Other useful blocks

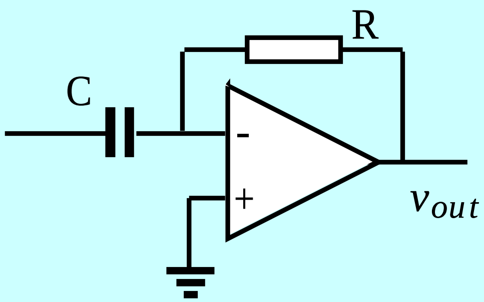
- Differentiator

  $i = C dV/dt$

  $v_{out} = -RC dV/dt$

  or

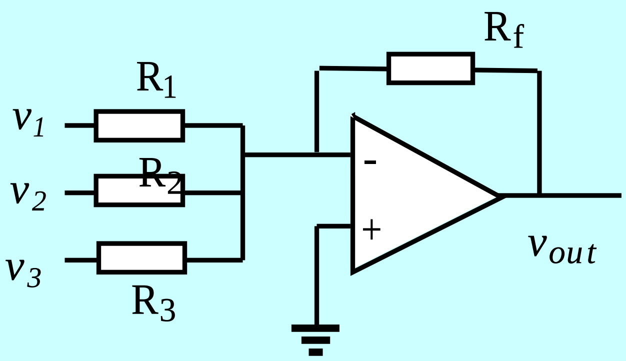
  $v_{out}/v_{in} = -j\omega RC$



- Summing amplifier

  weighted sum of inputs

  (consider currents)

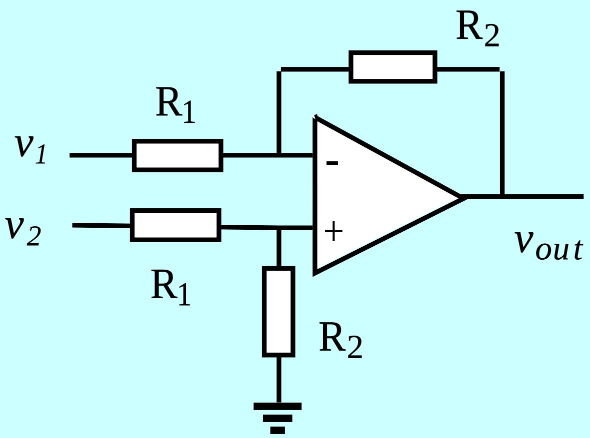


- Differential amplifier

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

  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 $v_1 = u_1 + v_{cm}$ $v_2 = u_2 + v_{cm}$

    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

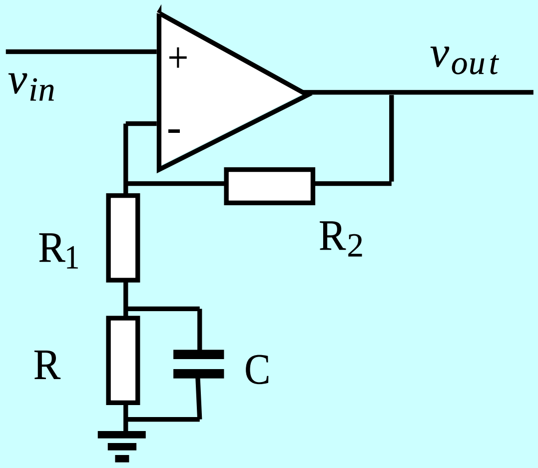
    CMRR = differential gain/common mode gain

    ~ 100-140dB for precision op-amps

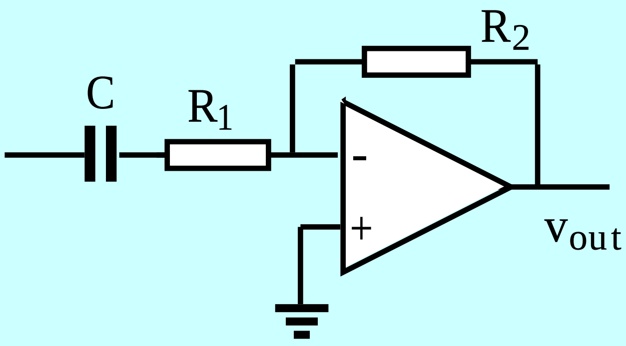
Many other possibilities

- 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!

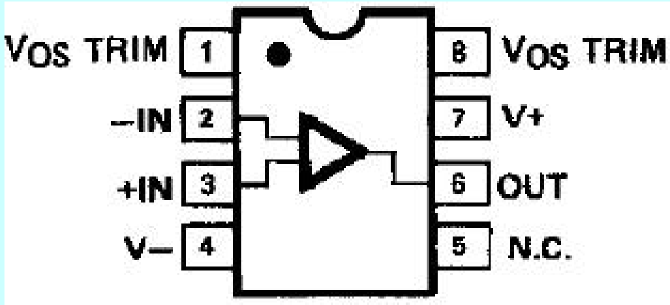
  frequency response and bandwidth - discuss further

- \- 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)

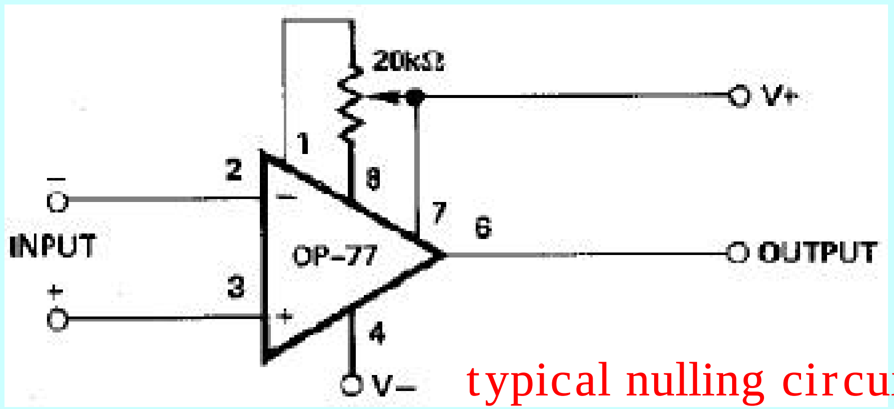
maximum dv_0/dt ~ V/µs

•Power Supply Rejection Ratio (PSRR)

small changes in V_S can resemble signals

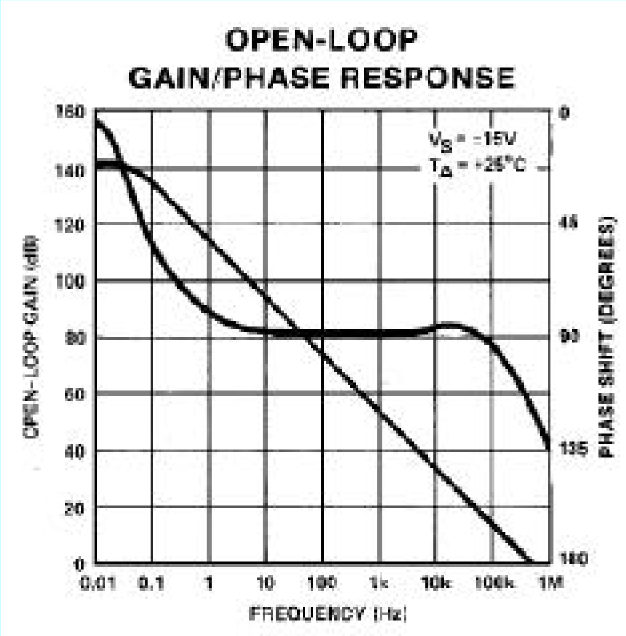
dB or µV/V

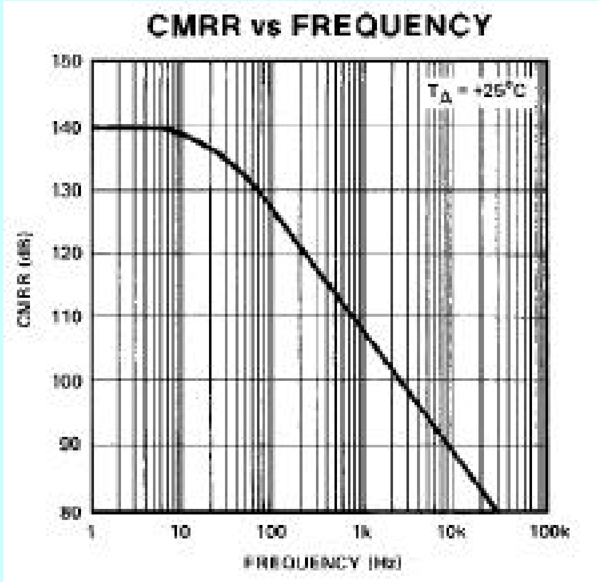
•Noise voltage & current (for later)

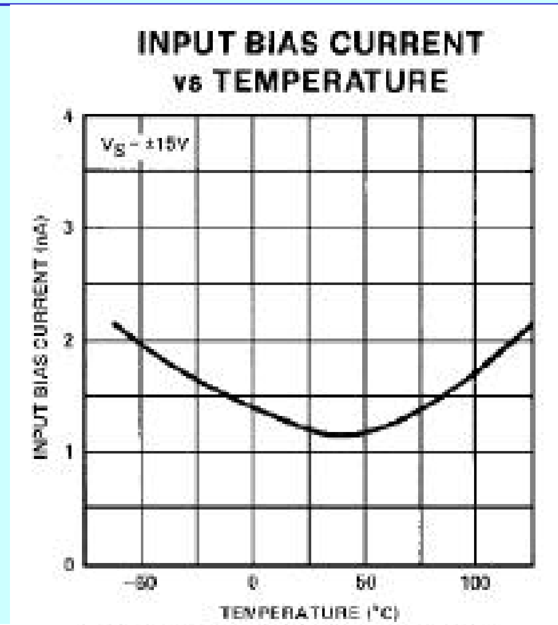


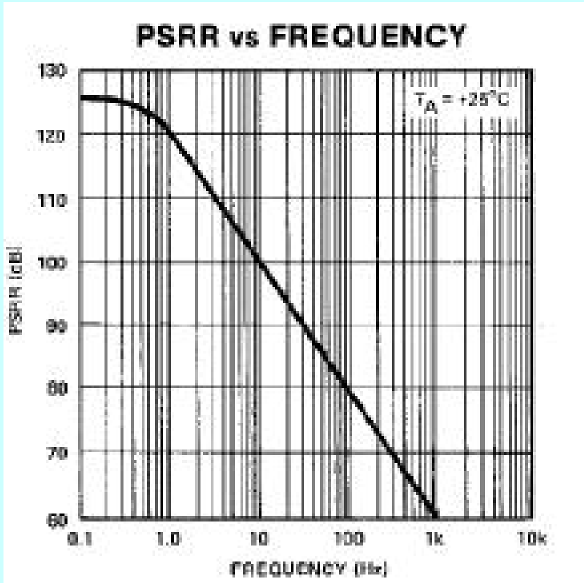
typical nulling circuit

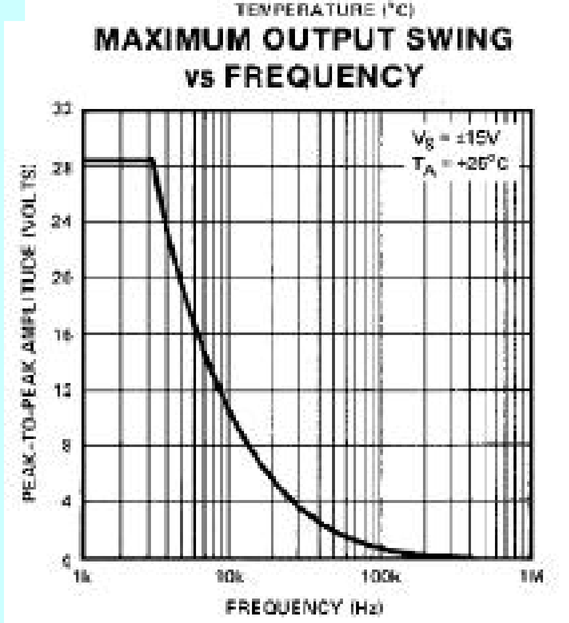
Real op-amp data - OP77











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

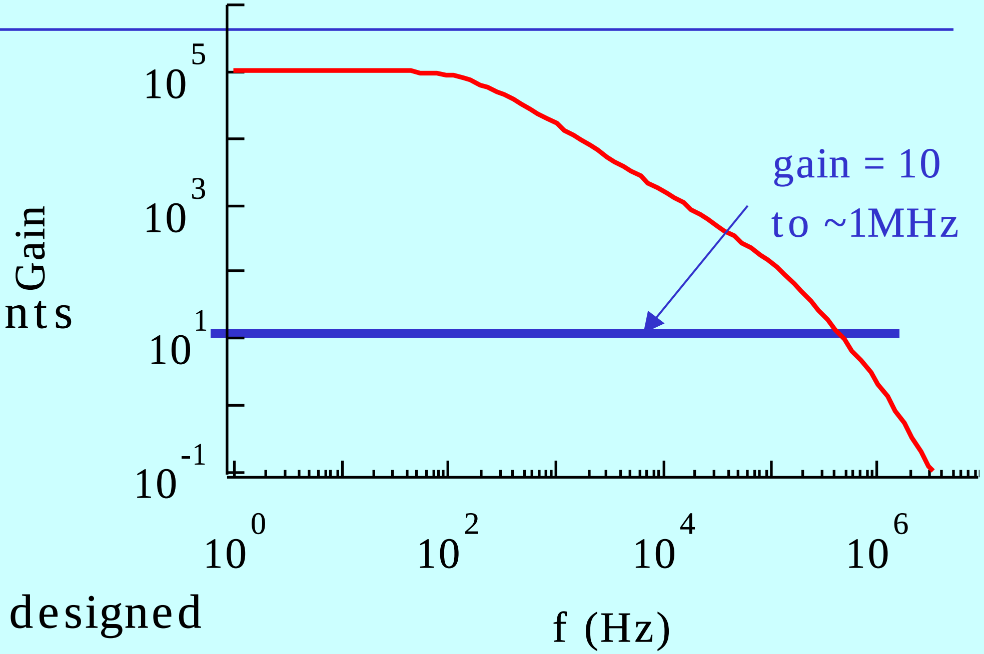
real gain depends on frequency

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