Amplifiers in systems

- Amplification

  single gain stage rarely sufficient

  add gain to avoid external noise eg to transfer signals from detector

  practical designs depend on detailed requirements

  constraints on power, space,... cost in large systems

  e.g. ICs use limited supply voltage which may constrain dynamic range

- Noise will be an important issue in many situations

  most noise originates at input as first stage of amplifier dominates

  often refer to Preamplifier = input amplifier

  may be closest to sensor, subsequently transfer signal further away

- In principle, several possible choices

  V sensitive

  I sensitive

  Q sensitive

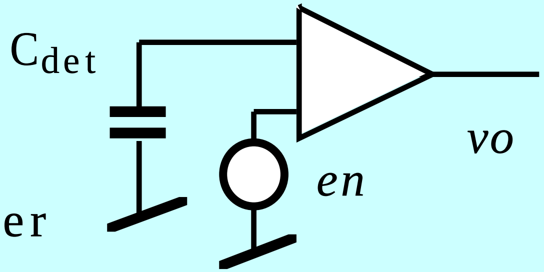
Voltage sensitive amplifier

- As we have seen many sensors produce current signals but some examples produce voltages - thermistor, thermocouple,...

  op-amp voltage amplifier ideal for these

  especially slowly varying signals - few kHz or less

- For sensors with current signals voltage amplifier usually used for secondary stages of amplification



- Signal $V_{out} = Q_{sig}/C_{tot}$

  C_{tot} = *total input capacitance*

  C_{tot} will also include contributions from wiring and amplifier

  V_{out} depends on C_{tot}

  not desirable if C_{det} is likely to vary

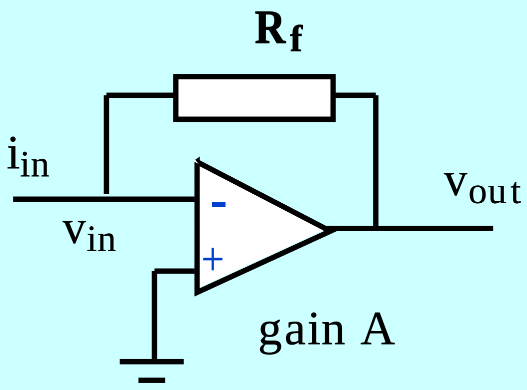
  eg with time, between similar sensors, or depending on conditions

- Noise to be discussed more later

  contribution from amplifier, and possibly sensor

  $S/N = Q_{sig}/(C_{tot}.v_{noise})$ can it be optimised?

Current sensitive amplifier



- Common configuration, eg for photodiode signals

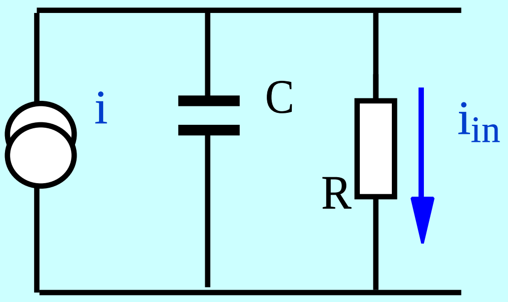
$v_{out} = -Av_{in}$

$v_{in} - v_{out} = i_{in}R_f$

$v_{out} = -[A/(A+1)].i_{in}R_f \approx -i_{in}R_f$

- Input impedance

$v_{in} = i_{in}R_f/(A+1)$ $\qquad Z_{in} = R_f/(A+1)$



- Effect of C & R_{in} - consider in frequency domain

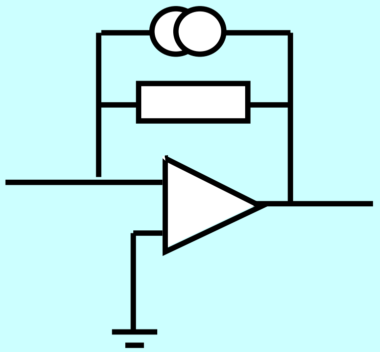
$v_0 = i(1/j\omega C||R_{in})$

$= i(\omega)R/(1 + j\omega\tau)$

input signal convoluted with falling exponential

increasing R_f to gain sensitivity will increase τ

fast pulses will follow input with some broadening



- Noise

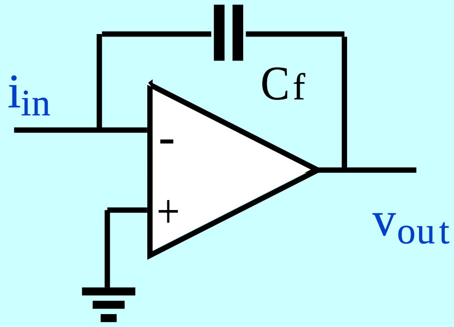
will later find that feedback resistor is a noise source

contributes current fluctuations at input ~ $1/R_f$

Charge sensitive amplifier

- Ideally, simple integrator with C_f

  but need means to discharge capacitor - large R_f



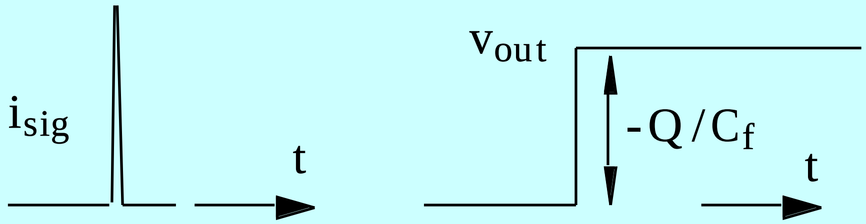
- Assume amplifier has Z_{in} very high (usual case)

  $v_{out} = -Av_{in}$

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

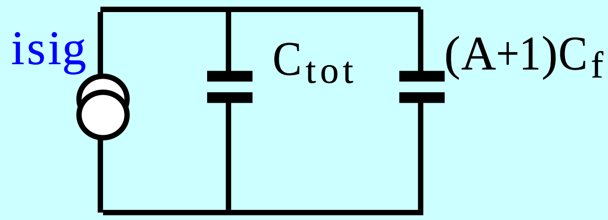
  $v_{out} = -[A/(A+1)].i_{in}/j\omega C_f \approx i_{in}/j\omega C_f$

  $\Rightarrow -Q/C_f$



- Input impedance

  $v_{in} = i_{in}/(A+1)j\omega C_f$ $\qquad C=(A+1)C_f$ at low f



so amplifier looks like large capacitor to signal source

low impedance but some charge lost

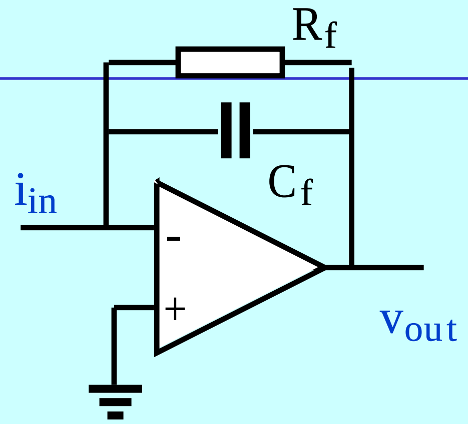
$$Q_A = Q/[1 + C_{tot}/(A+1)C_f]$$

e.g. $A = 10^3$ $\quad C_f = 1pF$

$C_{tot} = 10pF$ $\quad Q_A/Q = 0.99$

$C_{tot} = 100pF$ $\quad Q_A/Q = 0.90$

Feedback resistance



- Must have means to discharge capacitor so add R_f

  $Z_f = R_f || 1/j\omega C_f$

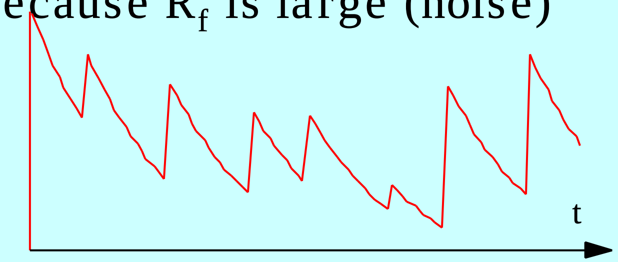
  $v_{out} = -[A/(A+1)].i_{in}Z_f$

  $= i(\omega)R_f/(1 + j\omega\tau_f) \qquad \tau_f = R_fC_f$

  step replaced by decay with ~ $\exp(-t/R_fC_f)$ τ is long because R_f is large (noise)

  easiest way to limit pulse pileup - differentiate

  ie add high pass filter



- Pole-zero cancellation

  exponential decay + differentiation => unwanted baseline undershoot

  introduce canceling network

  $v_0 = 1/(1 + j\omega\tau_f)$

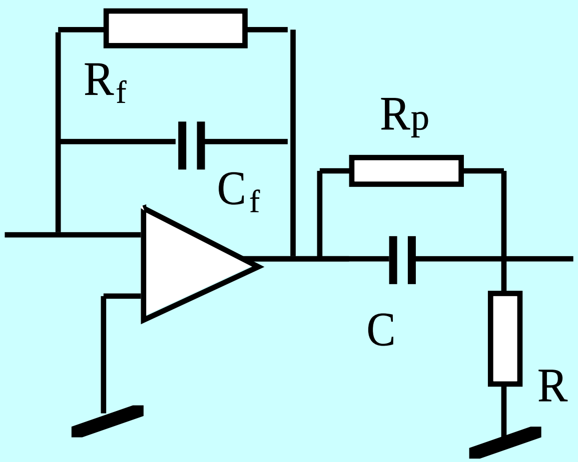
  $v_1 = 1/(1 + j\omega\tau_f)(1 + j\omega\tau_1)$

  $\tau_1 = RC < \tau_f$

  add resistor R_p so $R_pC = \tau_f$

  then

  $v_1' = 1/(1 + j\omega\tau_3)$ with $\tau_3 = (R||R_p)C < \tau_f$



Effect of finite bandwidth

- Realistic input stage of amplifier

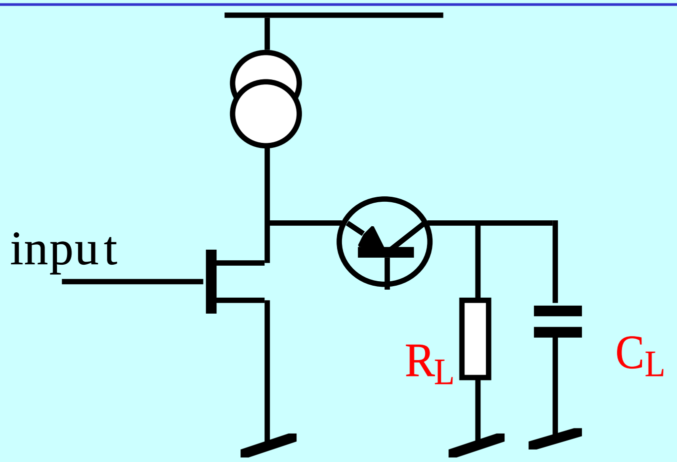
$v_{out} = i_d(R_L||C_L) \qquad i_d = g_m v_{in}$

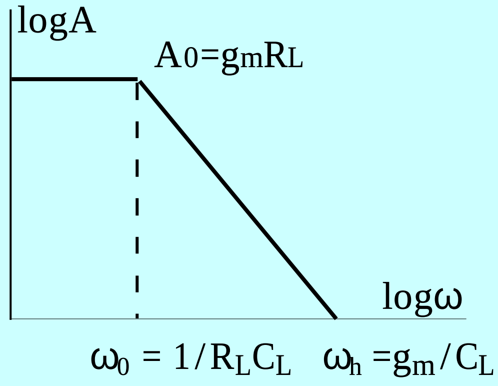
$A = g_m R_L$ low f

$A = g_m / j\omega C_L$ high f

(NB phase change)

$Z_{in} \approx 1/A.j\omega C_f = C_L/g_m C_f$ resistive!

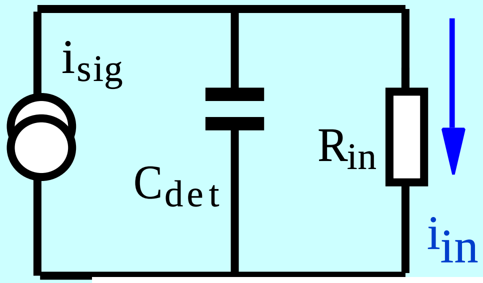




Irrespective of detailed design

$A \approx A_0\omega_h/j\omega \qquad \omega_h$ = gain-bandwidth product

$= 1/A_0\omega_h C_f$



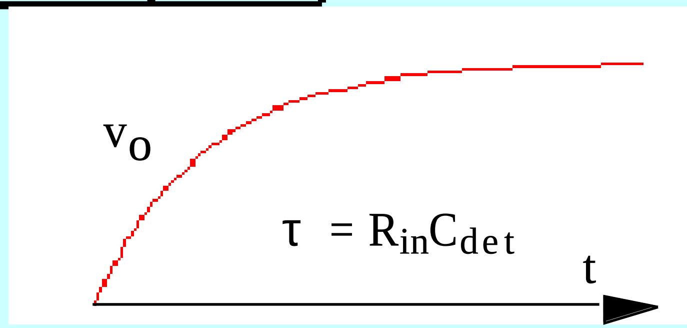
- Effect of R_{in}

signal current shared between R_{in} & C_{det}

$v_{out} = i_{in}Z_f \approx i/[j\omega C_f(1 + j\omega\tau_{rise})]$

$\sim 1 - \exp(-t/\tau)$

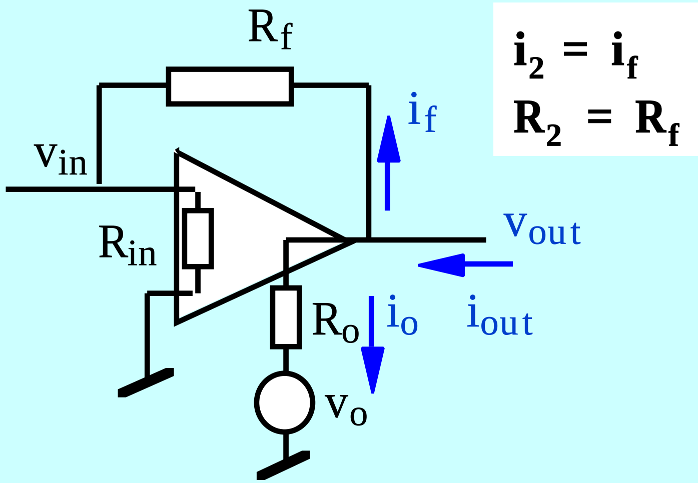
high frequencies in leading edge



leading edge of output pulse

Output impedance

- Usual method of varying v_{out} and finding i_{out} - generally messy algebra
- Current sensitive amplifier, open loop gain = A



$v_{out} = i_2(R_2 + R_{in})$

$v_{in} = i_2 R_{in}$

$v_o = -Av_{in} = -Ai_2R_{in}$

$i_o = (v_{out} - v_0)/R_o = (v_{out} - Ai_2R_{in})/R_o$

$Z_{out} = v_{out}/i_{out} = R_o (R_2 + R_{in})/[Ro + R_2 + R_{in}(A+1)]$

$\approx R_o/(A+1)$

since $R_{in} >> R_2$, R_o

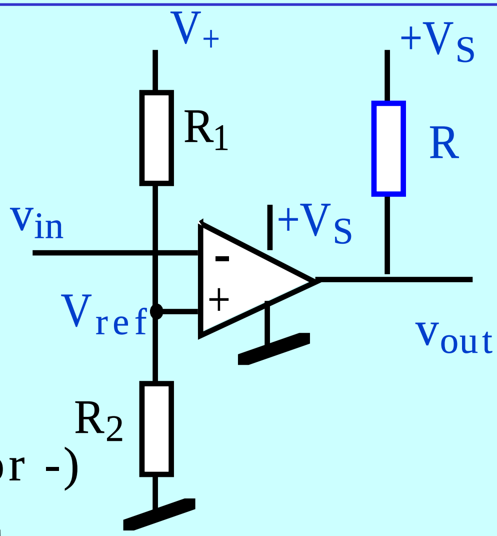
R_o = open loop output impedance

- In general

$Z_{out} = R_o/(1+Ab)$ if voltage is sampled at output   b = feedback fraction

$Z_{out} = R_o(1+Ab)$ if current is sampled at output

Comparators



- Frequently need to compare a signal with a reference
  - eg temperature control, light detection, DVM,...
  - basis of analogue to digital conversion -> 1 bit
- Comparator
  - high gain differential amplifier,
    - difference between inputs sends output to saturation (+ or -)
  - could be op-amp - without feedback - or purpose designed IC
  - Sometimes ICs designed with open-collector output so add pull-up R to supply
    - also available with latch (memory) function
- NB
  - no negative feedback so $v_- \neq v_+$
  - saturation voltages may not reach supply voltages - check specs
  - speed of transition
- Potential problem
  - multiple transitions as signal changes near thresholdf