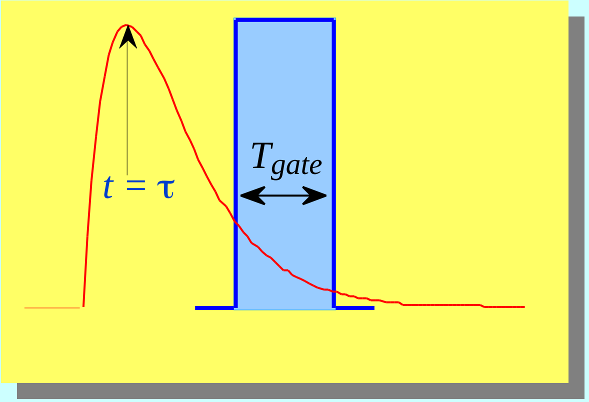
Integrating Analogue to Digital Converter (ADC)

- Integrate signal during application of gate - another time variant filter

  convert charge to digital number



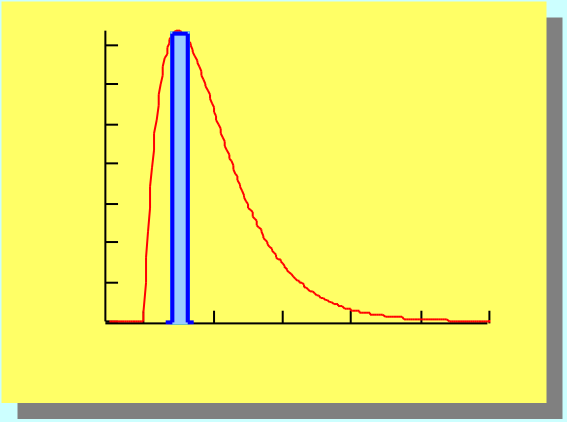
- = **convolution** of pulse shape with gate

  so

  $w(t) = h(t) * g_{gate}(t)$

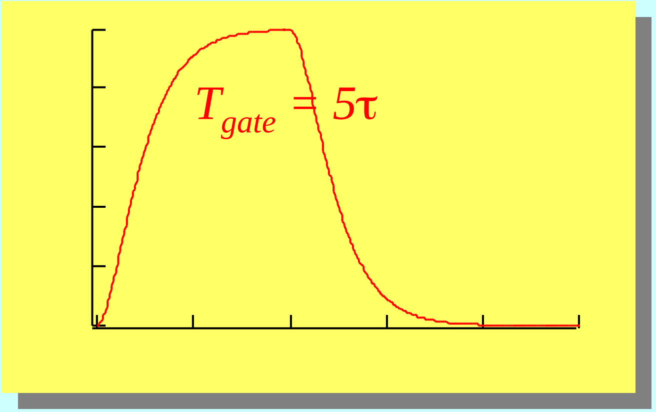
  (ignoring t reflection)

- $T_{gate} \ll \tau$



$w(t) = h(t)$

$T_{gate} \gg \tau$



new, wider weighting function

can change filtering and **increase** or **decrease** noise

Digitisation noise

- Eventually need to convert signal to a number

  quantisation (rounding) of number = noise source

  the more precise the digitisation, the smaller the noise

- After digitisation all that is known is that

  signal was between $-\Delta/2$ and $\Delta/2$

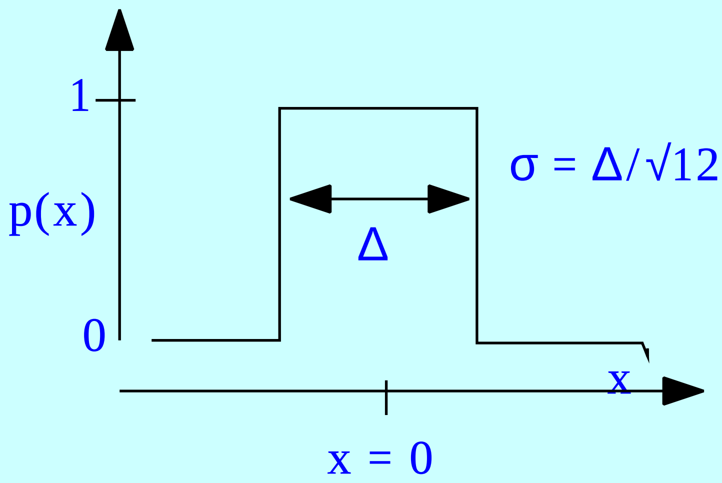
  $\langle x \rangle = \int x.p(x).dx / \int p(x).dx$

  $\sigma^2 = \langle x^2 \rangle = \int x^2.p(x).dx \;/ \int p(x).dx$

  $\int p(x).dx \quad = \int_{-\Delta/2}^{\Delta/2} dx = [x]_{-\Delta/2}^{\Delta/2} = \Delta$

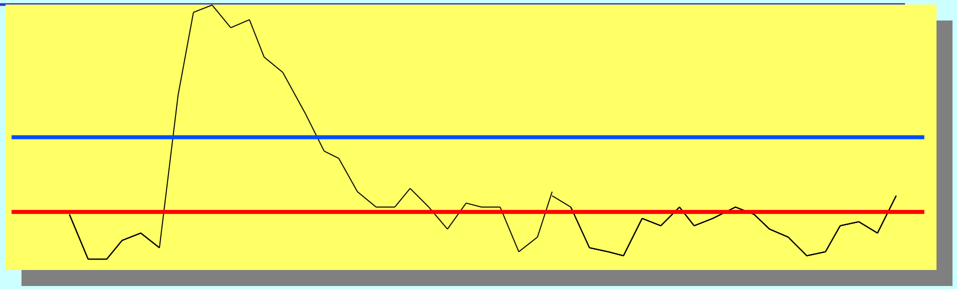
  $\int x^2.p(x).dx \quad = \int_{-\Delta/2}^{\Delta/2} x^2.dx = [x^3/3]_{-\Delta/2}^{\Delta/2} = 2\Delta^3/24$

  so $\sigma^2 = \Delta^2/12$



- ie statistical noise which is proportional to digitisation unit

Level crossing statistics



- Binary counting systems have noise !

  fluctuations cause threshold crossing

- Rate of zero (level) crossing f_Z

  proportional to spectral density of noise w(f)

$$f_Z = 2\left[\frac{\int_0^\infty f^2 w(f)\,df}{\int_0^\infty w(f)\,df}\right]^{1/2}$$

- General proof is complicated:

  imagine noise at several distinct frequencies: f_0, f_1,...

  $w(f) = \delta(f-f_0) + \delta(f-f_1) + \ldots$

$$f_Z = 2\left[\frac{\int_0^\infty f^2 \delta(f-f_0)\,df}{\int_0^\infty \delta(f-f_0)\,df}\right]^{1/2} + 2\left[\frac{\int_0^\infty f^2 \delta(f-f_1)\,df}{\int_0^\infty \delta(f-f_1)\,df}\right]^{1/2} \ldots = 2f_0 + 2f_1 +$$

factor 2 because crossings can occur in both directions

Positive level crossing rate

- If we know level crossing rate f_V

  by measurement or calculation

- Rate of crossing, in positive direction, of level V

  is

$$f_v = \frac{f_Z}{2}\exp\left(\frac{-v^2}{2\sigma^2}\right)$$

- because noise has gaussian distribution of amplitudes

  factor 1/2 because one direction

- so improvement for any other threshold X, compared to threshold Y

$$\frac{f_X}{f_Y} = \exp\left(\frac{-(X^2 - Y^2)}{2\sigma^2}\right)$$

Time measurements and noise

- When did signal cross threshold ?

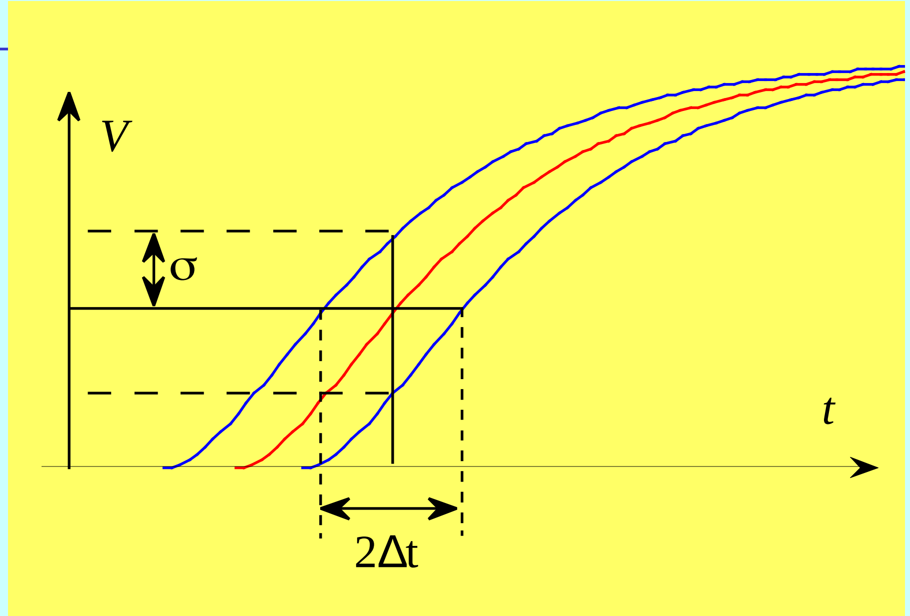
  noise causes “jitter”

  $\Delta t = \sigma_{noise}/(dV/dt)$

- compromise between

  bandwidth (increased dV/dt)

  noise (decreased bandwidth)



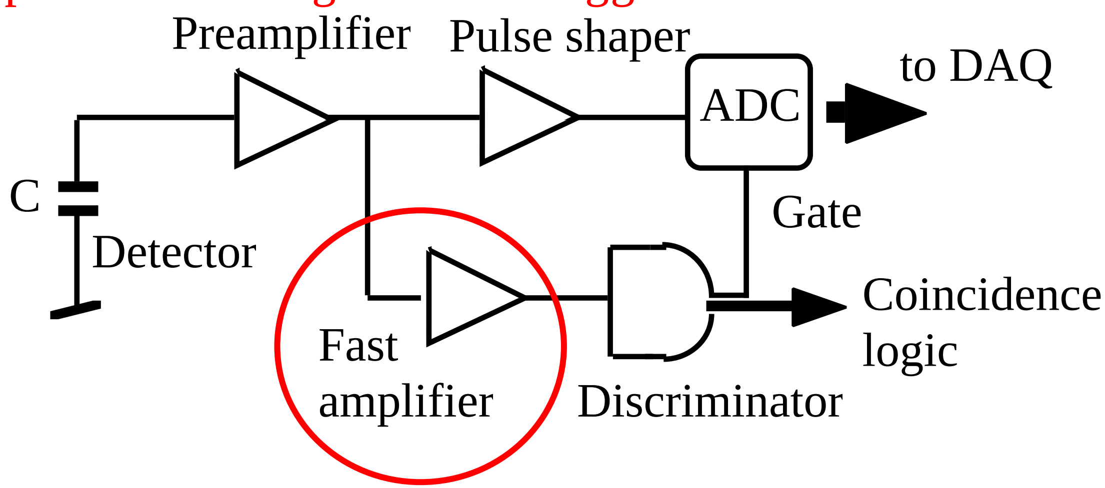
- limits systems where preamplifier pulse used to generate trigger

  eg x-ray detection

- typical preamp response

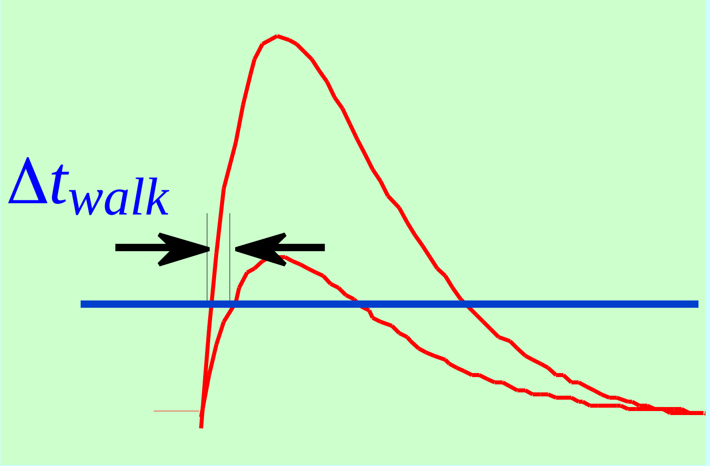
  $V = V_{max}(1-e^{-t/\tau_{rise}})$

  so $\Delta t \approx \sigma_{noise}\tau_{rise}/ V_{max}$ $t \ll \tau$



Time and amplitude

- Time "walk" due to amplitude variation



- solutions:

  constant fraction discriminator

  not simple circuit but easily possible

  or

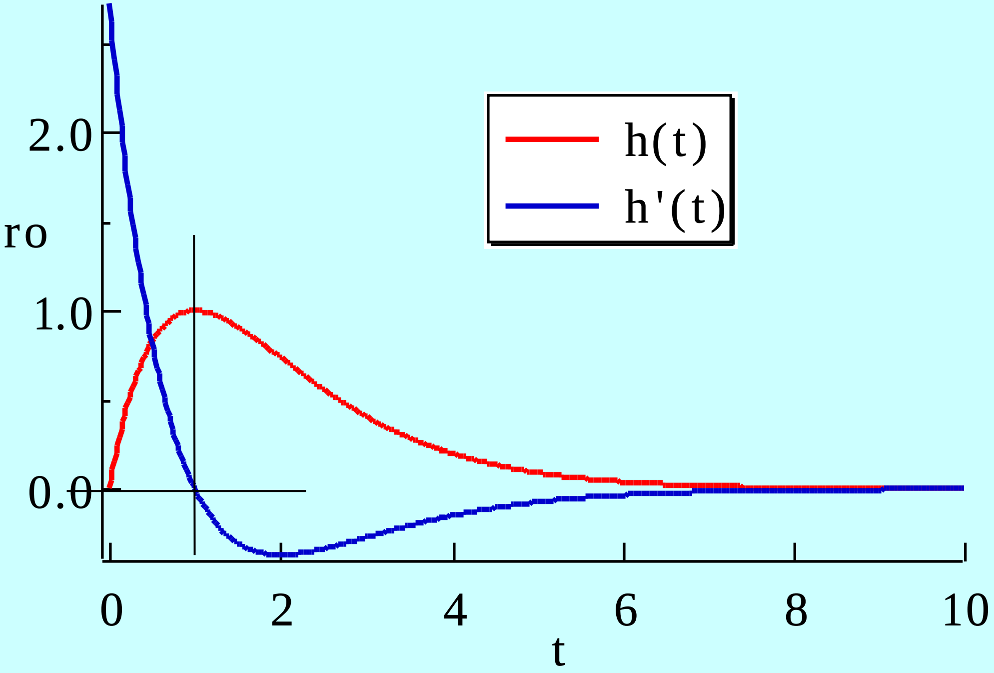
  zero-crossing discriminator

  differentiate pulse

  measure time when output crosses zero

  invariant pulse shape

  always peaks at same time



- penalty

  differentiation also adds noise !

  more high frequencies passed

Extrinsic noise

- or Why Things Don't Always Work

even though you thought you'd done everything right

Practical instrument systems composed of electrical components

define geometry of potentials and electric fields in system

measurement of charge <==> rearrangement of potentials in system

ie current flows

- we can't take the current paths for granted - why?

already know that electrostatic (capacitive) and magnetic (inductive) connections are present between components - as well as simple conductive connections

so usually there are several routes along which current can flow, especially depending on frequency range covered by instrument

- we need to plan them

Simple example

- Thunderstorm

  dramatic movement of charges with obvious consequences

  but even at some distance from lightning strike, observe induced and conductive current flows

  frequent source of damage to electronics

  fax machines, modems, telephones,..

Sources of pickup

- Lights

    typically ~50Hz but...

- Power supplies - in almost all apparatus!

    50Hz "hum" - often transformers

    Switched mode: AC rectified -> DC -> DC chopped -> square wave (~kHz)

    uses capacitors and diodes to generate high(er) voltages - eg kV for TV

- RF pickup

    capacitive coupling of high frequencies from...

    ... computers, radio or TV, mobile phones,...

    ... digital logic inside system

- Microphonics

    surface vibrations of metal surface, cause capacitance variations

        motors, vacuum pumps, transformers, ...

How to find noise sources

- Lights
  - Do I need to say?
- 50Hz mains and higher frequencies
  - analogue oscilloscope, varying time base and trigger
- RF
  - analogue scope
  - spectrum analysis
    - *can sometimes be misleading without experience*
- Varying conditions, eg ground connections
  - sometimes hard to avoid in practice
  - but not the best way of improving things, especially if hit-or-miss

- How to avoid or eliminate extrinsic noise?

Shielding

•place sensitive amplifier- detector in metal enclosure

- external E field lines terminate on surface

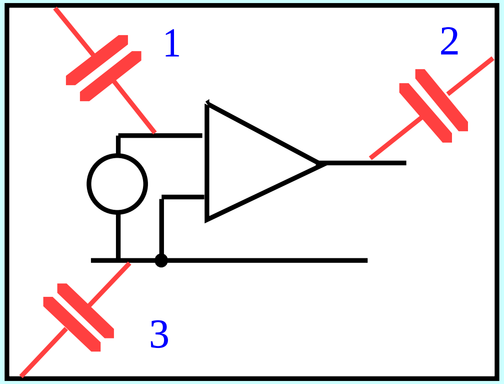
Incident EM waves reflected

$E_{ref}/E_{inc} \approx (1\text{-}Z/Z_0)$ $\quad Z_0 = (\mu_0/\varepsilon_0)^{1/2} = 377\Omega$

Absorbed wave limited to skin depth

$\sim e^{-x/\delta}$ $\quad \delta = (2/\mu\sigma\omega)^{1/2}$

Al: $\delta \sim 100\mu m$ at 1MHz



•Potential problems

capacitances to shield - feedback

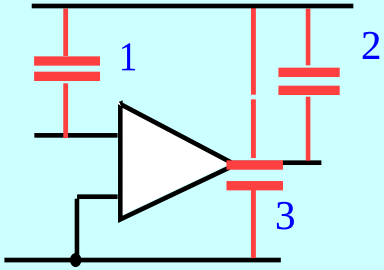
shield connection

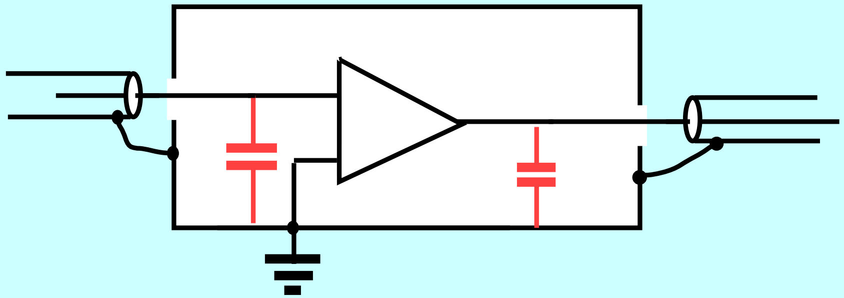
how to get signals in and out?

try to make tight connections

with low resistance

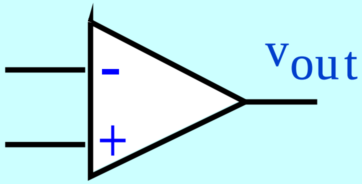
E field can penetrate gaps $\ll \lambda$





Ground loops

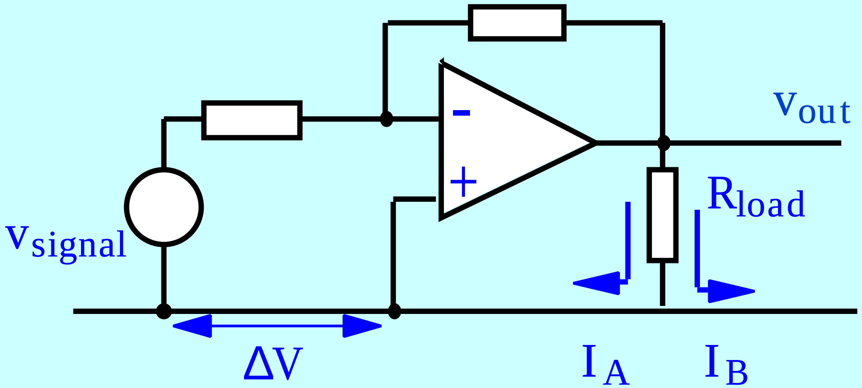
- Real amplifiers have more than 3 terminals



Inputs draw no current but output provides current
 - where does it go?

- Route for output current

does it flow where it should?



$v_{out} >> v_{signal}$

I large

R in line -> ΔV

- If current flows in reference line (usually ground) expect voltage drops

ie ground is not 0V everywhere - even if circuit diagram assumes so

ensure large currents, especially later amplifier stages, provided separately

Inductive and conductive paths

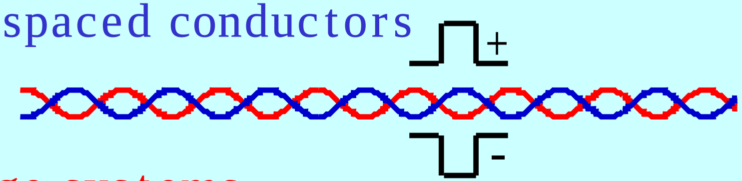
•Inductive paths

Long paths can form loops in which other currents flow

currents => changing magnetic field

B induces current noise

Avoid with balanced signals, flowing in closely spaced conductors



•May still be difficult to implement in remote, large systems

optical data transmission can remove a large part of loop

•Routing noise out of sensitive locations

large capacitors to ground, or DC point

at frequencies where $\omega C \gg 1$, noise sees low impedance path to ground

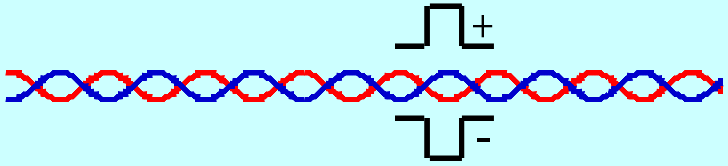
Other solutions

- Differential transmission and receivers

    same noise appears on both lines

    can subtract common mode signals

        at expense of loss of some dynamic range, eg...



- Battery power

    eliminate AC from supply

- Filter

    if signal is limited to a freqency range, eg by bandpass noise filter

    should be protected against noise outside range of interest

    if insufficient, add more filtering