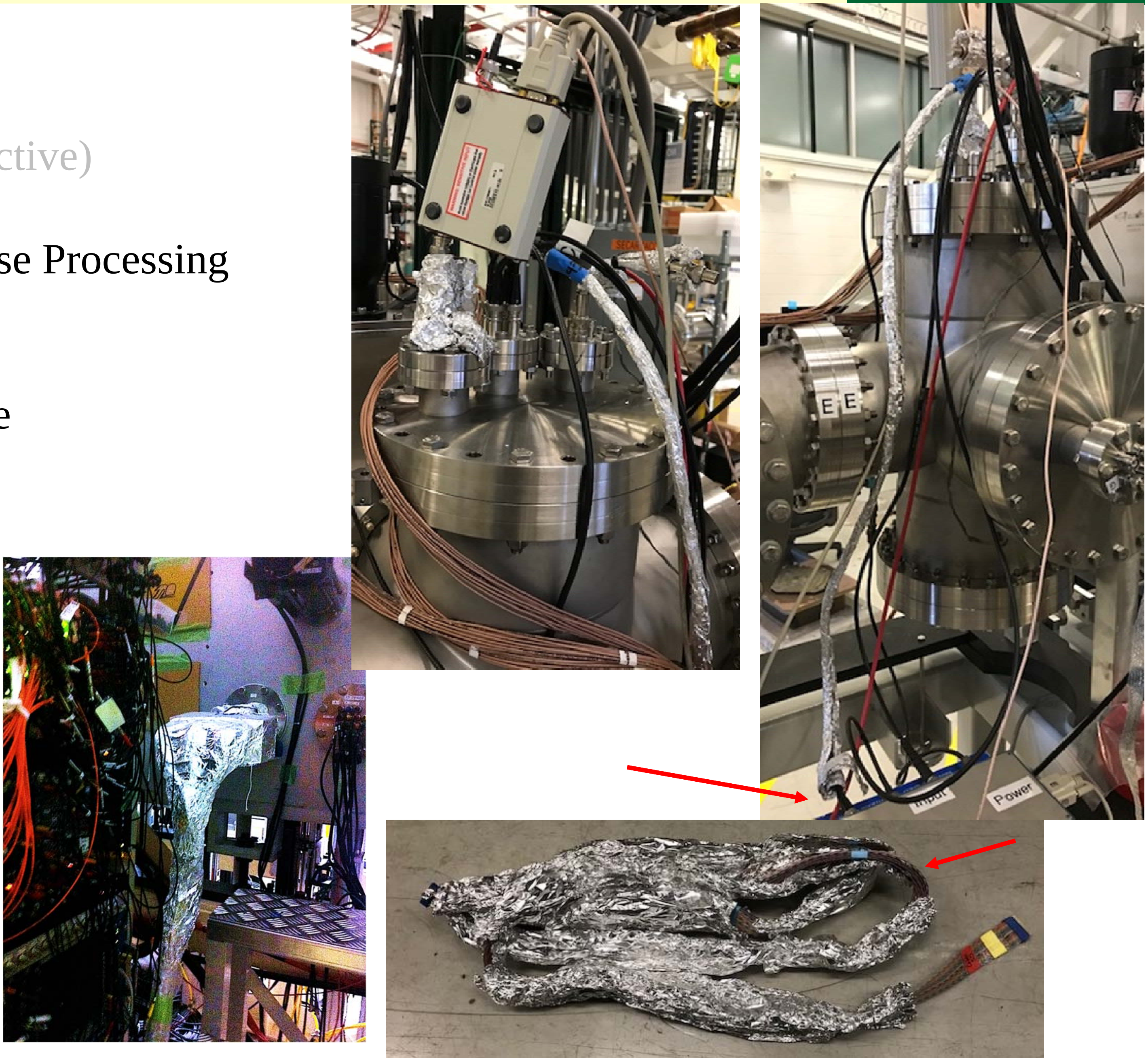
Week 12: Chap. 17 Linear & Logic Signals

Pulse Processing (active)

Linear & Logic Pulse Processing
-- Noise
-- Preamplifiers
--- Voltage sensitive
--- Charge sensitive
-- Discriminators
--- LED, Z/C, CFD

Pulse Analysis



Pulse Analysis: Noise –1–

Noise in an electronic system is an unwanted signal that obscures the wanted signal.
For our purposes there are two classes of electronic noise:

- External noise: pickup of signals from sources outside the detector/electronics. Very often motors of various types, lights, ground loops. In principle, external noise can be avoided by careful construction, grounding, and operation. (more on this in a moment)

- Internal noise: fundamental property of the detector/electronic components – can't be avoided but should be minimized by good design. There are three subclasses of internal noise, two come directly from the relation $I = n\, q_e\, v / L$ for a current carried by "n" electrons with average velocity "v" in an object of fixed length, L. N.B. fluctuations in n or v are possible.

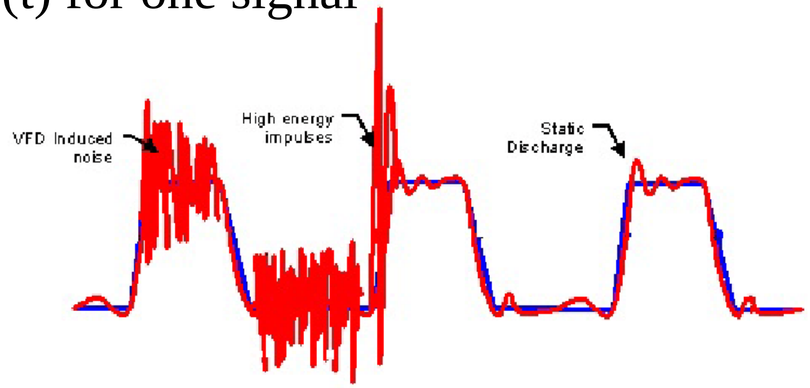
Thermal noise (Johnson noise, series noise, "v"): *mean value is zero* but one expects fluctuations around zero. For a resistor: $\sigma(V) \sim \mathrm{Sqrt}(\ 4\ kT\ R\ \Delta f\ )$ where Δf is the frequency range of observation (bandwidth) – the variance tends to be small except for highest frequencies (fastest signals) – *a White Noise* J.B. Johnson, PR 32 (1928) 97
e.g. $\sigma(V) \sim \mathrm{Sqrt}(\ 4{*}0.026\mathrm{eV}{*}1.6\mathrm{e}{-}19\mathrm{J/eV}{*}R{*}\Delta f\ ) \rightarrow 30\ \mu V$ at 50 Ω, 1ns and 300 K
Real components with R & C in parallel: $\sigma(V) \sim \mathrm{Sqrt}(\ kT/C\ )$

*Shot noise (*parallel noise, "n"*)*: fluctuations in the current due to quantization of electrons.
$\sigma(I) \sim \mathrm{Sqrt}(\ 2\ q_e\ I_{DC}\ \Delta f\ )$ where I_{DC} is the (macroscopic) DC current – *a White Noise*

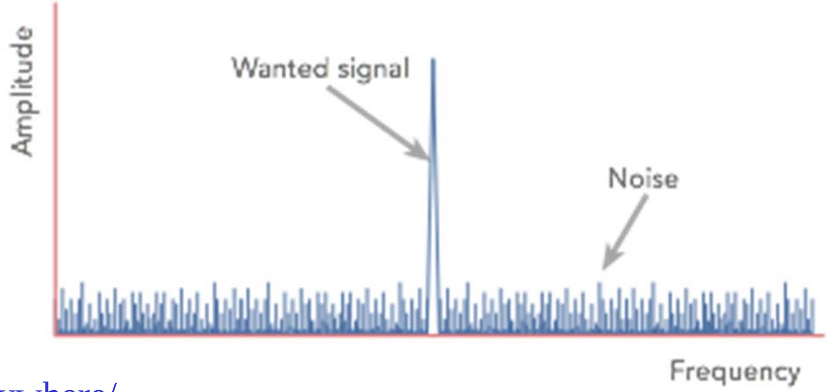
1/f noise: (flicker noise) a catch-all for the fact that many sources of fluctuations have a exponential time dependence which transforms into a 1/f power spectrum. *A Pink Noise*

Noise Spectra

V(t) for one signal

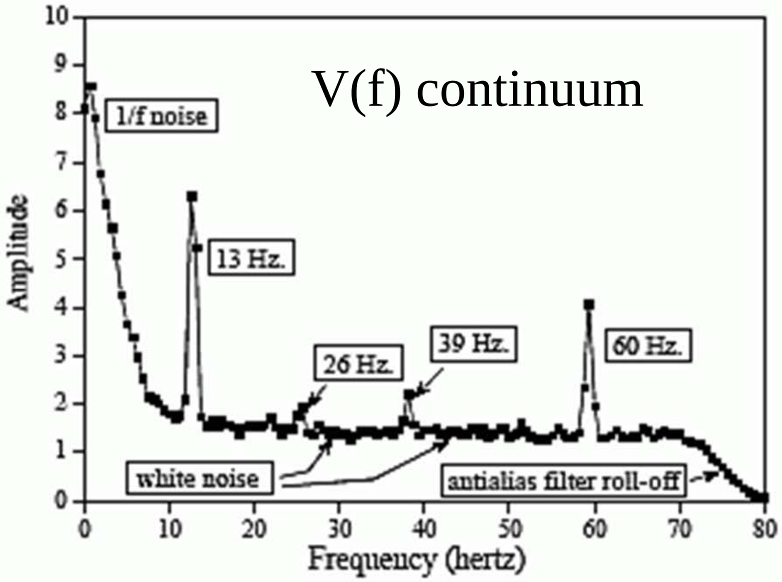


V(f) for one signal



https://www.analogictips.com/electrical-noise-can-come-from-anywhere/

FIGURE 9-2
Example frequency spectrum. Three types of features appear in the spectra of acquired signals: (1) random noise, such as white noise and 1/f noise, (2) interfering signals from power lines, switching power supplies, radio and TV stations, microphonics, etc., and (3) real signals, usually appearing as a fundamental plus harmonics. This example spectrum (magnitude only) shows several of these features.



V(f) continuum

The Scientist and Engineer's Guide to Digital Signal Processing, S.W. Smith
https://www.dspguide.com/ch9/1.htm

Pulse Analysis: Noise –2–

Why is the preamp discussed separately from the shaping amplifier?

Internal sources of noise tend to be most significant at the input stage where the true signal is smallest. First stage of amplification should be sufficient that signal >> noise pickup during transmission. Always test to determine if S/N depends on shaping amplifier gain.

Noise is generally referred to in terms of *Equivalent Noise Charge* (ENC or Q_{EN}) which can be directly compared to the number of electrons created in the detector and input into the preamplifier. The ENC can be given in Coulombs or more recently "electrons".

The variances of independent noise sources are to be combined in quadrature, as usual.

There is usually an optimum shaping time for a fast signal, longer times average over the thermal noise but tend to increase the shot noise.

$$Q_{EN}^2 = C^2 q_N^2 \, f_v / \tau \; + \; i_N^2 \, \tau \, f_i$$

i_N and q_N are the (source) noise terms
f_i and f_v are factors related to shaping circuit and close to unity but $f_i < f_v$

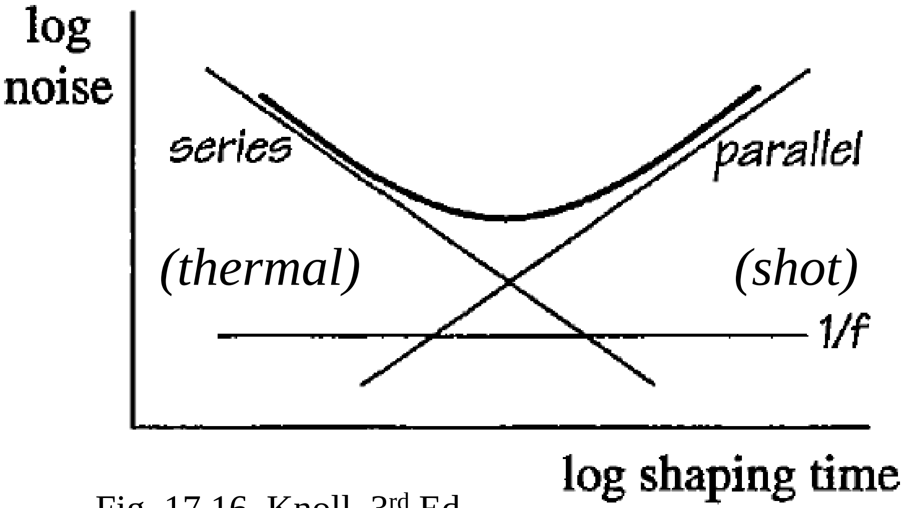


Fig. 17.16 Knoll, 3rd Ed.

17.26, 4th Ed.

Pulse Analysis: Noise –3–

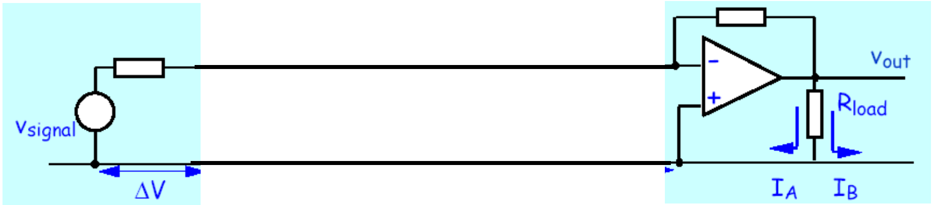
Sources of external noise:

Direct injection of EM energy – lights, fluctuations in power supply voltages (60 Hz, harmonics), High frequencies from switching power supplies (kHz).

Pickup of EM radiation through capacitive coupling – Motors (60 Hz) … TMP’ s (MHz), RF systems, Computers and Data-buses in CAMAC, VME crates, AC-Welders

Microphonics – mechanical variation of (detector) capacitance

Ground loops – local & long distance



Solutions?

Complete metal enclosure, gaps must be << λ (3cm at 1 MHz, 3μm at 1 GHz) and thick!
Penetration of EM wave falls exponentially with coefficient, δ=sqrt(ρ / π f μ) = 85mm/sqrt(f)
e.g. ~0.1mm @1 MHz, 1mm @ 0.01MHz in Al, aluminum foil is 0.5 mil .. 0.013 mm

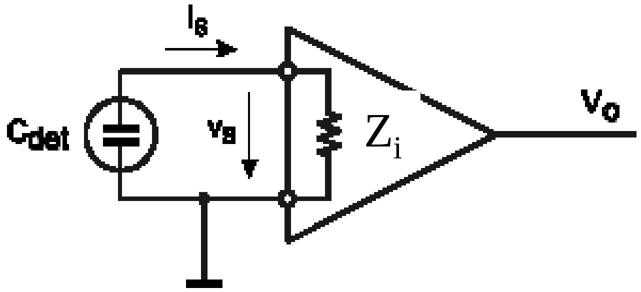
Bypass capacitors from signal line to ground with capacitance: $\omega C >> 1$

Opinion: Ground all components with very low impedance connections (keep distances short for analogue signals, use differential signals, optical transmission over long distances)

Pulse Analysis: preamplifiers (op-amp reminder)

Operation amplifier – voltage gain, A

$V_{out} = A\,V_{in}$, Impedance Z_i



<u>Concept: connect op amp to detector?</u> – output pulse shape (in time) depends on product of $Z_i\,C_{det}$ as discussed before .. Doesn't work well for radiation detectors, as is, Z_i should be ∞ in ideal device, real input impedance depends on details of construction – could vary significantly from chip to chip!

<u>Voltage sensitive amplifier</u>: -A & $Z_i \sim \infty$

($V_{out} = -A\,V_{in}$ with no feedback)

$V_{out} \sim -(R_2 / R_1)\,V_{in}$ when $A \gg R_2 / R_1$

(R_1 is an important thermal noise source)

Recall $V_{in} = Q_{in} / C_{det}$ … if C_{det} varies then trouble

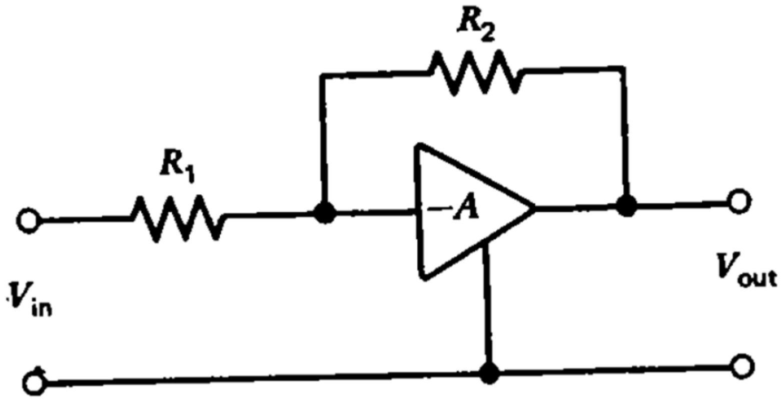
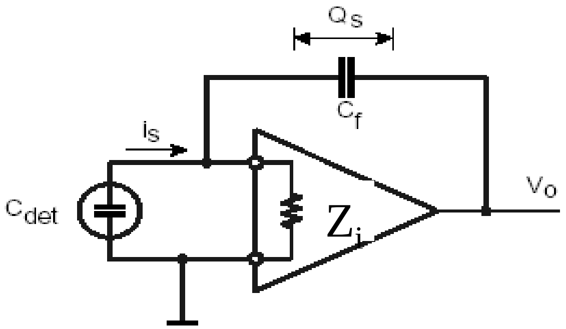


Fig. 17.1 Knoll, 3rd Ed.

16.12, 4th Ed.

Pulse Analysis: charge sensitive preamplifier

Charge sensitive system: inverting, -A & $Z_i \sim \infty$



$V_{out} = -A\,V_{in}$; $Q_{out} = Q_{in}$ ($Z_i \sim \infty$, $A \sim$ large)

Note: same problem with direct connection of detector, add C_i

Then: $V_{out} = -A\,Q_{in} / [C_i+(A+1)\,C_f\,] \sim -\,Q_{in} / C_f$

$V_{out} \sim -(Q_{in} / C_f\,)\,e^{-t/R_fC_f}$ with feedback R_f to drain C_i

Pulser or "test" input

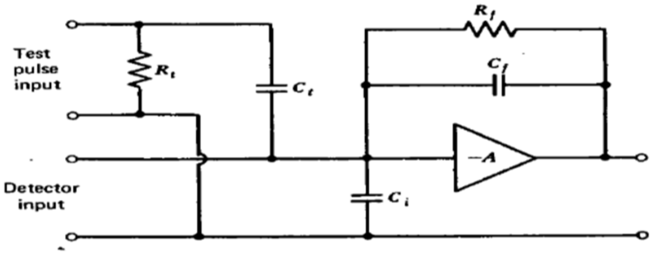


Fig. 17.2 Knoll, 3rd Ed.

16.17, 4th Ed.

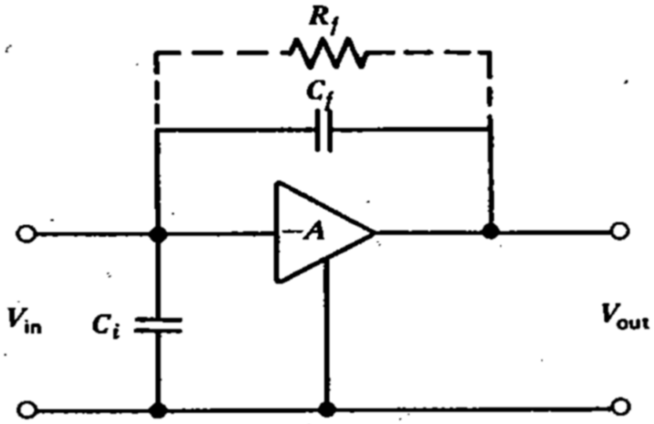
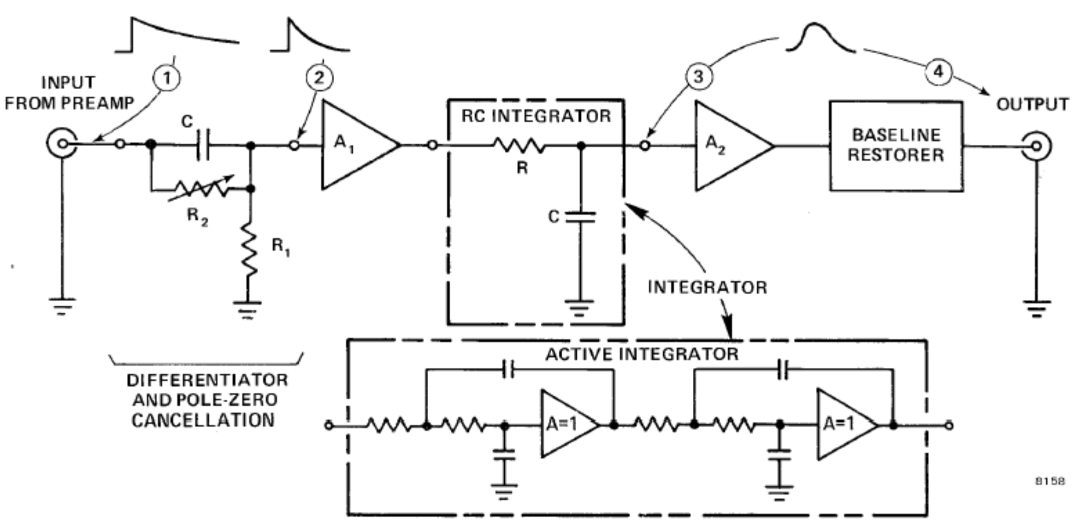


Fig. 17.2 Knoll, 3rd Ed.

16.13, 4th Ed.

Pulse Analysis: CR-(RC)^n shaper



Adding integration stages makes the output more symmetric and thus gives a shorter pulse.

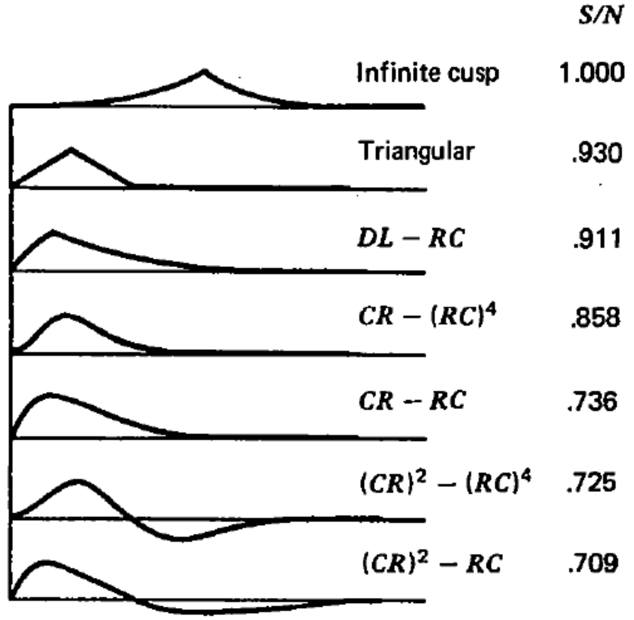


Fig. 17.15 Knoll, 3rd Ed.

17.24, 4th Ed.

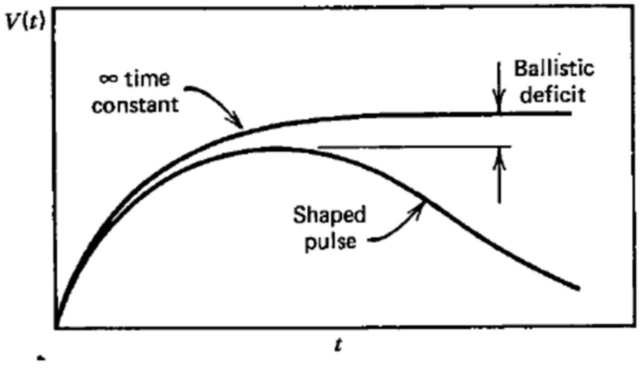


Fig. 17.13 Knoll, 3rd Ed.

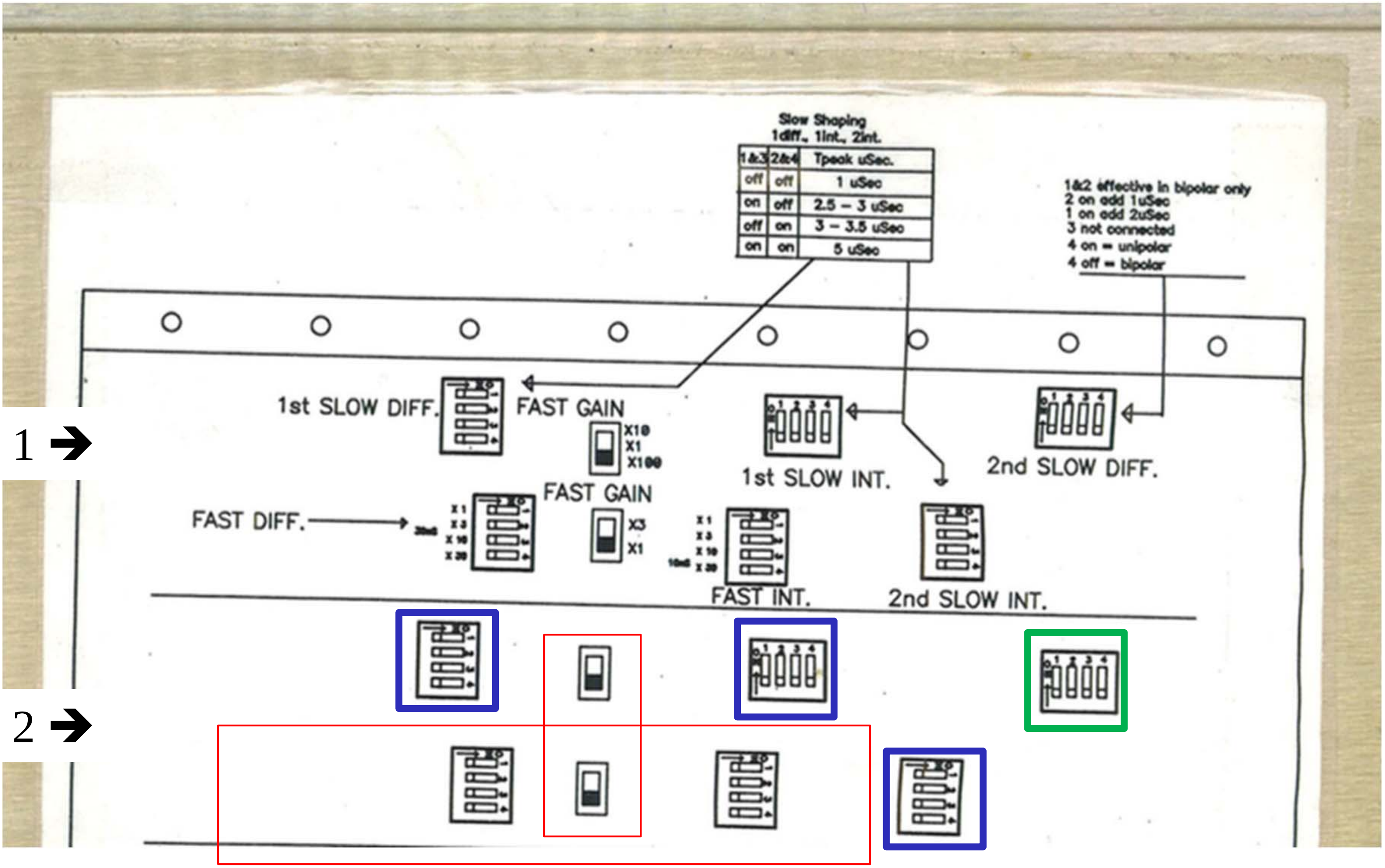
17.22, 4th Ed.

One more issue with shaping amps:
Can the shaping time be too short? Yes …

Thus, variations in the rise time will lead to signals with different pulse heights. Most significant for Ge detectors and proportional counters without grids.

Example: Quad Shaper

“Quad” refers to four identical linear channels.   Each has “fast” and “slow” outputs



Slow Shaping
1diff., 1int., 2int.

1&3	2&4	Tpeak uSec.
off	off	1 uSec
on	off	2.5 – 3 uSec
off	on	3 – 3.5 uSec
on	on	5 uSec

1&2 effective in bipolar only
2 on add 1uSec
1 on add 2uSec
3 not connected
4 on = unipolar
4 off = bipolar

Channel 1 ➔

Channel 2 ➔

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Pulse Analysis: aside on S/N & shapes

IEEE/NS 15(1968)455_Radeka-NoiseAndShape

NIM 41(1966)173_E.Gatti-SigToNoise (white noise)

NIM A287(1990)513_E.Gatti-OptimumShapes (1/f & white noises)

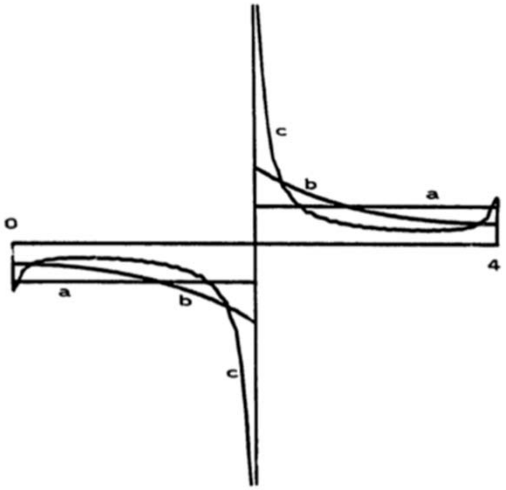
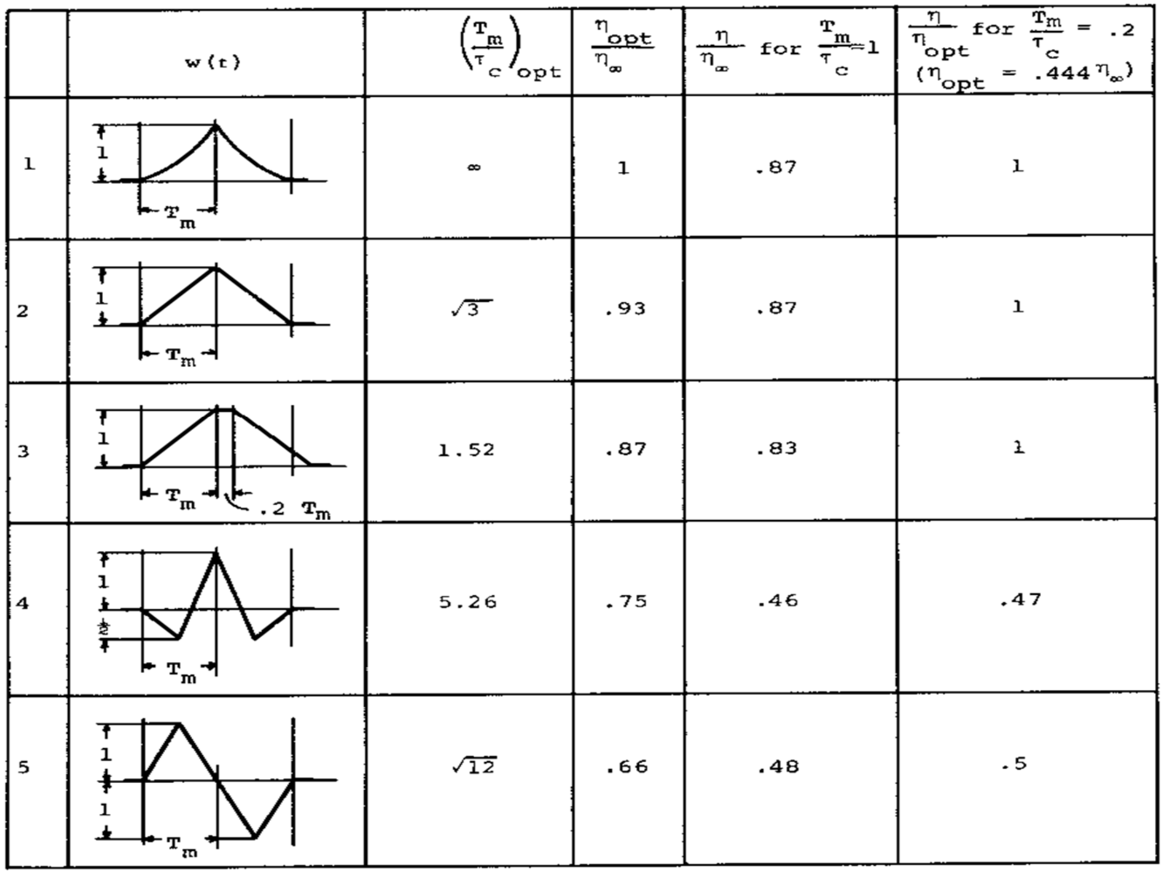


Fig. 7. Weighting functions calculated at the output of the integrating preamplifier, when only series white noise is present (curve a), when series and parallel white noises are present (curve b) and when $1/f$ noise is added (curve c). Processing time is equal to $2T_p = 4\tau_c$.

a – series, thermal, “v”
b – a & parallel, shot, “n”
c – a & b & 1/f

TABLE I

Signal-to-Noise Ratio for Various Weighting Functions



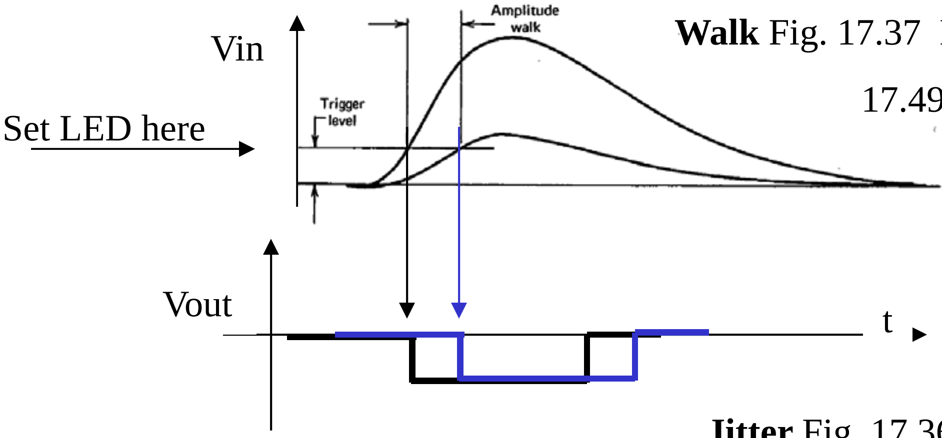
	w(t)	$\left(\frac{T_m}{\tau_c}\right)_{opt}$	$\frac{\eta_{opt}}{\eta_\infty}$	$\frac{\eta}{\eta_\infty}$ for $\frac{T_m}{\tau_c}=1$	$\frac{\eta}{\eta_{opt}}$ for $\frac{T_m}{\tau_c} = .2$ ($\eta_{opt} = .444\,\eta_\infty$)
1	1 T_m	∞	1	.87	1
2	1 T_m	$\sqrt{3}$	.93	.87	1
3	1 T_m .2 T_m	1.52	.87	.83	1
4	1 $\frac{1}{2}$ T_m	5.26	.75	.46	.47
5	1 1 T_m	$\sqrt{12}$	.66	.48	.5

η_∞ = signal-to-noise ratio for matched filter and $T_m \rightarrow \infty$

τ_c = noise-corner time constant

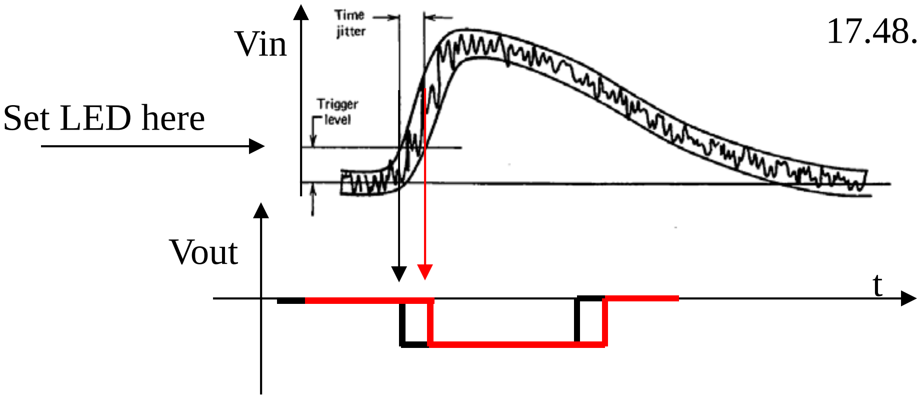
Pulse Analysis: Leading Edge Discriminator

We need a way to generate a logic pulse from the analogue signal that will maintain a fixed time relationship to the original interaction of the radiation in the detector. Two sources of problems: walk and jitter.



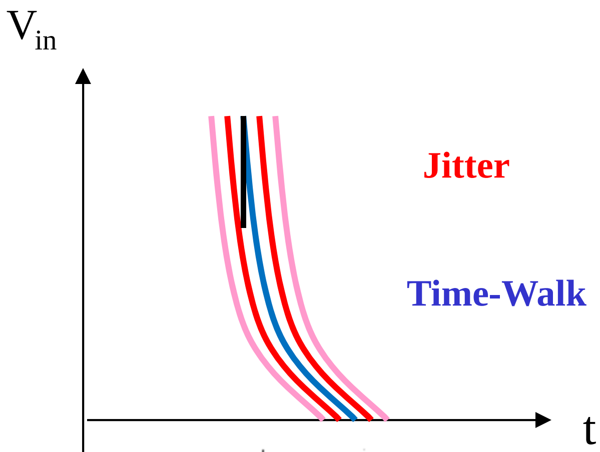
Walk Fig. 17.37 Knoll, 3rd Ed.

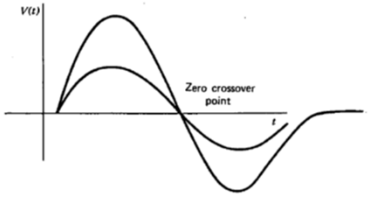
17.49 4th Ed.



Jitter Fig. 17.36 Knoll, 3rd Ed.

17.48. 4th Ed.





Z/C of bipolar pulse is constant in time but slow

Fig. 17.39 Knoll, 3rd Ed. 17.51, 4th Ed.

Pulse Analysis: Constant Fraction Discriminator

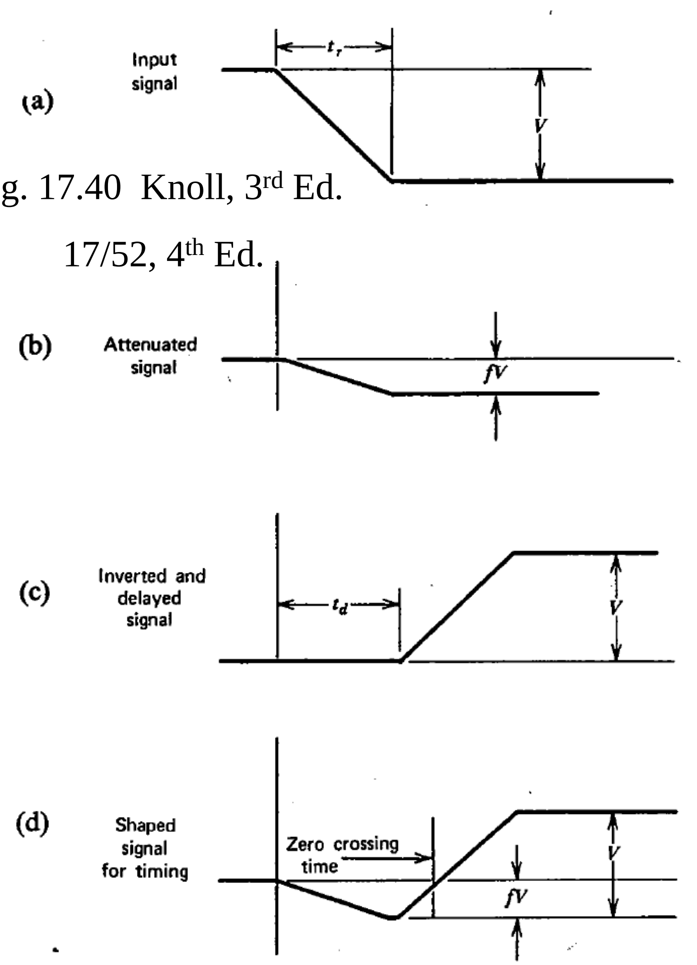


Fig. 17.40 Knoll, 3rd Ed.

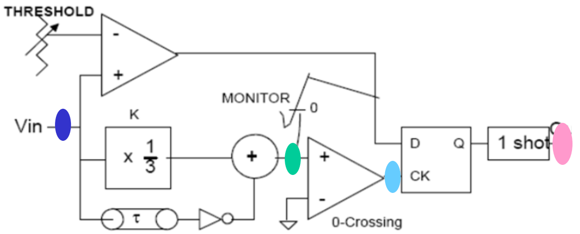
17/52, 4th Ed.

For a linear rise (or fall) slope zero-crossing occurs at t = t_d / 1-f

Thus: set t_d = f * t_r

Phillips 715

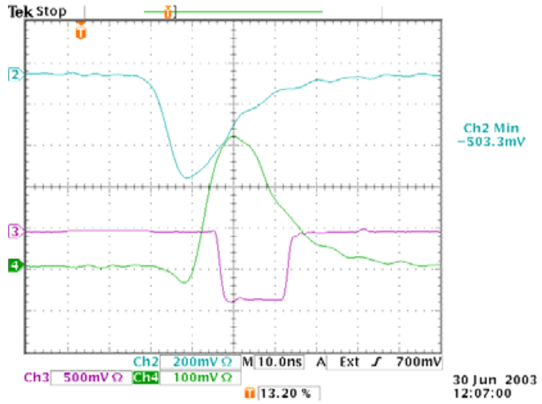
f =1/3



Input

Output

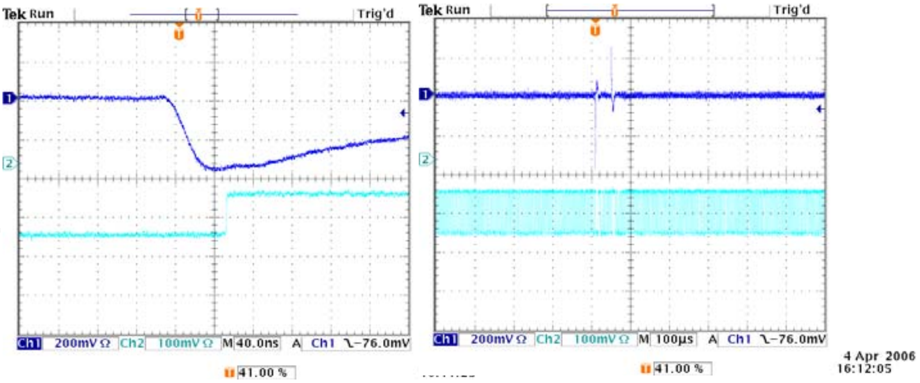
Monitor



Tennelec-455 f=0.2

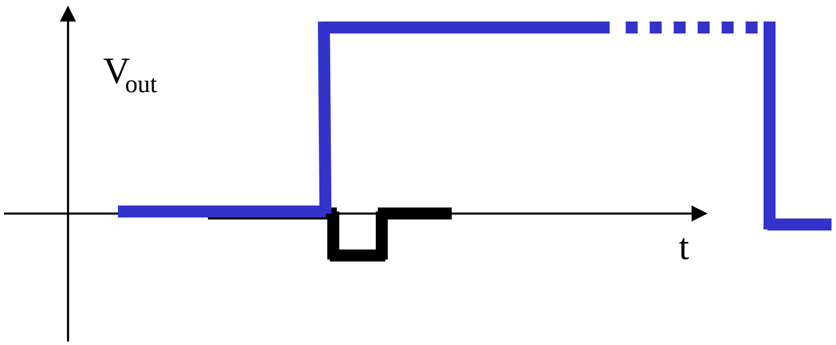
Input

Monitor



Time width is given by rise-time / (S/N)

Pulse Analysis: Aside on “logic” pulses

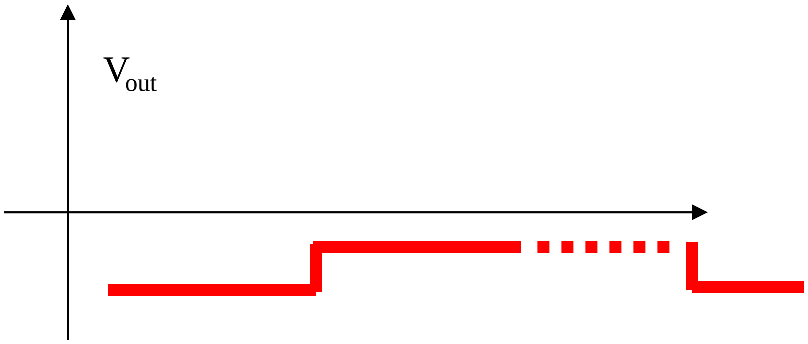


TTL logic, +5V, ≥ 1μs

“positive” logic, high-true

NIM logic, -1V, ≥ 10ns

“negative” logic, “low-true”



ECL logic, -1.75 or -0.9V

“positive” logic, high-true but < 0V

N.B. Differential Signals

Chap. 17 – Pulse Analysis: Question

A charge-sensitive preamp is attached to a surface barrier detector for detecting alpha particles. What is the maximum *equivalent noise-charge* (ENC) for the preamp if the user wants to resolve the two alpha lines emitted by an ^{241}Am source?