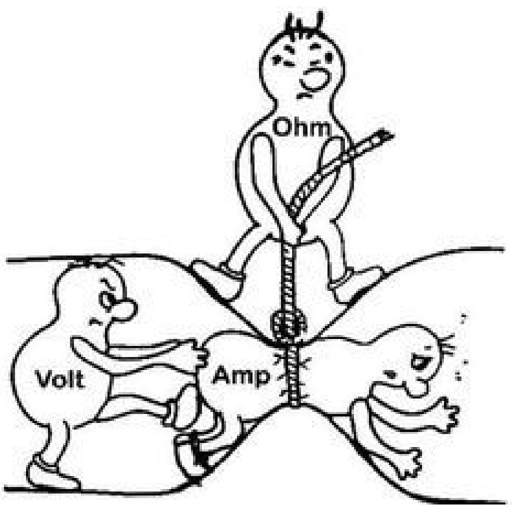
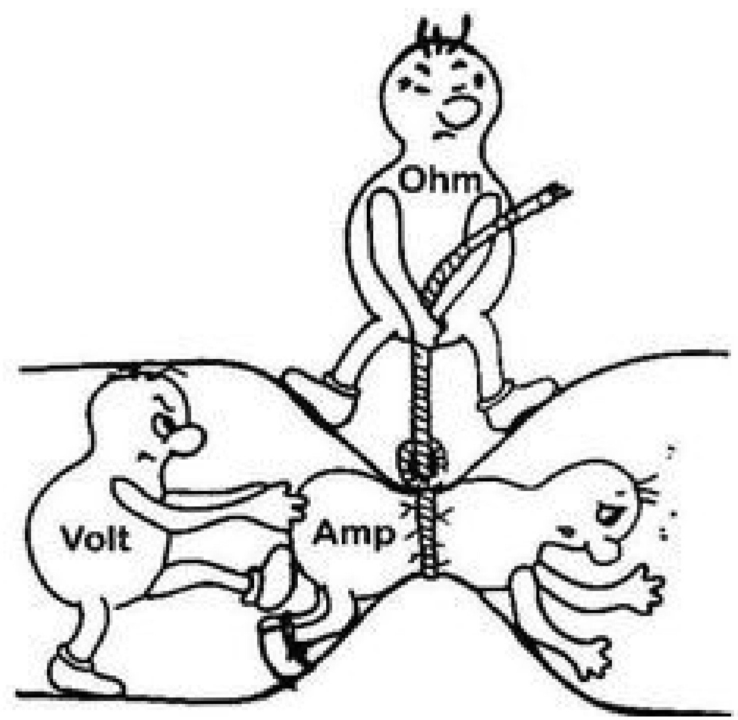
ELECTRONICS

Lecture 6



Electronics: a bit of history



A leap forward: the Manhattan Project

Los Alamos, 1943-1945

ELECTRONICS

Experimental Techniques

by

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and

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Gen. L. Groves describes the Manhattan Project as "a generation of scientific development compressed into three years"; this is surely the case for the advancement in electronics and instrumentation.

Belgian flavor

Figure 12. The Nobel Price Laureates 1957 in Physics for the invention of the transistor. From left to right William Shockley, John Bardeen and Walter Brattain

In Belgium Bell Telephone (Hoboken-Antwerp) had a nuclear division producing advanced transistorised modular instrumentation (NUK-modules) in the early ‘60s.

Nuclear electronics as pioneer in laboratory instrumentation

The firm MBLE (Brussels, Belgium) produced instrumentation for nuclear research around 60-s

MBLE preamplifier for scintillation detector

Early modular nuclear instrumentation

High voltage power supply for Geiger Muller counters and control unit for angular correlation measurements, **Antwerp company**

Later on, developed instrumentation were used in all fields of instrumentation, NIM(Nuclear instrumentation Modules) and CAMAC (Computer Aided Measurement & Control) became new standards of instrumentation, until now widely used.

Figure 14. Top: low-noise preamplifier model 103 for semiconductor detectors with 6 vacuum tubes by ORTEC (Oak Ridge, TN, USA) 1969
Bottom: transistorised low-noise preamplifier with field effect transistor input stage by Princeton γ-TECH (Princeton, NJ, USA) 1971

Figure 15. NIM-modules: shaping amplifier with P/Z and BLR (TENNELEC, USA), SCA-discriminator (Nuclear Enterprises, UK) and 4 kV bias power supply for semiconductor detectors (Wenzel, D)

Other important consequences of the computers in (nuclear) physics

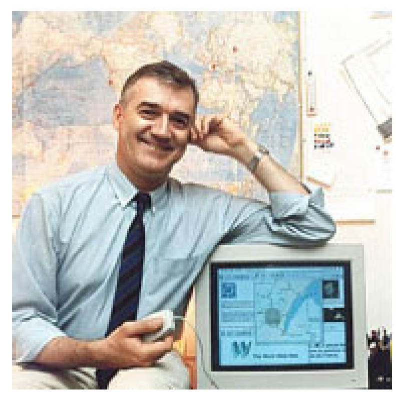
Development of "supercomputers" like the Control Data (CDC) and Gray series
The data-handling division of CERN played an important role

Control Data CDC at CERN (~1967)

Gray X/MP supercomputer at CERN (1988-1993)

At CERN around 1989-1990

The Belgian R. Cailliau and the British T. Berners-Lee developed together, at CERN, Geneva, the World Wide Web (www) concept with URL and hyperlinks. This was primarily developed as an internal CERN tool but was soon upgraded to the internet.



Robert Cailliau,
doctor honoris UGent in 2000

Sir Tim-Berners-Lee

From radioactivity to WWW…

Nuclear electronics has played a pioneering role in the evolution of laboratory instrumentation in the 20 the century. It was gradually taken over by other research fields like medical instrumentation and imaging, space research, telecom (GSM), GPS etc.

Jos Uyttenhove

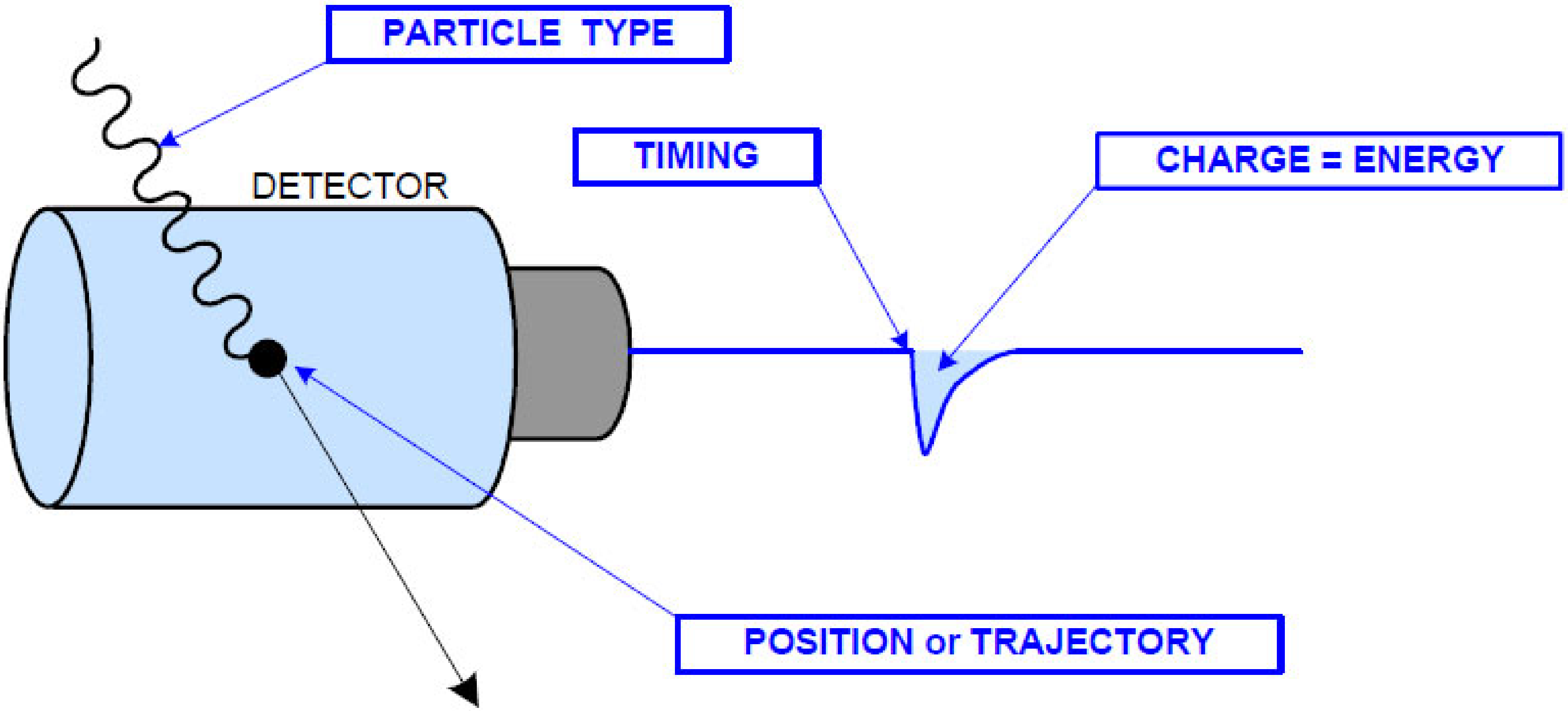
Section 1

Introduction

Introduction

- Detector signal processing plays an important role in extracting information from detector
- Most detectors generate as signal an electric current $\rightarrow$ electronics
  - Faint signals $\rightarrow$ Amplification
  - Fast signals $\rightarrow$ Shaping
- Important information that we can extract from detector signals
  - Amplitude: $\propto$ deposited charge. Energy, spectroscopy
  - Timing: Coincidences, tracking, particle id
  - Shape: particle id

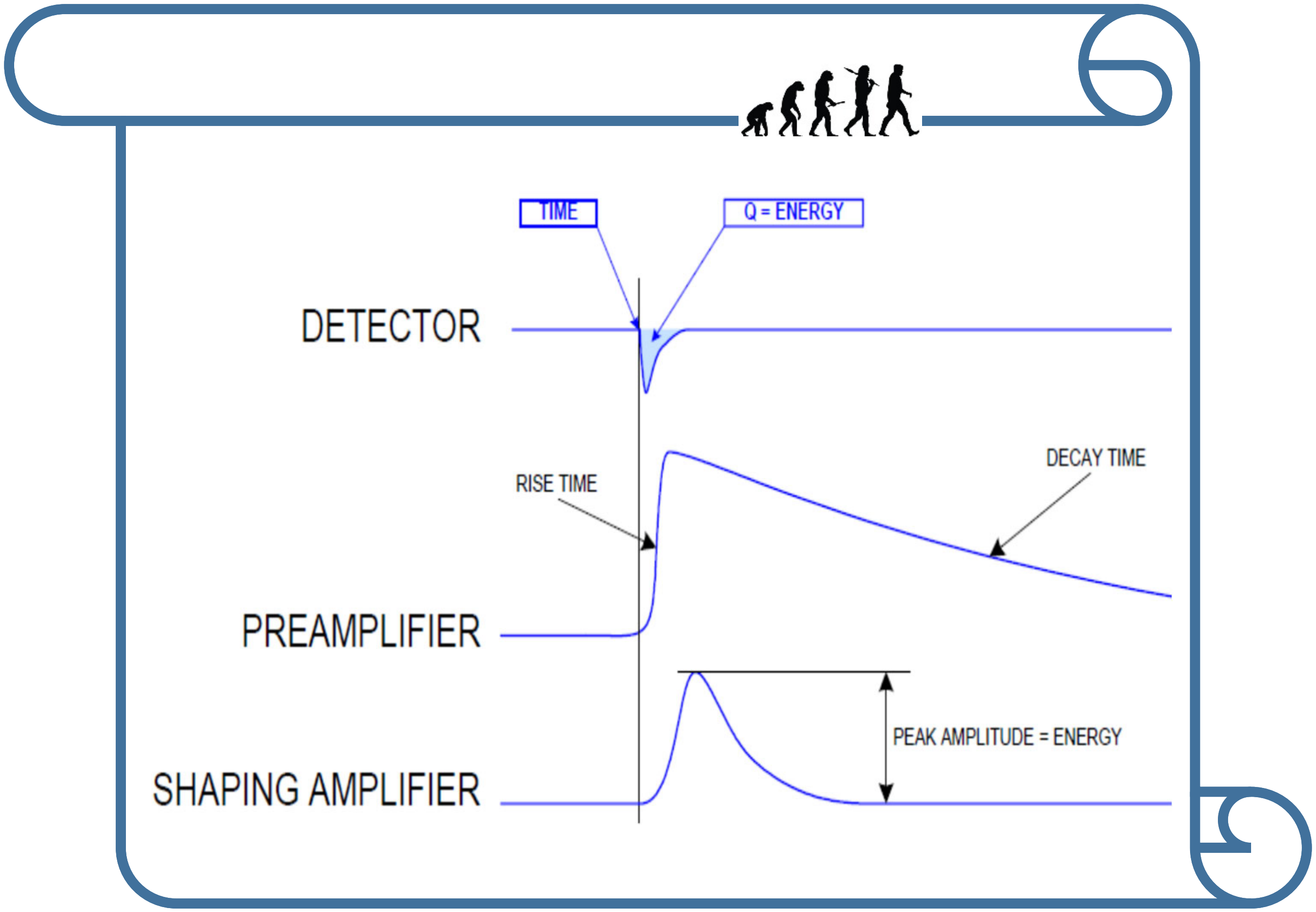
Electrical charge pulse generated by a detector



“Life” of the pulse

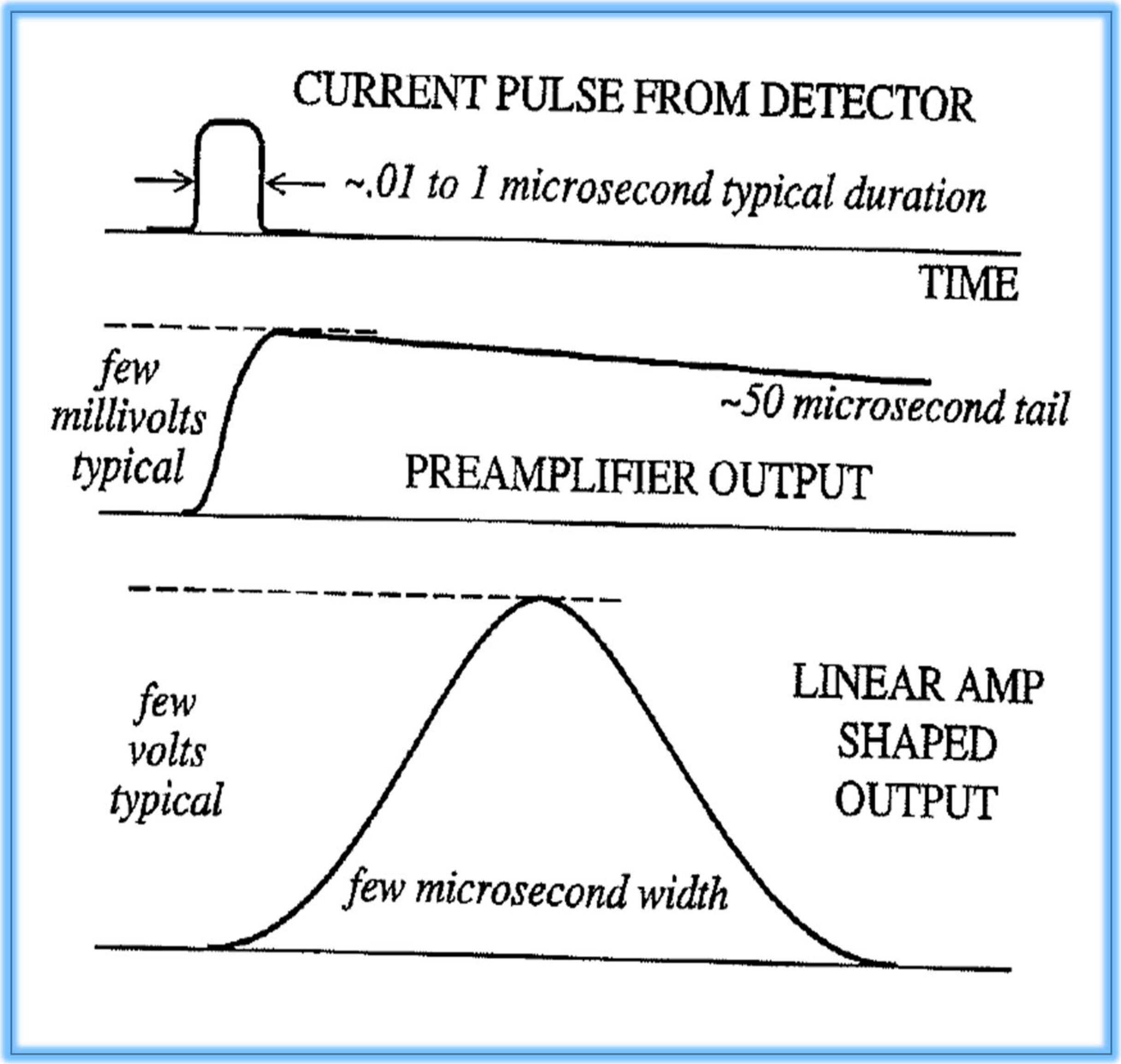
I(t)

Detector → ... EVOLUTION

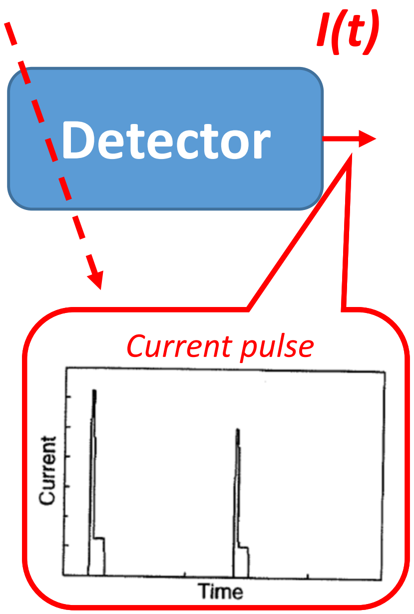


... ⟹ **Measurement**

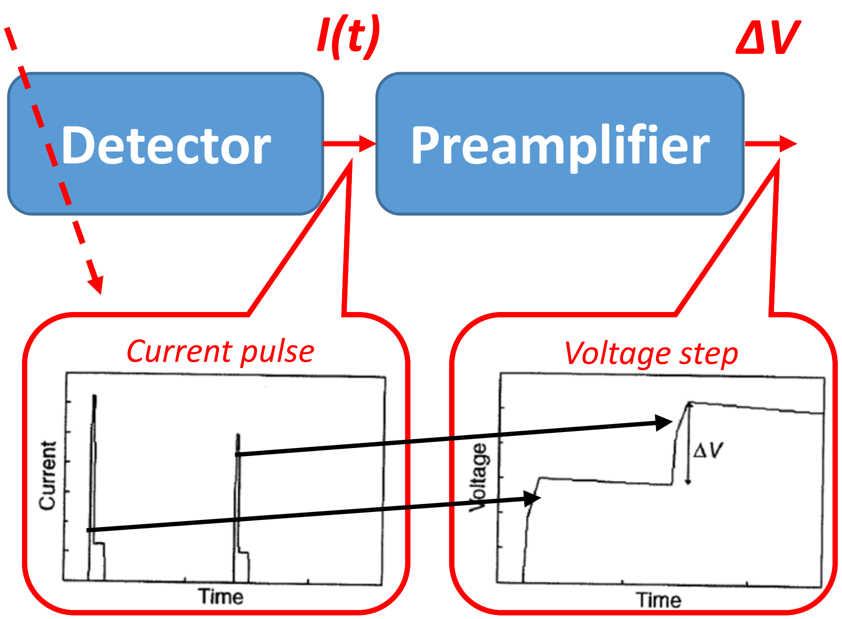
Feeling of timing



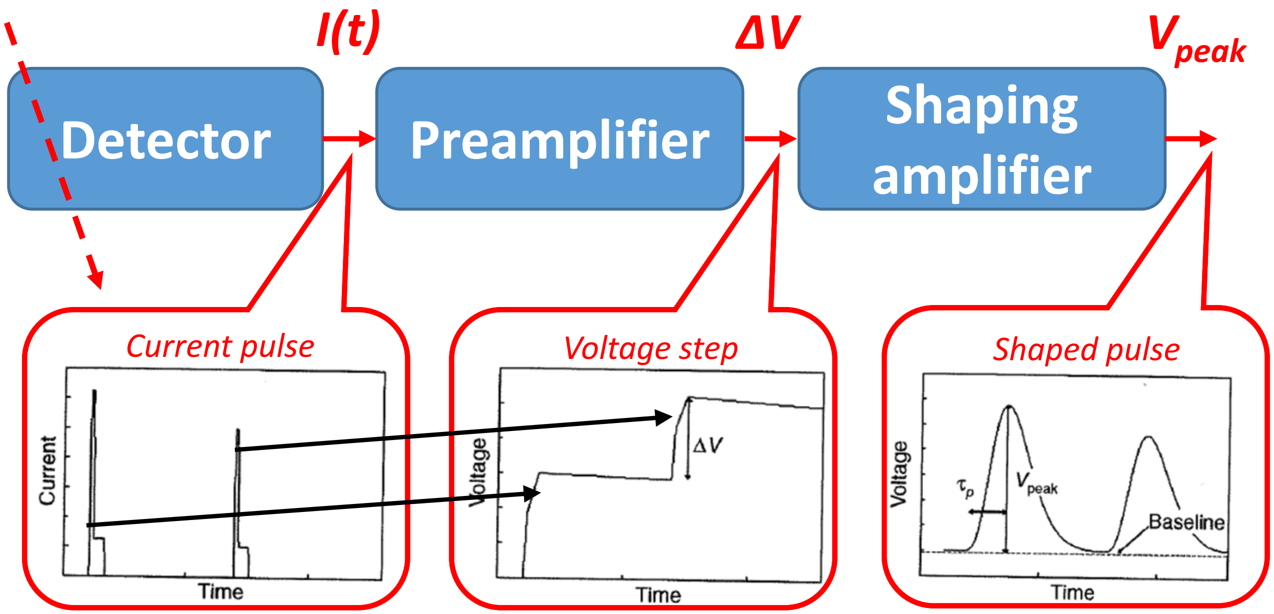
Implementation: reality of full picture



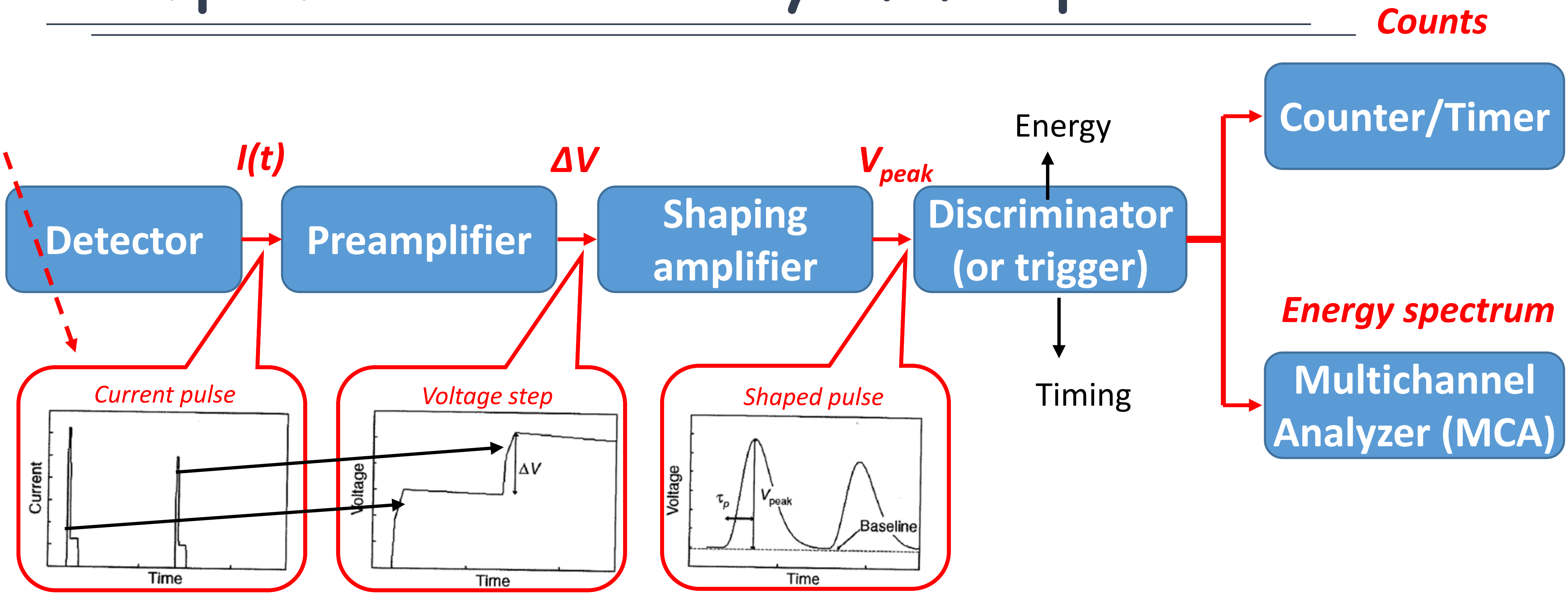
Implementation: reality of full picture



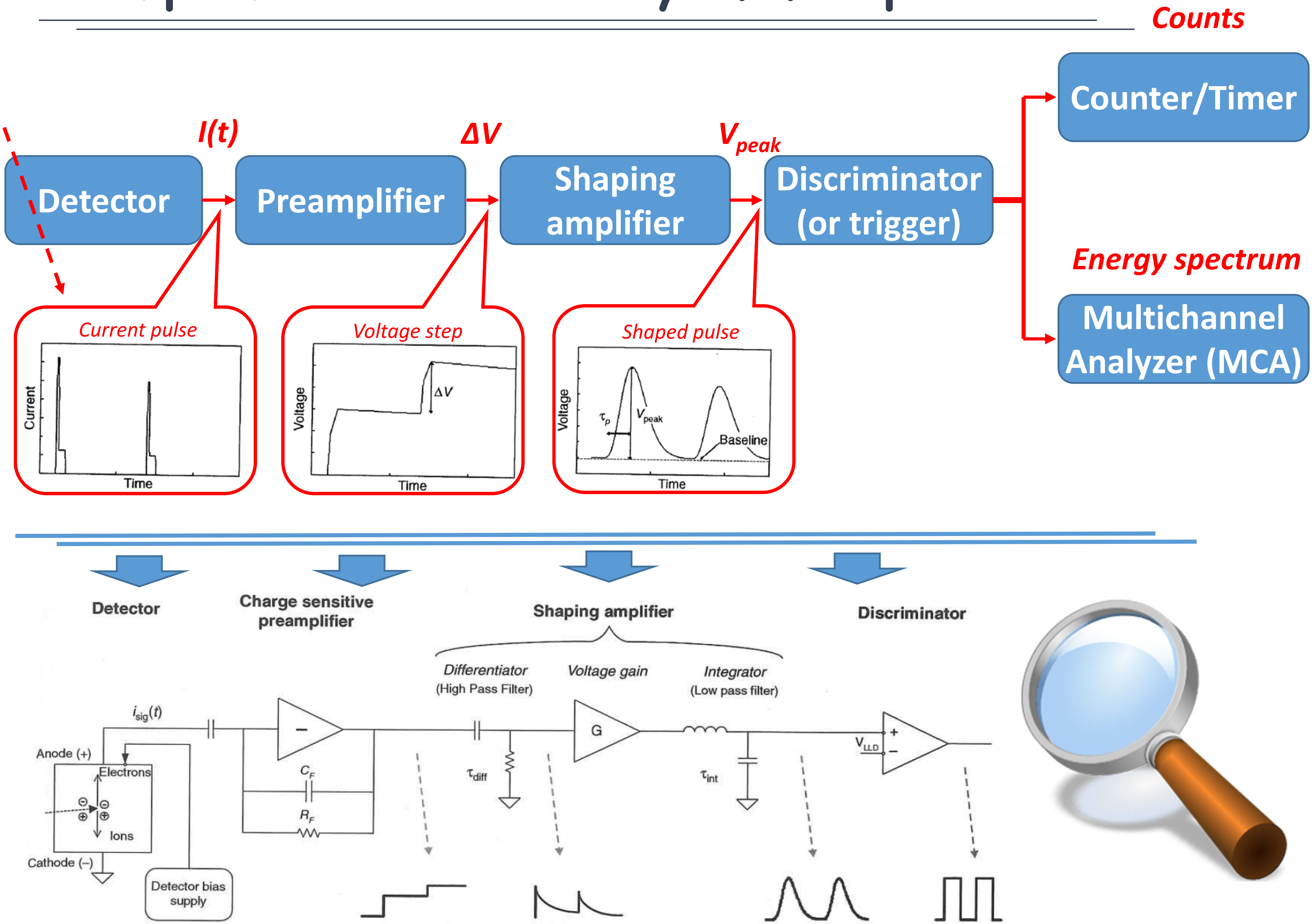
Implementation: reality of full picture

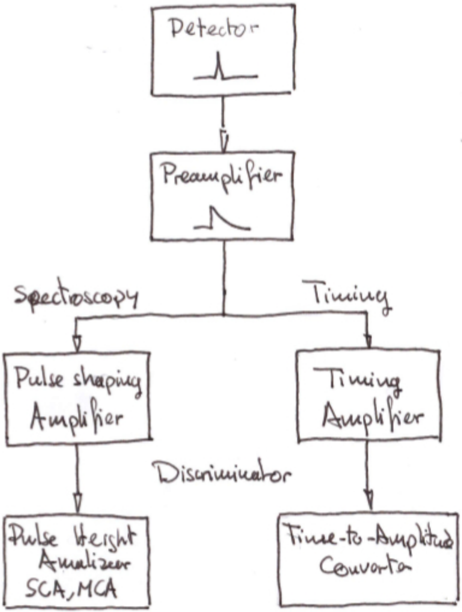


Implementation: reality of full picture



Implementation: reality of full picture




Detector
Preamplifier
Spectroscopy
Timing
Pulse shaping Amplifier
Timing Amplifier
Discriminator
Pulse Height Analizer SCA, MCA
Time-to-Amplitude Converter

Section 2

Electronics basics

Some technical details to keep in mind

- Cable properties and details

  - Coax cables shield against external signals with frequencies up to about 100 kHz

    Triax cables shield against even higher frequencies

    Ideal is to have the signal cables in a metal tube.

  - Signal speed in coax cable is ~0.66 c → ~5 ns/m
    → possible attenuation of signal is > for 10 m long cable

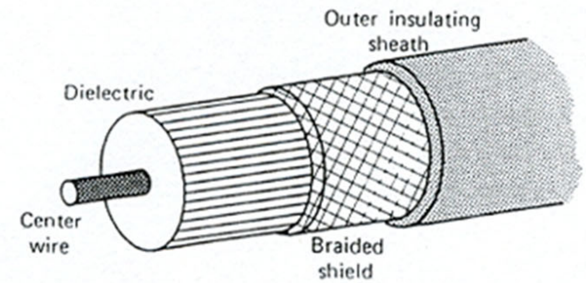


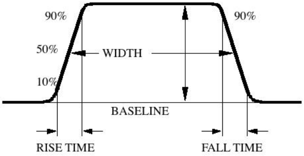
Figure 16-2 Construction of a standard coaxial cable.

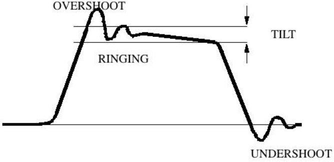
- Grounding

  Always try to have a common ground for all parts of the detection setup, to obtain the best signal quality (e.g. best energy resolution)

Electronic pulses

- Coding of information used in electronics is in the form of electronic pulses
- Information can be coded in polarity, amplitude, signal shape, frequency



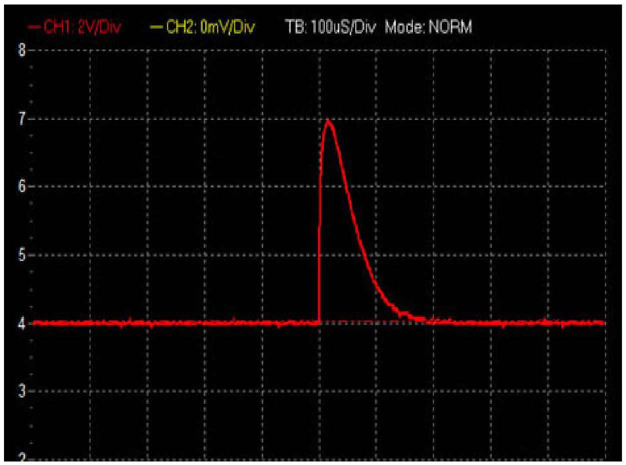


- Analog Pulses:
  - Codes continuously information by varying one or more of its characteristics
- Digital Pulses:
  - Takes a discrete number of states (typically 2 represented by 0/1)
  - Major advantage: digital signals are less affected by noise and distortions

Pulse: main actor

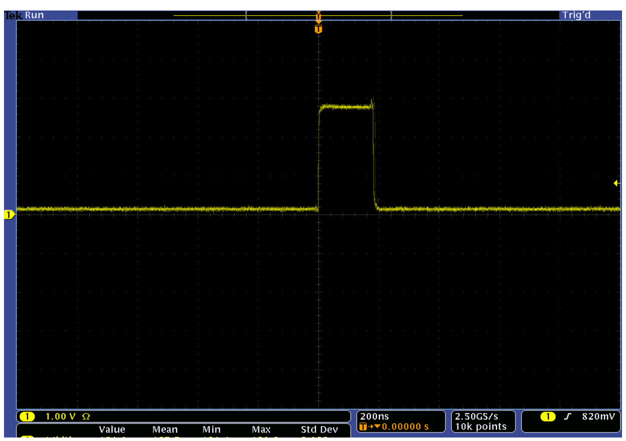
PULSES:

Linear:

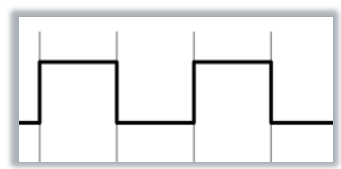


- Collection of output current by circuit;
  rise and fall generated by same history of current generated by interaction of particle with detector
- the analysis of the <u>amplitudes</u> constitutes the end result of a typical application;
- signal amplitude is proportional to the parameter of interest (ex: **<u>energy</u>**);

Logic:



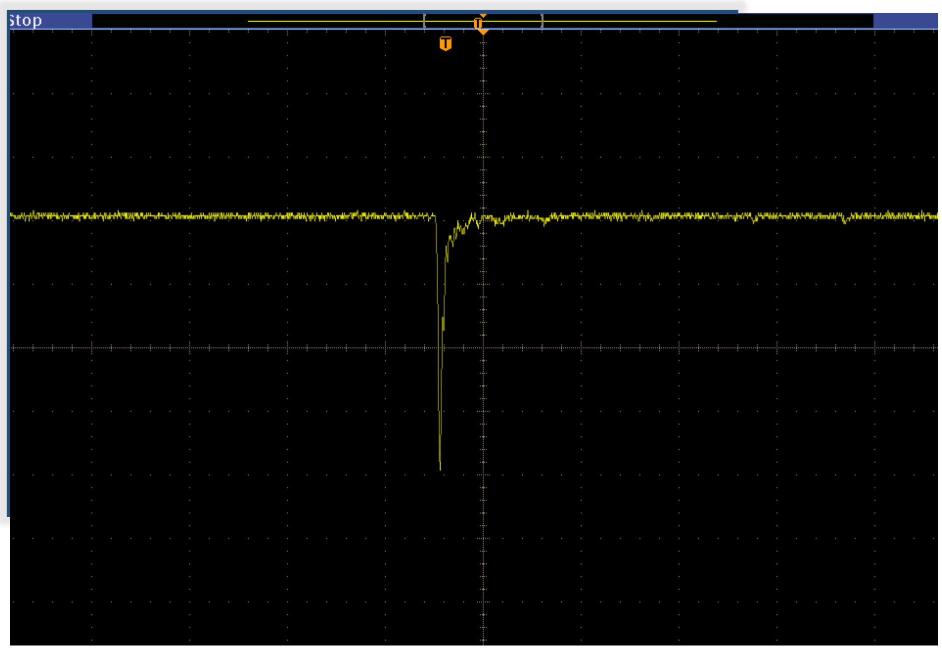
- have a <u>fixed shape and amplitude</u>;
- convey information by their presence, absence, or relation to time (**<u>counts</u>**, **<u>timing</u>**).



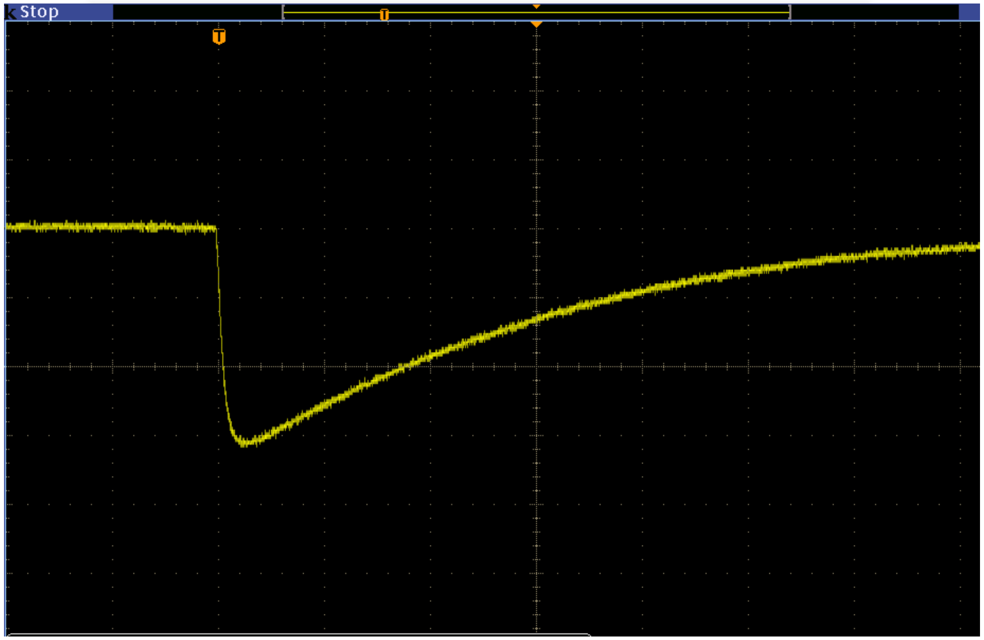
Final goal: counts, energy, timing

Just some feeling of real times

Fast vs. slow



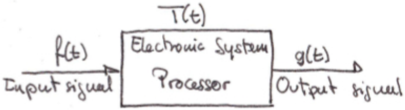
Very short pulse, a few nanoseconds or less



Very long pulse, hundreds of nanoseconds or greater

Electronics basics

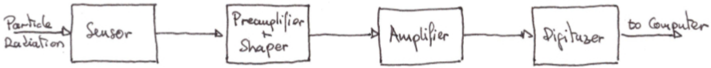
- Electronics: Signal processing technique
  - One or more input signals are processed producing one or more output signals



Transfer function

$$g(t) = T(t)f(t)$$

- Electronic systems can be chained one after the other



- Electronics deals with voltage/current interaction in a network or passive elements (resistor,capacitors,etc) and/or active elements (transistors,amplifiers,etc)

Signal processing basics

- Signal processing is based on few basis
  - Linearity of the transfer function

$$\left.\begin{aligned} g_1(t) &= T(t)f_1(t) \\ g_2(t) &= T(t)f_2(t) \end{aligned}\right\} \qquad T(t)\left(\alpha f_1(t) + \beta f_2(t)\right) = \alpha g_1(t) + \beta g_2(t)$$

  - Permanency of the transfer function: $T(t)$ is independent of tim
  - Transparency theorem: In a permanent and linear system, if the input is an exponential $f(t) = Ae^{pt}$ the output will be equal to $g(t) = B(p)e^{pt}$ where B and p are time independent
  - Any periodic and real function may be expanded in the interval [0,T] as a series of sines and cosines

Fourier Analysis

Any periodic and real function may be expanded in the interval [0,T] as a series of sines and cosines

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left[a_n' cos(n\omega t) + b_n \sin(n\omega t) \right]$$

$$a_n = \frac{2}{T} \int_0^T f(t) \cos(n\omega t) dt$$

$$b_n = \frac{2}{T} \int_0^T f(t) \sin(n\omega t) dt$$

where $\omega = \frac{2\pi}{T}$ and n=integer positive

ote 1: Integrals in the previous equation can be evaluated over any complete period (i.e. $[-\frac{T}{2}, \frac{T}{2}]$

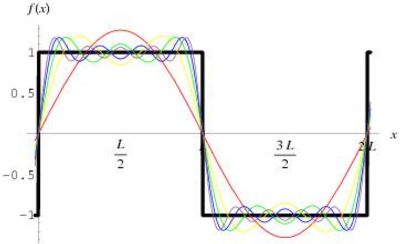
Fourier Analysis: Example

Square wave of lenght $2L$

$$f(t) = 2\left[H\left(\frac{t}{L}\right) - H\left(\frac{t}{L} - 1\right)\right] - 1$$

$T{=}2L$ $\qquad$ $\omega{=}\frac{2\pi}{T}{=}\frac{\pi}{L}$

$f(t)$ is odd $\rightarrow a_n = a_0 = 0$



$$b_n = \frac{2}{T}\int_0^T f(t)\sin(n\omega t)dt = \begin{cases} 0 n \text{ is even} \\ \frac{4}{n\pi} n \text{ is odd} \end{cases}$$

$$f(t) = \frac{4}{\pi}\sum_{n=1,3,5,\ldots}^{\infty}\frac{1}{n}\sin\left(\frac{n\pi t}{L}\right)$$

Visit http://www.jhu.edu/ signals/fourier2/index.html

Fourier Analysis

$$\left.\begin{aligned} \cos(n\omega t) &= \frac{1}{2}\left(e^{jn\omega t} + e^{-jn\omega t}\right) \\ \sin(n\omega t) &= \frac{1}{2}\left(e^{jn\omega t} - e^{-jn\omega t}\right) \end{aligned}\right\} \qquad f(t) = \sum_{n=-\infty}^{\infty} c_n e^{jn\omega t}$$

$$\begin{aligned} c_n &= \frac{1}{2}(a_n - ib_n) \\ c_0 &= \frac{1}{2}a_0 \\ c_{-n} &= \frac{1}{2}(a_n + ib_n) \end{aligned}$$

c_n coefficients depends on frequency

$$c_n \equiv F(n\omega) \quad \rightarrow \quad f(t) = \sum_{n=-\infty}^{\infty} F(n\omega)e^{jn\omega t}$$

$$F(n\omega) = \frac{2}{T}\int_0^T f(t)e^{-jn\omega t}dt \longleftarrow \text{ Fourier Transform}$$

Fourier Analysis

- With this transformation we pass from a representation in the time space to a representation in the frequency space. In this space the coefficients $F(n\omega)$ represent the spectrum of the signal.
- So far we have talked avout periodic signals, but this formalism can be extended to non-periodic signals. In this case we will not have a series of harmonics but a so called Fourier integral, leading to a continuous spectra:

$$f(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} F(\omega) e^{j\omega t}$$

$$F(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t) e^{-j\omega t}$$

- Up to now we have been using infinities to both frequency and time. In practice infinites can be cut to maximal and minimal values relevant to the signals

Transfer function revisited

- Fourier analysis in combination with transparency theorem allows us to easily write any output function
  - Input/output signals are decomposed in a series of exponentials

$$f(t) = \sum_{-\infty}^{\infty} F(n\omega)e^{jn\omega t} \qquad g(t) = \sum_{-\infty}^{\infty} G(n\omega)e^{jn\omega t}$$

$$g(t) = T(t)f(t)$$

  - For each term in the input signal we will obtain a term in the output signal $T(t) \rightarrow T(\omega)$

$$g(t) = \sum_{-\infty}^{\infty} G(n\omega)e^{jn\omega t} = \sum_{-\infty}^{\infty} T(n\omega)F(n\omega)e^{jn\omega t}$$

  - Transparency theorem assures that the relation between input and output is not time dependent but can depend on frequency

$$G(n\omega) = T(n\omega)F(n\omega)$$

  - $T(n\omega)$=Transfer function. In general is a complex number (=it can produce a phase shift)

Time Domain - Frequency Domain

- Time Domain: Description of the electrical signal wrt time
- Frequency Domain: Description of the electrical signal wrt frequency
- Time domain and Frequency domain are related by Fourier Integrals:

$$F(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t) e^{-j\omega t}$$

- Fourier integrals are Laplace Transforms with $s = j\omega$: s-Domain

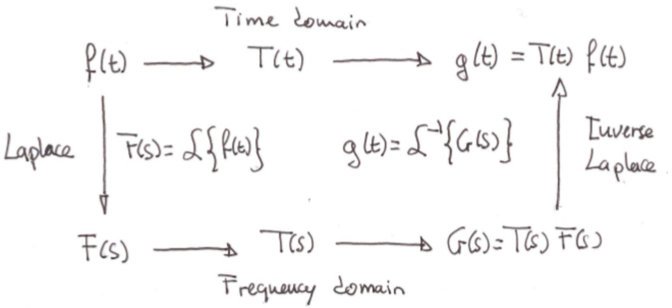
$$\mathcal{L}\{f(t)\} = F(s) = \int_{-\infty}^{\infty} e^{-st} f(t) dt$$

$$\mathcal{L}^{-1}\{F(s)\} = f(t) = \frac{1}{2\pi j} \int_{-j\infty}^{+j\infty} e^{st} F(s) ds$$

$$\mathcal{L}\{af(t) + bg(t)\} = a\mathcal{L}\{f(t)\} + b\mathcal{L}\{g(t)\}$$

s-Domain

- Most of the times it is easier to compute the transfer function in the s-Domain



$$v_{out}(t) = T(t)v_{in}(t) \qquad \rightarrow \qquad v_{out}(t) = \mathcal{L}^{-1}\{T(s)V_{in}(s)\}$$

$$V_{out}(s) = T(s)V_{in}(s) \qquad \qquad v_{out}(t) = \mathcal{L}^{-1}\{T(s)\mathcal{L}\{v_{in}(t)\}\}$$

Electronics basics

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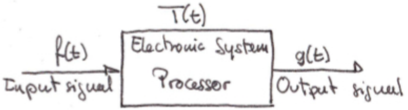
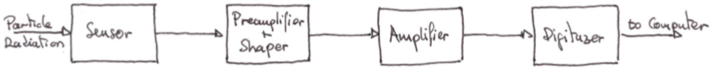


Transfer function
$g(t) = T(t)f(t)$

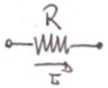
- Electronic systems can be chained one after the other



- Electronics deals with voltage/current interaction in a network or passive elements (resistor,capacitors,etc) and/or active elements (transistors,amplifiers,etc)

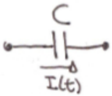
Passive components: Ohm's Law

- Resistance (R): Measure of how difficult it is for an electric current to flow through a conductor



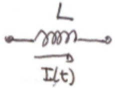
$$V = IR$$

- Capacitance (C): Ability to store electrical charge



$$C = \frac{Q}{V} \rightarrow I = \frac{dQ}{dt} = C\frac{dV}{dt}$$

- Inductance (L): Property of conductors to try to resist a change in a magnetic field



$$V = L\frac{dI}{dt}$$

Impedance. Generalized Ohm's Law

- When dealing with AC current we can generalize the Ohm's Law to

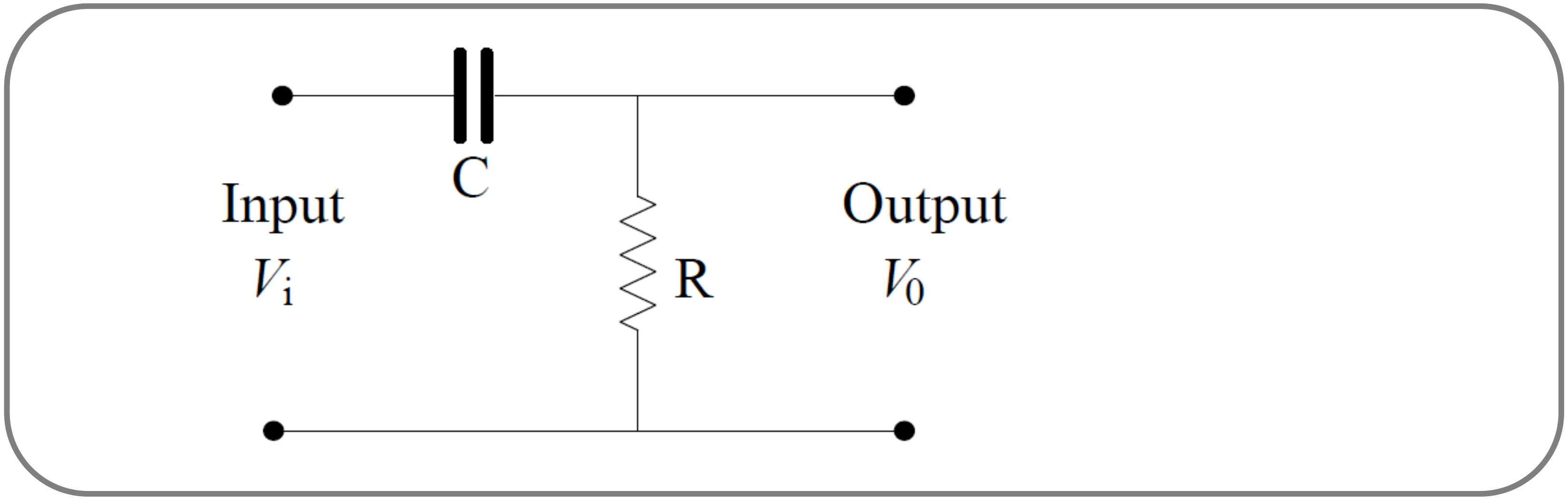
$$V = ZI$$

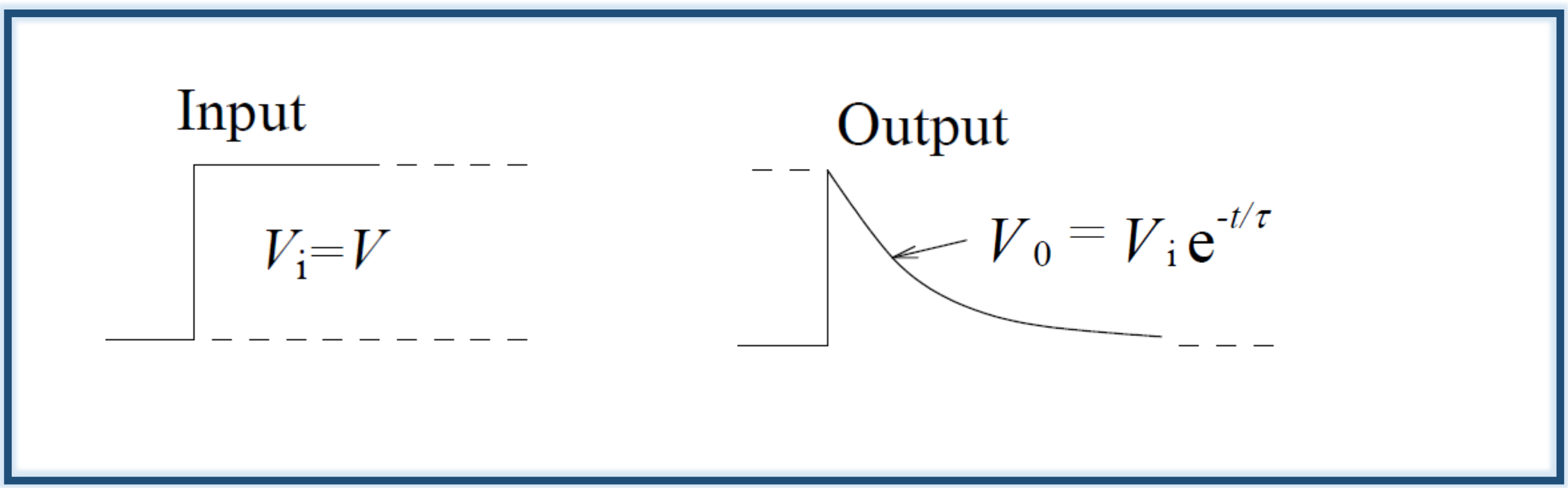
where Z is the overall opposition of a component to the current

$$\begin{array}{ll} \text{Resistance} & Z_R = R \\ \text{Capacitance} & Z_C = \dfrac{-j}{\omega C} \\ \text{Inductance} & Z_L = j\omega L \end{array}$$

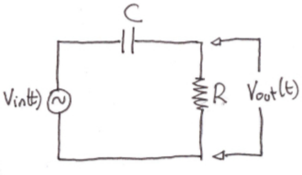
- Serial combination: $Z_{ser} = \sum_i Z_i$
- Parallel combination: $Z_{par}^{-1} = \sum_i Z_i^{-1}$
- Impedance will allow to write transfer functions in an easy way

CR-differentiator (High-pass filter)



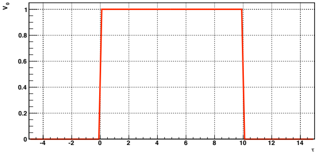


CR circuit in the time domain



$$v(t) = v_C + v_R$$

$$v_C(t) = RC\frac{dv_i(t)}{dt}$$



Capacitor charging

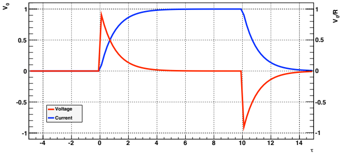
$$i(t) = \frac{V_0}{R}\left(1 - e^{-\frac{t-t_c}{RC}}\right)$$

$$v_c(t) = V_0 e^{-\frac{t-t_c}{RC}}$$

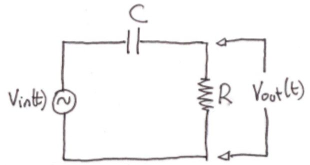
Capacitor discharging

$$i(t) = \frac{V_0}{R} e^{-\frac{t-t_d}{RC}}$$

$$v_c(t) = -V_0 e^{-\frac{t-t_d}{RC}}$$



CR circuit: High pass filter



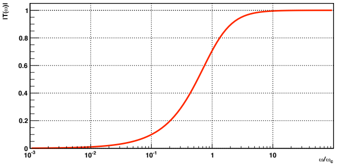
$$V_{out}(\omega) = \frac{Z_R}{Z_R + Z_C} V_{in}(\omega) = \frac{j\omega RC}{1 + j\omega RC}$$

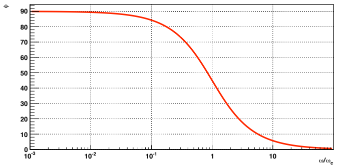
$$T(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)}$$

$$= \frac{j\omega RC}{1 + j\omega RC} \rightarrow T(s) = \frac{s/\omega_c}{1 + s/\omega_c}$$

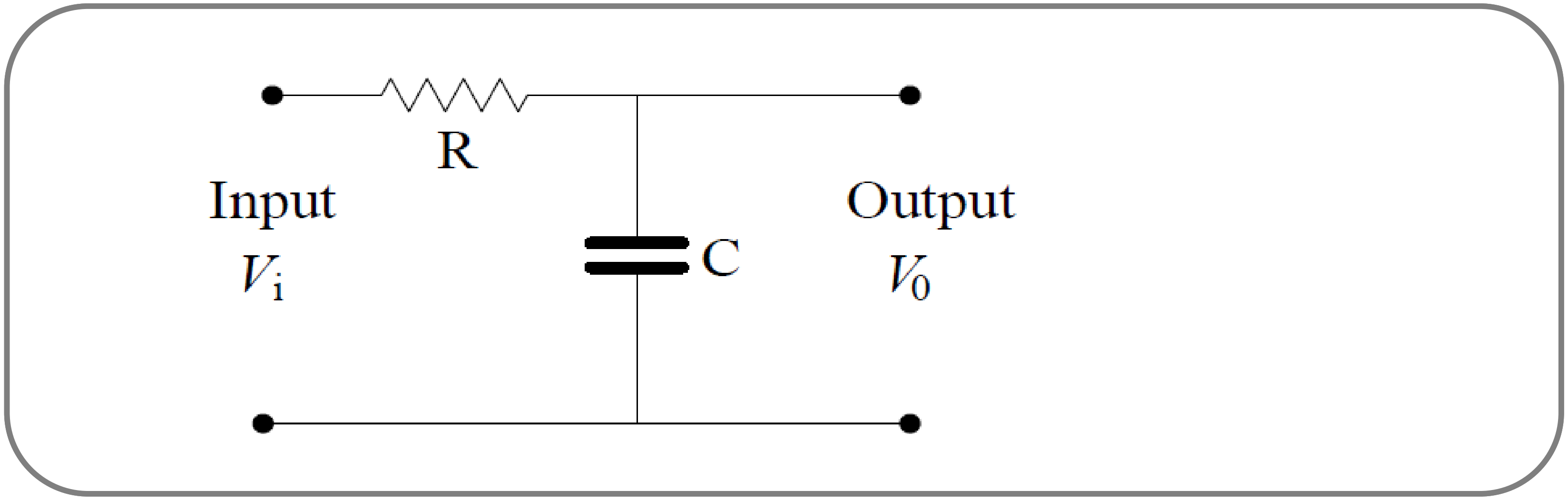
$$\tau = RC$$

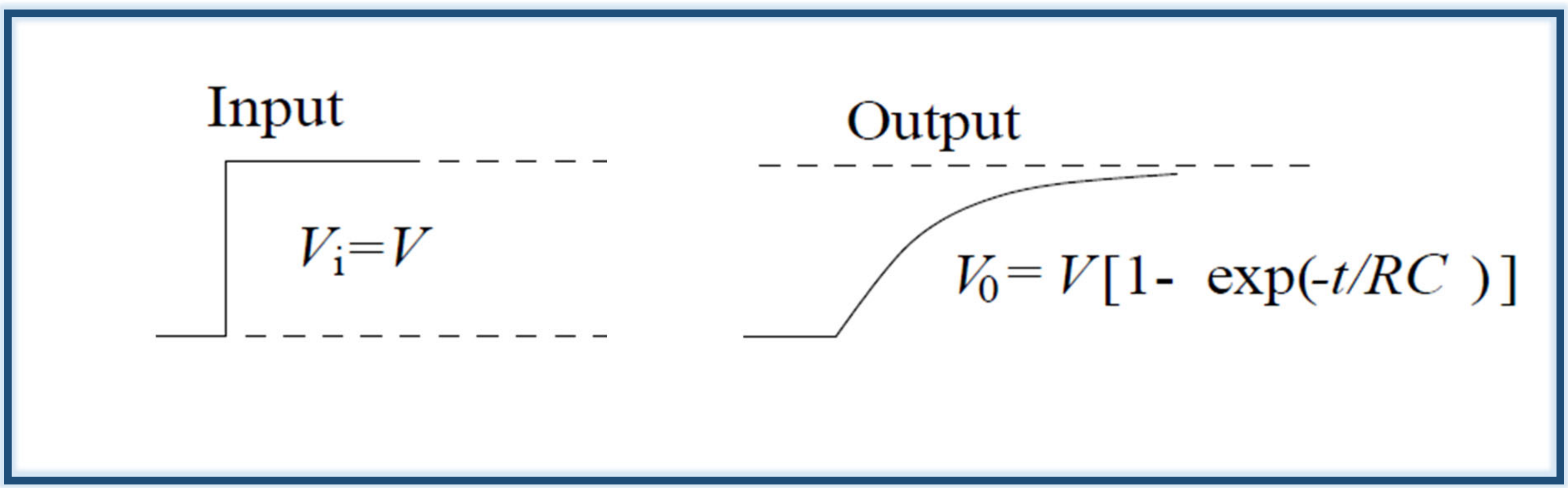
$$\omega_c = \frac{1}{RC}$$



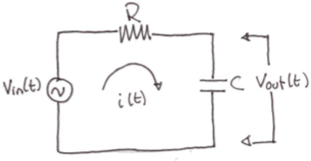


RC-integrator (Low-pass filter)





RC circuit in the time domain



$$v(t) = v_R + v_C$$

$$v_C(t) = \frac{1}{RC}\int v_i(t)dt$$

Capacitor charging

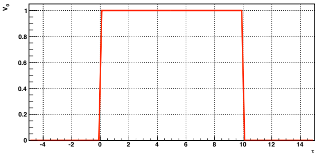
$$i(t) = \frac{V_0}{R} e^{-\frac{t-t_c}{RC}}$$

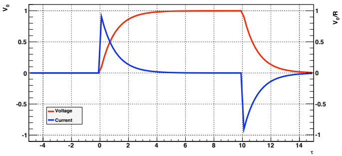
$$v_c(t) = V_0\left(1 - e^{-\frac{t-t_c}{RC}}\right)$$

Capacitor discharging

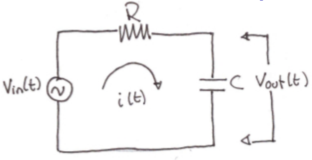
$$i(t) = -\frac{V_0}{R} e^{-\frac{t-t_d}{RC}}$$

$$v_c(t) = V_0 e^{-\frac{t-t_d}{RC}}$$



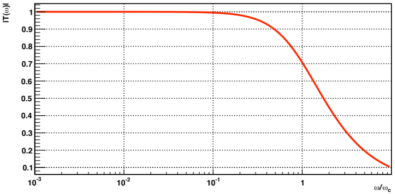


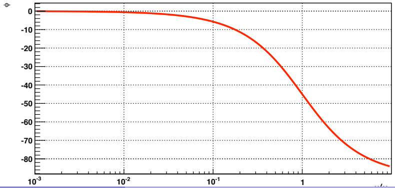
RC circuit: Low pass filter



$$V_{out}(\omega) = \frac{Z_C}{Z_R + Z_C} V_{in}(\omega) = \frac{1}{1 + j\omega RC}$$

$$T(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{1}{1 + j\omega RC} \rightarrow T(s) = \frac{1}{1 + s/\omega_c}$$





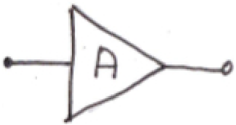
$$\tau = RC$$

$$\omega_c = \frac{1}{RC}$$

Amplifiers

- In almost all readout circuits there are one or many amplification stages
- Any amplification stage has two main purposes
  - Amplify low level signals coming from previous stages
  - Adapt impedances between stages

- An amplifier is represented by the symbol



- It's characterized by:
  - Gain: A
  - Input resistance R_i
  - Input capacitance C_i
  - Bandwidth

Section 3

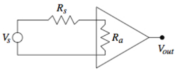
Preamplification

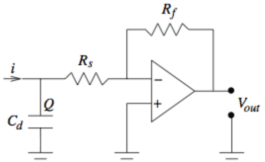
Preamplification

- The analog signal produced after the passage of radiation through a detectors is
  - Very narrow = fast (few 10's ns) → needed "fast" electronics
  - Very faint amplitude → difficult treatment
- A preamplifier is a "simple" amplifier that is connected directly to the detector and that is going to solve these problems
  - Adapted to input signal and dynamic range
  - Large enough bandwidth
  - Low power consumption
  - Minimize pile up
- Preamplifiers used in radiation detection are basically of three types:
  - Voltage Sensitive Amplifier
  - Current Sensitive Amplifier
  - Charge Sensitive Amplifier

Voltage Sensitive Amplifier

- Most basic type of preamplifier: It's function is just to amplify the potential at its input stage





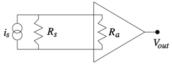
$$V_a = \frac{R_a}{R_s + R_a} V_s \quad \rightarrow \quad R_a >> R_s \rightarrow V_a \simeq V_s$$

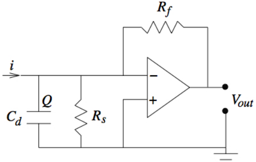
$$V_{out} = AV_a \simeq AV_s \simeq A\frac{Q}{C_d}$$

- PROS: Low output impedance that can be externally controlled
- CONS: Direct dependence on detector capacitance. Stray capacitances.
- $t_d << R_a C_d$ and both R_a and C_d cannot be externally controlled

Current Sensitive Amplifier

- Measures the instantaneous current generated by the detector
- Requires a low input impedance





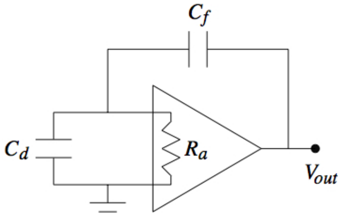
$$I_a = \frac{R_s}{R_s + R_a} I_s \quad \rightarrow \quad R_a << R_s \rightarrow I_a \simeq I_s$$

$$V_{out} \propto I_s$$

- Charge collection time $t_d >> R_s C_d$
- Again special attention with stray capacitances

Charge Sensitive Amplifier

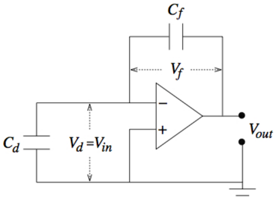
- Instead of current or voltage, what is amplified is the charge accumulated on the detector and input capacitances and integrated on an external capacitance
- By far the most used preamplifer



$$V_{out} \propto \frac{Q_f}{C_f} \propto \frac{Q_d}{C_f}$$

- $Q_f \simeq Q_d$ if no current flows into preamplifier $\rightarrow$ $R_a \simeq \infty$

Charge Sensitive Amplifier



$$V_{out} = -AV_d$$

with $A >> 1$

$$\begin{aligned} V_d &= V_f + V_{out} \\ &= V_f - AV_d \end{aligned} \quad \xrightarrow{A>>} \quad V_f = (A+1)V_d$$

$$\frac{Q_f}{C_f} = (A+1)\frac{Q_{in}}{C_{in}} \quad \rightarrow \quad C_{in} = (A+1)C_f\frac{Q_{in}}{Q_f} \xrightarrow{Q_{in} \simeq Q_f} C_{in} \simeq (A+1)C_f$$

$$A_Q = \frac{V_{out}}{Q_{in}} = \frac{AV_{in}}{C_{in}V_{in}} = \frac{A}{C_{in}} = \frac{A}{A+1}\frac{1}{C_f} \simeq \frac{1}{C_f}$$

$$V_{out} = \frac{Q_d}{C_f}$$

Charge Transfer Efficiency

- Previous results are only valid if $Q_f \simeq Q_d$
- We define the charge transfer efficiency as

$$\eta_{in} = \frac{Q_{in}}{Q_t} \qquad Q_t = Q_d + Q_{in}$$

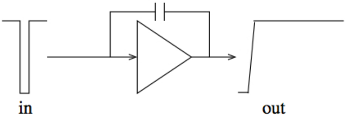
It characterizes the efficiency transfer of charge on detector's capacitance to the feedback capacitance

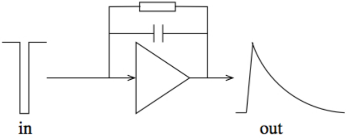
- Ideally it should be 100%

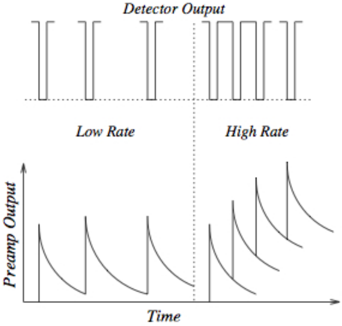
$$\eta_{in} = \frac{Q_{in}}{Q_{in} + Q_d} = \frac{1}{1 + Q_d/Q_{in}} = \frac{1}{1 + C_d/C_{in}}$$

- $\eta_{in} \sim 100\%$ if $C_d << C_{in}$ or $C_d << (A+1)C_f$

CSA: Resistive Feedback Mechanism

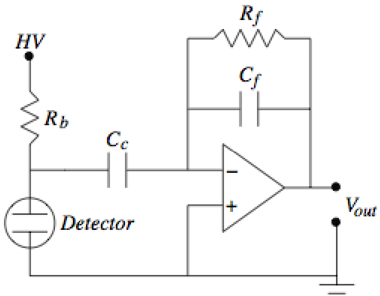




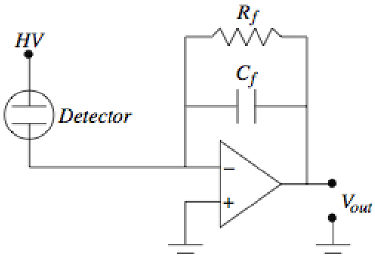


CSA: AC and DC coupling

AC-coupling



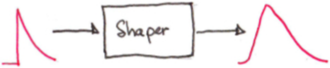
DC-coupling



Section 4

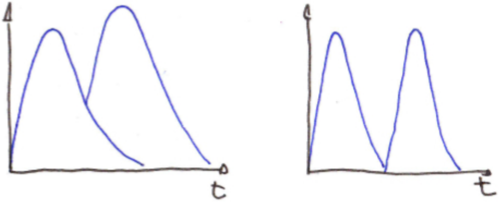
Pulse Shaping

- Technique that convert a narrow/fast signal into a broader one with a rounded maximum



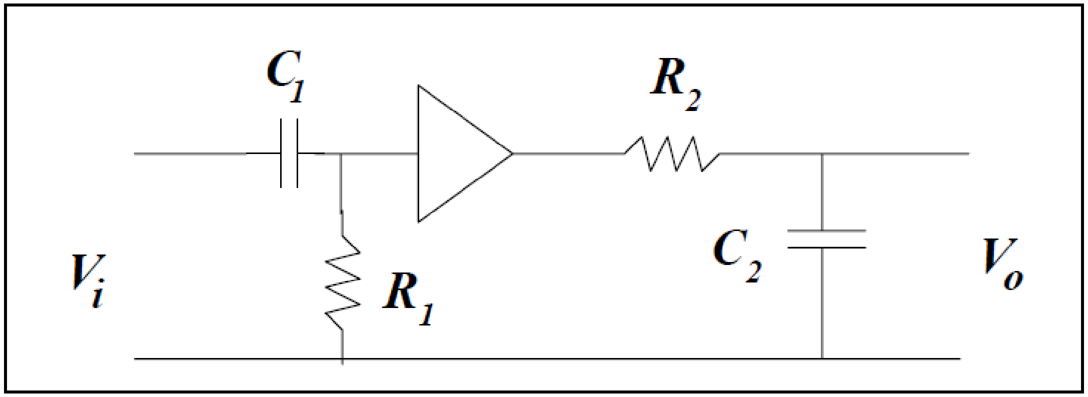
  - Increase signal to noise ratio. The wider the signal $\rightarrow$ the better S/N
  - Measure the amplitude with precision

- In case of high rate, pile-up effects can appear: shaping time should be decreased

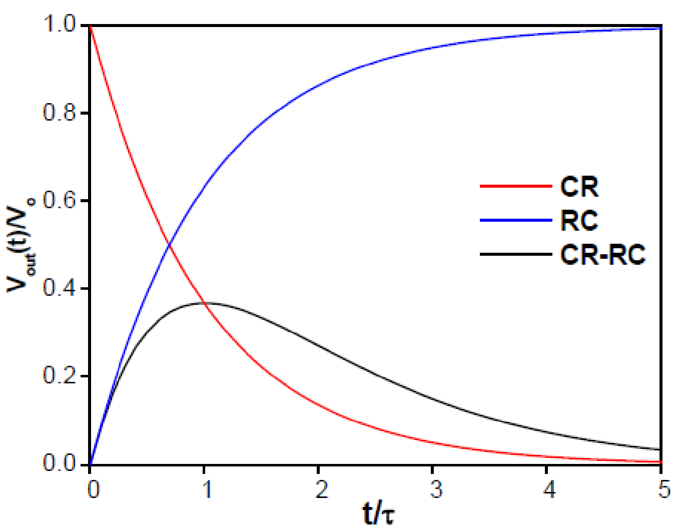


- Several shaping methods: the choice is application dependent

CR-RC-shaping



$$V_0 = \frac{V_i \tau_1}{\tau_1 - \tau_2}\left(e^{-t/\tau_1} - e^{-t/\tau_2}\right)$$



Information

The first part of the circuit is a high-pass filter. The output voltage is given by Equation (2.10): $V_S = V_i e^{-t/\tau_1}$, where $\tau_1 = R_1C_1$.

The second part is a low-pass filter, whose behavior is given by Equation (2.12) with $V_i = V_S$, i.e. $\frac{dV_0}{dt} + \frac{V_0}{\tau_2} = \frac{V_S}{\tau_2}$, where $\tau_2 = R_2\,C_2$.

Multiply by $\exp(t/\tau_2)$: $\exp(t/\tau_2)\frac{dV_0}{dt} + \frac{V_0}{\tau_2}\exp(t/\tau_2) = \frac{d}{dt}(V_0\exp(t/\tau_2)) = \frac{V_S\exp(t/\tau_2)}{\tau_2}$.

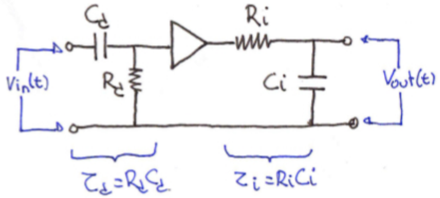
Substitute for V_S: $\frac{d}{dt}(V_0\exp(t/\tau_2)) = \frac{V_i\exp[t(1/\tau_2 - 1/\tau_1)]}{\tau_2}$.

Integrate: $V_0\exp(t/\tau_2) = \frac{V_i\tau_1\exp[t(1/\tau_2 - 1/\tau_1)]}{(\tau_1 - \tau_2)} + K$.

Setting the condition: $V_0 = 0$ when $t = 0$, $K = -V_i\tau_1/(\tau_1 - \tau_2)$ from which we get Equation

CR-RC Pulse shaping

- Simplest and most used method for shaping preamplificated pulses
- It consists of a CR differentiator followed by a RC integrator



$$T(s) = T_d(s) \cdot T_i(s)$$

$$\begin{aligned} T_d(s) &= \frac{\tau_d s}{\tau_d s + 1} \\ T_i(s) &= \frac{1}{\tau_i s + 1} \end{aligned} \rightarrow T(s) = \frac{\tau_d s}{(\tau_d s + 1)(\tau_i s + 1)}$$

$$v_{out}(t) = \mathcal{L}^{-1}\left\{T(s)\mathcal{L}\{v_{in}(t)\}\right\}$$

CR-RC Pulse shaping

In we assume that the preamplifier output is a step function: $(\tau_{preamp} << \tau_{shaper})$

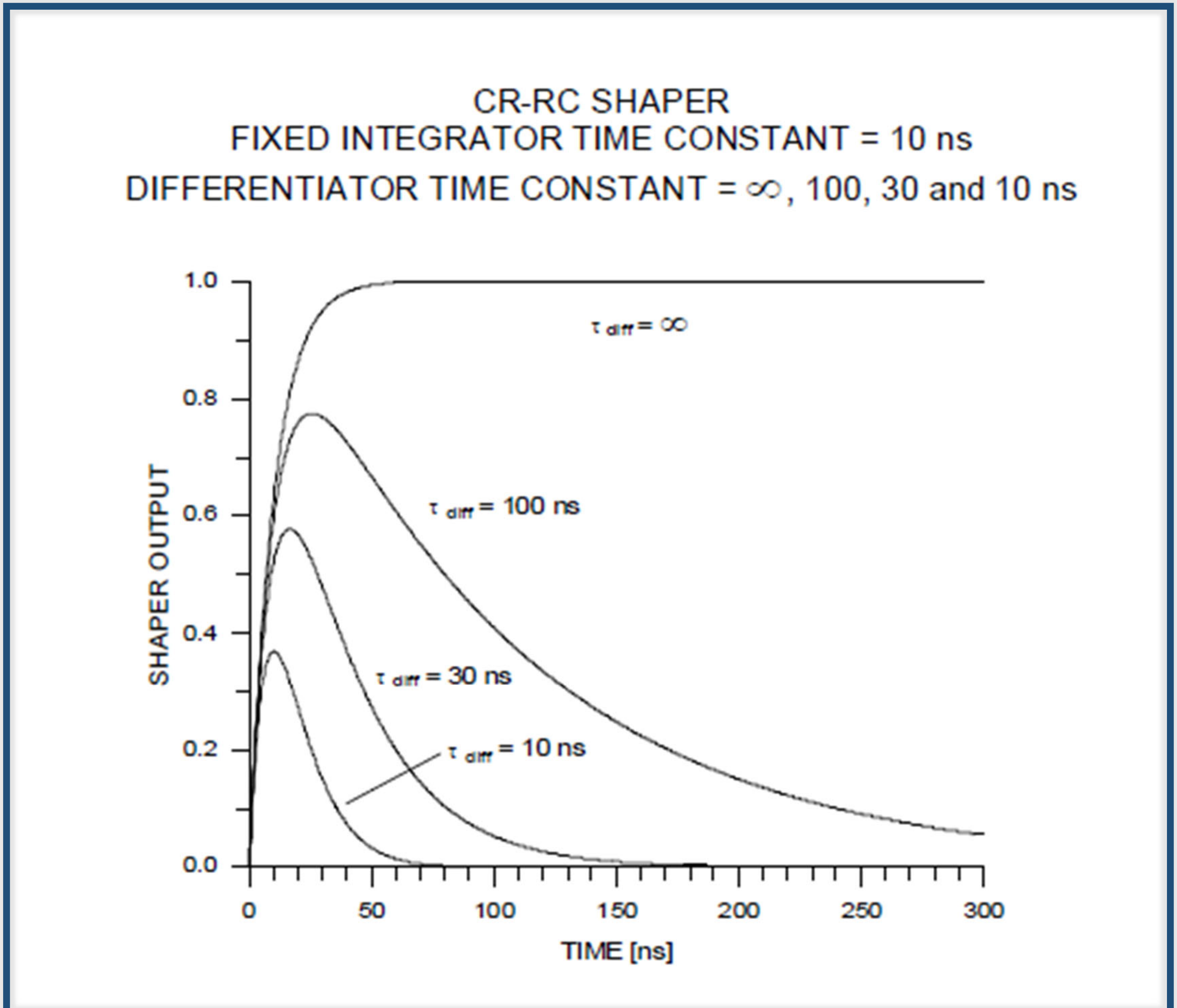
$$\begin{aligned} v_{in}(t) &= V_0 \quad t \geq 0 \\ &= 0 \quad t < 0 \end{aligned} \rightarrow \mathcal{L}\{v_{in}(t)\} = V_0 \int_0^{\infty} e^{-st} dt = V_0 - \frac{e^{-st}}{s}\Big|_0^{\infty} = \frac{V_0}{s}$$

$$v_{out}(t) = \mathcal{L}^{-1}\left\{ V_0 \frac{\tau_d}{(\tau_d s + 1)(\tau_i s + 1)} \right\}$$

$$\tau_d \neq \tau_i \quad v_{out}(t) = V_0 \tau_d \frac{e^{-t/\tau_d} - e^{-t/\tau_i}}{\tau_d - \tau_i}$$

$$\tau_d = \tau_i \quad v_{out}(t) = V_0 \frac{t e^{-t/\tau}}{\tau}$$

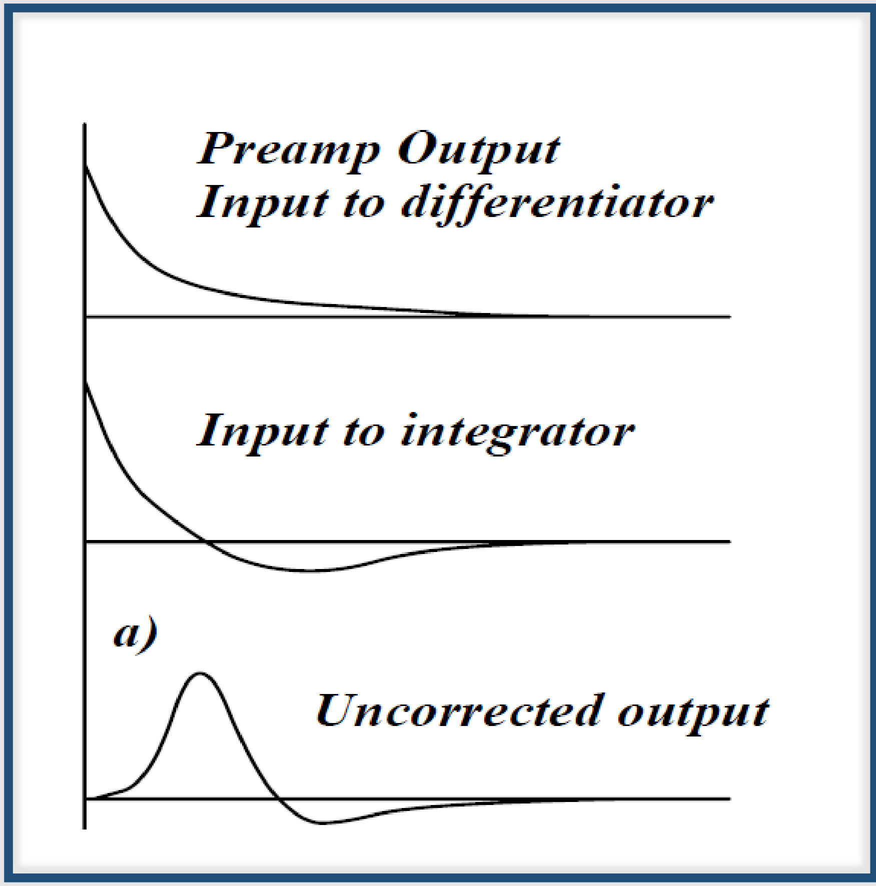
CR-RC-shaping: example

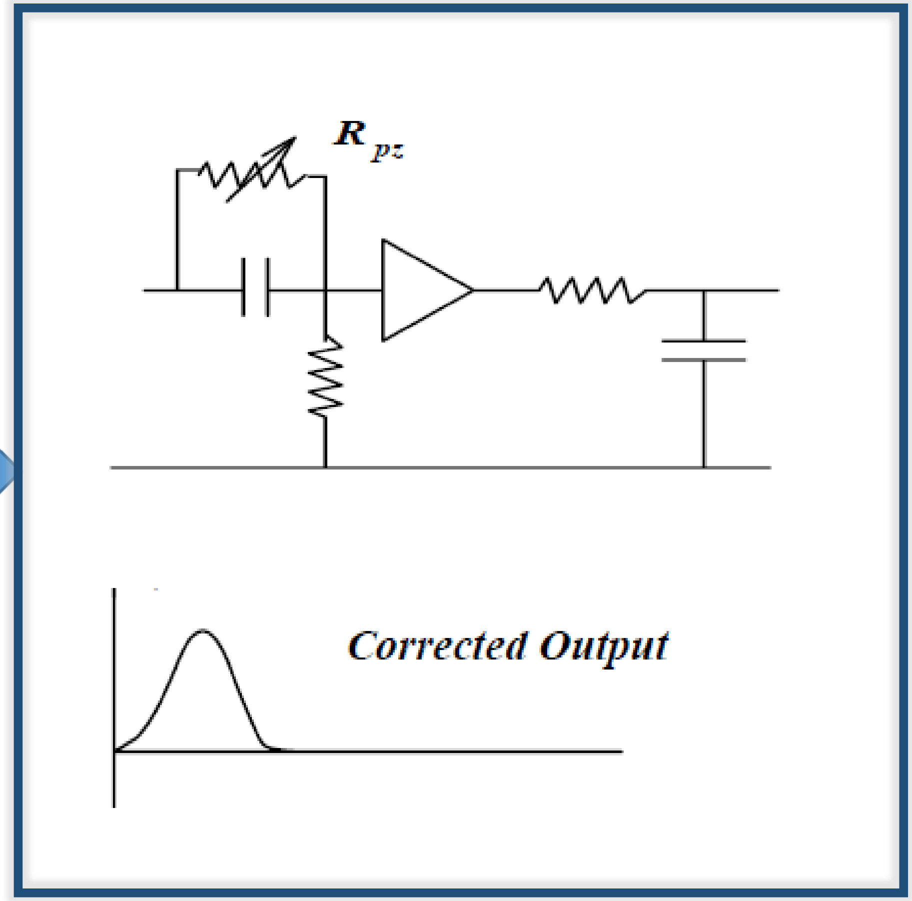


Closer look: “Undershoot”

- ❑ Undershoot

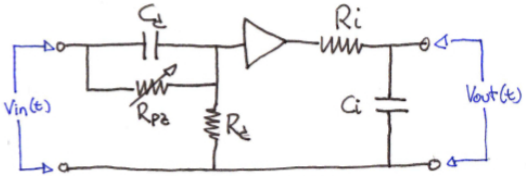
Solution: pole-zero cancellation





CRRC: Pole-Zero cancellation

- Undershoots can be eliminated if the responsible pole is somehow removed from the function.
  - Modifications in the circuit that will make appear in the numerator a quantity (a zero) that cancel the pole.
  - It's clear that the faulty pole is the one introduced by the preamplificator $\rightarrow \frac{1}{\tau_p}$ is the pole that has to be removed
- Easiest modification is just to add a resistor in parallel to R_d



CRRC: Pole-Zero cancellation

- The transfer function of the pole-zero circuit is:

$$T(s) = \frac{\tau_p s}{(\tau_p s + 1)} \frac{\tau_d (R_{pz} C_d s + 1)}{(R_{pz} C_d \tau_d s + R_{pz} C_d + \tau_d} \frac{1}{\tau_i s + 1}$$

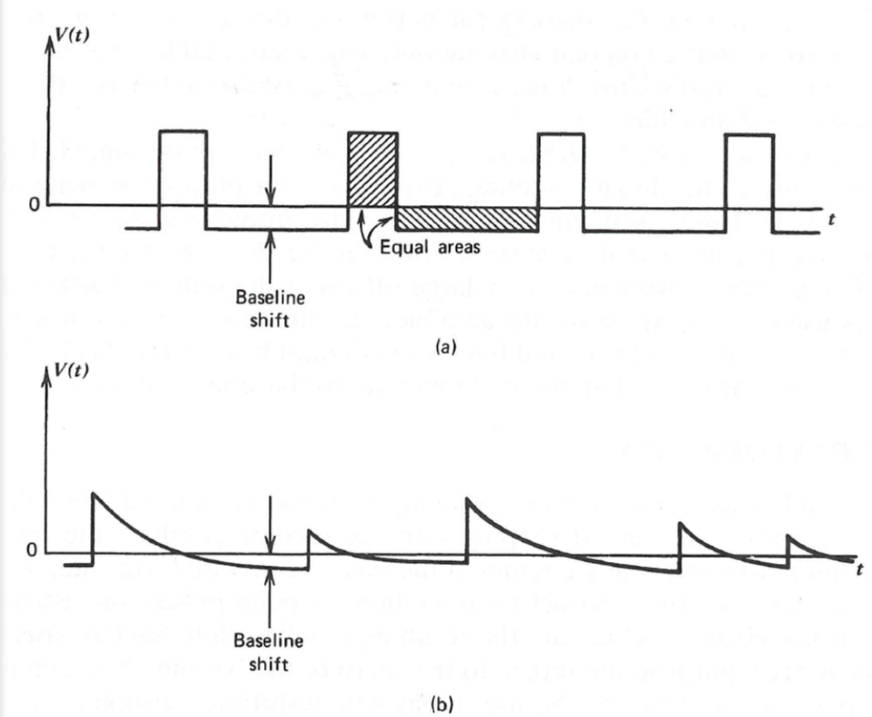
- If $R_{pz} = \frac{\tau_p}{C_d}$ the numerator $(R_{pz} C_d s + 1) \rightarrow (\tau_p s + 1)$, canceling exactly the faulty zero.

$$T(s) = \frac{\tau_p \tau_d s}{\tau_p (\tau_d s + 1) \tau_d} \frac{1}{\tau_i s + 1}$$

- Attention: This strategy cancel the pole perfectly, but ...
  - Simplistic approach: R_{pz}, τ_p and C_d can drift
  - Slight modification of any of these parameters $\rightarrow$ reappearance of the undershoot
  - This circuit is widely used because of its easy implementation not its effectiveness

Base-line shift

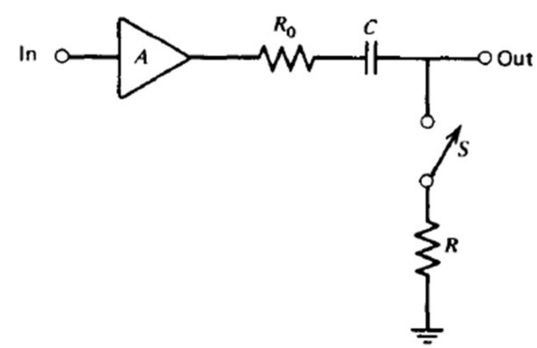
❑ Base-line shift



Solution: bipolar pulses, restoration

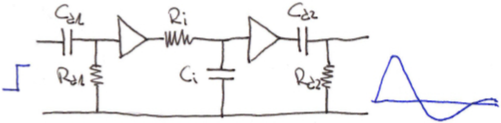
- bipolar

- restoration



Baseline Shift

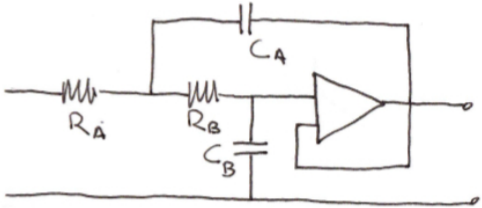
- In many applications, the shaper is AC-coupled to next stages
- It may produce a baseline shift in the signal (due to the charging of the coupling capacitor) that may vary with the rate
- In order to minimize it, a baseline restorer circuit is added
  - An extra differentiator after the integrator that minimize the baseline shift
  - Output is a bipolar pulse
  - Longer pulse duration → unsuitable for high rates applications
  - S/N ratio worse than the simple CR-RC shaper



High order active integrators

- In applications where high resolution is required and S/N has to be enhanced, instead of simple RC stages active higher order integrators can be used
- Most usual choice is to use the second order Sallen-Key active integrators.
- These circuits improve S/N decreasing the width of the output pulse

$$\tau = \sqrt{R_A R_B C_A C_B}$$

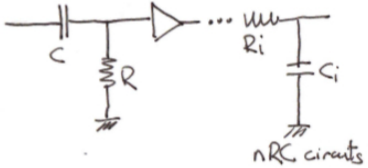


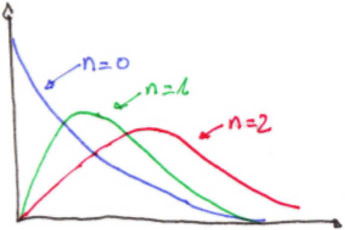
Semi-Gaussian Pulse Shaping

- If a single CR stage is followed by several stages of RC integration, the output pulse shape becomes close to Gaussian.
- Shapers in this way are called semi-Gaussian. In case $\tau_d = \tau_{i,n}$

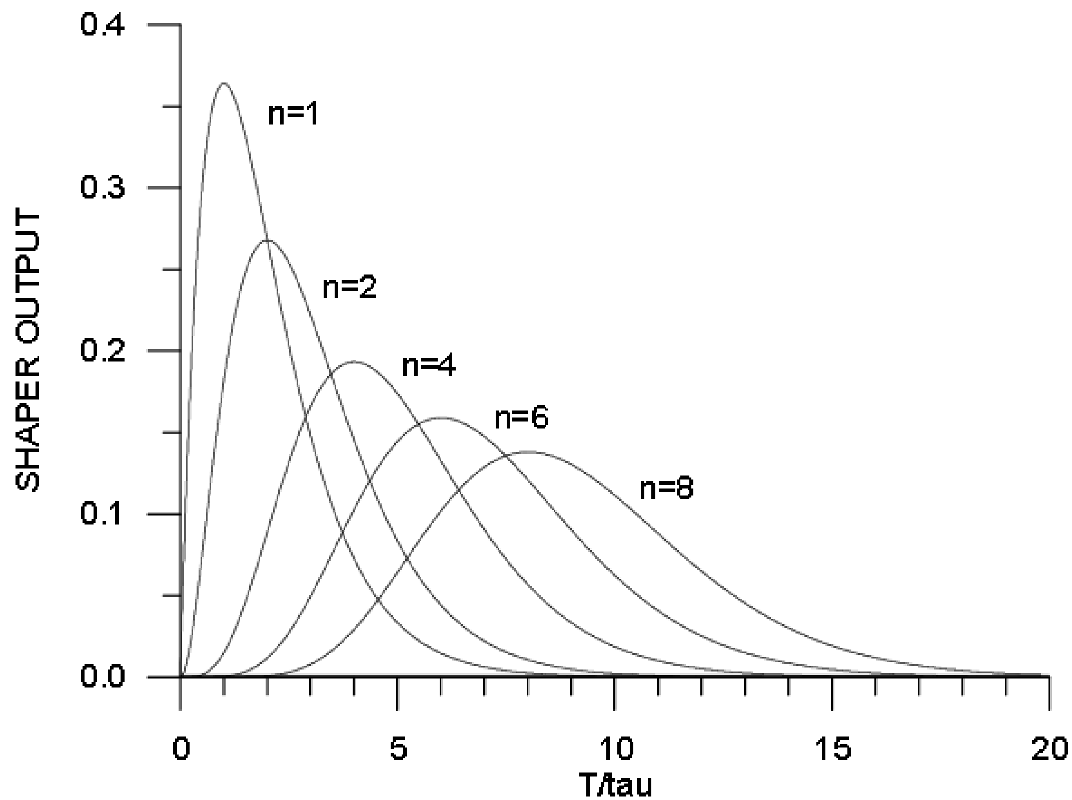
$$V_{out}(t) = V_0 \left(\frac{t}{\tau}\right)^n e^{-t/\tau} \qquad \text{n=number integrators}$$

- Peaking time= $n\tau$
- More symmetric shape $\rightarrow$ faster return to baseline





CR-RC-shaping with equal $\tau = \tau_1 = \tau_2$



$$V_0 = V_i \frac{t}{\tau} e^{-t/\tau}$$

Information

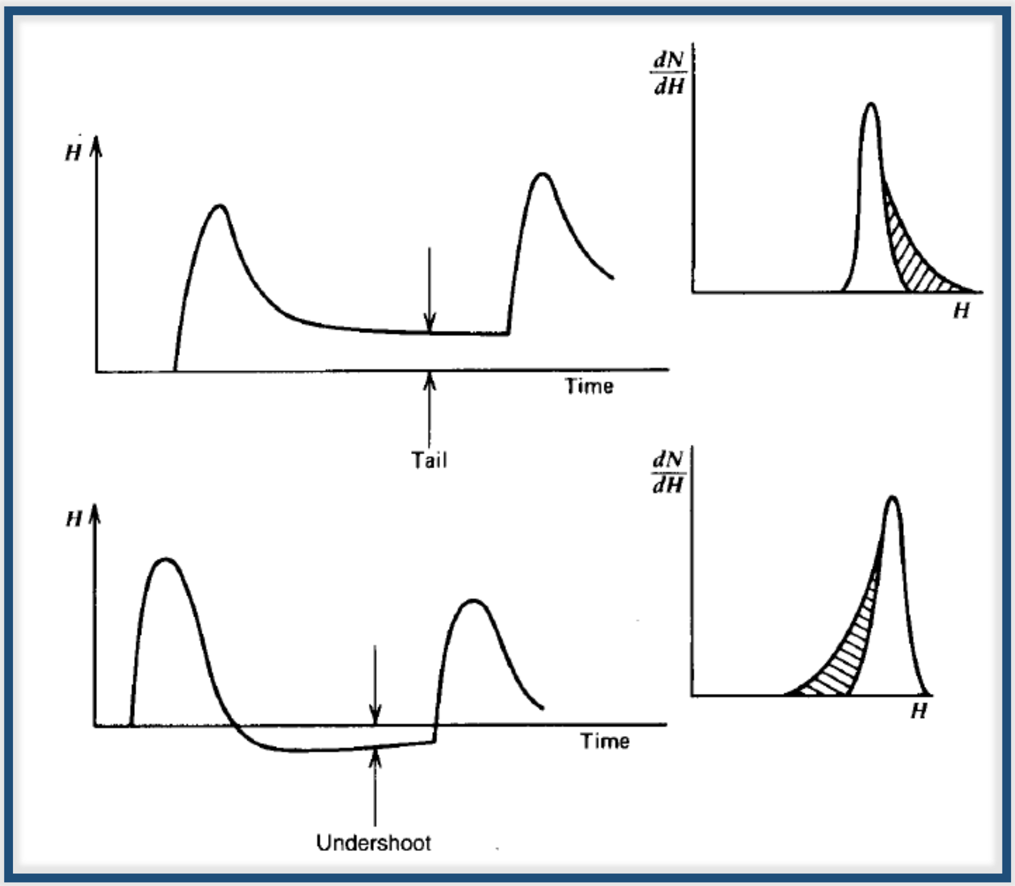
Derivation of Equation (2.16):

If $\tau_1 = \tau_2 = \tau$, rewrite Equation (2.15) as $V_0 = \frac{V_i \tau_1}{\tau_1 - \tau_2} e^{-t/\tau_2}\left(e^{-t(1/\tau_1 - 1/\tau_2)} - 1\right)$ and expand the first term in brackets to first order in t:

$$V_0 = \frac{V_i \tau_1}{\tau_1 - \tau_2} e^{-t/\tau_2}\left[1 - t\left(\frac{1}{\tau_1} - \frac{1}{\tau_2}\right) - 1\right] = \frac{V_i \tau e^{-t/\tau}}{\tau_1 - \tau_2}\left[\frac{t(\tau_1 - \tau_2)}{\tau^2}\right],$$ giving Equation (2.16).

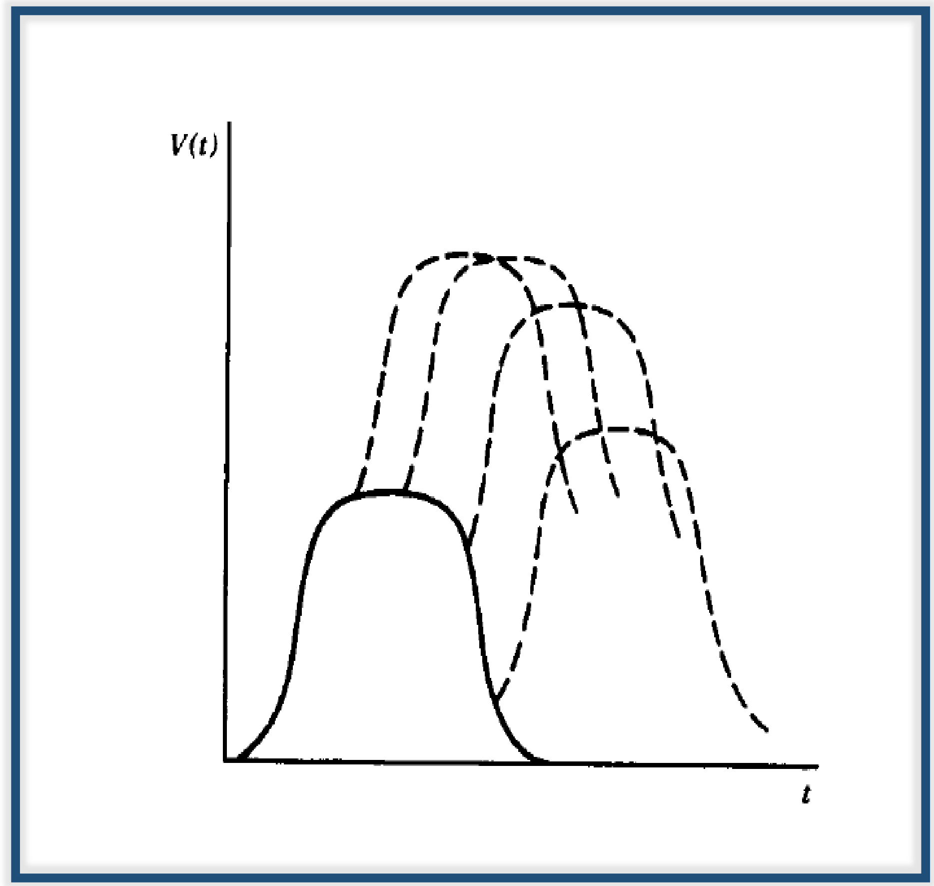
Pile-up

- Tail pile-up



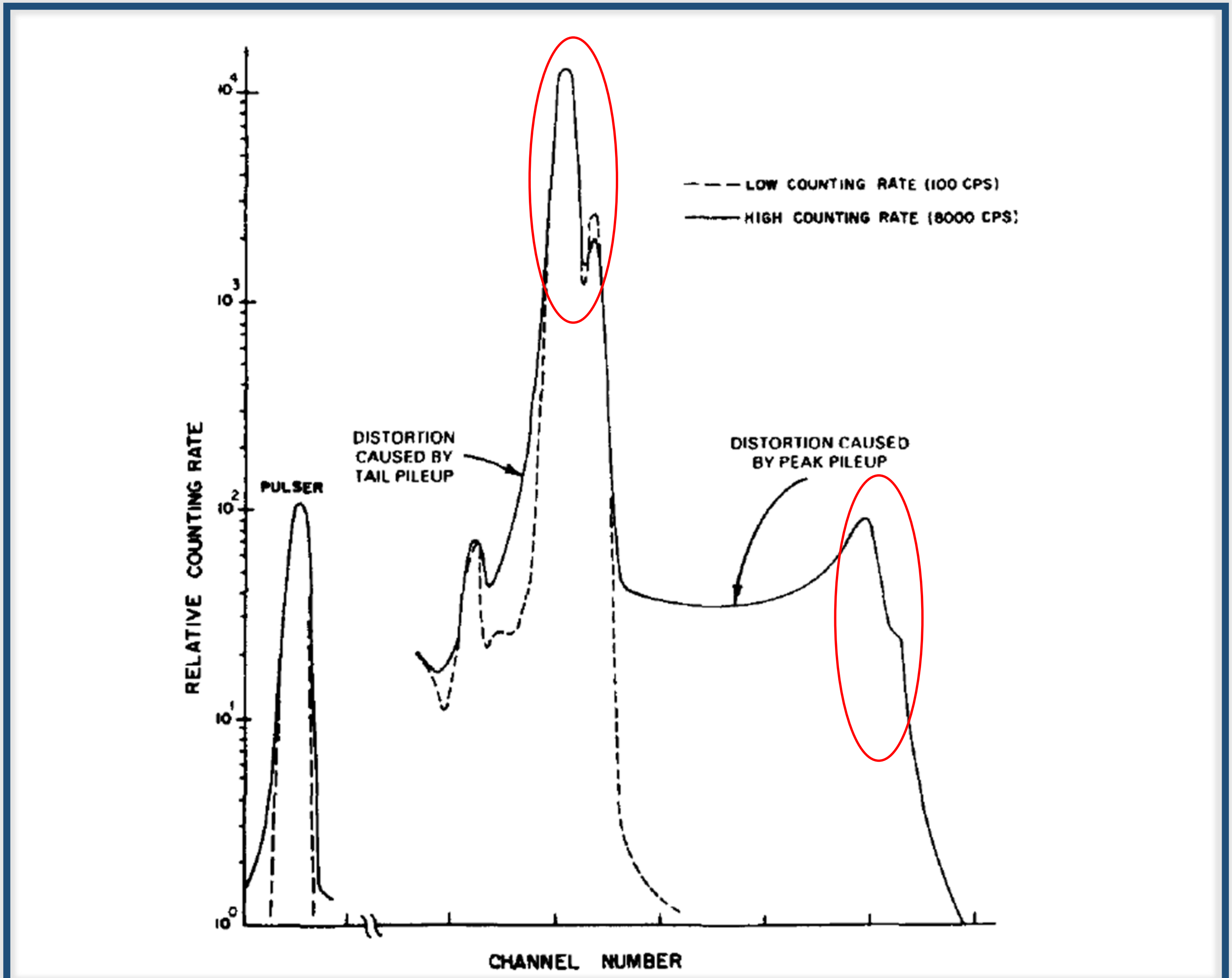
Solution: proper shaping

- Peak pile-up



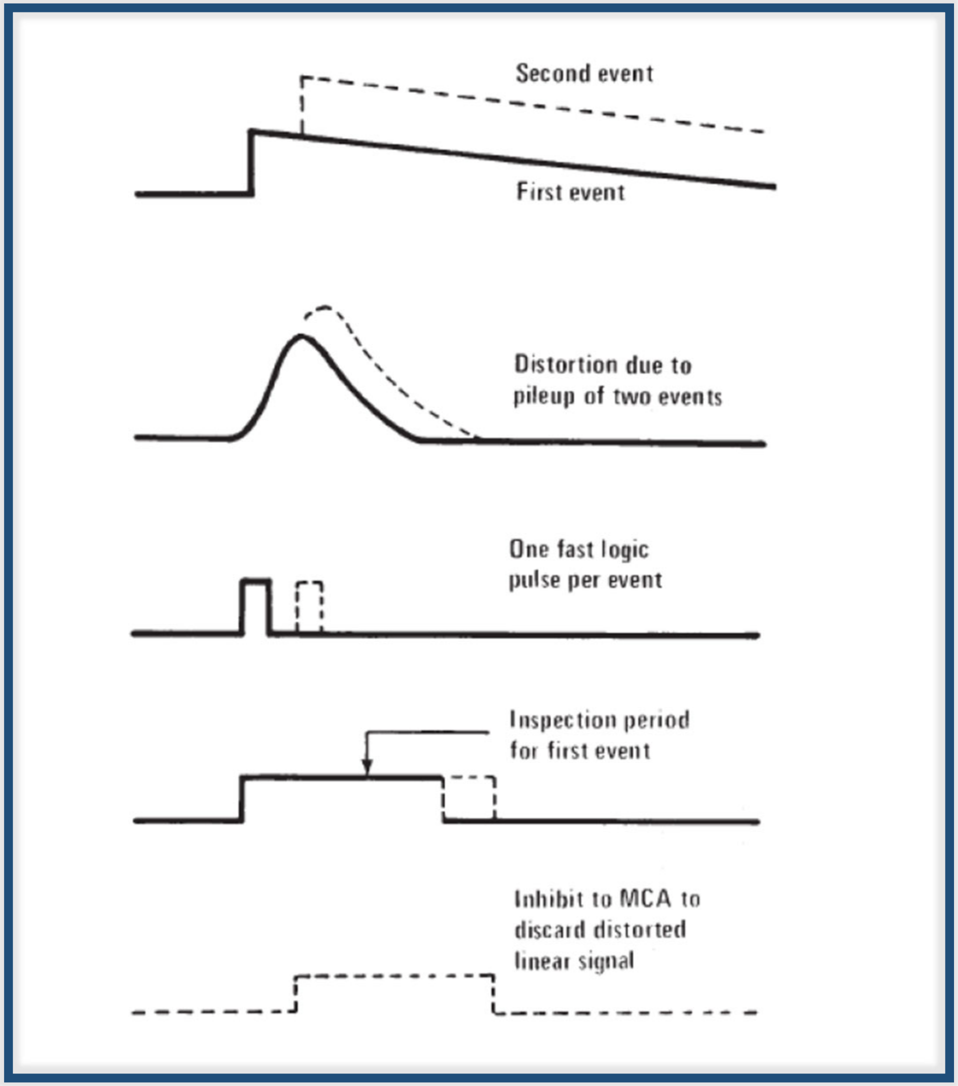
Solution: fast/slow lines (rejectors)

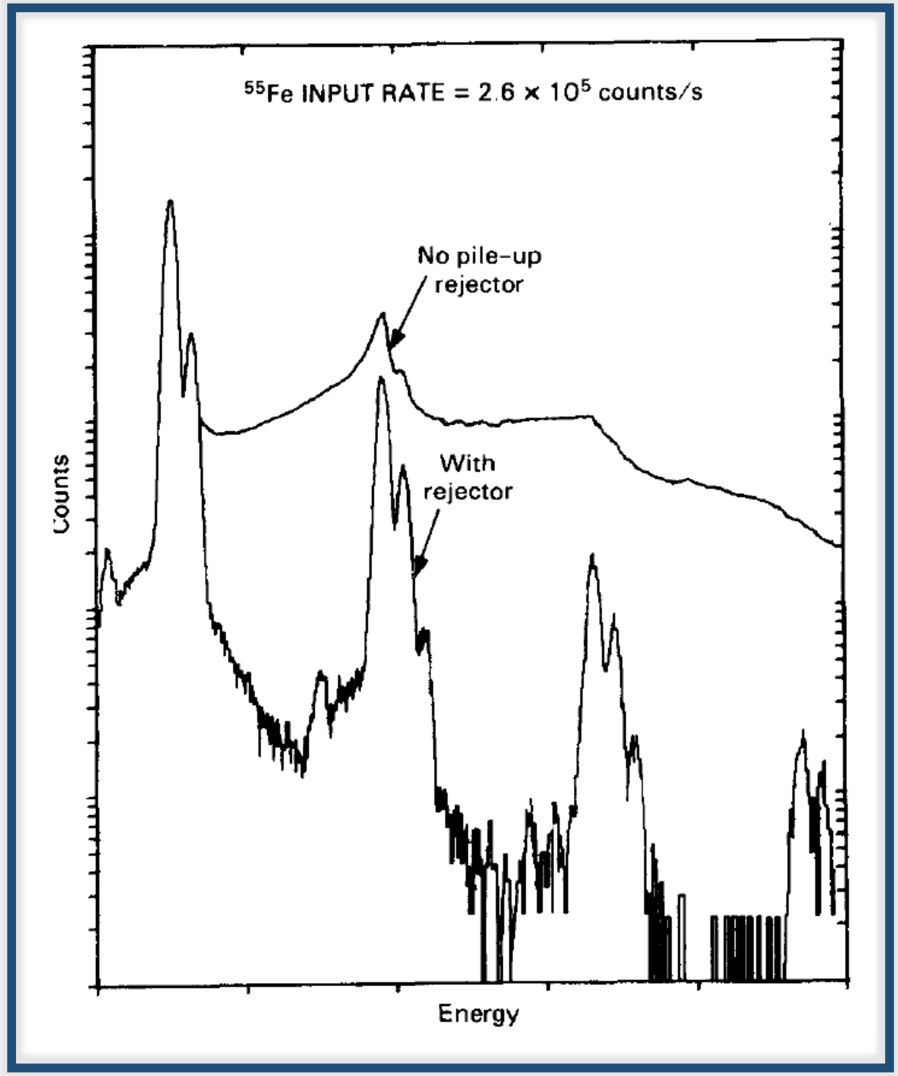
Pile-up: example



Pile-up solution: rejectors

Fast/slow lines





Self-check

- ❖ Explain why, starting from pre-amplified pulses, the output pulses of a CR-RC circuit usually present an "undershoot" (zero crossover)?

- ❖ Describe the different kind of pile-up which can affect measurements with high rate. Define an electronic scheme which can reduce them.

- ❖ What is the advantage of bipolar shaped pulses over monopolar shaped pulses? Do they present drawbacks?