# V.2. Signal Acquisition

- Determine energy deposited in detector

- Detector signal generally a short current pulse

  Typical durations

| | |
|---|---|
| Thin silicon detector (10 ... 300 μm thick): | 100 ps – 30 ns |
| Thick (~cm) Si or Ge detector: | 1 – 10 μs |
| Proportional chamber (gas): | 10 ns – 10 μs |
| Gas microstrip or microgap chamber: | 10 – 50 ns |
| Scintillator + PMT/APD: | 100 ps – 10 μs |

The total charge $Q_s$ contained in the detector current pulse is $i_s(t)$ proportional to the energy deposited in the detector

$$E \propto Q_s = \int i_s(t)\, dt$$

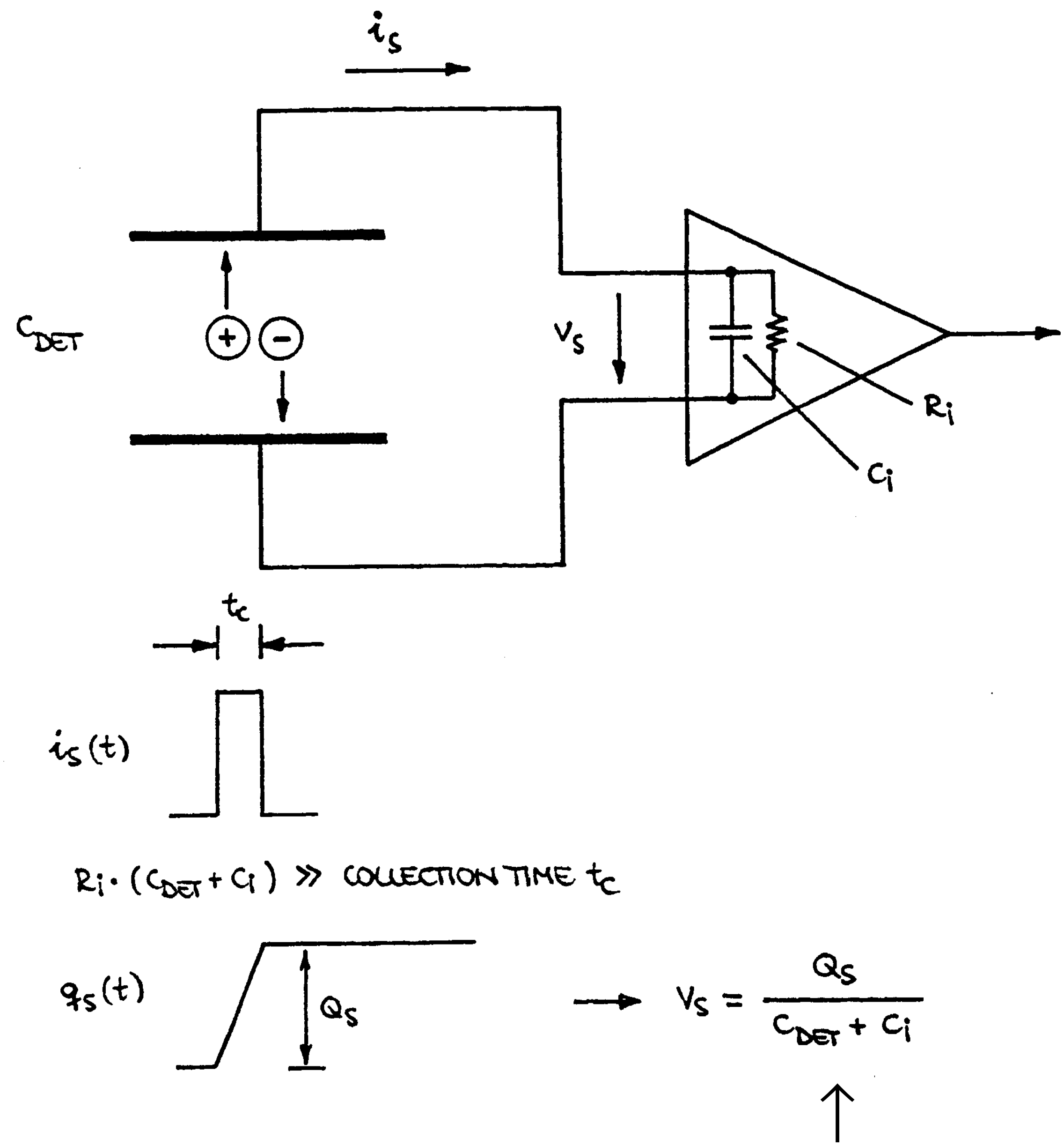
- Necessary to integrate the detector signal current.

Possibilities: 1. Integrate charge on input capacitance

2. Use integrating ("charge sensitive") preamplifier

3. Amplify current pulse and use integrating ("charge sensing") ADC

# Signal integration on Input Capacitance




System response depends
on detector capacitance !

Detector capacitance may vary within a system or change with bias voltage (partially depleted semiconductor diode).

⇒ make system whose gain ($dV_{out}/dQ_s$) is independent of detector capacitance.

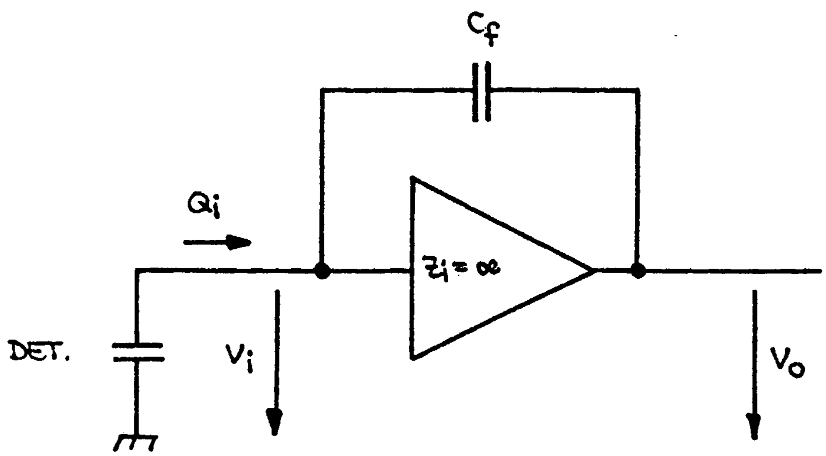
# Active Integrator ("charge-sensitive amplifier")

Start with inverting voltage amplifier

Voltage gain $dV_o/dV_i = -A \quad \Rightarrow \quad v_o = -A\, v_i$

Input impedance = ∞ (i.e. no signal current flows into amplifier input)

Connect feedback capacitor $C_f$ between output and input.




Voltage difference across $C_f$: $\quad v_f = (A+1)\, v_i$

⇒ Charge deposited on $C_f$: $\quad Q_f = C_f v_f = C_f (A+1)\, v_i$

$Q_i = Q_f$ (since $Z_i = \infty$)

⇒ Effective input capacitance

$$C_i = \frac{Q_i}{v_i} = C_f\,(A+1)$$

("dynamic" input capacitance)

**Gain**

$$A_Q = \frac{dV_o}{dQ_i} = \frac{A \cdot v_i}{C_i \cdot v_i} = \frac{A}{C_i} = \frac{A}{A+1} \cdot \frac{1}{C_f} \approx \frac{1}{C_f} \quad (A>>1)$$

$Q_i$ is the charge flowing into the preamplifier ....

but some charge remains on $C_{det}$.

What fraction of the signal charge is measured?

$$\frac{Q_i}{Q_s} = \frac{C_i v_i}{Q_{\det} + Q_i} = \frac{C_i}{Q_s} \cdot \frac{Q_s}{C_i + C_{\det}}$$

$$= \frac{1}{1 + \frac{C_{\det}}{C_i}} \approx 1 \quad (\text{if } C_i >> C_{\det})$$

Example:

A = $10^3$

$C_f$ = 1 pF ⇒ $C_i$ = 1 nF

$C_{det}$ = 10 pF: $Q_i / Q_s$ = 0.99

$C_{det}$ = 500 pF: $Q_i / Q_s$ = 0.67

↑

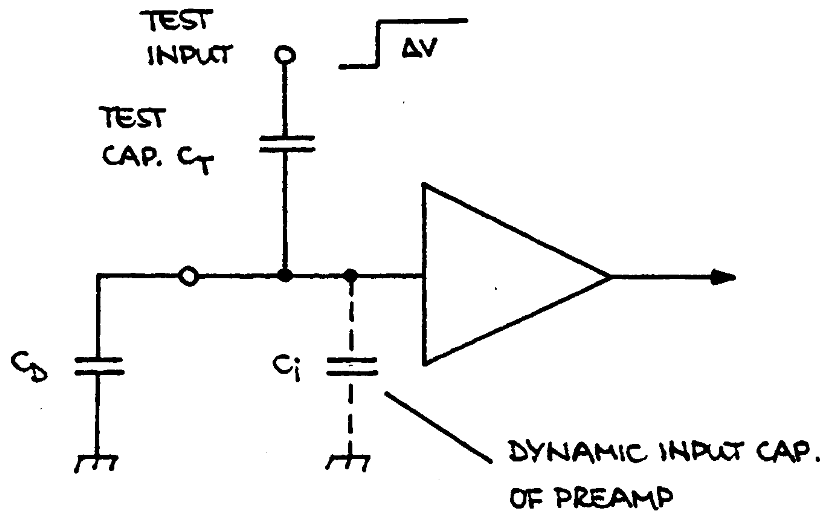
Si Det.: 50 µm thick
500 mm$^2$ area

Note: Input coupling capacitor must be >>$C_i$ for high charge transfer efficiency.

# Calibration

Inject specific quantity of charge  -  measure system response

Use voltage pulse (can be measured conveniently with oscilloscope)




$C_i >> C_T$ $\Rightarrow$ Voltage step applied to test input develops over $C_T$.

$\Rightarrow$ $Q_T = \Delta V \cdot C_T$

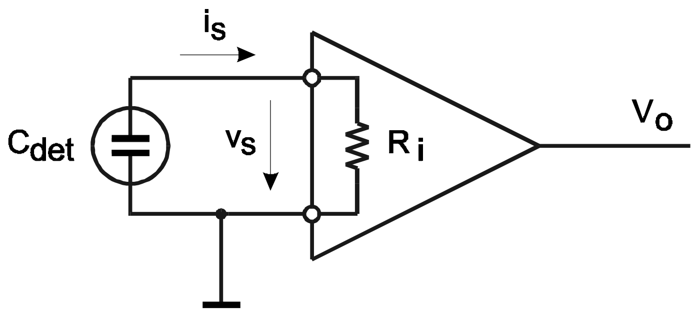
Accurate expression:

$$Q_T = \frac{C_T}{1+\frac{C_T}{C_i}} \cdot \Delta V \approx C_T \left(1 - \frac{C_T}{C_i}\right) \Delta V$$

Typically: $C_T / C_i = 10^{-3} – 10^{-4}$

# Summary of Amplifier Types

1. Simple Amplifiers




Output voltage $V_o$ = voltage gain $A_v \times$ input voltage $v_s$.

Operating mode depends on charge collection time $t_{coll}$ and the input time constant $R_iC_{det}$ :

a) $R_i C_{det} << t_{coll}$ detector capacitance discharges rapidly

$$\Rightarrow \quad V_o \propto i_s(t)$$

current sensitive amplifier

b) $R_i C_{det} >> t_{coll}$ detector capacitance discharges slowly

$$\Rightarrow \quad V_o \propto \int i_s(t)dt$$

voltage sensitive amplifier

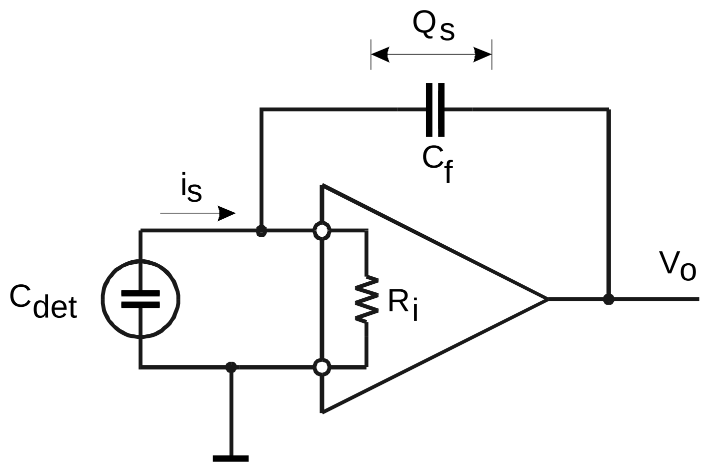
In both cases the ouput signal voltage is determined directly by the input voltage.

## 2. Feedback Amplifiers

Basic amplifier as used above.

High input resistance: $R_i C_{det} >> t_{coll}$

Add feedback capacitance $C_f$




Signal current $i_s$ is integrated on feedback capacitor $C_f$ :

$$V_o \propto Q_s / C_f$$

Amplifier output directly determined by signal charge,
insensitive to detector capacitance

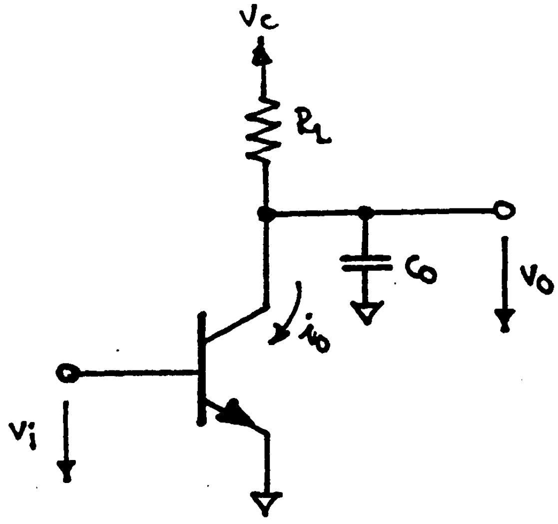
⇒ charge-sensitive amplifier

# Realistic Charge-Sensitive Preamplifiers

The preceding discussion assumed idealized amplifiers
with infinite speed.

- How do “real” amplifiers affect charge response?
- How does the detector affect amplifier response?

# A Simple Amplifier




Voltage gain:

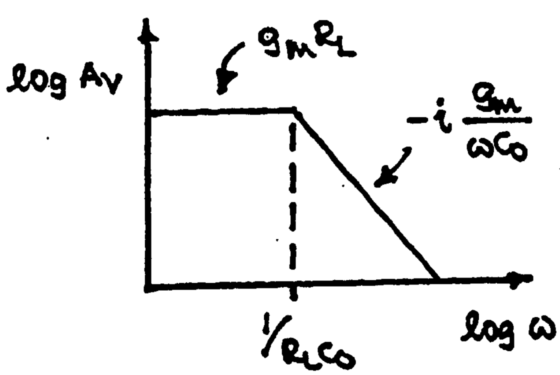
$$A_V = \frac{dv_o}{dv_i} = \frac{di_o}{dv_i} \cdot Z_L \equiv g_m Z_L$$

$g_m \equiv$ transconductance

$$Z_L = R_L \, / / \, C_o$$

$$\frac{1}{Z_L} = \frac{1}{R_L} + i\omega \, C_o \qquad \Rightarrow \qquad A_V = g_m \left( \frac{1}{R_L} \; + \; i\omega \, C_o \right)^{-1}$$

↑ low freq. ↑ high freq.



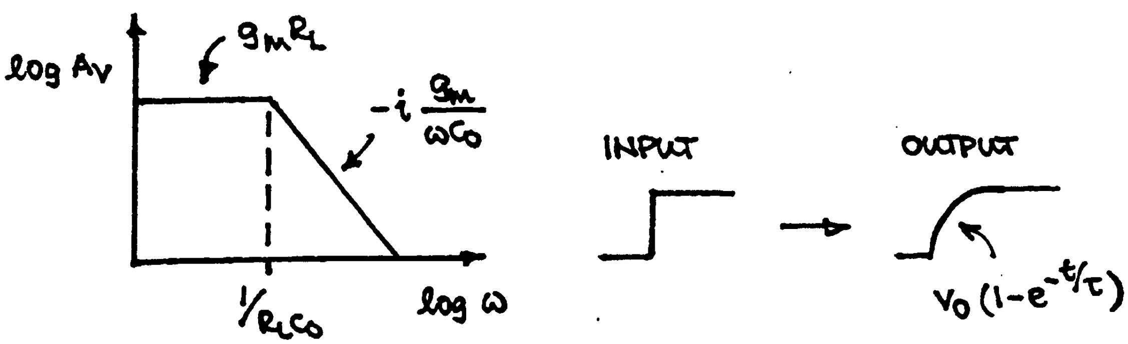

↑ upper cutoff frequency $2\pi \, f_u$

# Pulse Response of the Simple Amplifier

A voltage step $v_i(t)$ at the input causes a current step $i_o(t)$ at the output of the transistor.

For the output voltage to change, the stray capacitance $C_o$ must first charge up.

⇒ The output voltage changes with a time constant $\tau = R_L C_o$




Frequency Domain Time Domain

Note that $\tau$ is the inverse upper cutoff frequency $1/(2\pi f_u)$

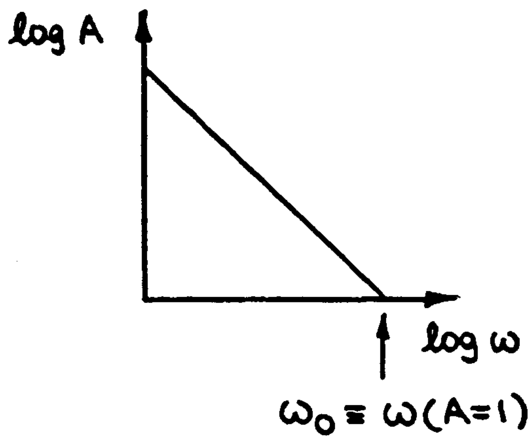
# Input Impedance of a Charge-Sensitive Amplifier

Input impedance

$$Z_i = \frac{Z_f}{A+1} \approx \frac{Z_f}{A} \quad (A >> 1)$$

Amplifier gain vs. frequency beyond the upper cutoff frequency

$$A = -i \frac{\omega_0}{\omega}$$




Gain-Bandwidth Product

Feedback Impedance

$$Z_f = -i \frac{1}{\omega C_f}$$

⇒ Input Impedance

$$Z_i = -\frac{i}{\omega C_f} \cdot \frac{1}{-i \frac{\omega_0}{\omega}}$$

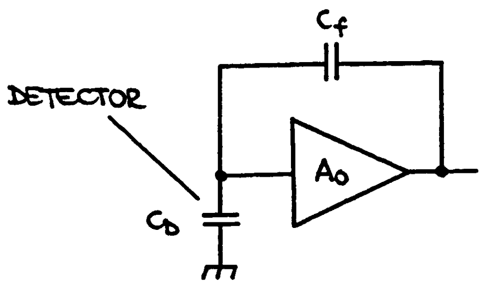
$$Z_i = \frac{1}{\omega_0 C_f}$$

*Imaginary component vanishes* ⇒ *Resistance:* $Z_i \rightarrow R_i$

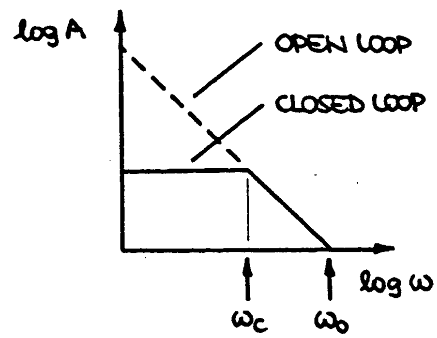
# Time Response of a Charge-Sensitive Amplifier

Closed Loop Gain

$$A_f = \frac{C_D + C_f}{C_f} \quad (A_f << A_0)$$




$$A_f \approx \frac{C_D}{C_f} \quad (C_D >> C_f)$$




Closed Loop Bandwidth

$$\omega_C A_f = \omega_0$$

Response Time

$$\tau_{amp} = \frac{1}{\omega_C} = C_D \; \frac{1}{\omega_0 C_f}$$

Alternative Picture:  Input Time Constant

$$\tau_i = R_i C_D$$

$$\tau_i = \frac{1}{\omega_0 C_f} \cdot C_D = \tau_{amp}$$

Same result as from conventional feedback theory.