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

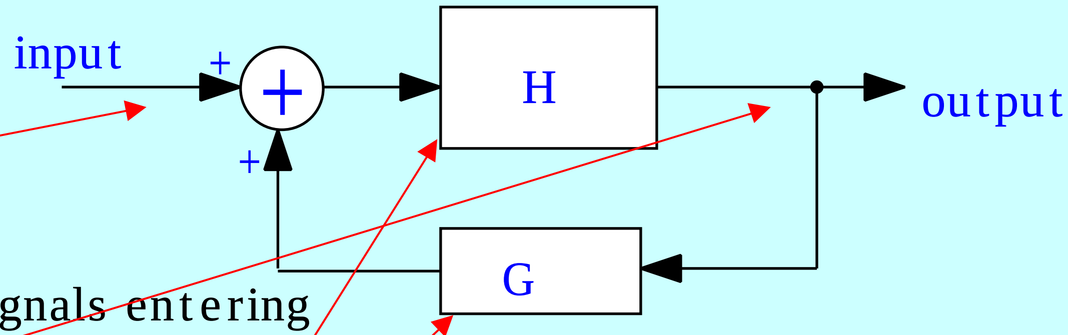
and sensor - it is not usually easy to get large signals

data have to be transferred over long distances without errors

safest with “large” signals

System block diagrams

- Introduction to...



Feedback

- 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,..

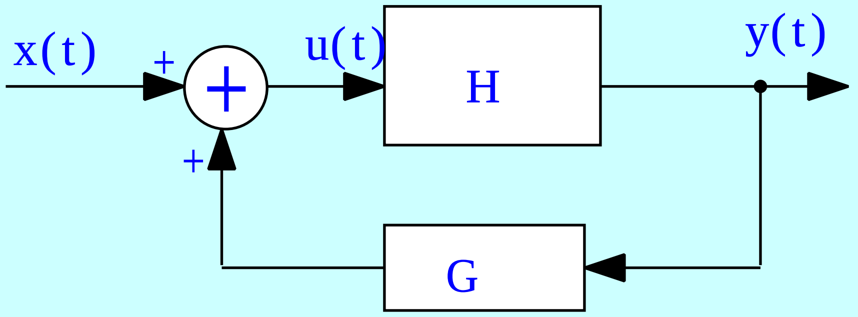
- How to manipulate?

  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

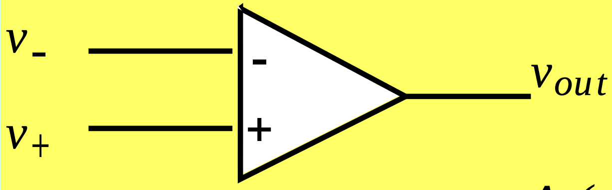
  single output

  dual, differential inputs, infinite impedance

  amplifies difference in voltages between inputs

  inputs are DC coupled

Gain = *A*



$v_{out} = A\,(v_+ - v_-)$

- 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)

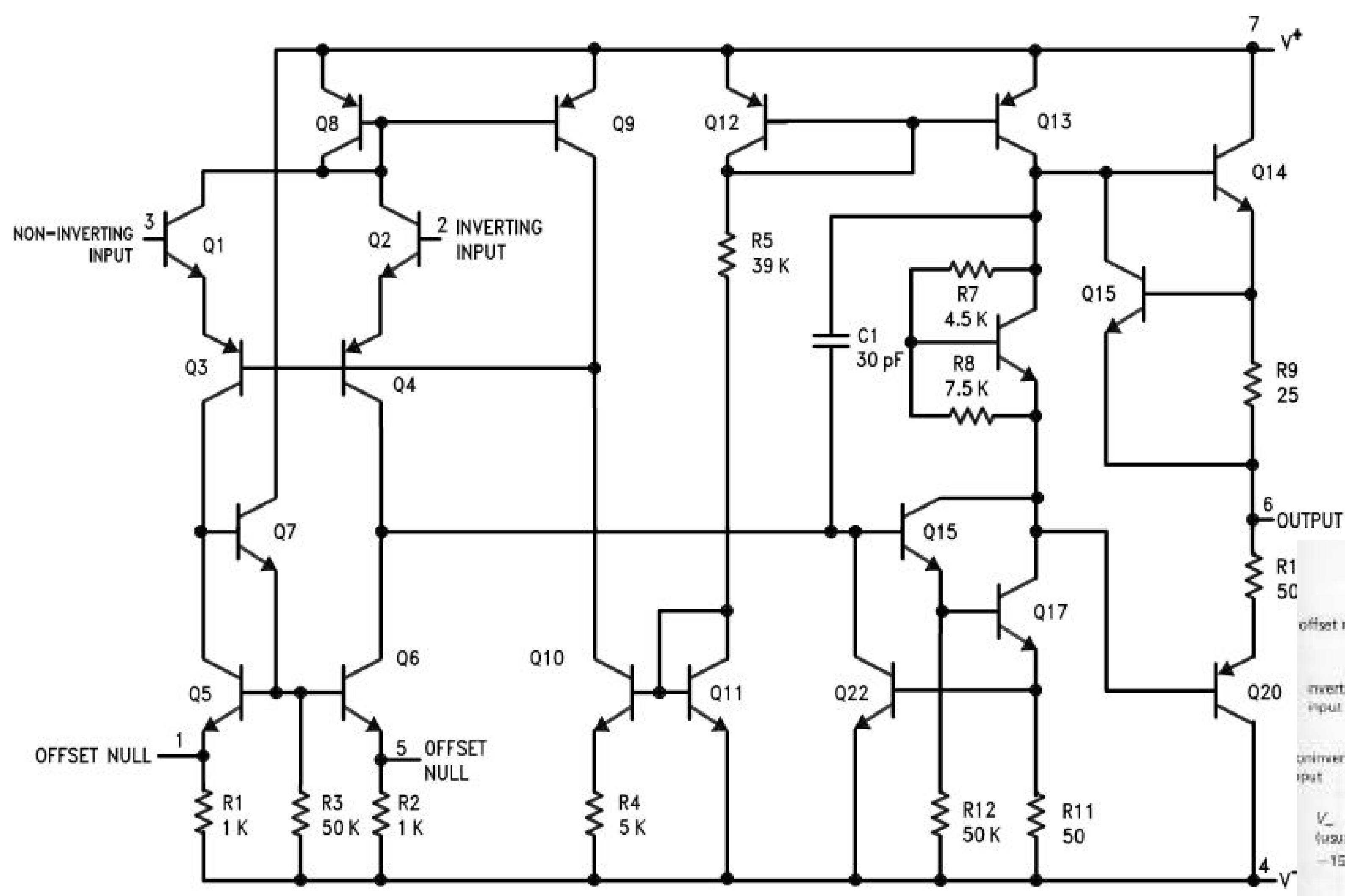
  (i) inputs approach same voltage ($v_+ = v_-$)

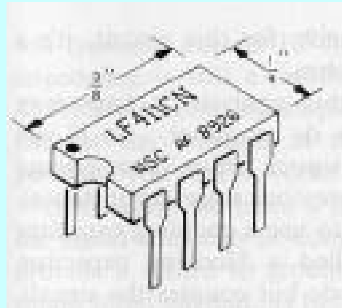
  (ii) inputs draw no current

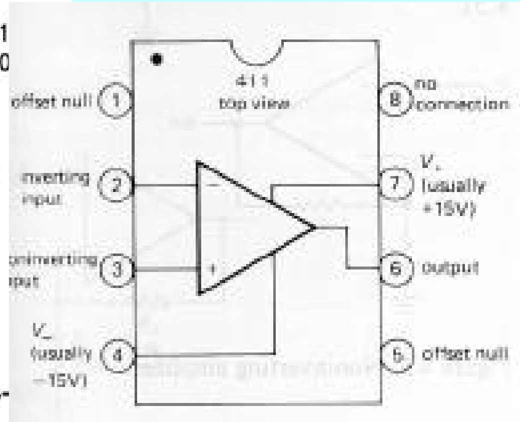
  only possibility for stability

A quick look inside…

- We may take another look later…







Inverting amplifier

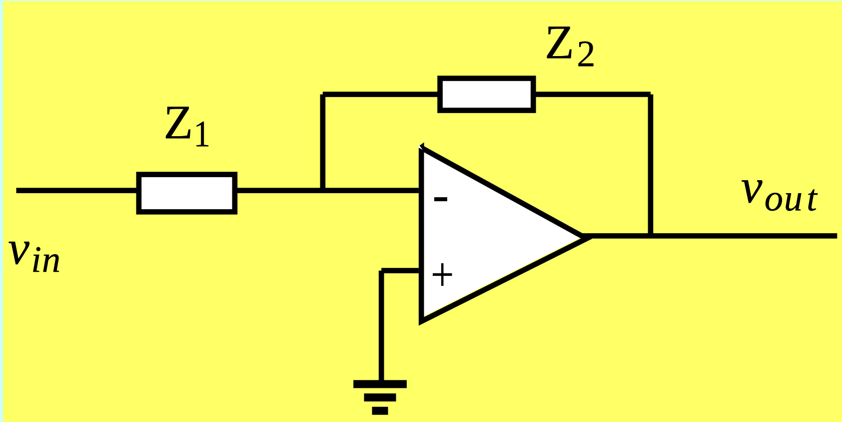
- Apply these rules

  $v_- = v_+ = 0$

- 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 <u>virtual ground</u>

  held at 0V by rule (i)

- Input impedance

  source at input sees only Z_1 to ground

  so effective input impedance $\approx Z_1$

  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

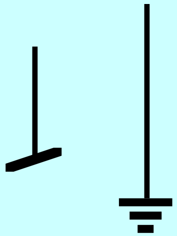
$i = \Delta I$ or $i = I_0 e^{j\omega t}$

etc

•Symbols

ask if you don't recognise a symbol

For ground:



Non-inverting amplifier

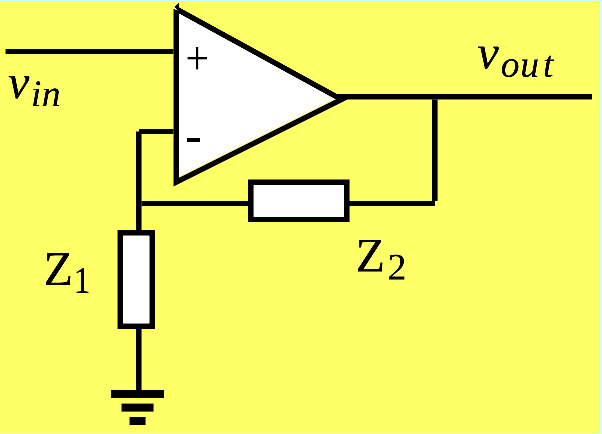
•Apply rules

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

•Voltage divider in feedback network

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

$Gain_{closed\ loop} = v_{out}/v_{in} = 1 + Z_2/Z_1$



NB connections

•Input impedance

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

convenient for driving from any source

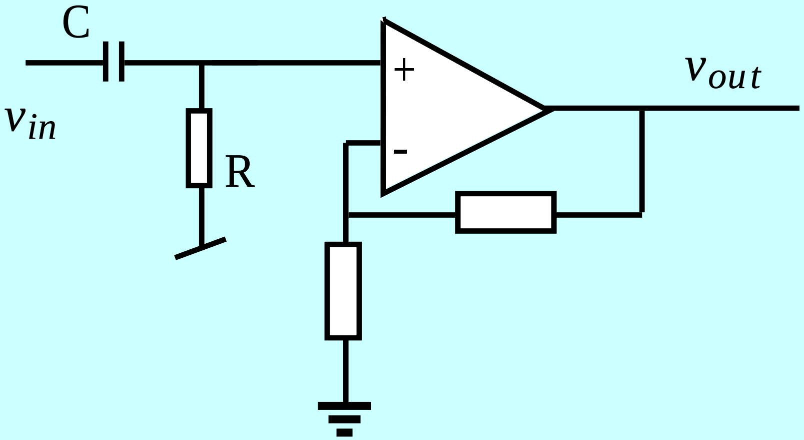
•Coupling signals in

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



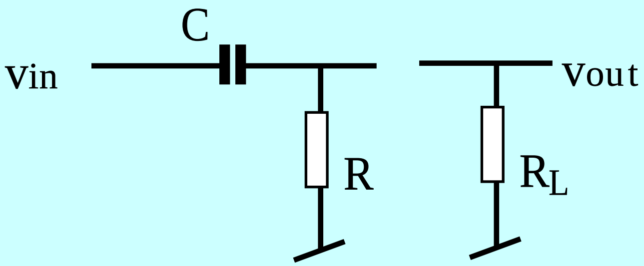
Buffers and loading

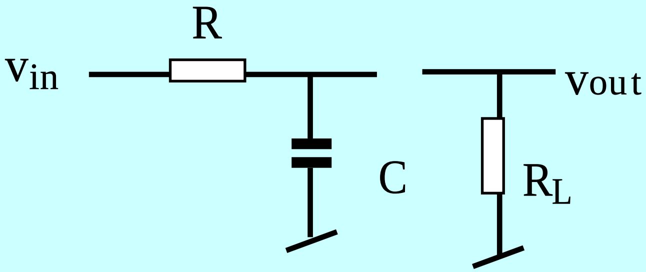
- Play an important role in connecting circuit elements or blocks

  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…

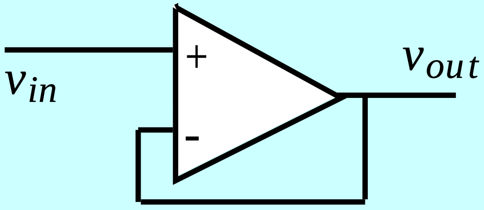




to overcome, insert a stage which matches impedances better

ie. isolates one stage from another

eg



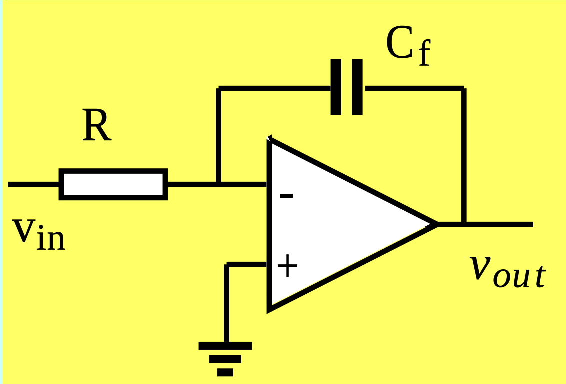
Integrator

- 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

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

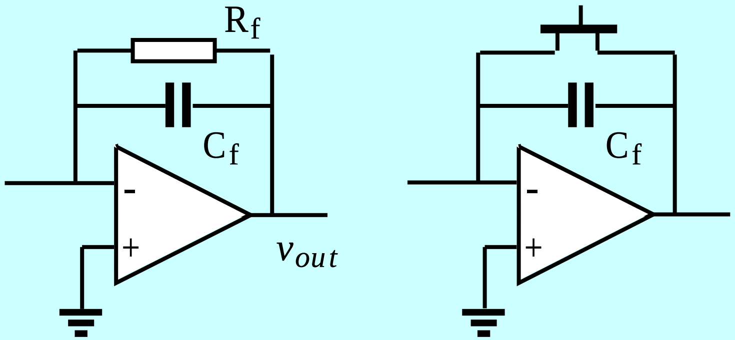
  R is noise source and adds to input impedance

  remove for charge integrator

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

- Must have a means of resetting the amplifier

  provide a parallel resistor or a transistor switch



R_fC_f >> integration time

Other useful blocks

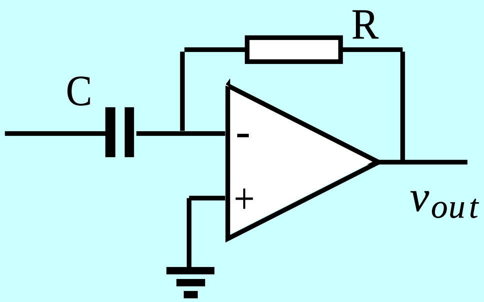
- Differentiator

  i = CdV/dt

  v_{out} = -RCdV/dt

  or

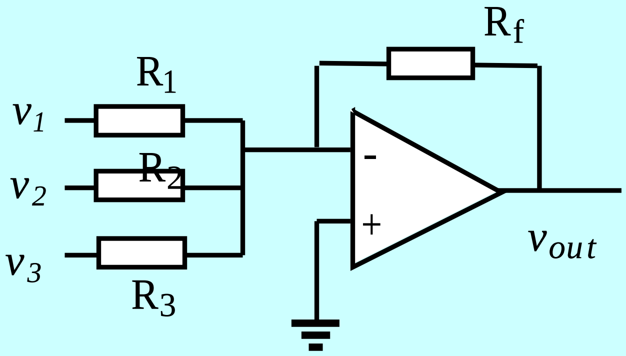
  $v_{out}/v_{in} = -j\omega RC$



- 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 <u>common mode</u> signal