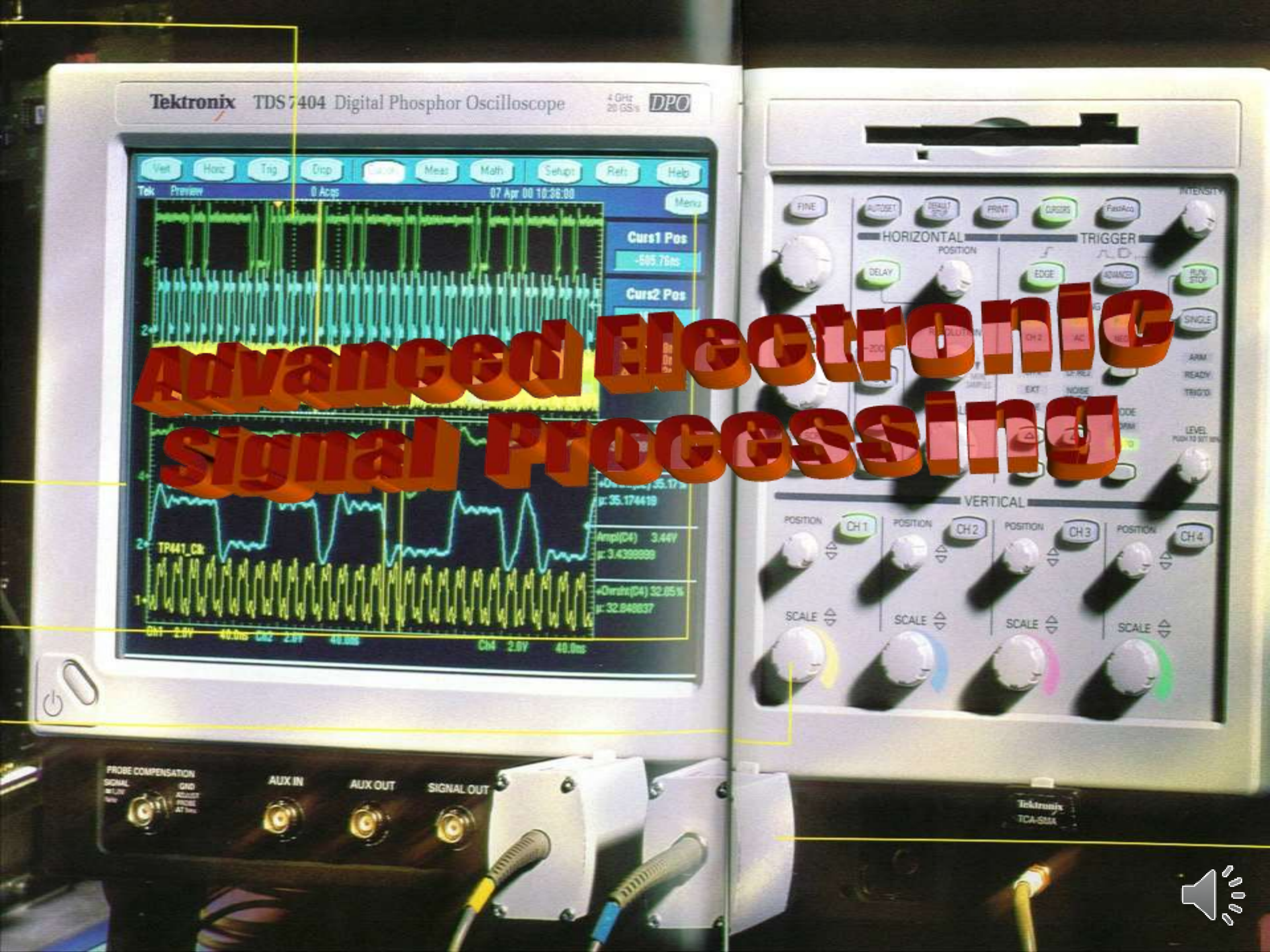
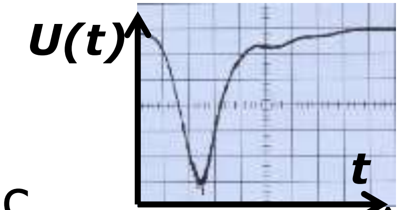
Advanced Electronic Signal Processing



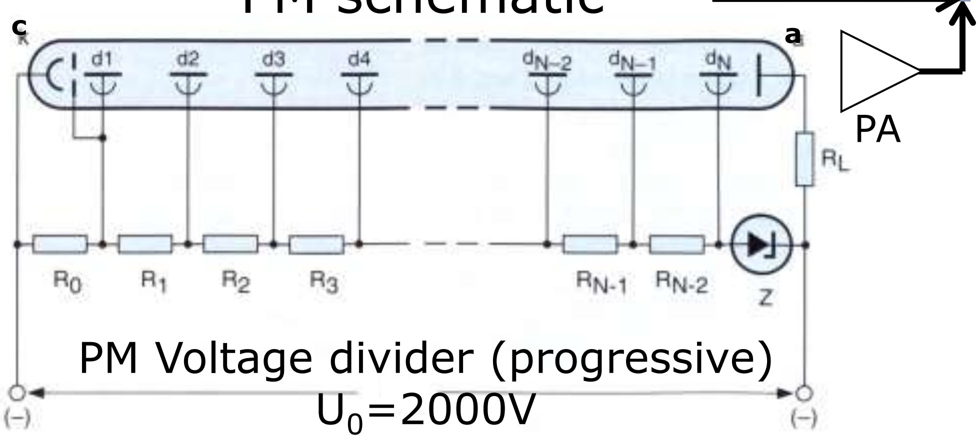
PM Operation

Fast PM: pulse rise time ~2ns, gain: $3{\cdot}10^7$

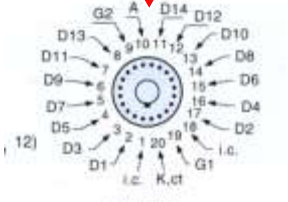
Philips XP2041
5″ dia cathode
14 dynodes
\+ focussing
electrodes



PM schematic

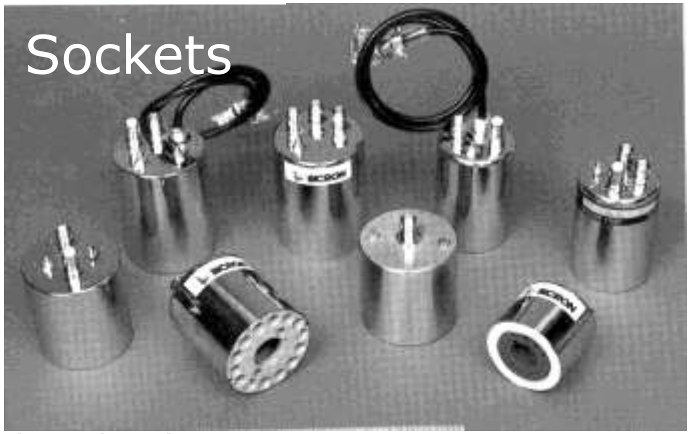


PM Voltage divider (progressive)
U_0=2000V

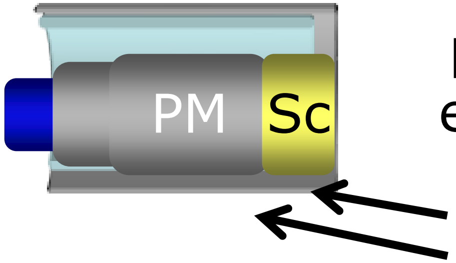


FE1120

Socket FE1120
pin connections



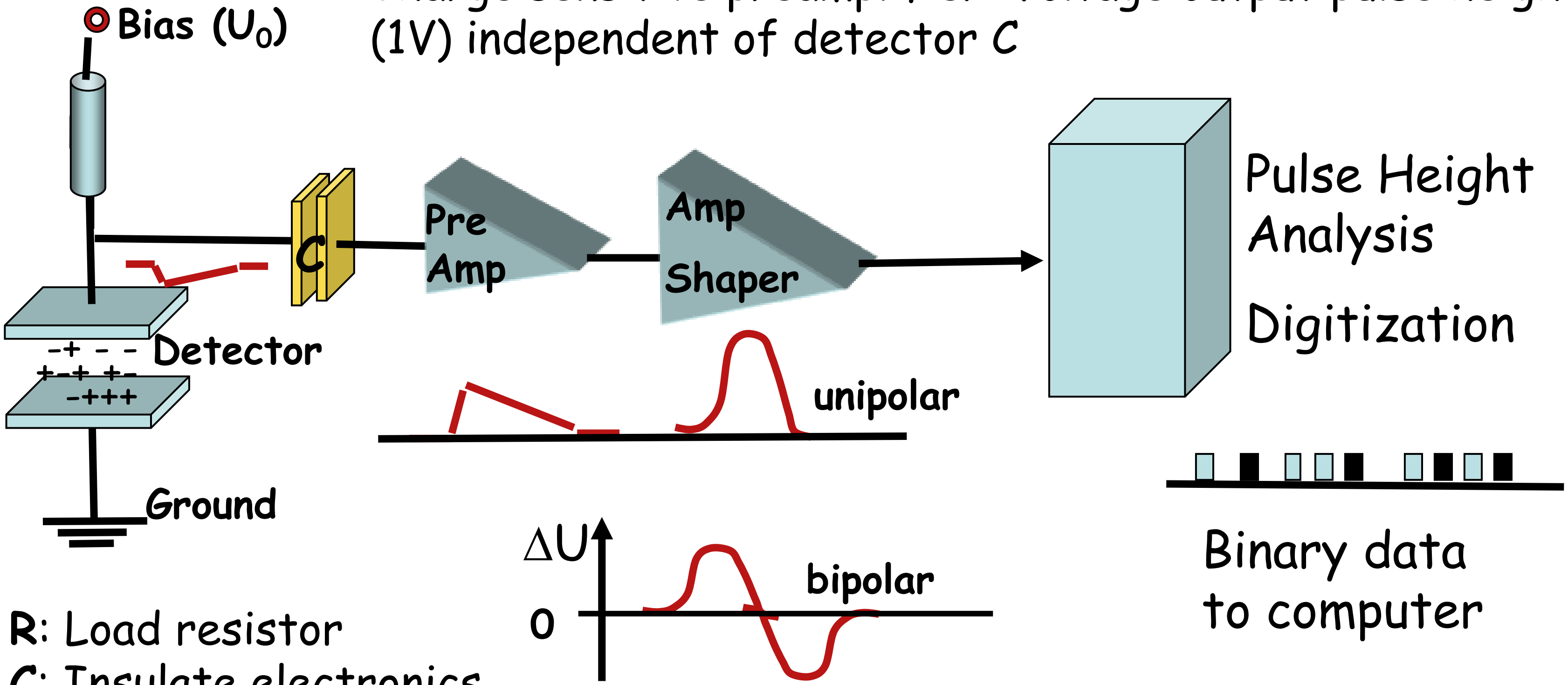
mu-metal shield
tube provides
protection from
external B field.



mu metal
soft iron

Basic Counting System

Charge sensitive preamplifier: Voltage output pulse height (1V) independent of detector C



R: Load resistor
C: Insulate electronics from high voltage (bias)
Pulse height 100 mV

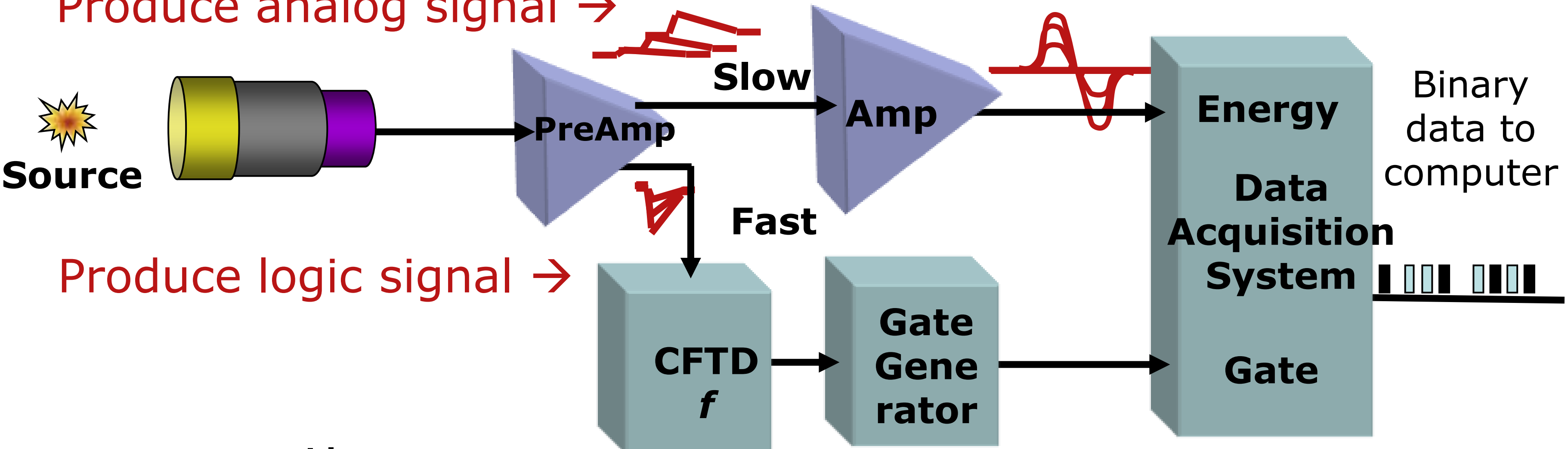
Amplifier/Shaper: differentiates (1x or 2x)

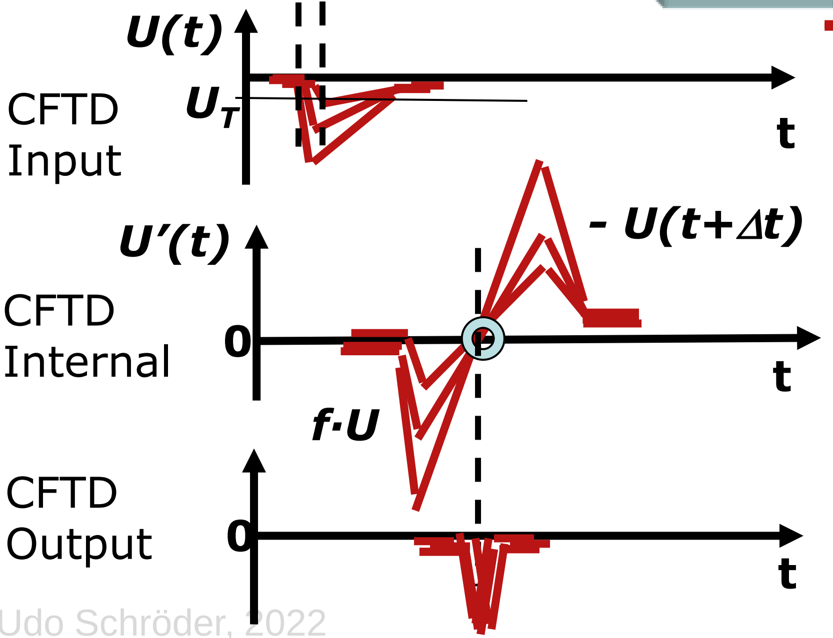
Final amplitude 2-10V

Fast-Slow Signal Processing

Produce analog signal →

Produce logic signal →





Constant-Fraction Timing Disc.:
Corrects for "***walk***" ***t*****(U)**

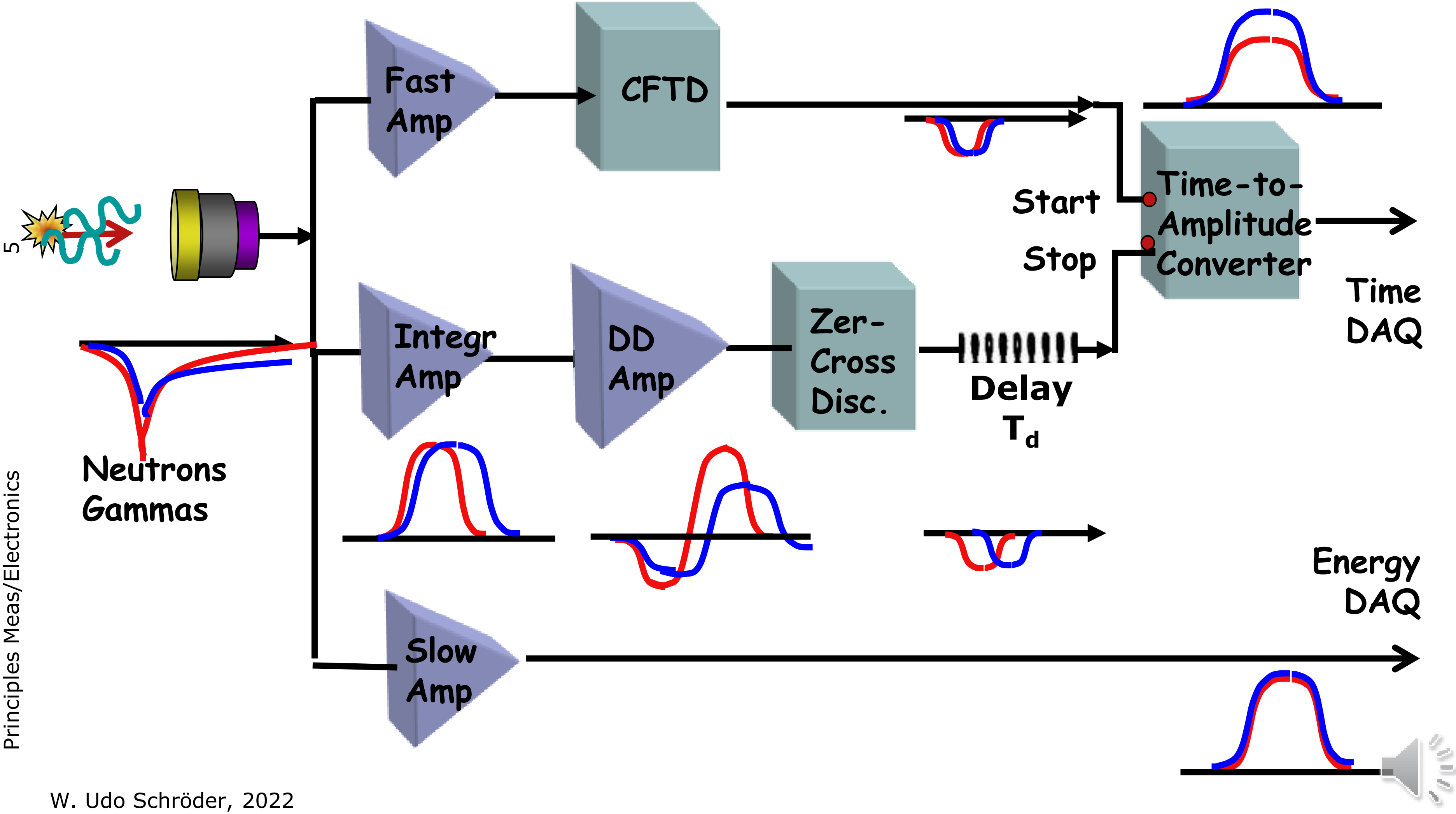
$$U'(t) = f \cdot U(t) - U(t+\Delta t)$$

→t (U′=0) independent of *U*
t(U′=0)-t(U=U$_T$) *measures* ***t$_R$*** *rise time*

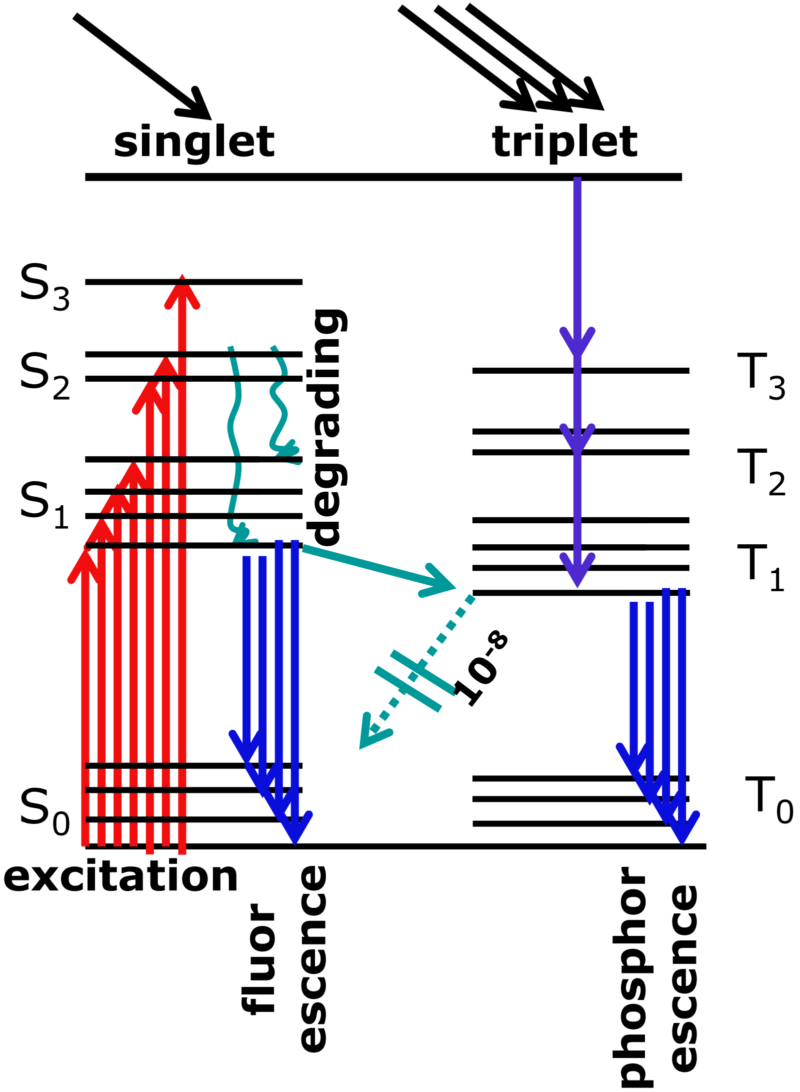
(here fraction *f* = 0.5)

Pulse Shape Analysis

Different signal decay times for 2 radiation types are translated into different amplitudes



Scintillation Mechanism: Organic Scintillators



Excitation of molecular states determined by π electrons: singlets (⍰⍰) and triplets (⍰⍰). Form vibrational band heads

Trapping of e- in triplet states, slow decay to S_0 ground state

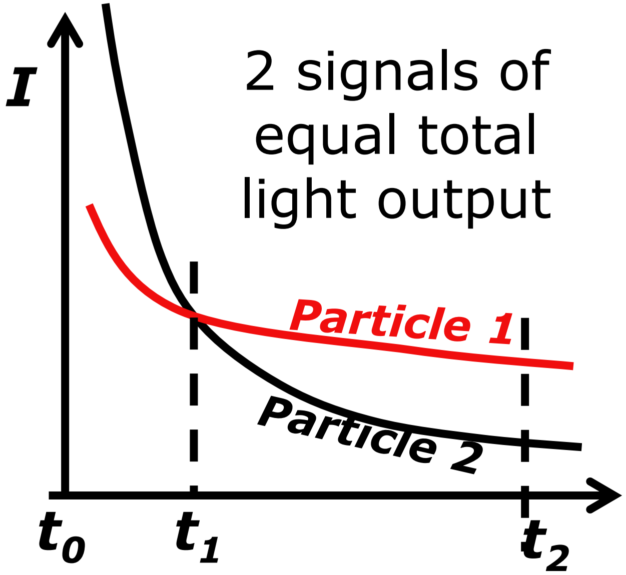
Triplet excited (3:1) via ion recombination.

Decay via collisions ***TT → SS+phonons*** (τ~ 300 ns)

E1 excitation/radiation less transitions depends on ionization density (A,Z,E).

Electromagnetic radiation and heavy particles have different excitation patterns, sequential fluorescence/phosphorescence → PSD discrimination.

Pulse Shape Analysis



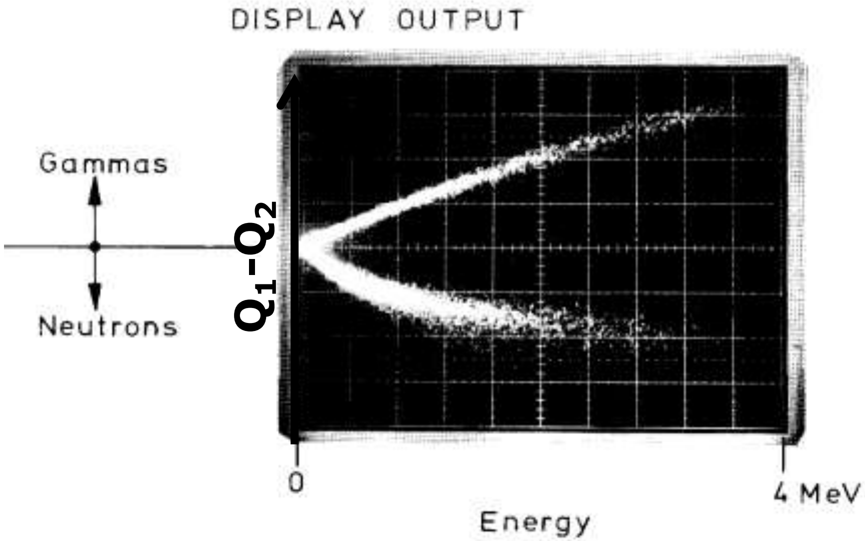
2 signals of equal total light output

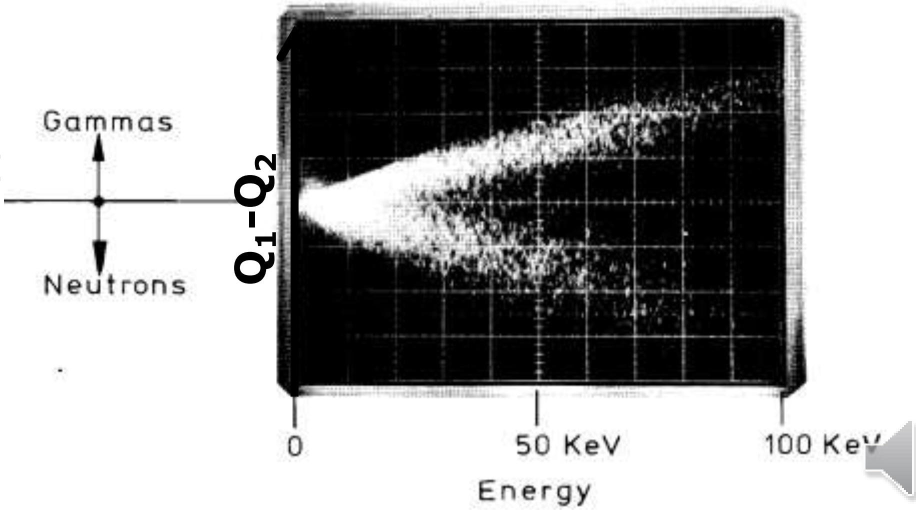
$$Q_1 = \int_{t_0}^{t_1} I(t)dt$$

$$Q_2 = \int_{t_1}^{t_2} I(t)dt$$

fast component slow

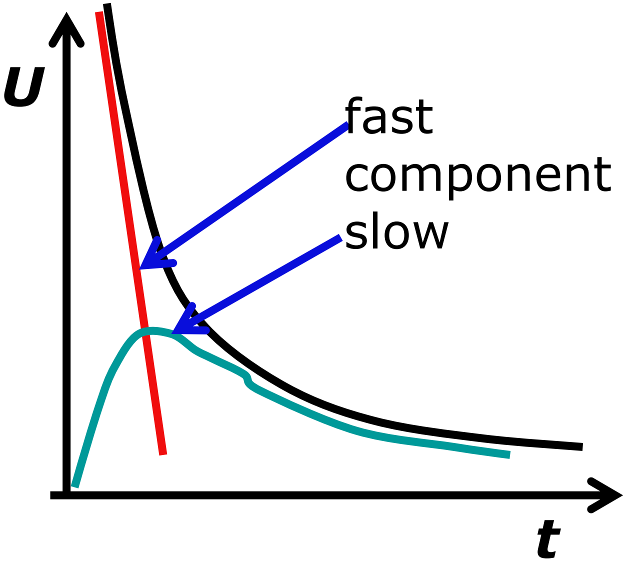
$$Q_1 + Q_2 = Q \propto L(Energy)$$

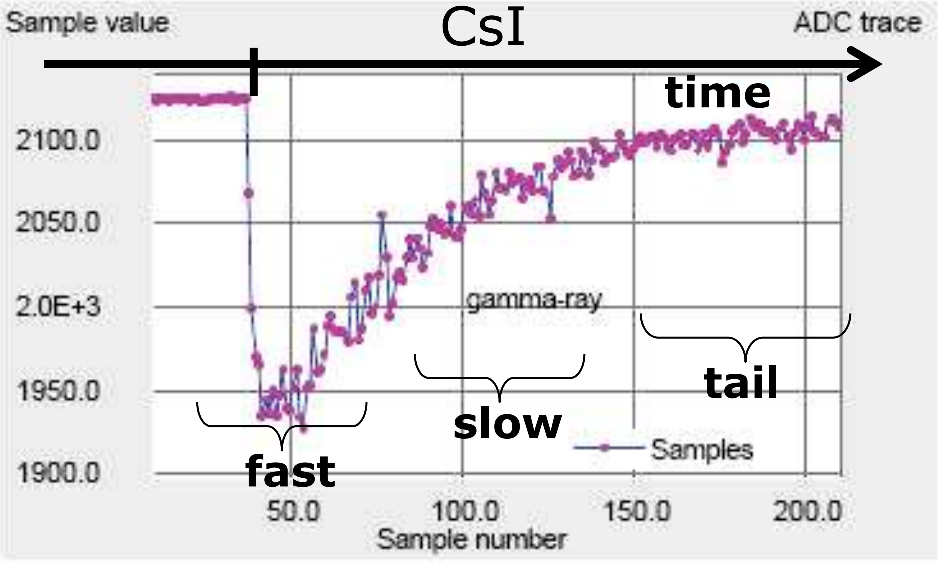




Radiation Specific Light Output Response

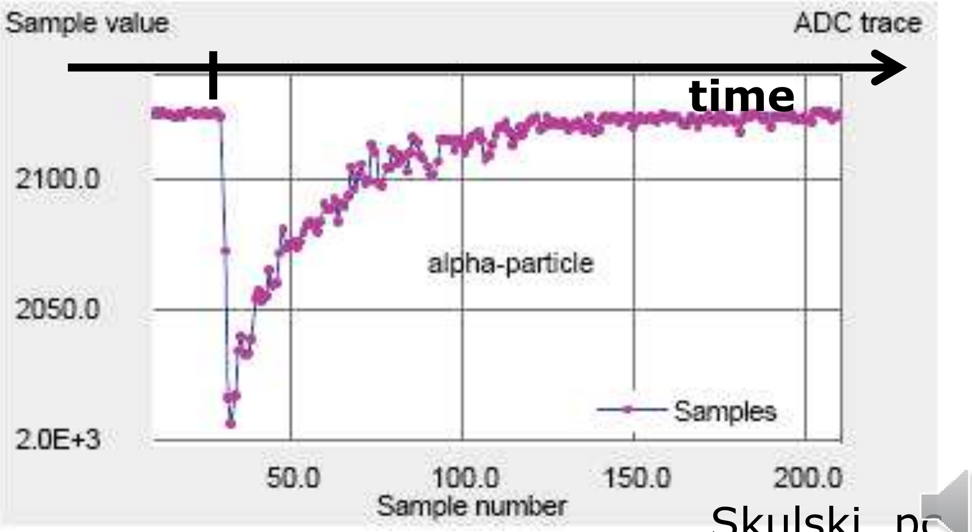
Similar to organic scintillators but not quite as distinct.





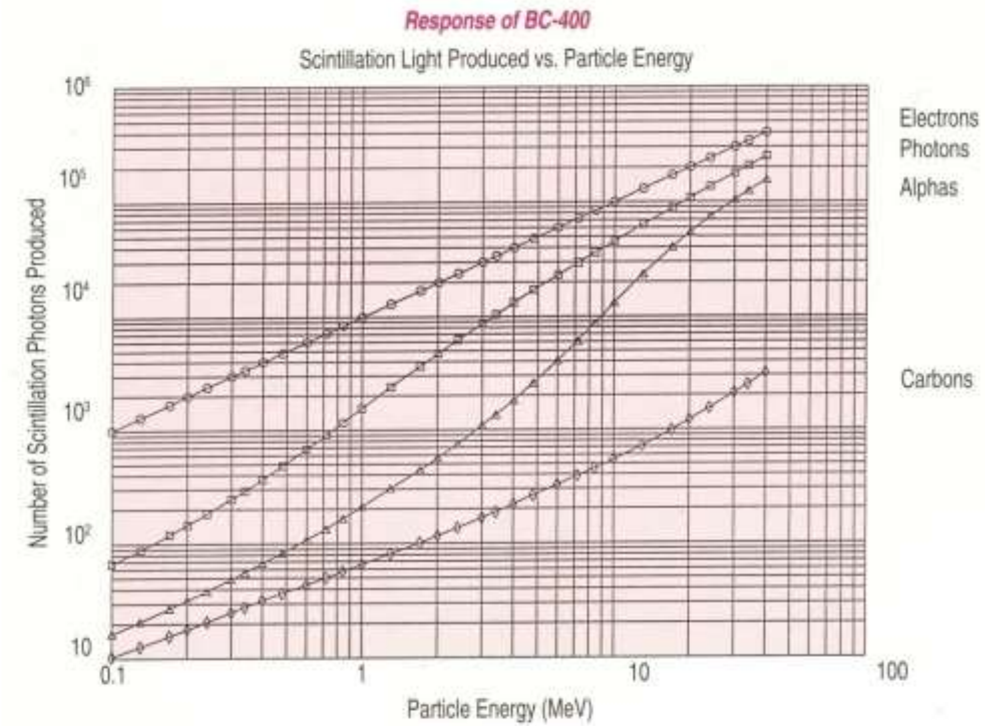
Different radiation leads to different mix of fast and slow → ID

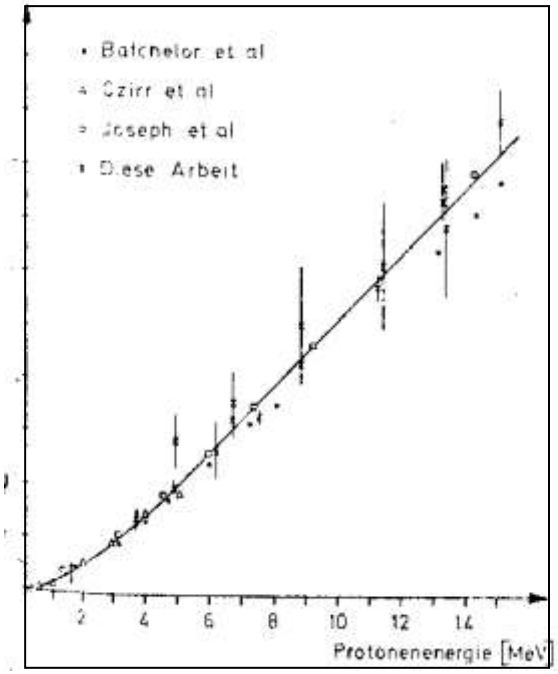
Pulse shape discrimination retained electronically →



Skulski, pc

Non-Linear Light Output Response





For a given energy, electrons (photons) have the highest light output.
Heavy particles leave weaker useful signals/energy. They are associated with ion recombination/quenching

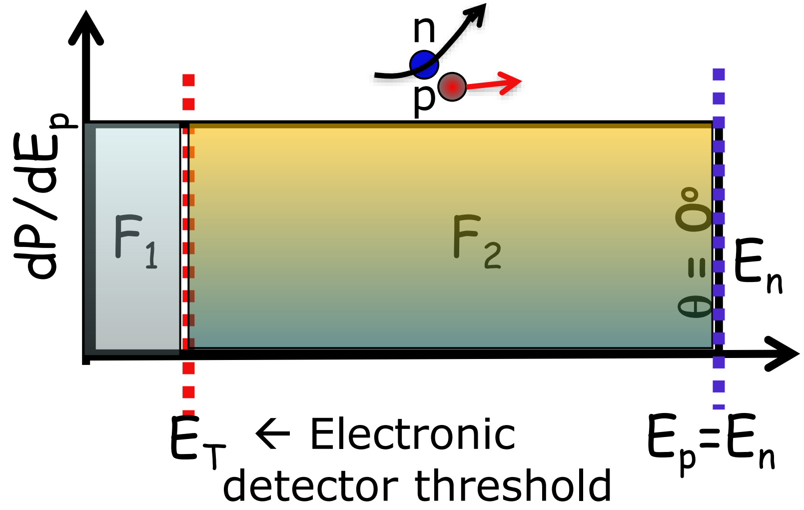
NE 213 liquid scintillator: electron-equivalent (ee) and proton recoil energies E_e ←→ E_p

$$E_e(E_p) = \begin{cases} \left(0.18 MeV^{-1/2}\right) E_p^{3/2} & E_p < 5.25 MeV \\ 0.63 E_p - 1.10 MeV & E_p \geq 5.25 MeV \end{cases}$$

Efficiency of *p*-Recoil NeutronDetectors

Angle dependent n-p energy transfer → continuous recoil energy spectrum.

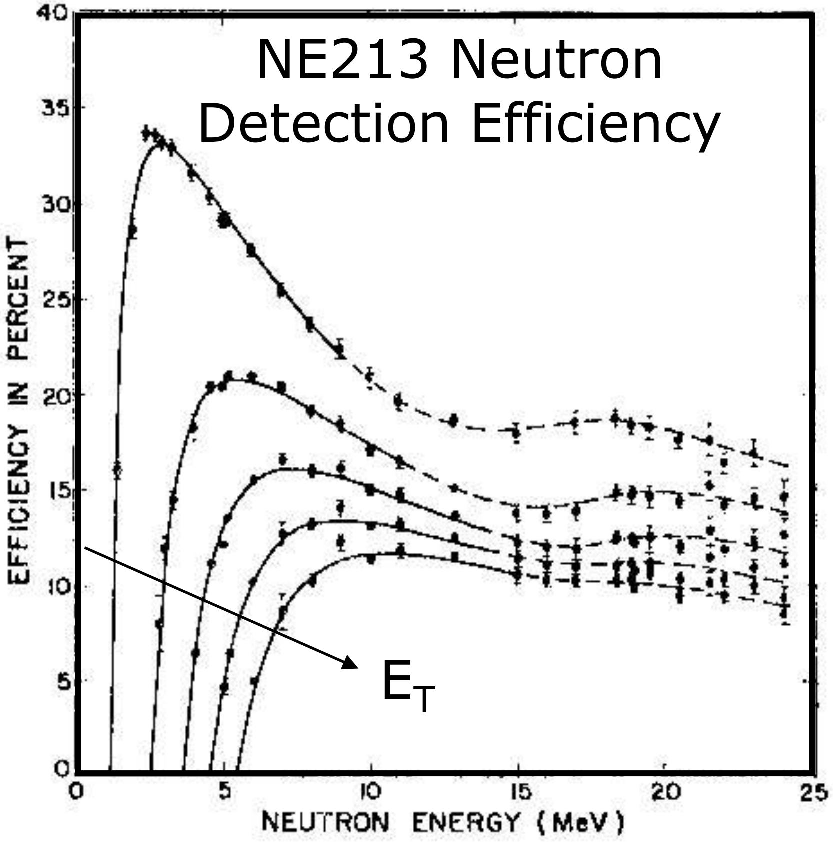
Idealized proton-recoil energy spectrum dP/dE_p:



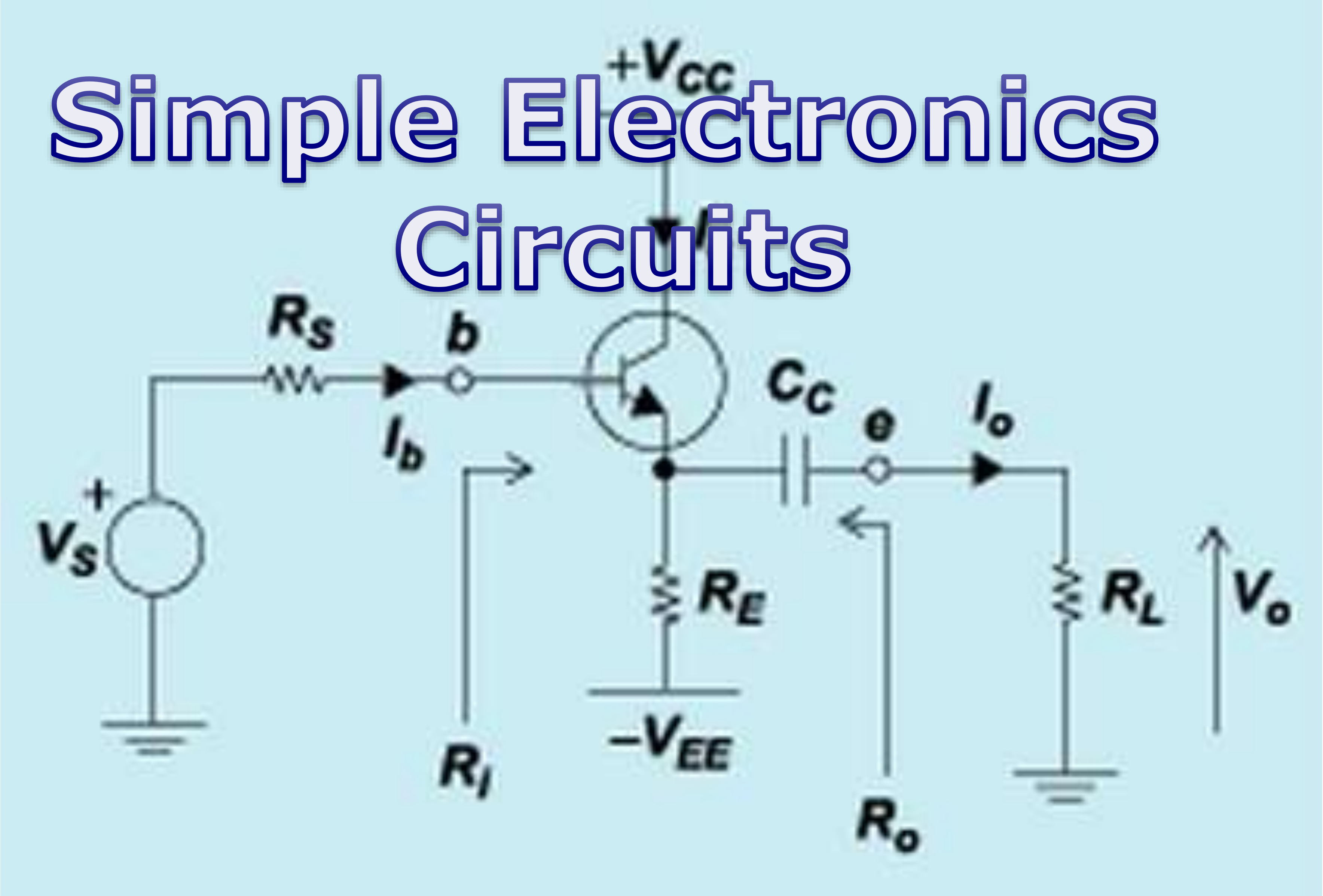
$$\varepsilon(E_n,E_T)=\frac{F_2}{F_1+F_2}$$

$$\approx\sigma(E_n)\left[1-\frac{E_T}{E_n}\right]$$

$$\sigma(E_n)=\sum_{X,y}\sigma_{X(n,y)}(E_n)\ \ all\ \ n-induced$$

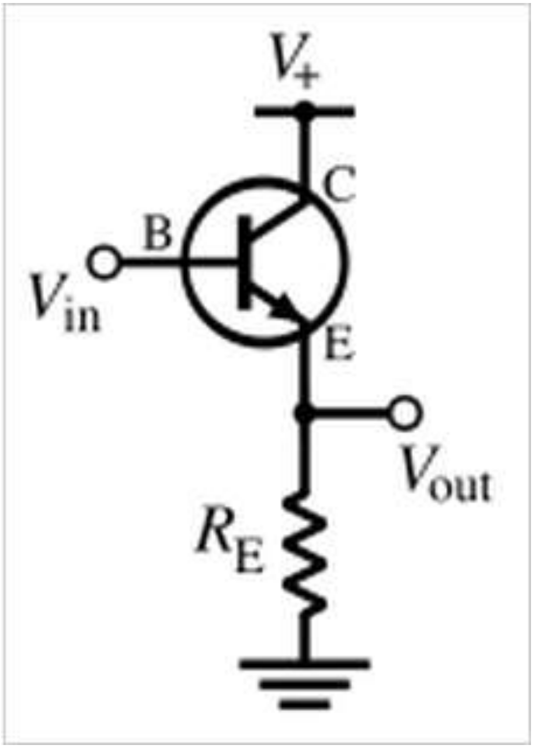

NE213 Neutron Detection Efficiency

Simple Electronics Circuits

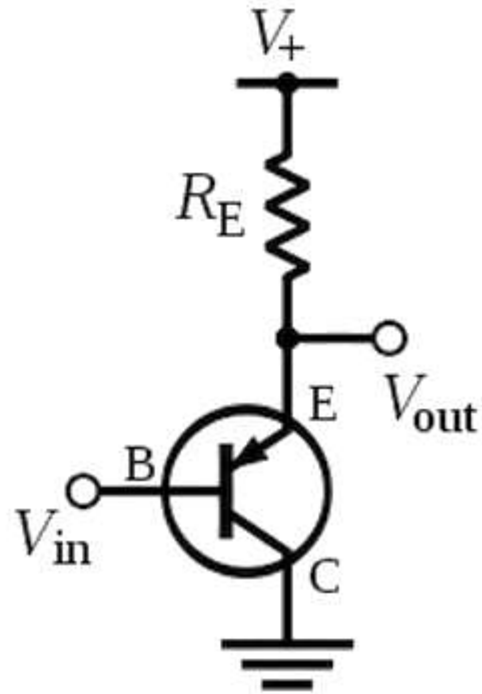


Transistor Amplifier (Emitter Follower)

Control
of water
current



npn transistor



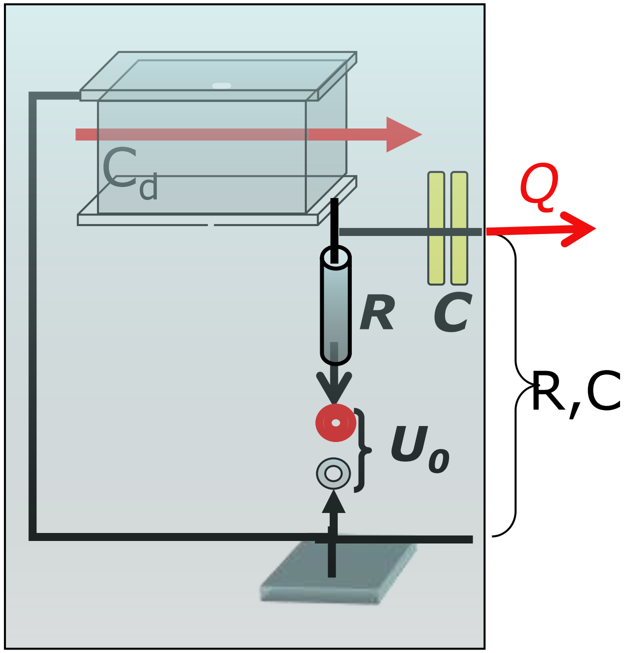
pnp transistor

Voltage gain: $A_v = \frac{v_{out}}{v_{in}} \approx 1$ current gain » 1

Pre-Amplifiers

Task: amplify weak detector signals (mV) to ~ 1V, transmit through cable.
Main types: **charge-sensitive** or **voltage-sensitive**

Charge sensitive preamps integrate charge $\boldsymbol{Q(t) \sim E_{deposit}}$ from detector directly. Use for semiconductor diodes.
Voltage sensitive preamps amplify $U(t) = Q(t)/C$, $C = const.!$ → *PM, PC*

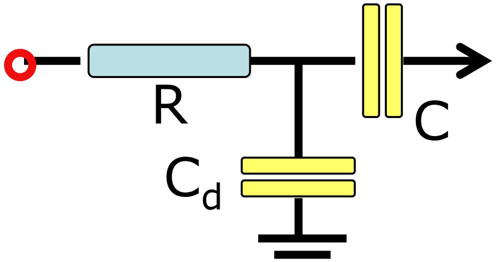


Detector is essentially a capacitor C_d, delivers a time dependent **charge *Q(t)*** and **current *I=dQ/dt***

For ***E*** measurement, integrate *Q*

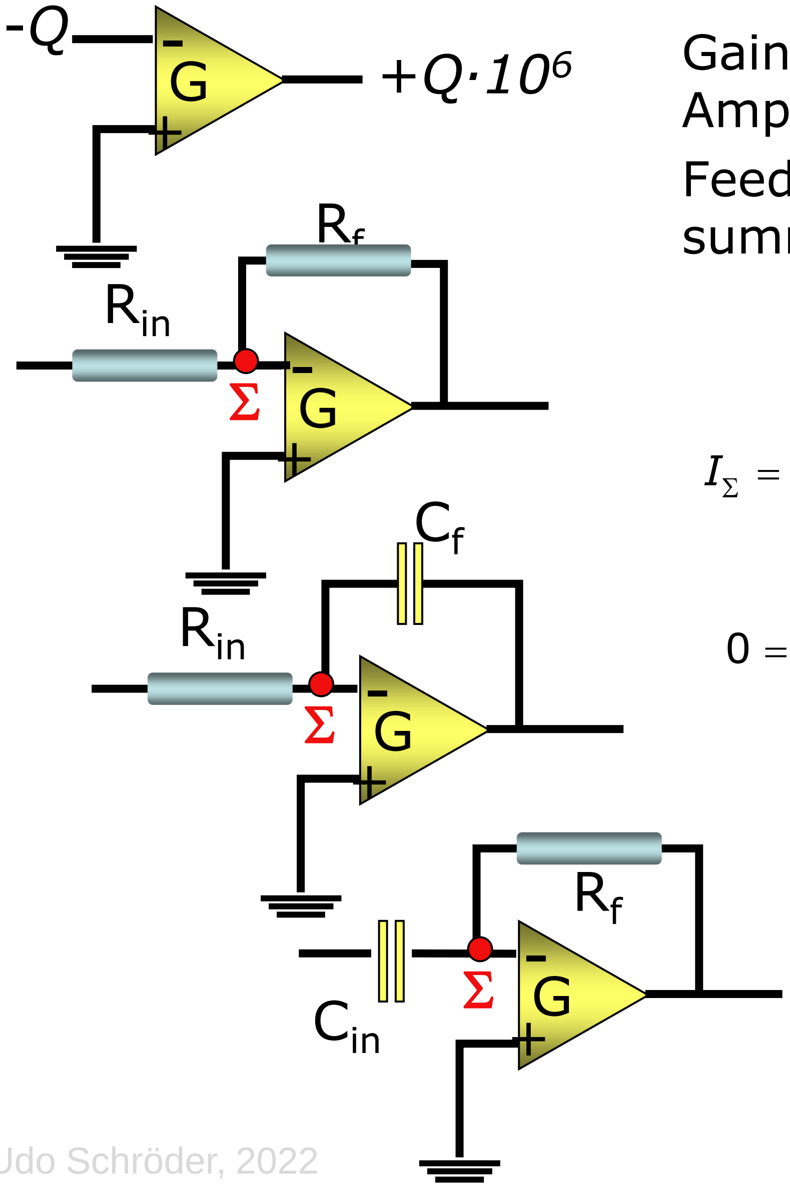
For ***t*** measurement, differentiate *Q*

*Use **operational amplifiers** (op-amp) for either and many other tasks.*



Replacement circuit for detector and decoupling

Operational Amplifiers



Gain is very high (~10⁶), inverting.
Amp properties determined by feedback c

Feeding back negative input signal to the summation point cancels the signal at Σ

$$I_\Sigma = 0 = I_{in} + I_f = \frac{U_{in}}{R_{in}} + \frac{U_{out}}{R_f} \rightarrow \boxed{U_{out} = -\frac{R_f}{R_{in}} \cdot U_{in}}$$

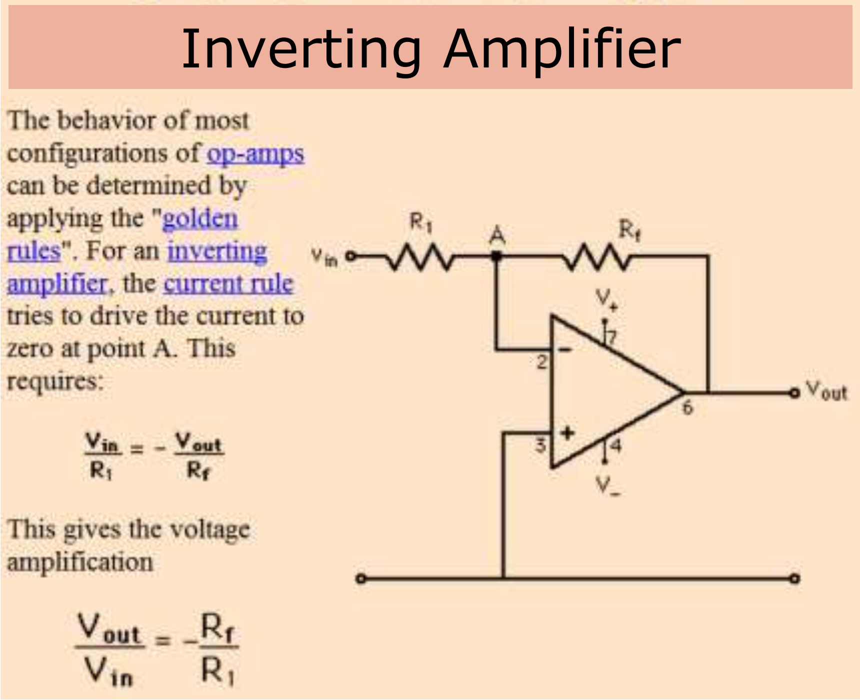
$$0 = I_{in} + I_f = \frac{U_{in}}{R_{in}} + C_f \frac{dU_{out}}{dt} \rightarrow \boxed{U_{out} = -\frac{1}{R_{in}C_f} \cdot \int U_{in} dt}$$

Integrator

$$\boxed{U_{out} = -C_{in} R_f \frac{dU_{in}}{dt}}$$

Differentiator

Amplifiers



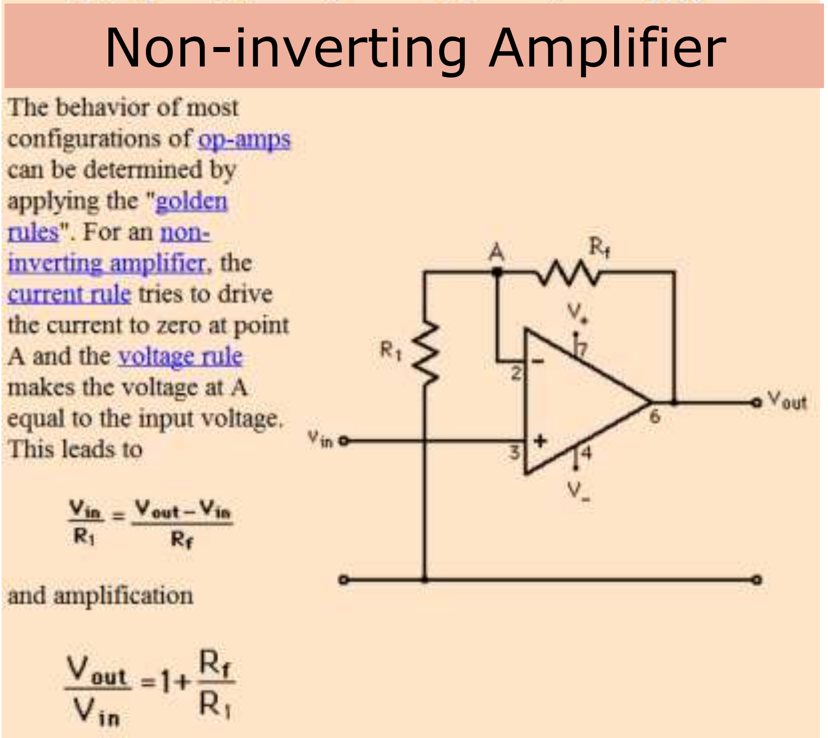
Inverting Amplifier

The behavior of most configurations of op-amps can be determined by applying the "golden rules". For an inverting amplifier, the current rule tries to drive the current to zero at point A. This requires:

$$\frac{V_{in}}{R_1} = -\frac{V_{out}}{R_f}$$

This gives the voltage amplification

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}$$



Non-inverting Amplifier

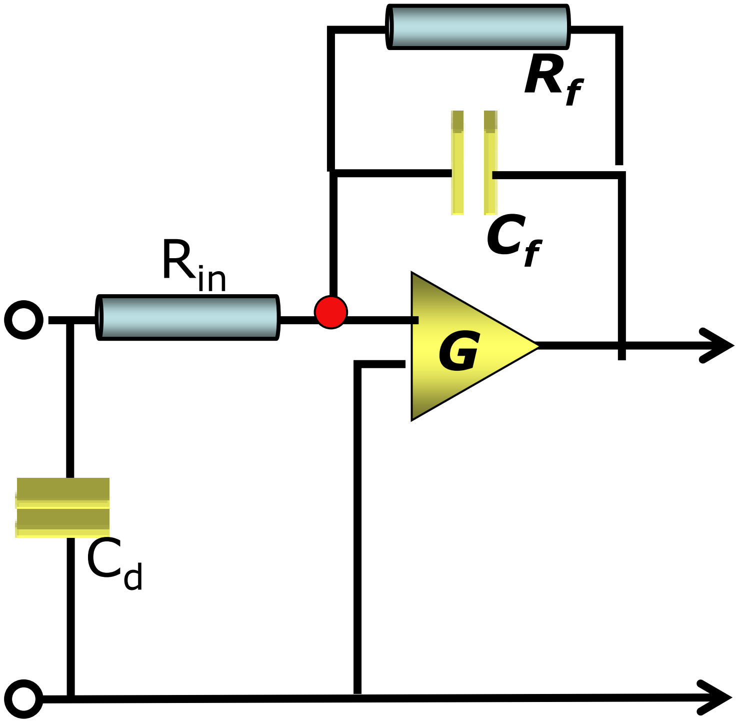
The behavior of most configurations of op-amps can be determined by applying the "golden rules". For an non-inverting amplifier, the current rule tries to drive the current to zero at point A and the voltage rule makes the voltage at A equal to the input voltage. This leads to

$$\frac{V_{in}}{R_1} = \frac{V_{out} - V_{in}}{R_f}$$

and amplification

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$$

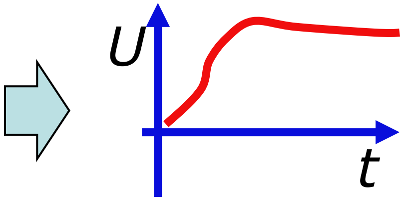
Charge Sensitive Preamp



Inverting, integrating preamp

Pulse decay governed by $t_{dec} \approx 1/R_f C_f$.

Additional amplifier necessary for pulse shaping and gain.

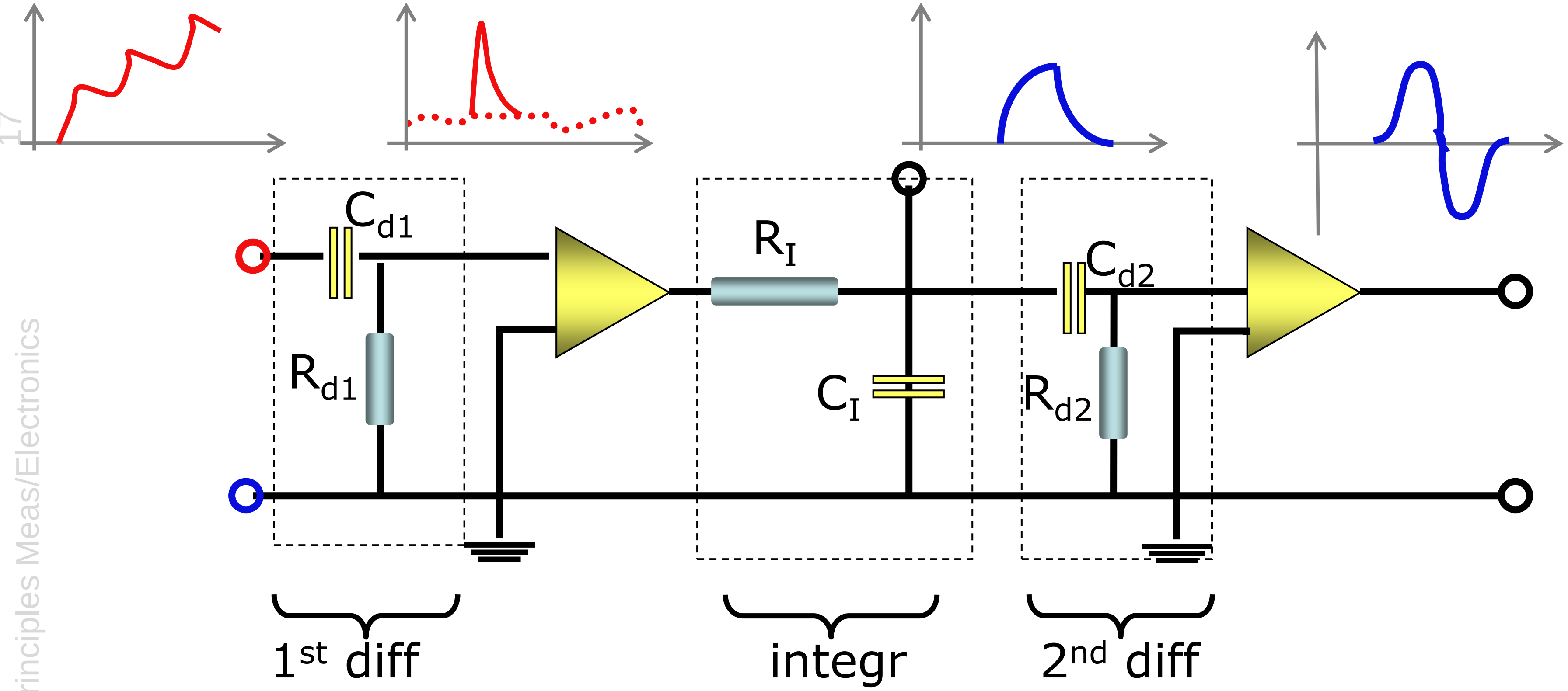


Main/Shaping Amplifiers

Tasks: 1) Linear amplification to pulse heights of U ≈(1-10)V

2) Improvement of signal/noise ratio (integration)

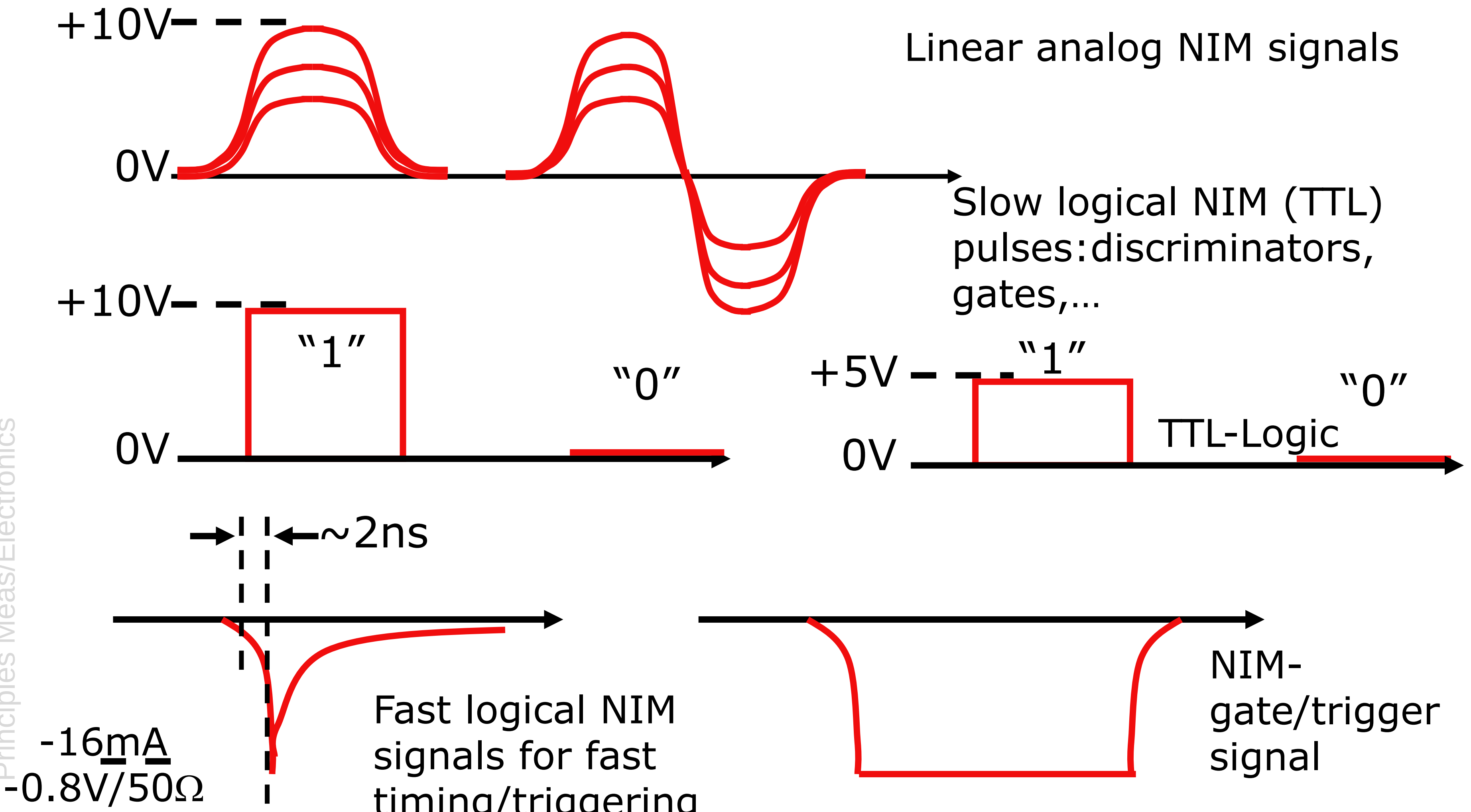
3) Pulse shaping (Gaussian shape is best)



More versatility: RC-circuits → active filters

NIM Signal Standards

(National Instruments Methods)



Linear analog NIM signals

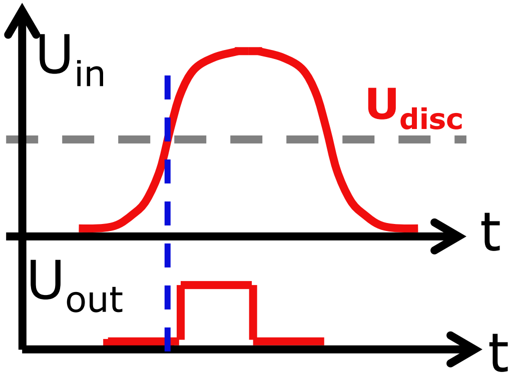
Slow logical NIM (TTL) pulses:discriminators, gates,...

TTL-Logic

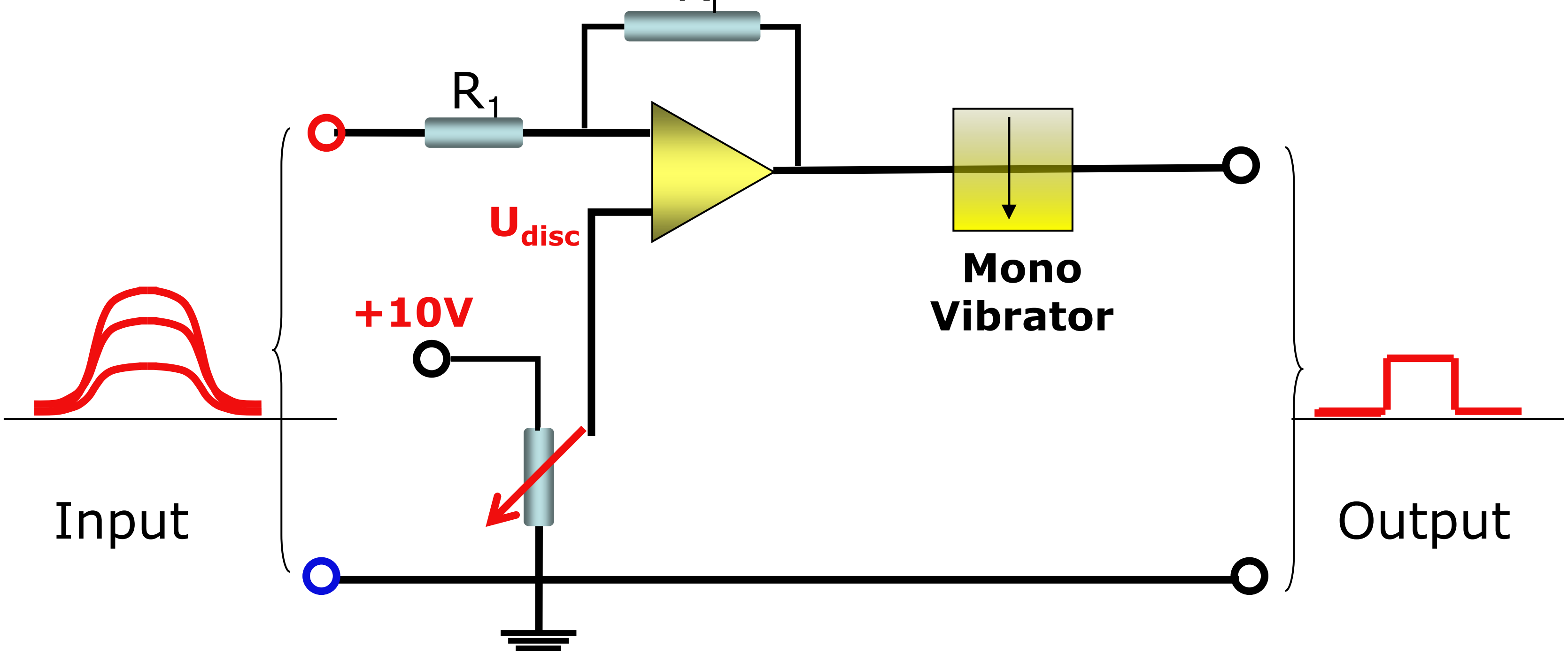
Fast logical NIM signals for fast timing/triggering

NIM-gate/trigger signal

Discriminator/Trigger

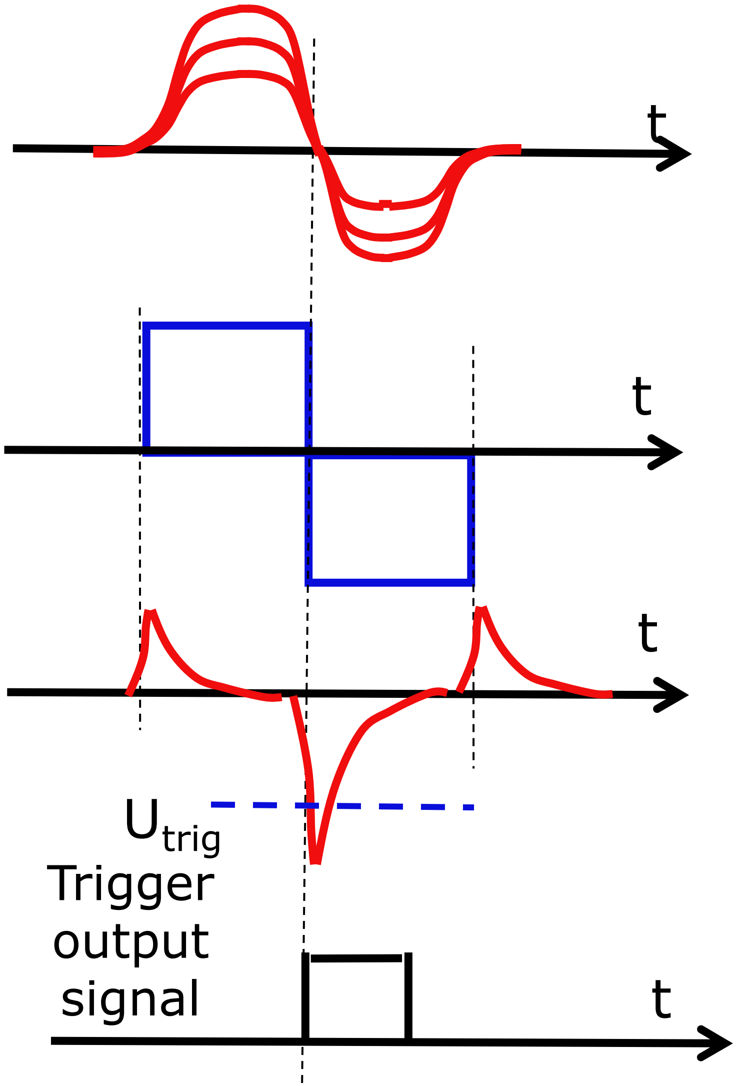


Task: Produce a logical signal, whenever analog signal exceeds threshold U_{disc}. Use for logical decisions (open acquisition,…). Exists for slow and fast pulses.



For fast timing, use negative NIM logic units

Zero-Crossing Triggering



Produce fast, bipolar linear pulse. Possible: different gains for positive and negative parts → zero crossing at different time (fraction of time to maximum)

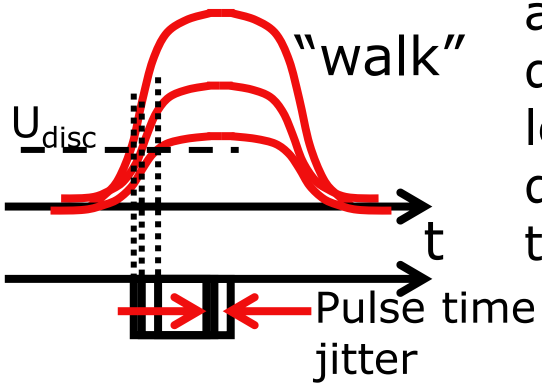
Produce "saturated" uniform pulse

Differentiate saturated pulse, use triplet pulse as input for trigger (negative pulse polarity).

Trigger output appears at zero crossing

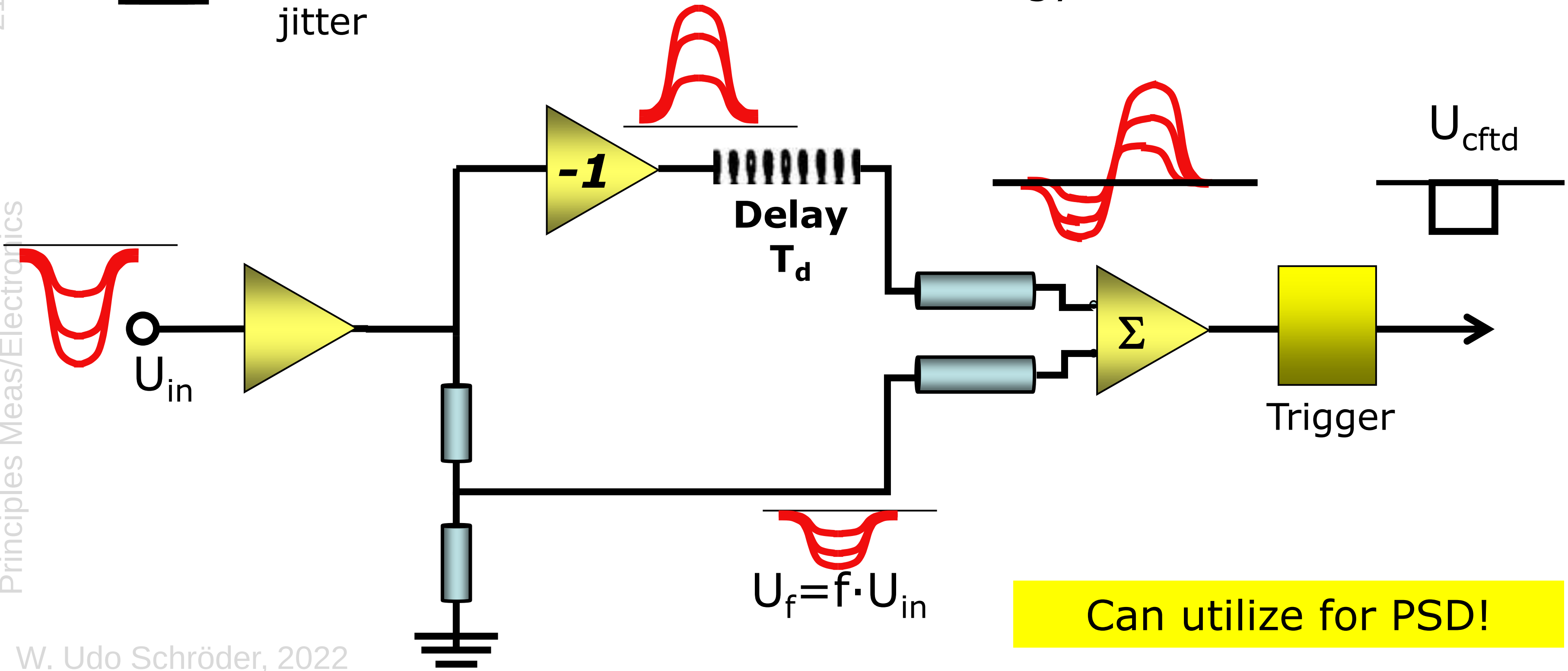
(Internal delays neglected)

Constant-Fraction Discriminator



amplitude dependent leading edge discr. output timing

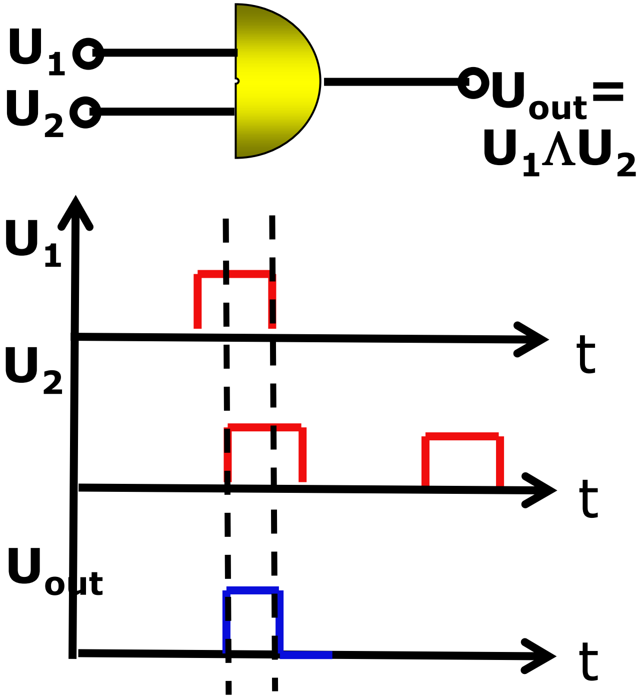
Zero crossing timing always at same physical time, independent of pulse amplitude for fixed pulse shape: no "walk" with energy



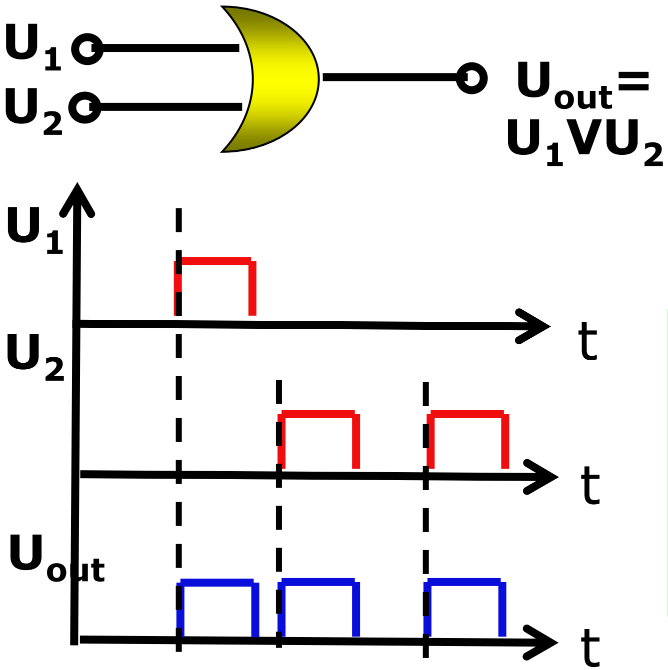
Can utilize for PSD!

Logic Modules

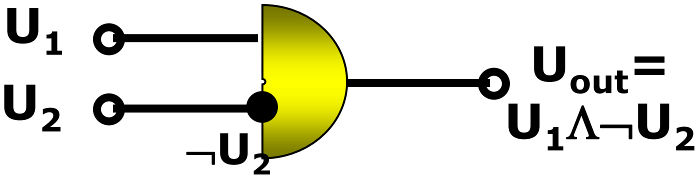
Overlap Coincidence



Or (inclusive)



For fast timing: use fast negative logic



Anti-Coincidence

Signal Transmission

Coaxial cables/transmission lines ←→ traveling waves in cavity resonators

Wave equation (R=0):

$$\boxed{\frac{\partial^2 U}{\partial z^2} = L \cdot C \cdot \frac{\partial^2 U}{\partial t^2}}$$

L: inductivity/length
C: capacity/length
depend on diameter and dielectric

signal propagation speed (speed of light):

$$c = 1/\sqrt{LC}$$

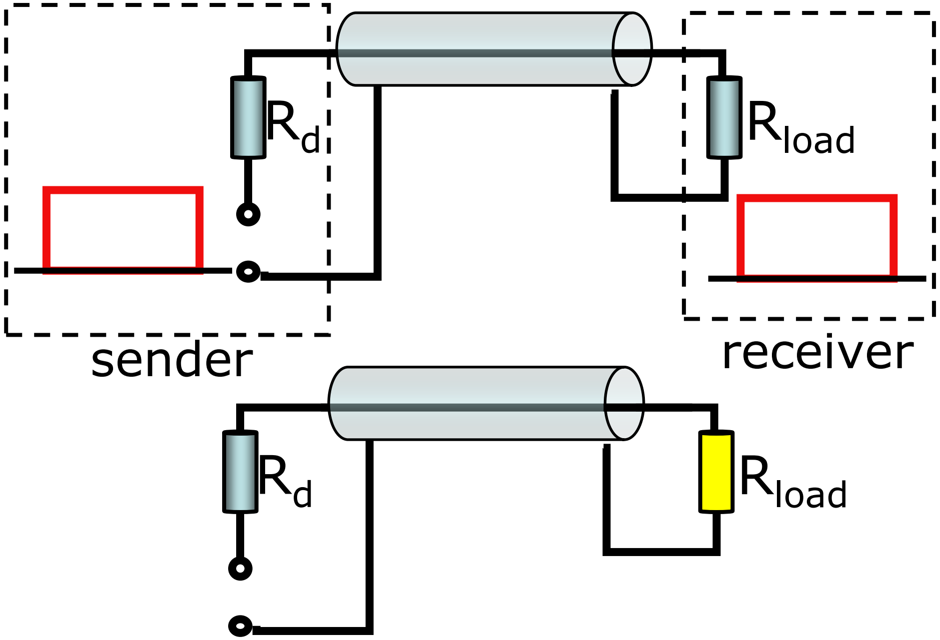
typically c^{-1}=5 ns/m

characteristic resistance
Z_0=Ohmic resistance!
For R≠0, $Z_0(\omega)$ complex

$$Z_0 = \sqrt{L/C}$$

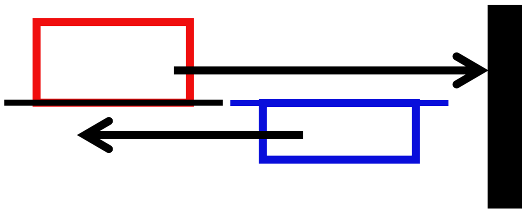
Z_0 = 50 Ω or 93 Ω used for timing, spectroscopy, resp.

Impedance Matching



For impedance matching, $R_{load}=Z_0$, cable looks infinitely long: no reflections from end.

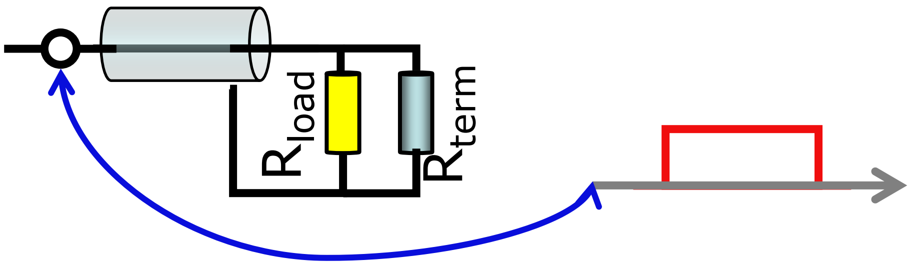
For mismatch, $R_{load} \neq Z_0$, reflection at end, traveling back, superimpose on signal



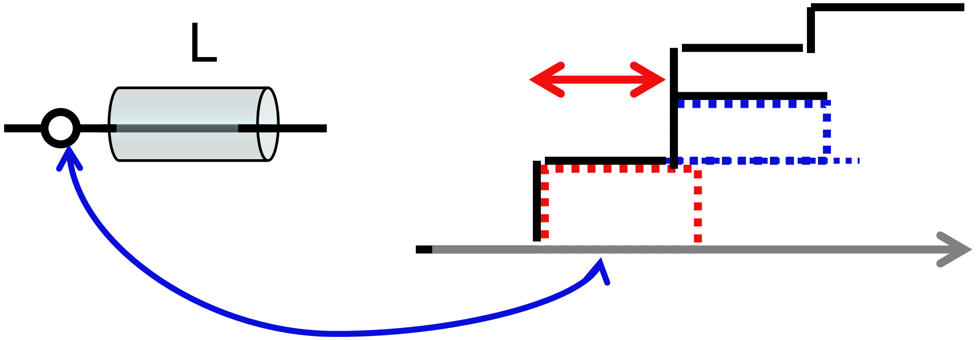
$$\frac{U_{refl}}{U_{in}} = \frac{R_{load} - Z_0}{R_{load} + Z_0}$$

Polarity of reflected signal $R_{load}=0, \infty$

Cable Reflections

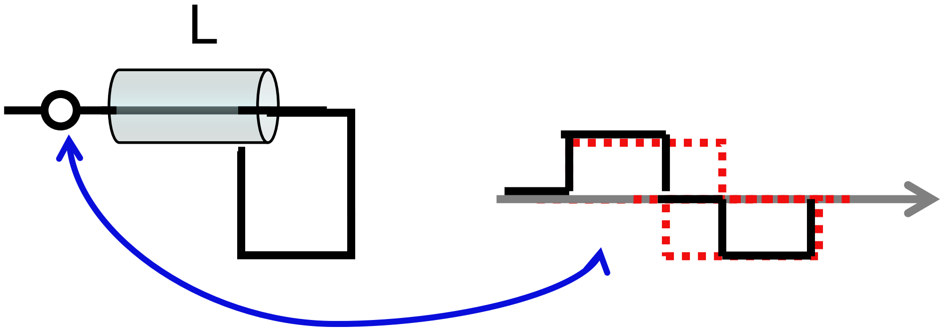


Receiver input impedance $R_{load} \neq Z_0$, → use additional Ohmic termination in parallel



Open end: $R_{load} = \infty$ Input and reflection equal polarity, overlap for t > $2T_{cable}$

$T_{cable} = 2L/c$



Short: $R_{load}=0$, Input and reflection opposite polarity, superposition = bipolar

Multiple (n) reflections attenuated by R^{-n}

The End