSP, has a frequency range of 1 mHz to 250 kHz and full-scale voltage sensitivities down to 2 nV and current sensitivities to 2 fA.

2. Pulsed techniques



a. Sample and hold

1. think of a switch that allows charge to accumulate on capacitor, when closed
2. logic switches (control signal – C) can open/close gate - signal (AI, buffered) charge capacitor, opamp sense/amplify voltage (AO)
3. time: you control the switch opening and can measure the charge
   switch can be MOSFET gate, pulse or "open/sample" applied to base

b. Box car averager–basically a moveable sample and hold

1. signal detected and integrated only during a gate (switch connected) – S&H
2. but can *move the gate* through the pulsed waveform
3. control of delay and width of gate permits profile measurement of shape
4. generally requires repeated pulses, if want form (e.g. relaxation decay, lifetime fluorescence, etc.)
5. idea was change of time scale, fast pulse or repeat, convert to slow scan
6. big benefit, separate signal and noise in time, low duty cycle, eliminate noise
7. available as computer boards, or NIMBIN modules

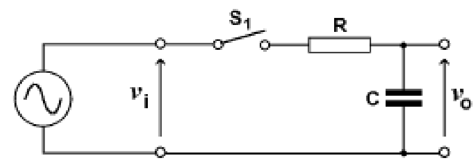


Figure 1, Gated Integrator

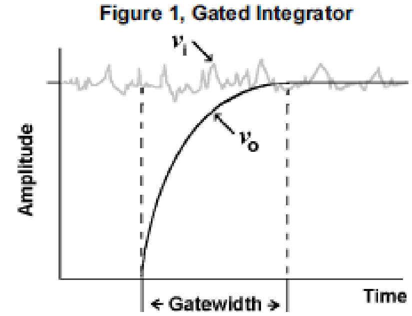


Figure 2, Gated Integrator Operation

c. Multichannel averager—

1. series of time windows, put pulse into "bin" (each at different delay time)
2. average over many pulses, distribution in bins gives profile in time
3. used in fluorescence lifetime, measure time to first photon, bin, get decay profile by sum

d. Transient recorder/digital oscilloscope -- digitize wave form of each event (see above)

1. writes out signal on a charge sensitive device and
2. reads back with digitizer (beam senses charge on device)

D. Computer data acquisition -- ubiquitous -- spectrometer control and data collection
Central idea change data form analog to digital form so can computationally process

a. **A/D converter** -- create digital form – various methods (clocks, discriminators, etc.)
   - i. at heart must be comparators—charge or integrating-divide voltage to levels
     1. switch charges capacitor for time. Pulses discharge, count pulses
   - ii. time for conversion (rate of data input) and digital precision are tradeoff
   - iii. 8-bit (256) fast,12-bit μs feasible, 16-bit slower, higher - special, typ. 1 or 10V
   - iv. readout can be binary, fastest and cheapest – direct to computer
   - v. or BCD – decimal, useful for displays

b. Storage of data - average repeated experiments - correct errors

   i. Read to interface, often board insert in computer
   ii. Direct memory access, faster methods
   iii. Process in later time than measure- asynchronous
   iv. – archive on disc or other media, through the processor as intermediate

c. Processing data – done digitally (computationally)

   i. Filter out noise or interferences
   ii. Average repeated data files, improve S/N, determine statistics, errors
   iii. Convert units, eg. $I/I_0 \rightarrow T \rightarrow A \rightarrow \varepsilon$, nm → cm^{-1}, etc.
   iv. Format into graphs, multiple data sets, colors etc.

d. Display data—graphics with interactive features very important

   i. CRT/screen in "real" – i.e. operator time, use software to make graph
      e.g. something like LABview can make measurements and do processing and formulate a display using graphical interface
   ii. Make plots on paper or other media—post processing

e. Write the paper!

this goes on, but open for discussion

Homework—

Discussion: chap 4-# 4,5

To hand in: chap. 4-17, plus below

3.1 It is desired to minimize a 60-Hz line voltage hum in an electronic circuit that will ordinarily carry 1–3 kHz signals. (a) Draw a simple *RC* filter that can be used. Choose a value for its cutoff frequency f_o and support your choice. Assume a roll-off of 20 dB per decade of frequency below f_o. (b) Select or calculate values for the filter components. Is there any advantage in picking $R = 1\ \text{k}\Omega$ instead of $10\ \text{k}\Omega$? Explain. (c) For strong rejection of a 60-Hz hum what attenuation in decibels would be desirable?

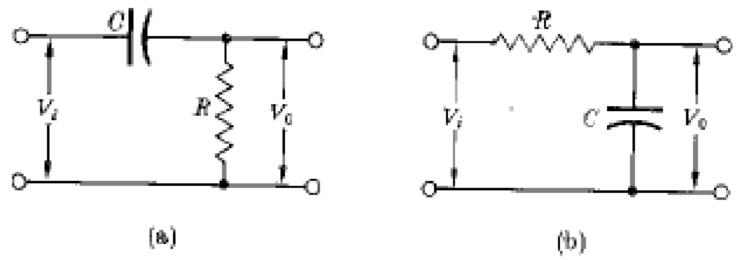
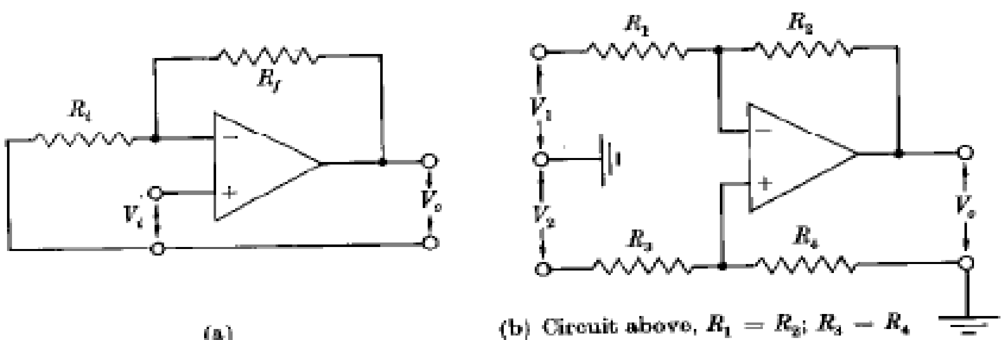


Fig. 3.2 Cutoff filters. (a) High-pass *RC* filter. (b) Low-pass *RC* filter. In each circuit the capacitor impedes low frequencies and blocks dc. Thus, low frequencies are attenuated in circuit (a) and passed in circuit (b).

3.3 What is the cut-on frequency f_o for the circuit of Fig. 3.2 if values of components are $C = 0.10\ \mu\text{F}$ and $R = 1\ \text{k}\Omega$?

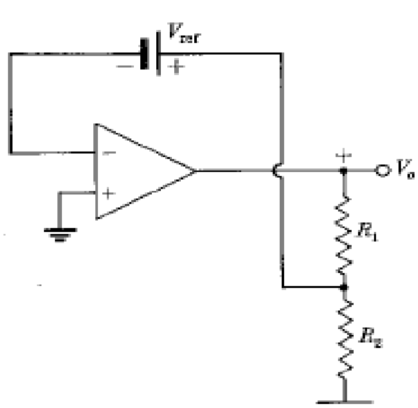
4.1 Develop an expression for the output voltage in each of the op-amp circuits of Fig. 4.26 in terms of the input voltage(s).



(b) Circuit above, $R_1 = R_2$; $R_3 = R_4$

(c) Circuit above, $R_1 \neq R_2$; $R_3 \neq R_4$

4.3 Show that the output voltage of the circuit in Fig. 4.27 is given by the expression $V_o = (1 + R_1/R_2)V_{ref}$.



Links

Lock-in Applet from Univ. Konstanz--worth doing

http://www.lockin.de/

Brown Univ. lab write-up on lock-in use and theory

http://www.chem.brown.edu/chem116/labs/exp8.html

Another lock-in simulator, must download

http://www.inform.umd.edu/EdRes/Topic/Chemistry/ChemConference/Software/Spreadsheets/WWW/lockin.html

Lock-in tutorial Stanford Research

http://www.thinksrs.com/downloads/PDFs/ApplicationNotes/AboutLIAs.pdf

Lockin companies

Ametek now covers EG&G lines (Princeton Applied Research/ PAR/ EG&G) as SIGNAL RECOVERY, plus some tech notes and explanatory pages: http://www.signalrecovery.com/index.html

lockins: http://www.signalrecovery.com/lockinde.htm

Boxcars: http://www.signalrecovery.com/SigAvDet.htm

http://www.signalrecovery.com/WhatIsASignalAverager.htm

Stanford Research Systems --http://www.thinksrs.com/products/sci.htm

Lockin—830 http://www.thinksrs.com/products/SR810830.htm

Oscilloscopes

Techtronix -http://www.tektronix.com/

http://www.tek.com/Measurement/cgibin/framed.pl?Document=/Measurement/scopes/home.html?wt=257&link=/Measurement/scopes/home.html&FrameSet=oscilloscopes

Hewlett Packard/ Agilent Technologies, old HP instruments

http://www.home.agilent.com/USeng/nav/-11145.0/ia.html

DVM, etc.

Fluke—multimeters etc,

http://www.fluke.com/

Many Others--

Digital companies—myriad of them!