Amplifiers

- This is a large and important part of this course

    amplifiers are needed for many instruments

- inescapable in electronic instruments

    even if not used to boost signals, amplifiers are the basis of most important functional blocks

- in many circumstances amplification, in the sense of “boosting” signals, is vital

    signals to be measured or observed are often small

        defined by source - or object being observed

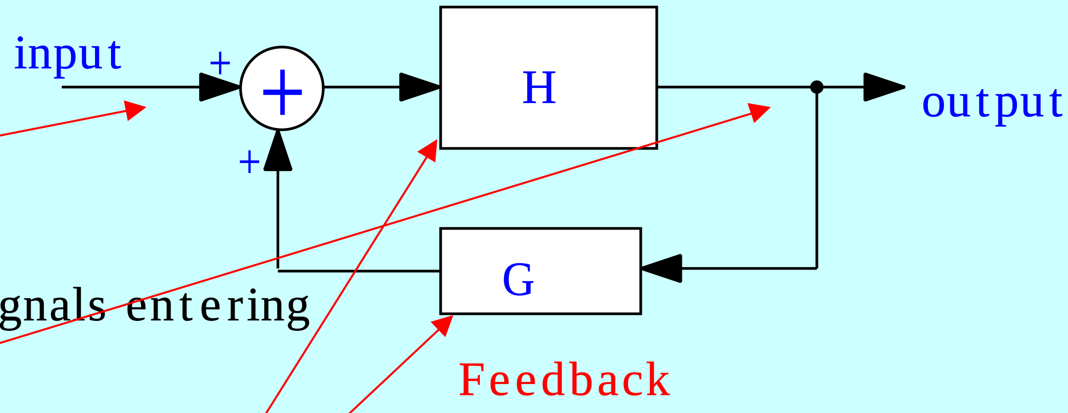
        and sensor - it is not usually easy to get large signals

    data have to be transferred over long distances without errors

        safest with “large” signals

System block diagrams

- Introduction to...



- Points to note

  summing node

  output from node = sum of signals entering

  note signs at entry

  pick-off node

  all outgoing signals = incoming signal

  functional blocks & directions of signals

  usually label with transfer function of block

don't always distinguish summing nodes from others in diagrams - but only if it's very clear

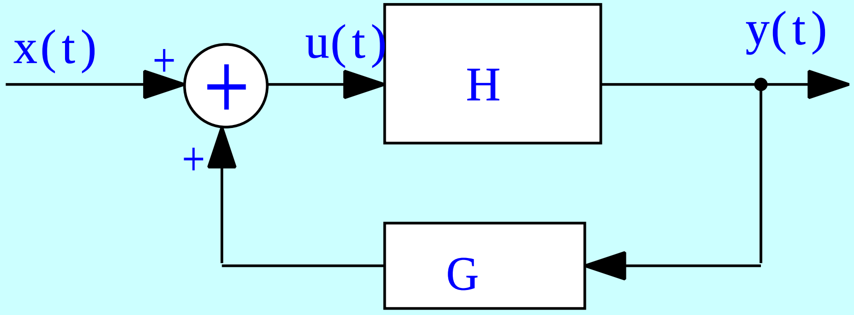
- What kind of system?

  electronic - but also mechanical, acoustic, optical,..

- How to manipulate?

  label with signals, then follow rules

Feedback



- After summing node

  $u(t) = x(t) + Gy(t)$

- At output

  $y(t)$, but also $Hu(t)$

  so $y(t) = H[x(t) + Gy(t)]$

  $H_{system} = y(t)/x(t) = H/(1 - GH)$

- Why is this useful?

  suppose $H \gg 1$ then $H_{system} = -1/G$ ie. system transfer function independent of H

  eg $0 < G < 1$ system provides constant amplification

  G = feedback fraction

- Problems -

  perhaps $G \to 1/H$ $H_{system} \Rightarrow \infty$ unstable - positive feedback

  system will always be stable with negative feedback

- Applications...

Operational amplifier

- A good starting point for analogue electronics

  will later consider devices and components used to build real amplifiers but the op-amp is a convenient idealisation

- building block

  much electronics consists in recognising building blocks which perform specific functions

  a large circuit can appear quite complex but can often be reduced to much simpler functional elements

- First questions to ask in analysing amplifying system

  what quantity is being amplified? - eg. current, charge or voltage

  what type of signals? eg. fast pulses or slow waveforms?

  what is the input and output impedance? ie how should it be connected?

  what is the gain?

- some more detailed information...

  frequency response, linearity, noise level, ...

Operational amplifier approximation

- very high gain **voltage** amplifier

  gain = A -> ∞

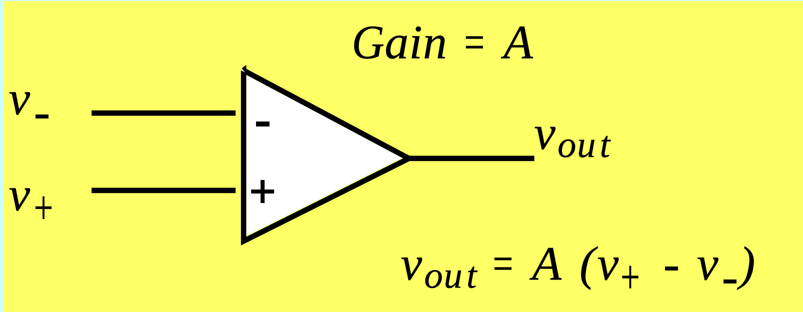
  infinite bandwidth

  single output

  dual, differential inputs, infinite impedance

  amplifies difference in voltages between inputs

  inputs are DC coupled



- Real op-amps almost invariably used with (negative) feedback

  fraction of the output voltage fed back to the inverting input and subtracted from input signal.

  open loop *gain refers to amplifier gain* ***without*** *feedback*

  closed loop *...* ***with*** *feedback*

- Rules for calculation - (only hold with negative feedback)

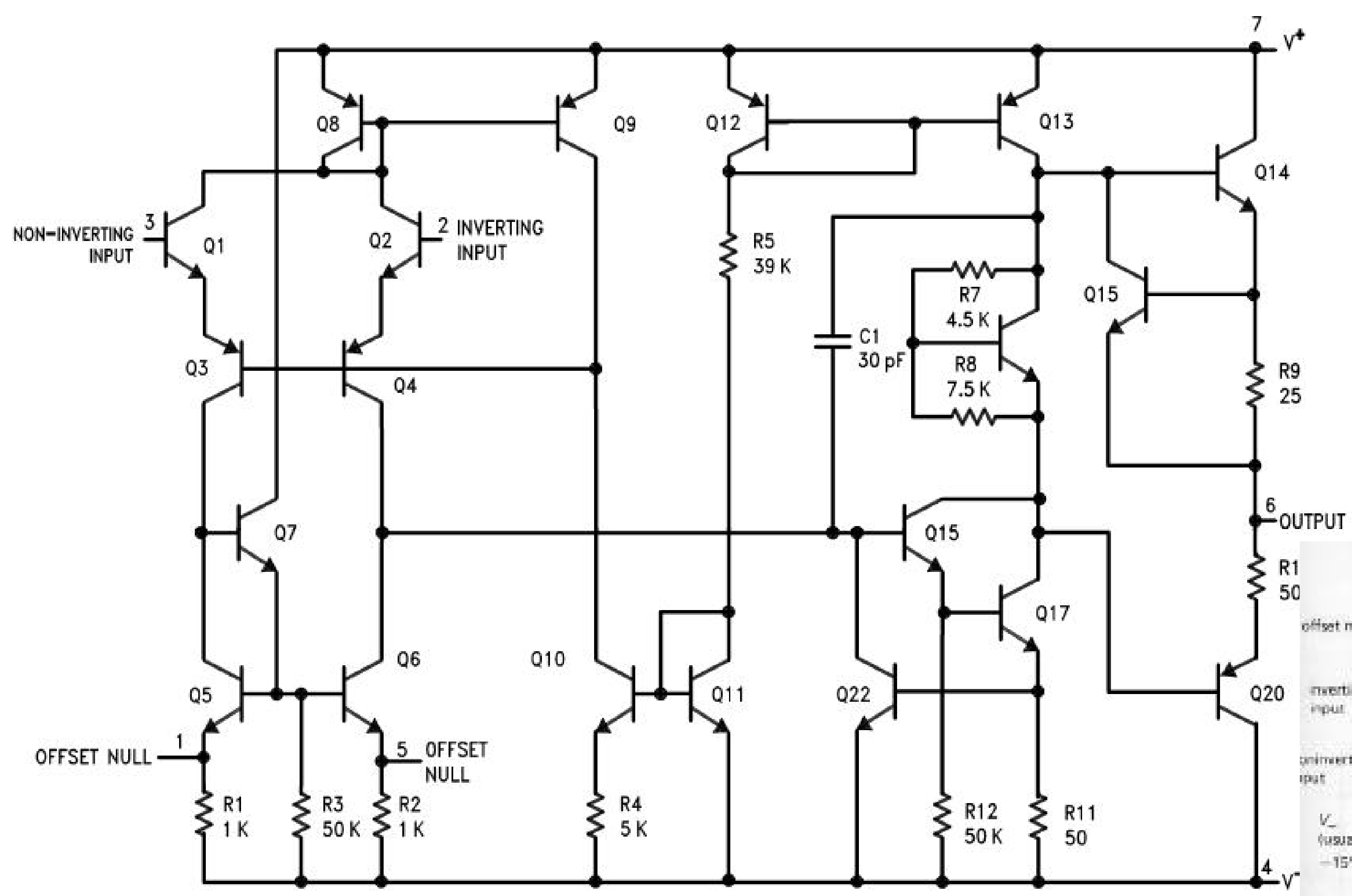
  (i) inputs approach same voltage ($v_+ = v_-$)

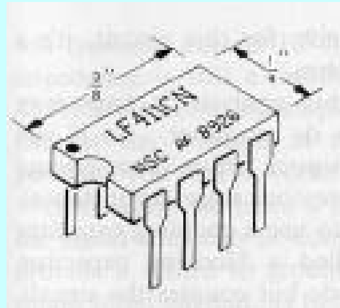
  (ii) inputs draw no current

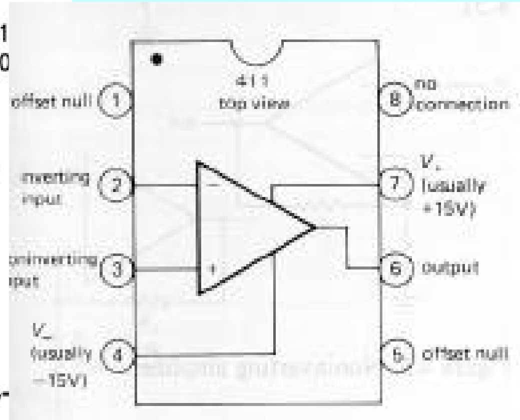
  only possibility for stability

A quick look inside…

• We may take another look later…







Inverting amplifier

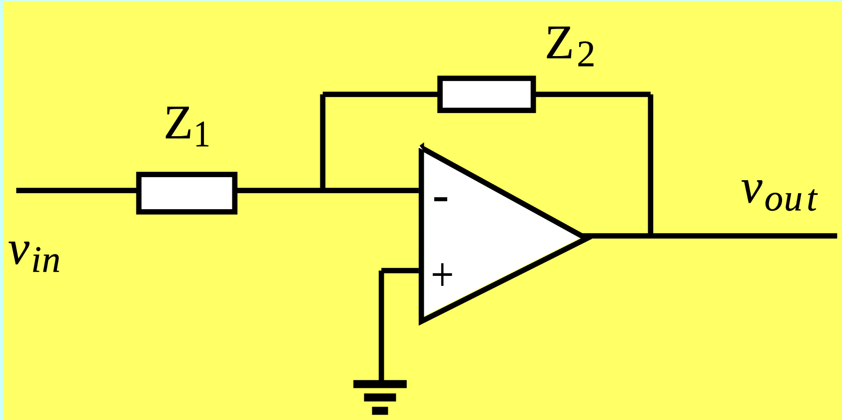
- Apply these rules

$v_- = v_+ = 0$

- Consider current flow

$(v_{in} - v_-)/(v_- - v_{out}) = Z_1/Z_2$

$Gain_{closed\ loop} = v_{out}/v_{in} = -Z_2/Z_1$



NB +/- connections

- Inverting input is virtual ground

held at 0V by rule (i)

- Input impedance

source at input sees only Z_1 to ground

so effective input impedance ≈ Z_1

usually low if aiming for - sometimes a disadvantage

Some conventions

- will often use upper case characters for DC values

  I, V

- use lower case values for perturbations or AC values

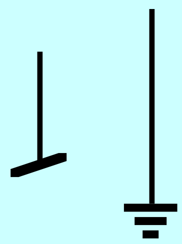
  $i = \Delta I$ or $i = I_0 e^{j\omega t}$

  etc

- Symbols

  ask if you don't recognise a symbol

  For ground:



Non-inverting amplifier

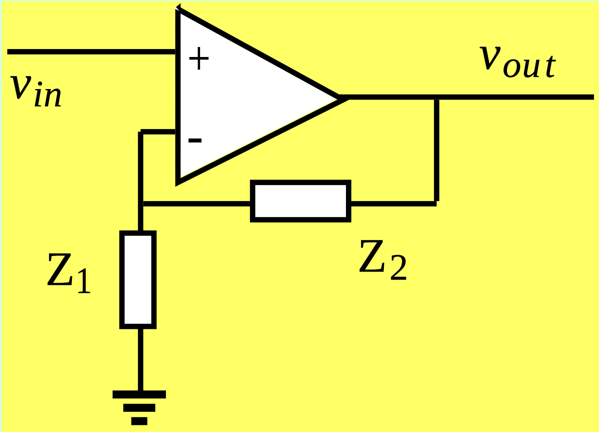
- Apply rules

  $v_{in} = v_+ = v_-$

- Voltage divider in feedback network

  $v_- = v_{out} Z_1/(Z_1 + Z_2)$

  $\text{Gain}_{\text{closed loop}} = v_{out}/v_{in} = 1 + Z_2/Z_1$



NB connections

- Input impedance

  source at input sees only input impedance of op-amp input = very high (∞)

  convenient for driving from any source

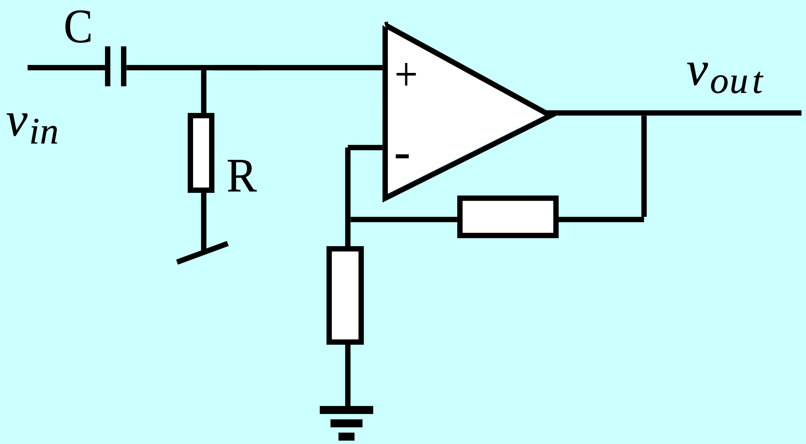
- Coupling signals in

  real amplifiers do draw small currents

  so if input is ac coupled, need a path for

  current to flow to ground

  make RC >> relevant time constant



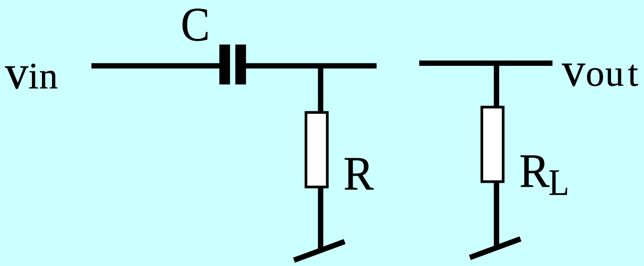
Buffers and loading

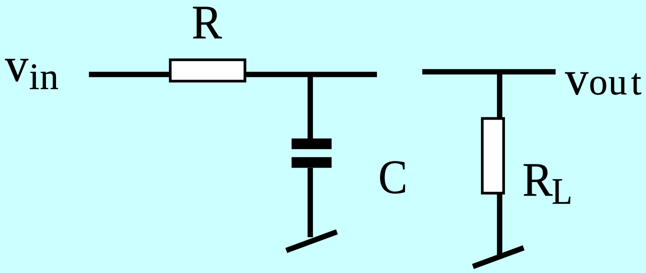
- Play an important role in connecting circuit elements or blocks

  eg a block may have a high output impedance where a low value is required

  or a high input impedance where ... etc

- A load can change the characteristics of the circuit...

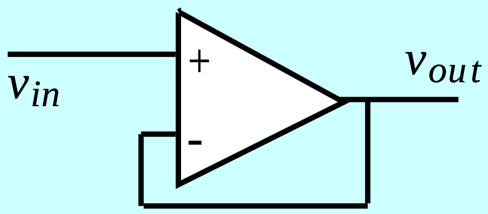




to overcome, insert a stage which matches impedances better

ie. isolates one stage from another

eg



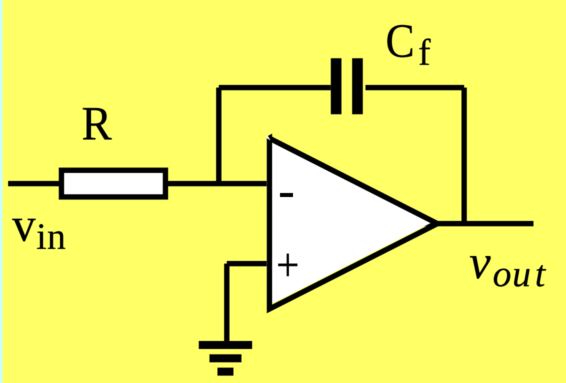
Integrator

- Variant of inverting amplifier where current is integrated on feedback capacitor

$i_{in} = v_{in}/R$

$V_{out} = -(1/RC_f)\int v_{in} dt$

useful for control circuits



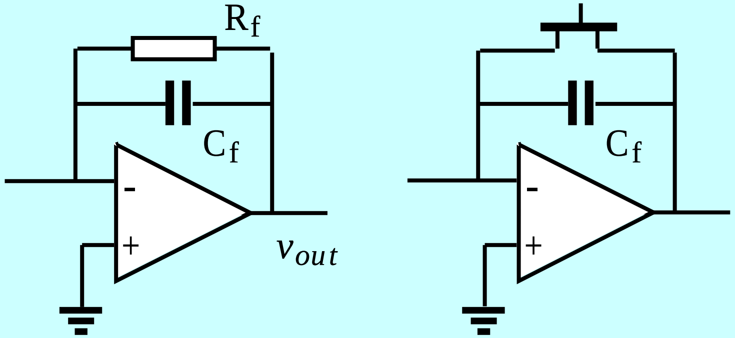
- it will often be convenient to analyse this circuit for pulse processing, where often more convenient to work in frequency domain

$v_{out} = -i_{in}/j\omega C_f$

R is noise source and adds to input impedance

remove for charge integrator

$v_{out} = -Q_{in} /C_f$



R_fC_f >> integration time

- Must have a means of resetting the amplifier

provide a parallel resistor or a transistor switch

Other useful blocks

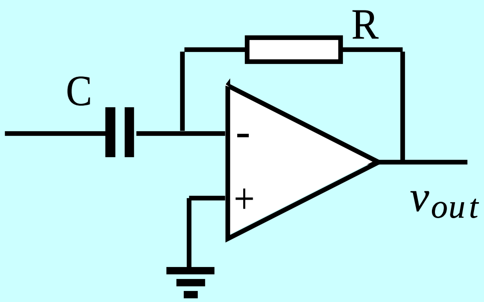
- Differentiator

  $i = CdV/dt$

  $v_{out} = -RCdV/dt$

  or

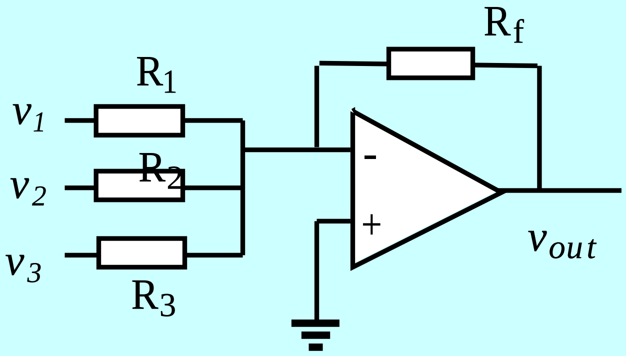
  $v_{out}/v_{in} = -j\omega RC$



- Summing amplifier

  weighted sum of inputs

  (consider currents)

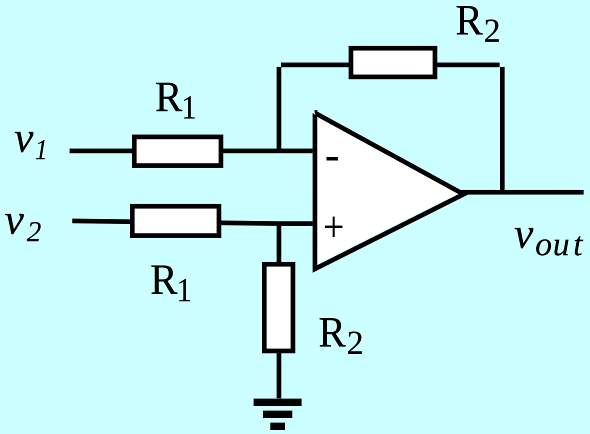


- Differential amplifier

  $v_{out} = (R_2/R_1)(v_2-v_1)$

  for matching need accurate component values

  nice feature: removes common mode signal



Common mode

- Suppose two signals at differential amplifier input are v_1 & v_2

  in many cases they may have a common component

  ie $v_1 = u_1 + v_{cm}$ $\quad\quad$ $v_2 = u_2 + v_{cm}$

  v_{cm} is called the common mode, remainder is normal mode

- The nice feature of a differential amplifier is

  $v_{out} = G(v_2 - v_1) = G(u_2 - u_1)$

  this is a very effective way of subtracting interference which affects both signals equally

  eg power supply ripple

  can't be used as universal remedy: lose dynamic range

- Common Mode Rejection Ratio - CMRR

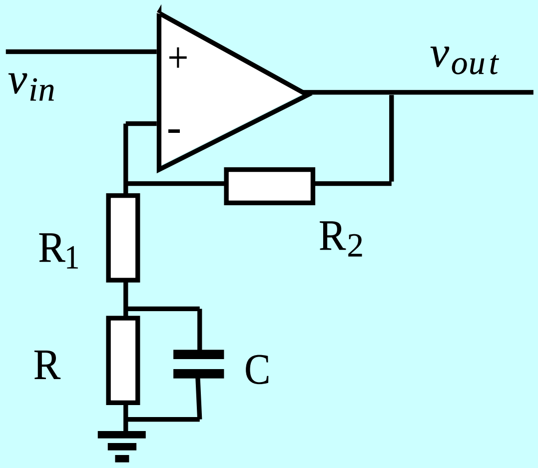
  CMRR = differential gain/common mode gain

  ~ 100-140dB for precision op-amps

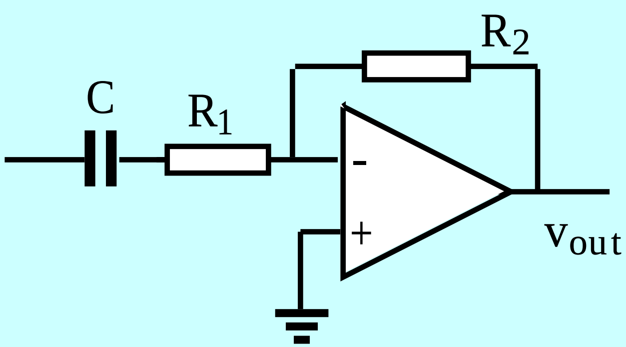
Many other possibilities

- Not restricted to using resistors only in circuit

eg gain at low f (or DC) with different value at high f



differentiator/high pass filter with gain & inversion



Non-ideal op-amp behaviour

- Just seen one example

  inputs do draw small currents - input impedances are finite

  real amplifiers do not have infinite gain but very high values can be obtained

  some examples of consequences later

- Practical considerations

  easy to assume zero output for zero input - may be true for ac, but not dc

  op-amps have nulling connections, and recommended compensation to adjust

  often simple potentiometer (screwdriver adjustment)

  output impedance - ideal op-amp has open-loop $R_{out} \approx 0$

  slew rate - how fast can output voltage change?

  applied voltages are limited - certainly can't expect to exceed supply voltages!

  behaviour can change with temperature - powered circuits need cooling!

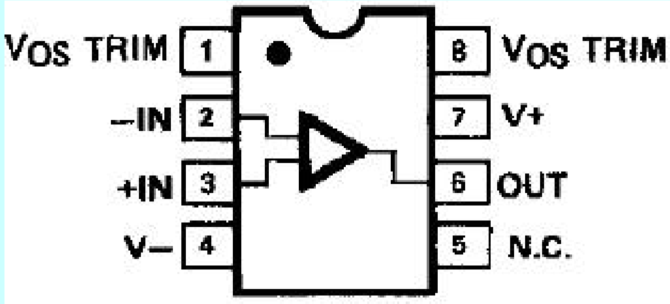
  frequency response and bandwidth - discuss further

- \- most parameters are clearly specified so should use manufacturer's data to select best component for application

  many of these are important in precision applications

Specifications & typical values

- Along with obvious parameters; R_{in}, R_{out}, CMRR, V_S, bandwidth, power consumption, gain and phase shift, manufacturer's data sheets also give:



- Input bias current I_B

  $0.5*(i_+ + i_-)$ with $v_+ = v_- = 0$ ~pA - nA

- Input offset current I_B

  $i_+ - i_-$ with $v_+ = v_- = 0$ ~fraction of I_B

- Input offset voltage V_{OS} & adjustment range

  v_{out} with $v_+ = v_- = 0$ ~ 10µV - 5mV

NB some of these are T dependent
so take care in assumptions when adjusted

- Input voltage range

  $\sim \pm|V_S|- 1V$

- Slew rate (f dependent)

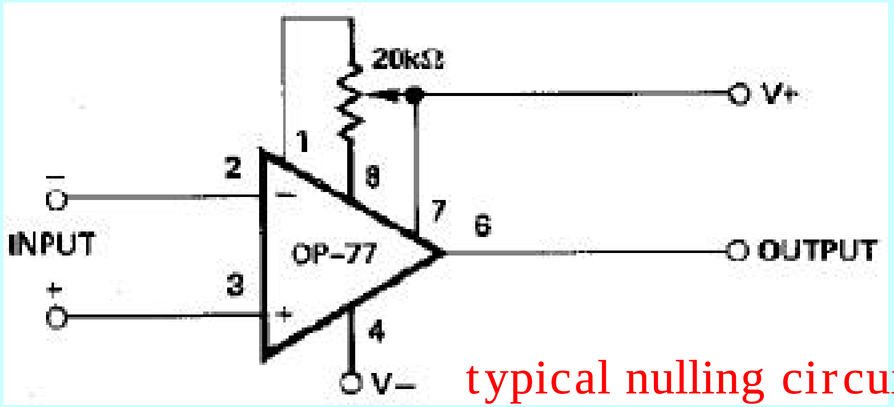
  maximum dv_0/dt ~ V/µs

- Power Supply Rejection Ratio (PSRR)

  small changes in V_S can resemble signals

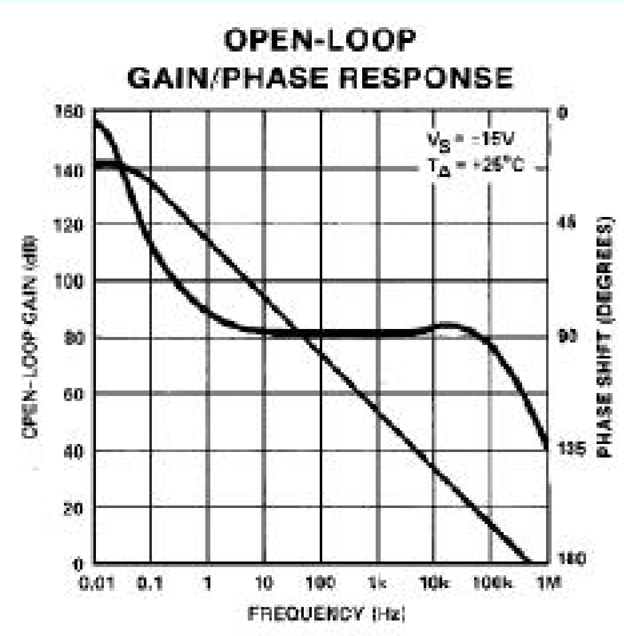
  dB or µV/V

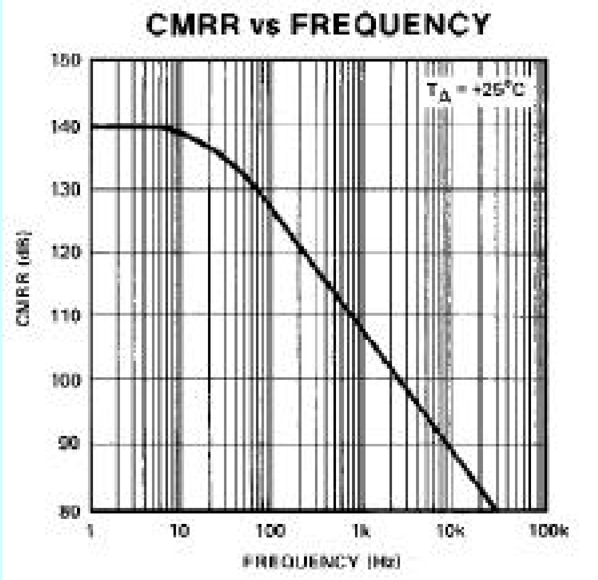
- Noise voltage & current (for later)

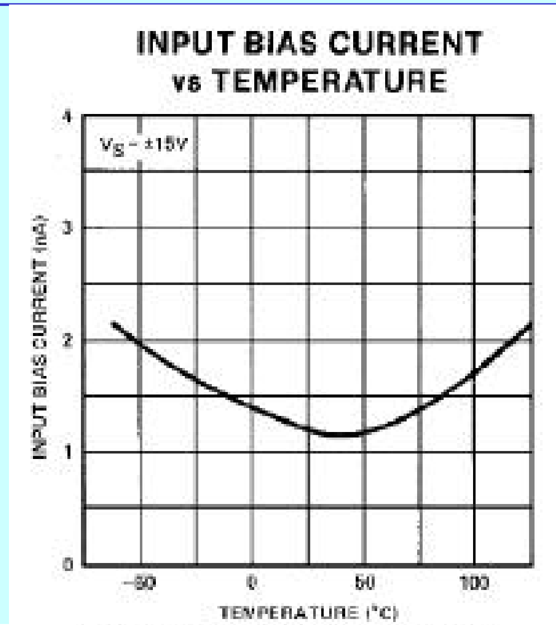


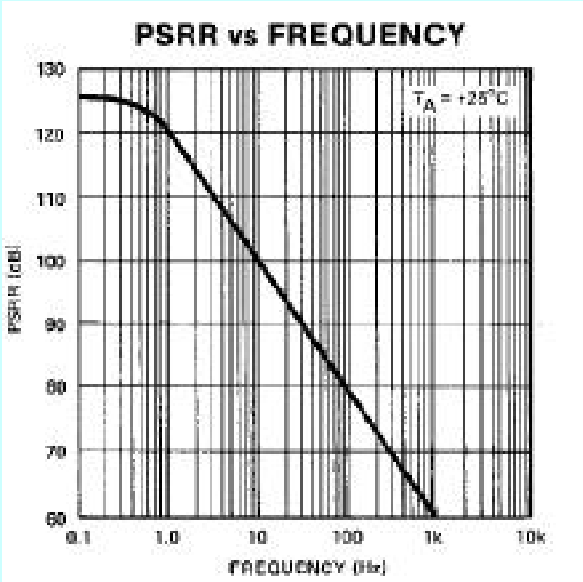
typical nulling circuit

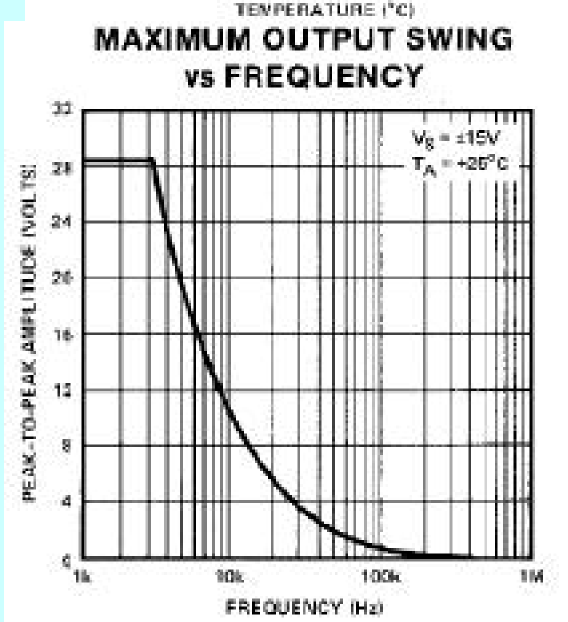
Real op-amp data - OP77











Advantages of feedback

•Why sacrifice gain?

even if amplifier gain is defined

component gain is not a reliable quantity

gain in feedback circuits fixed by components

can choose precision

negative feedback improves performance

stability, linearity, distortion

some components approaching ideal can be designed

eg current sources with very high output impedance

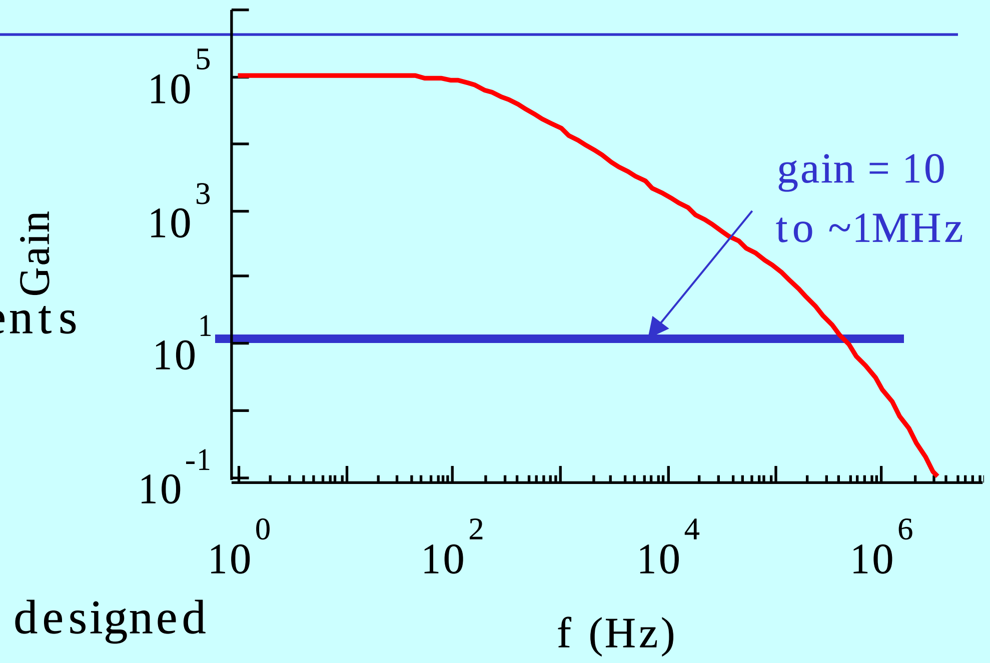
real gain depends on frequency

designing for lower closed loop gain extends f range where gain is uniform

- up to some limit

frequency dependent feedback can be used

simplifies some designs



positive feedback has uses - eg oscillators

Op-amp frequency response

- Reason for falling gain with frequency

  low pass filters in different stages

  formed by natural capacitances present in circuit

- Poles

  amplifier illustrated has poles at f_1, f_2, f_3

  can give stability problems

  if phase shift > 180° negative feedback becomes positive

  must ensure gain < 1 at frequency at which phase shift > 180°

  some op-amps have this built in

  if not, reduce gain

  if feedback network introduces phase changes, then this must be included in discussion