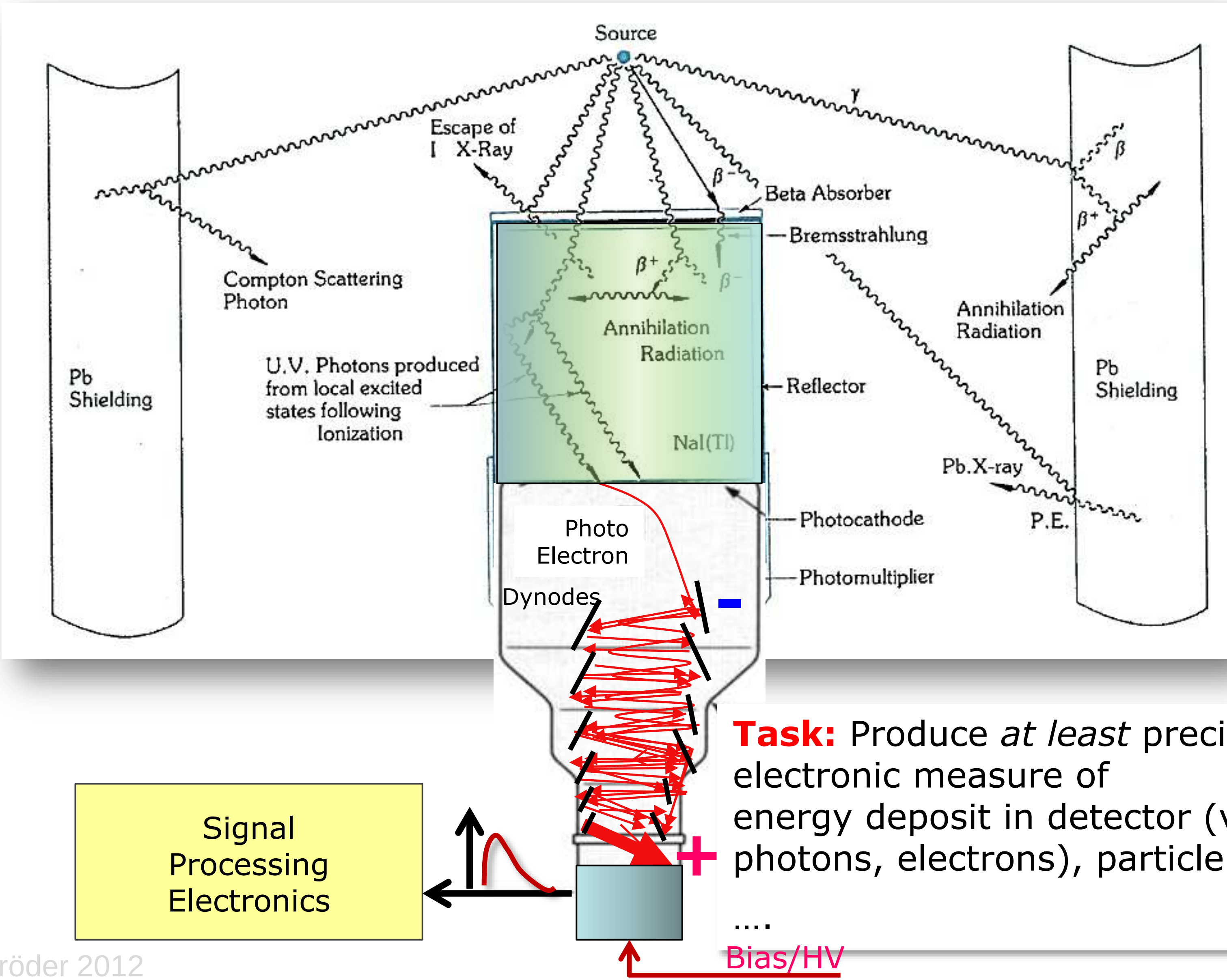
Intro to Electronic Signal Processing

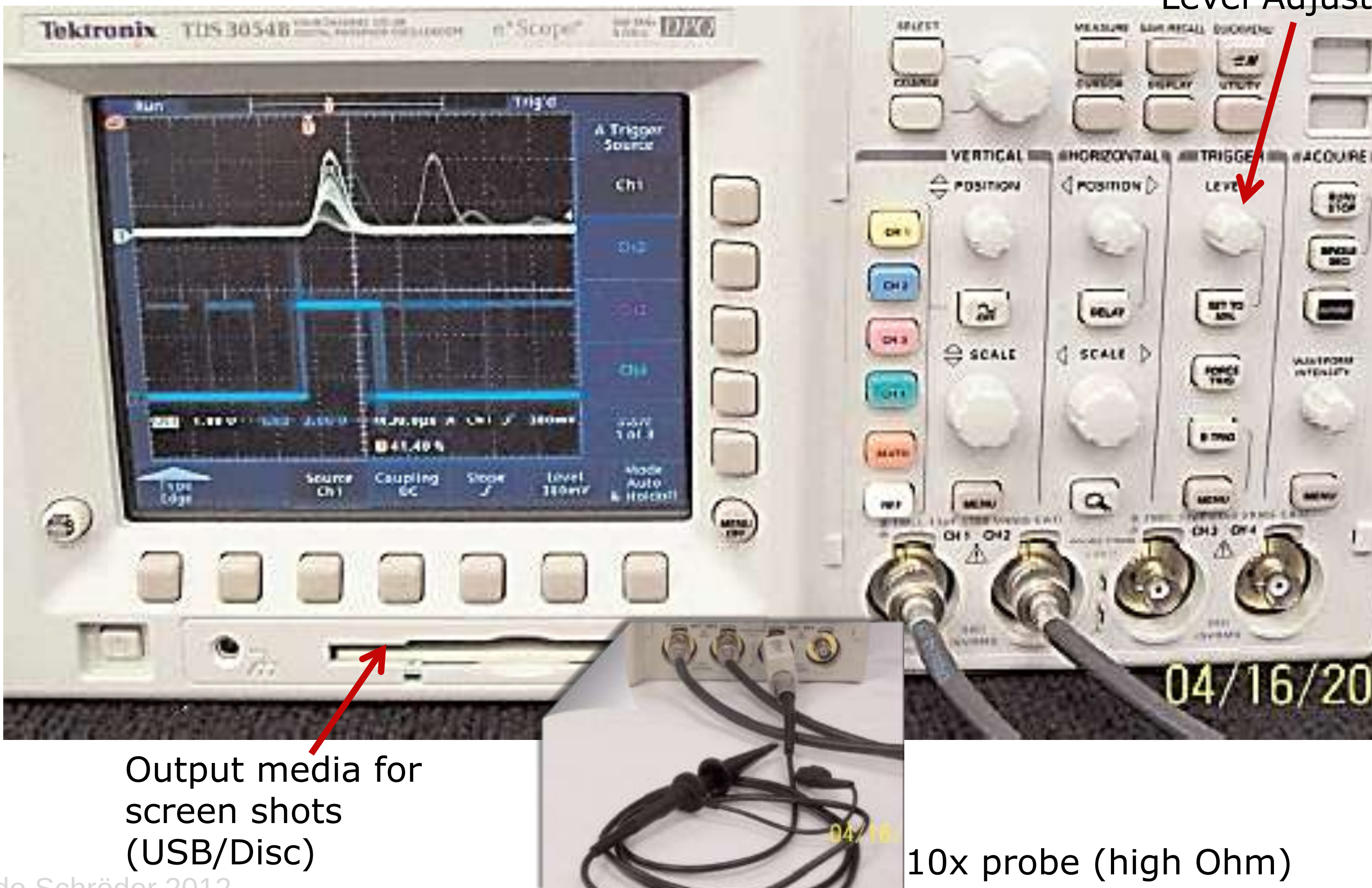
Detector Response to Radiation



Task: Produce *at least* precision electronic measure of energy deposit in detector (via. photons, electrons), particle ID, ...

Digital Sampling Oscilloscope

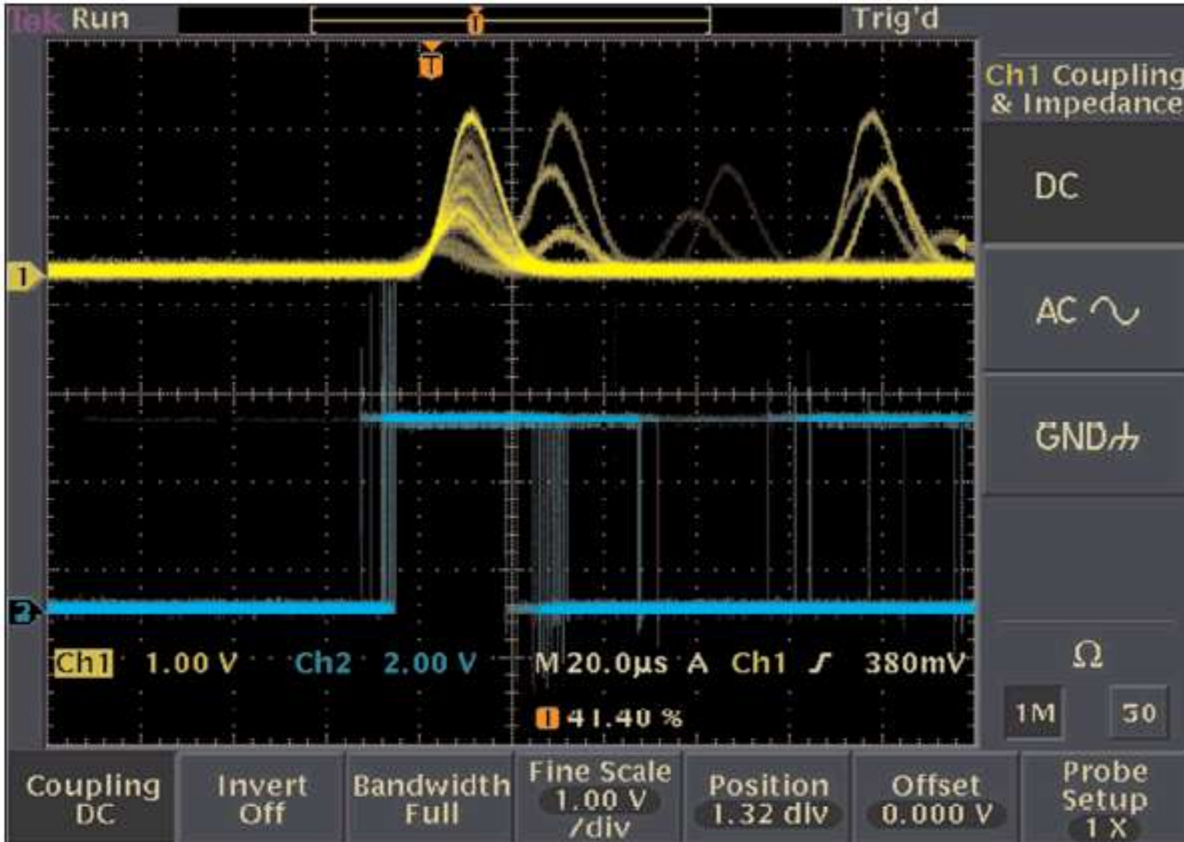
Signal Trigger
Level Adjust



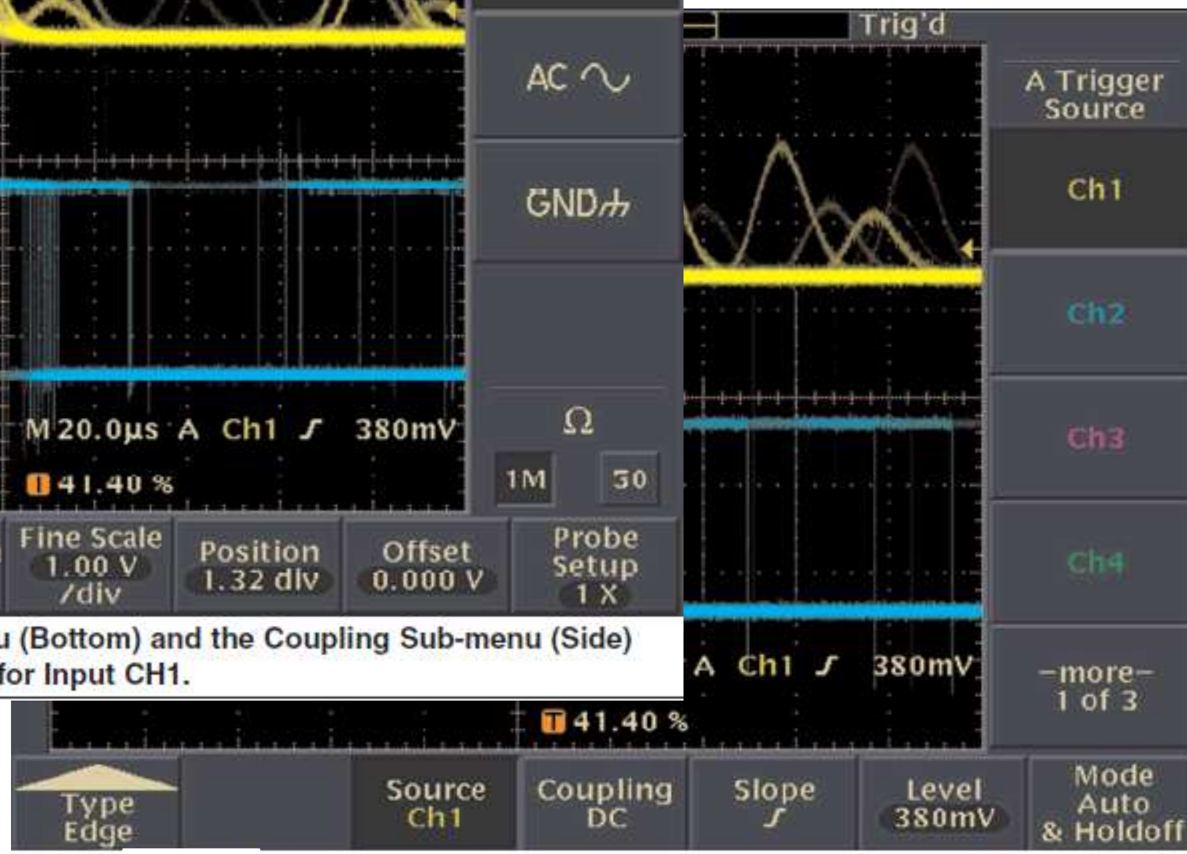
Output media for
screen shots
(USB/Disc)

10x probe (high Ohm)

Scope Screen Shots



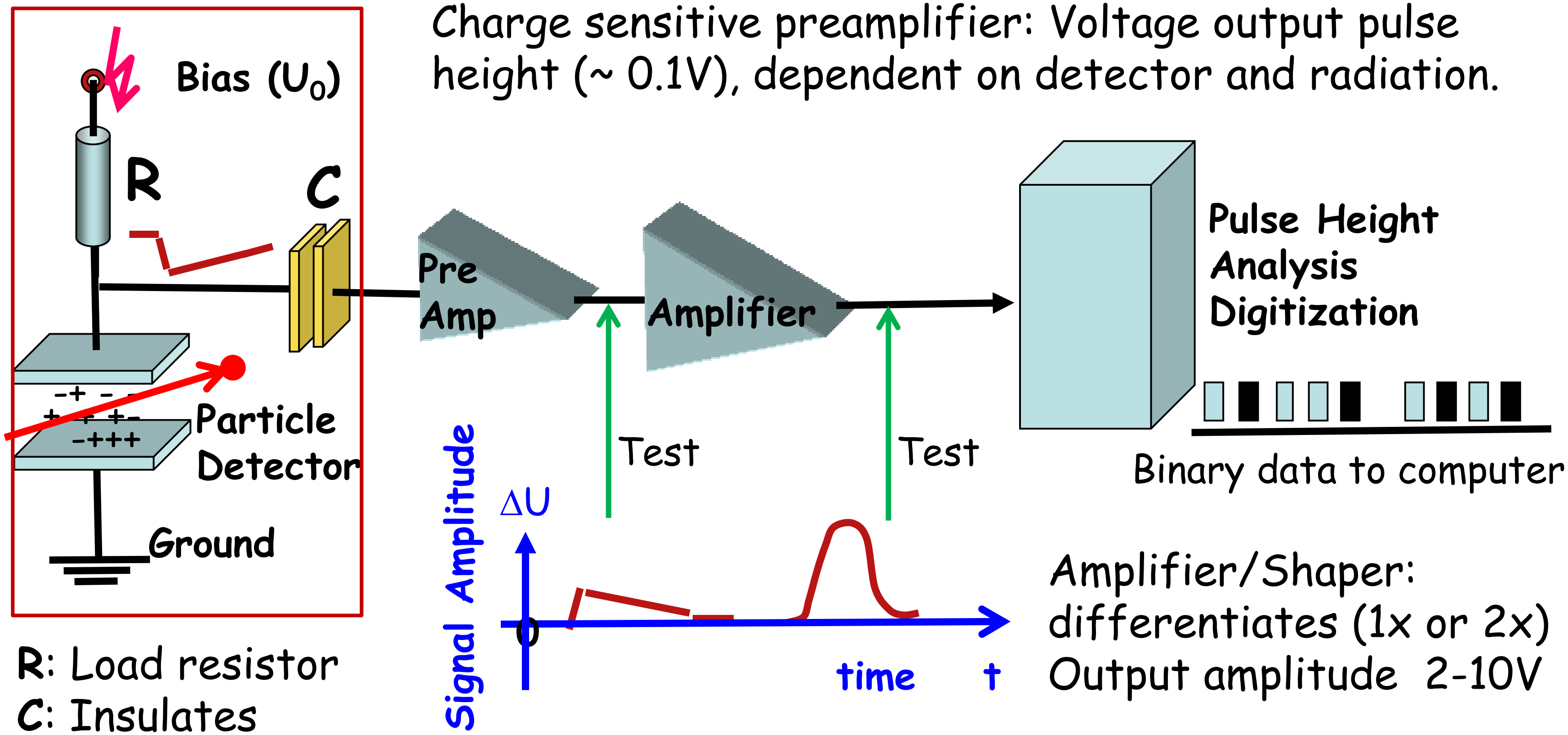
The Vertical Scale Menu (Bottom) and the Coupling Sub-menu (Side) for Input CH1.



The Trigger Menu (Bottom) and Source Sub-menu (Side).

Basic Radiation Detection/Counting System

Charge sensitive preamplifier: Voltage output pulse height (~ 0.1V), dependent on detector and radiation.



Amplifier/Shaper:
differentiates (1x or 2x)
Output amplitude 2-10V

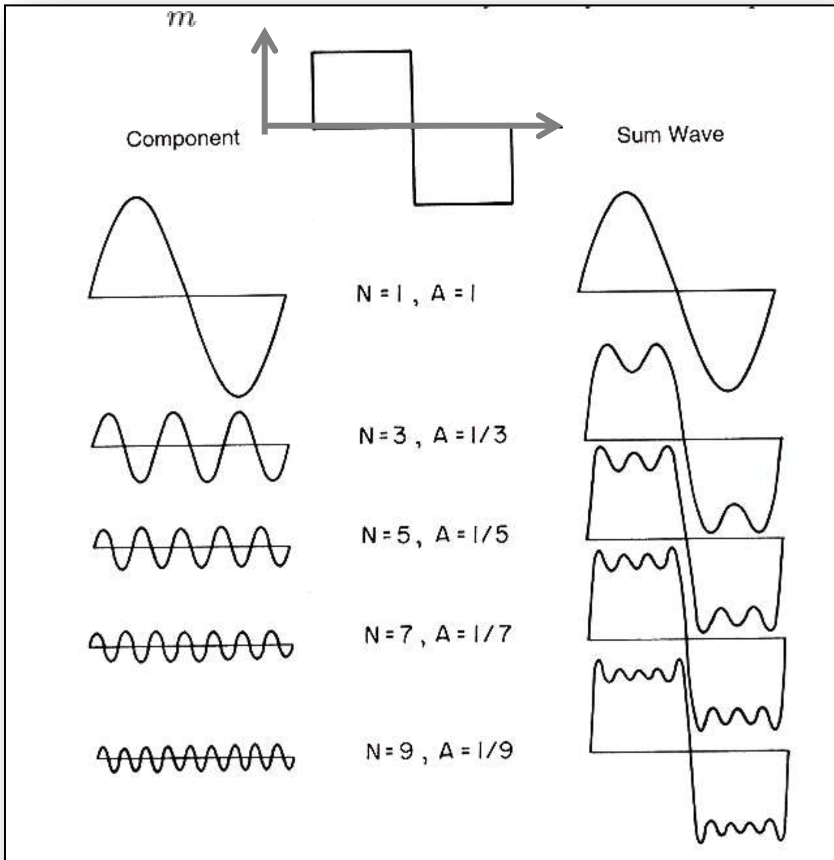
R: Load resistor
C: Insulates electronics from HV bias.
Pulse height 20-100 mV

Interaction of radiation with detector temporarily ionizes medium
→ time (frequency) dependent change ΔU in electric potential at collector electrodes, **transmitted as elm. Wave g(t)~f(ω).**

Time and Frequency Domains

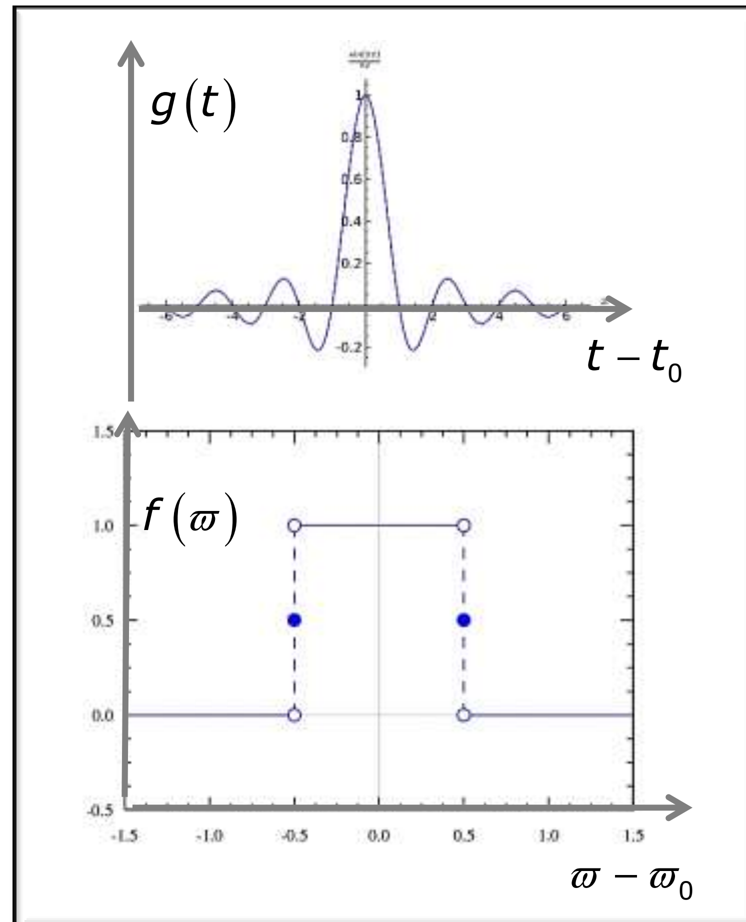
Fourier Series: adding harmonic components. Example $A_m=1/m$, $B_m=0$

$$f(t) = \sum_m [A_m \sin(2\pi m f t) + B_m \cos(2\pi m f t)]$$



Fourier Transforms: adding continuous frequency spectrum components.

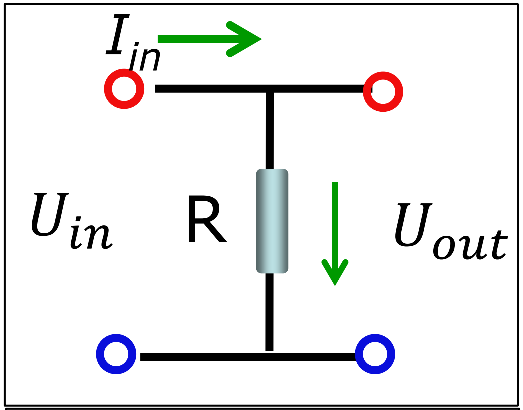
$$f(\varpi) = (2\pi)^{-1/2} \int g(t) \exp[i\varpi t] dt$$



Time dependent signals processed by frequency dependent electronics

W. U

Passive Electronic Circuit Components

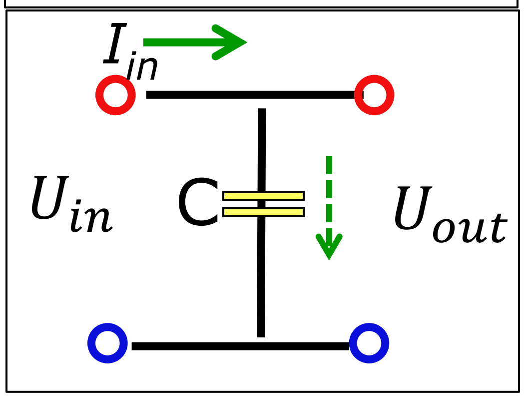


Assume no load on output ($R_{out} \rightarrow \infty$)

$$U_{out} = I_{in} \cdot R = U_{in} \rightarrow Z_R := R = U_{in} / I_{in}$$

Current flows continuously (DC or AC voltage)

$$U_{out}(t) = I_{in}(t) \cdot Z_R = U_{in}(t), \text{ Impedance } Z_R$$

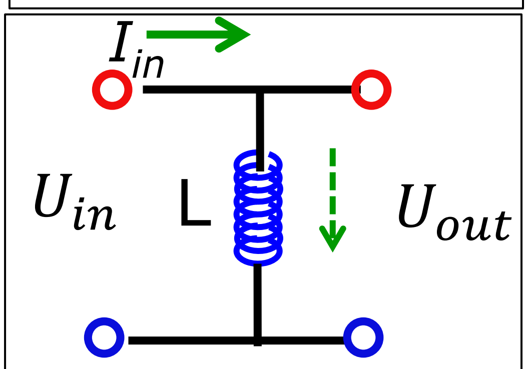


Current flows only until C is charged to $Q=C \cdot U_{in}$

$$I = \frac{dQ}{dt} = C \cdot \frac{dU_{in}}{dt} \rightarrow I = 0 \text{ for } U_{in} = const$$

$$U_{in}(t) = U_0 \cdot e^{i\varpi t} \rightarrow I(t) = (i\varpi C) \cdot U_{in}(t)$$

$$\text{Impedance } Z_C := U_{in}(t)/I(t) = (i\varpi C)^{-1} \xrightarrow[\varpi \rightarrow \infty]{} 0$$

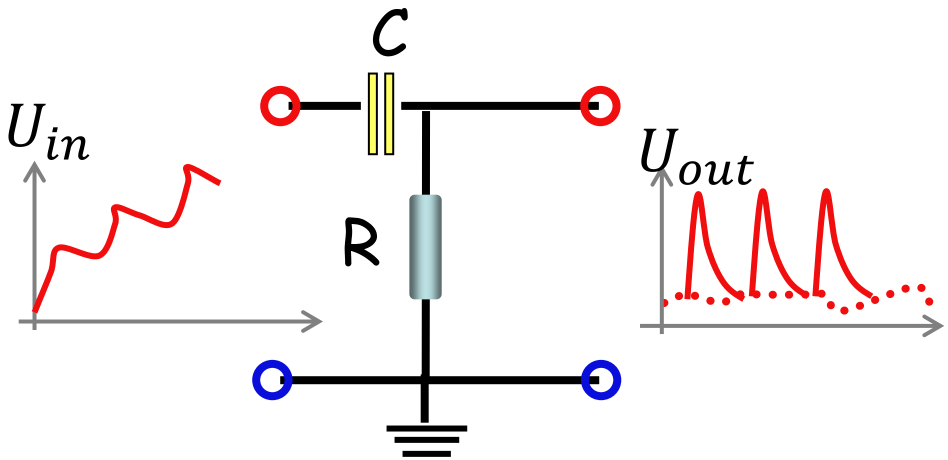


Inductance L makes a short circuit for U_{in} = const. → U_{out}=0. But for AC current/voltage

$$I_{in}(t) = I_0 \cdot e^{i\varpi t} \rightarrow U_{out} = -L\frac{dI_{in}}{dt} = -(i\varpi L) \cdot I_{in}(t)$$

$$\text{Impedance } Z_C := U_{in}(t)/I(t) = (-i\varpi L) \xrightarrow[\varpi \rightarrow \infty]{} \infty$$

Electronic Circuit Components

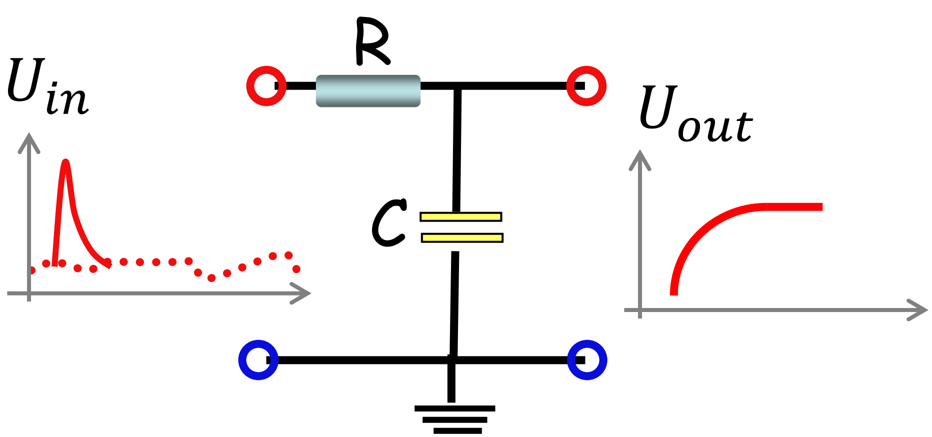


Differentiator (high pass)

$$U_{out} = \frac{R}{R + Z_C} U_{in}$$

$\omega \rightarrow \infty$: $Z_c \rightarrow 0$, $U_{out} = U_{in}$

Output images rapid changes of input signal $U_{out} \propto dU_{in}/dt$



Integrator (low pass)

$$U_{out} = \frac{Z_C}{R + Z_C} U_{in}$$

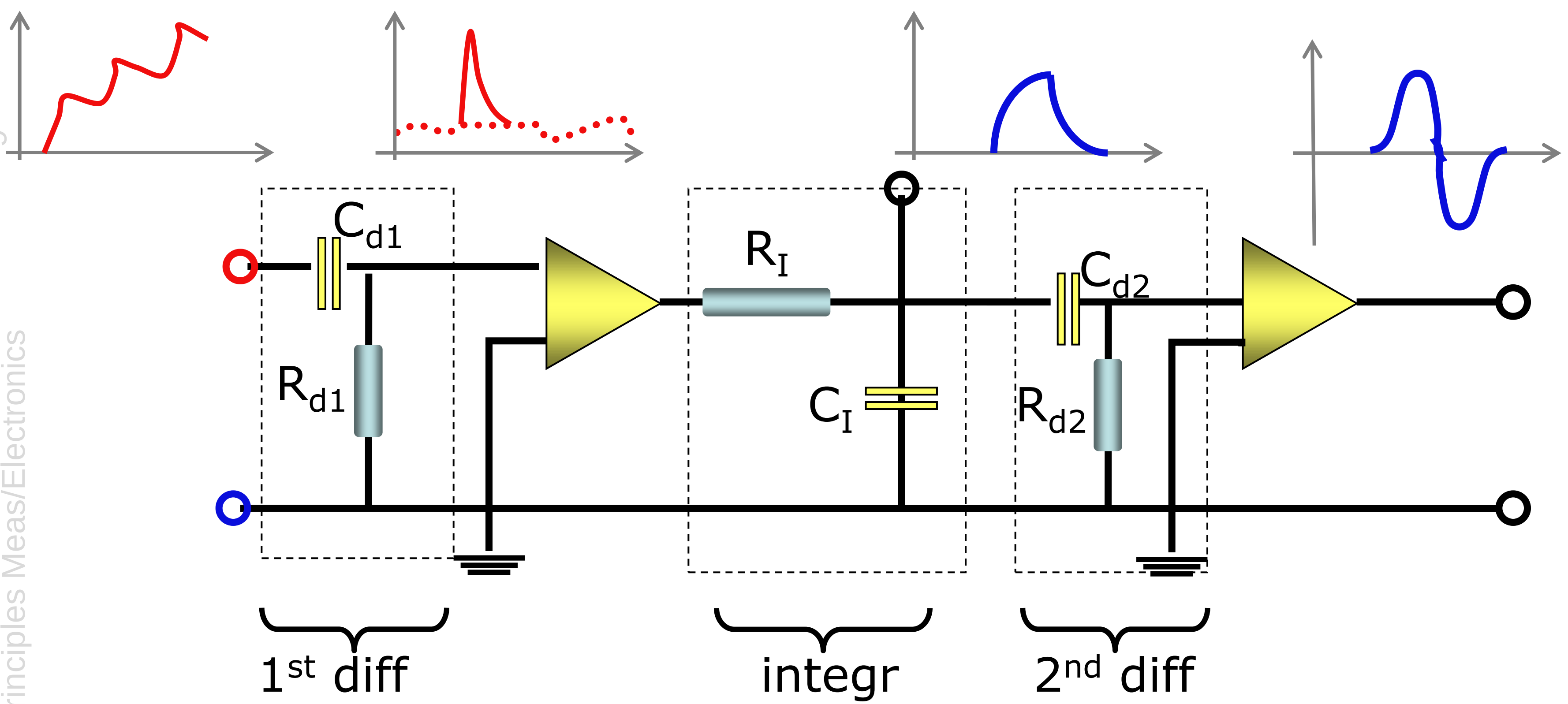
$\omega \rightarrow 0$: $Z_c \rightarrow \infty$, $U_{out} = U_{in}$

Filters out fast changes of input signal, smoothens input $U_{out} \propto \int U_{in} dt$

Combination of differentiators + integrators makes selective filter ("band pass")

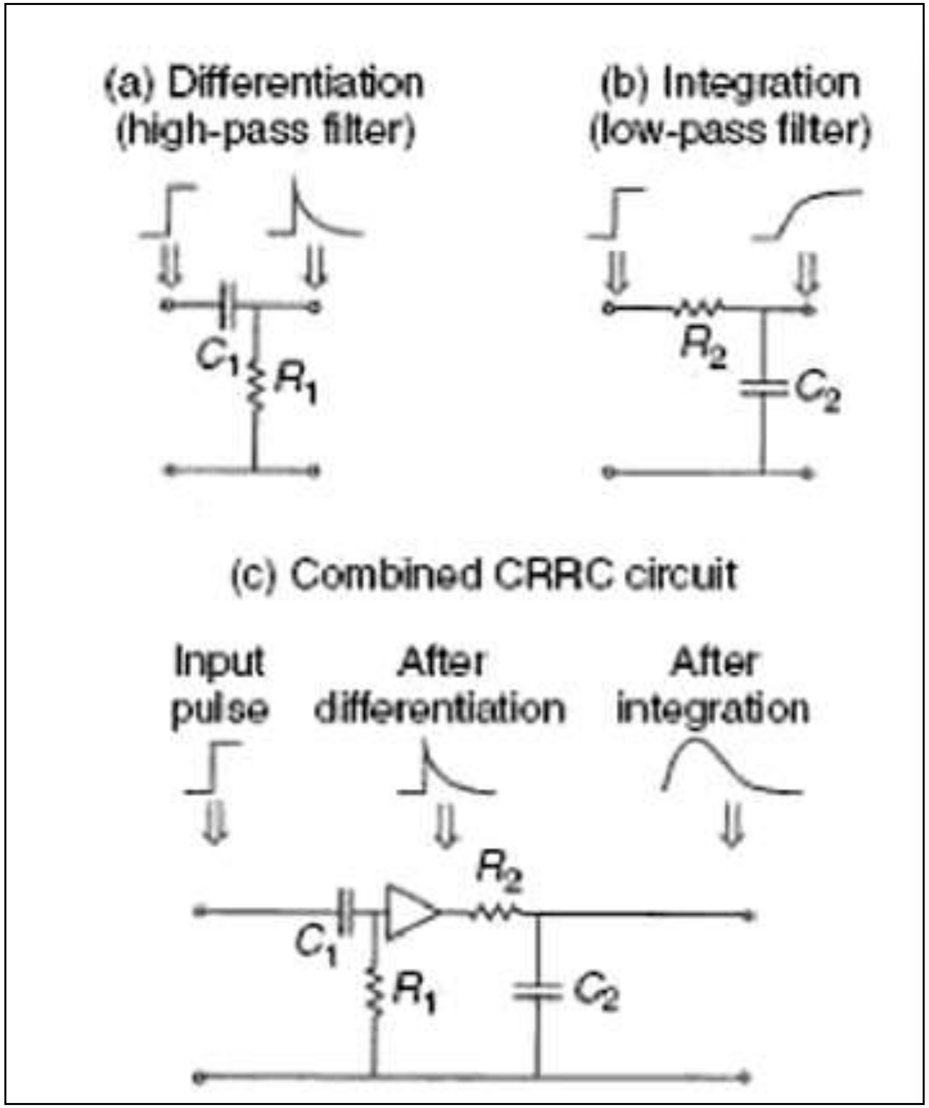
Main/Shaping Amplifiers

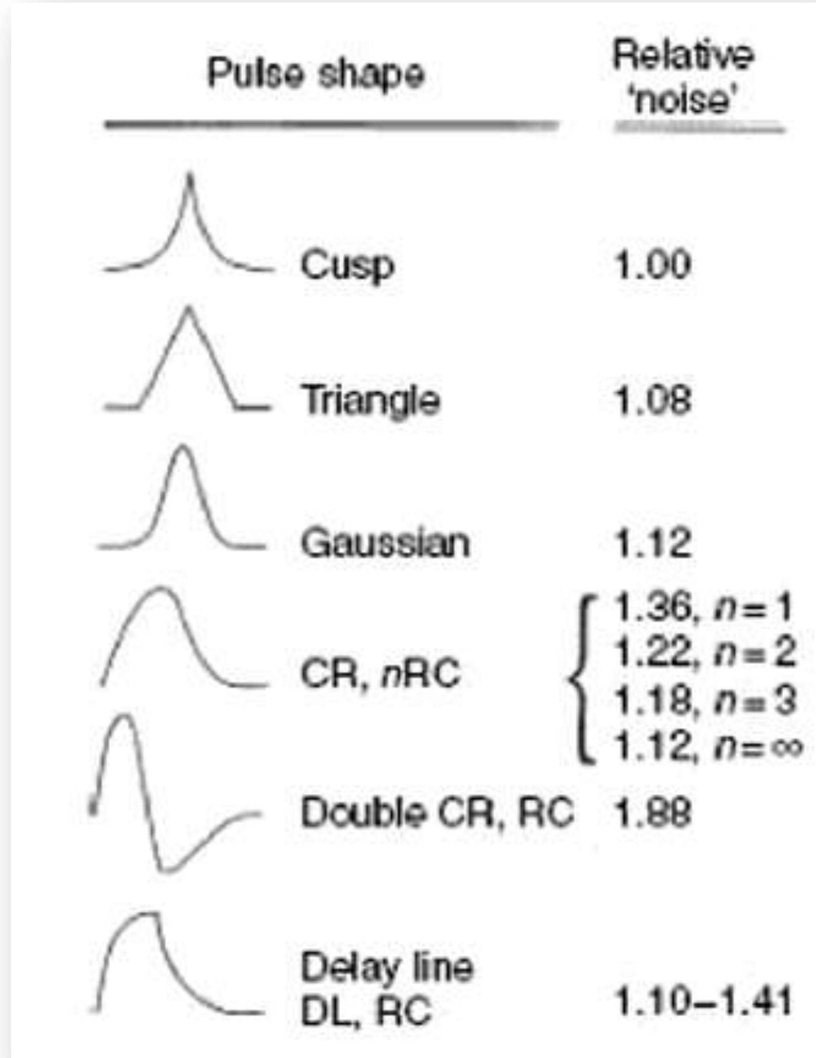
Tasks: 1) Linear amplification to pulse heights of U ≈(1-10)V
2) Improvement of signal/noise ratio (integration)
3) Pulse shaping (Gaussian shape is best)



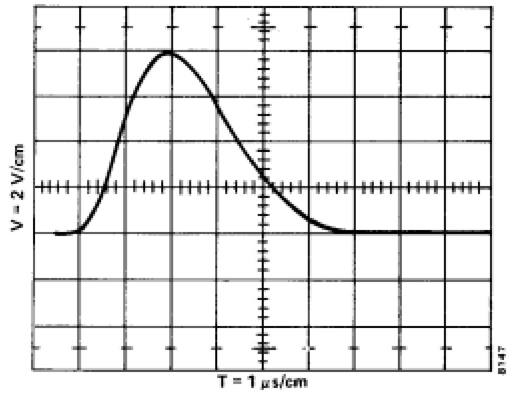
More versatility: RC-circuits → ω-selective filters

CRRC Pulse Shaping

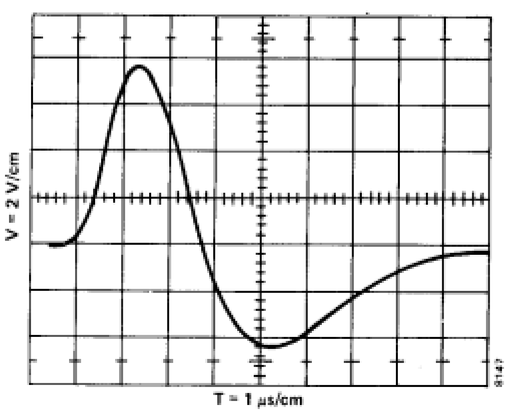




Main/Spectroscopy Amplifiers



Correct Amplifier Unipolar Output.

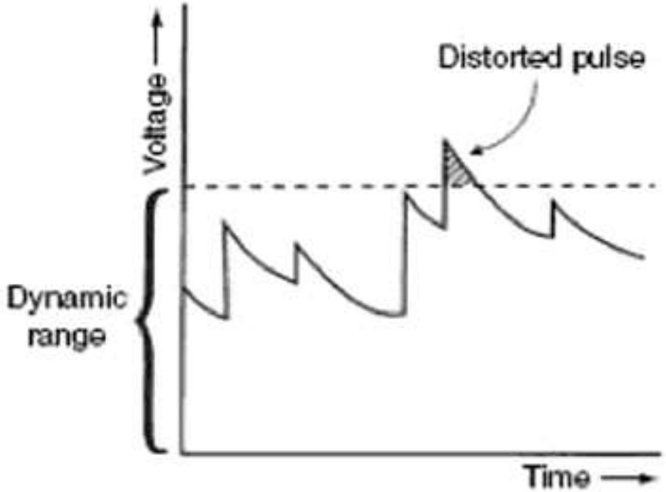


Correct Amplifier Bipolar Output.

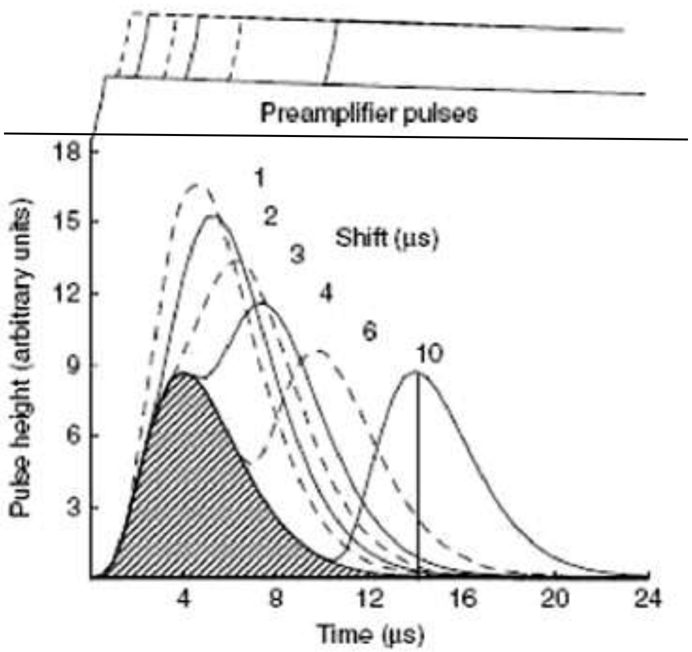
Tasks: Generate signal with amplitude **proportional** to collected detector charge. Needs absolute calibration of pulse amplitude.

← **Preamp Power**

Effects of Pile-Up



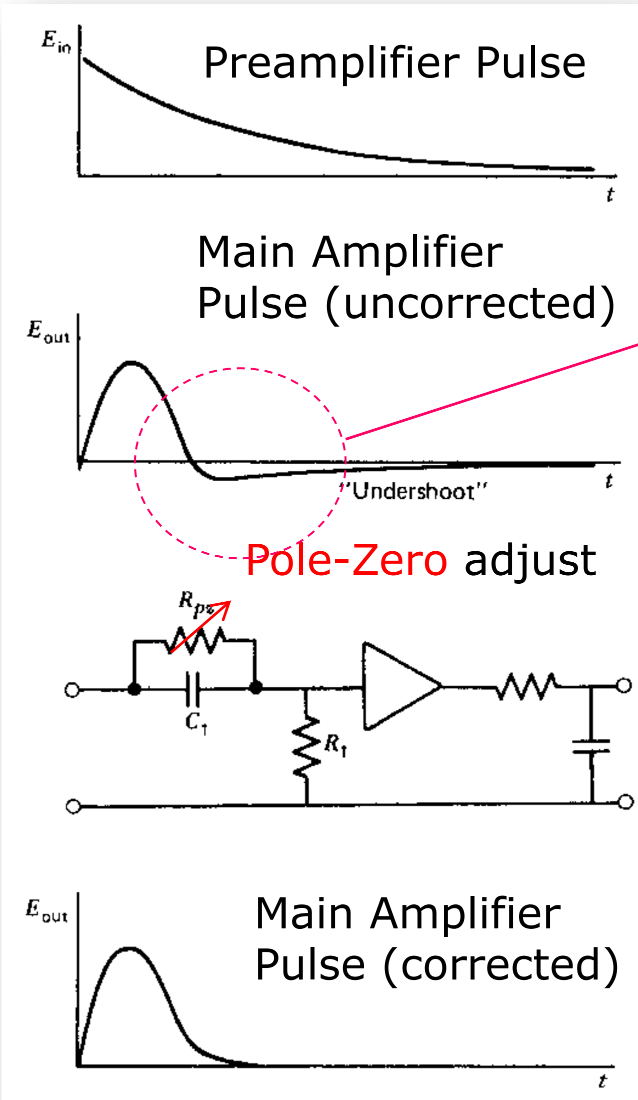
High count rate (relative to pulse length/decay time) can lead to pile up
→ from small non-linearities to serious distortions, line shapes "ghost lines"

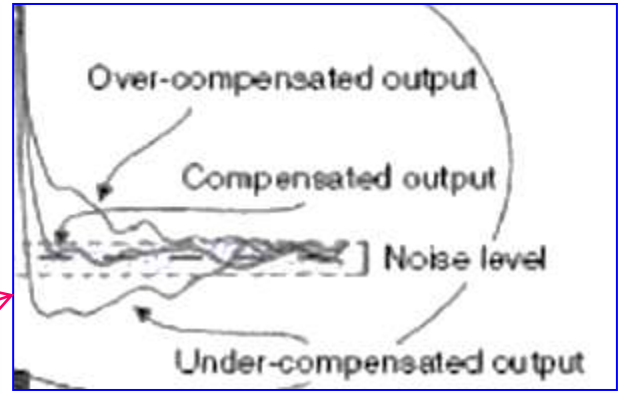


Artificial test of the pile-up effect. Successive signals add on to each other, creating an effectively non-zero base line.

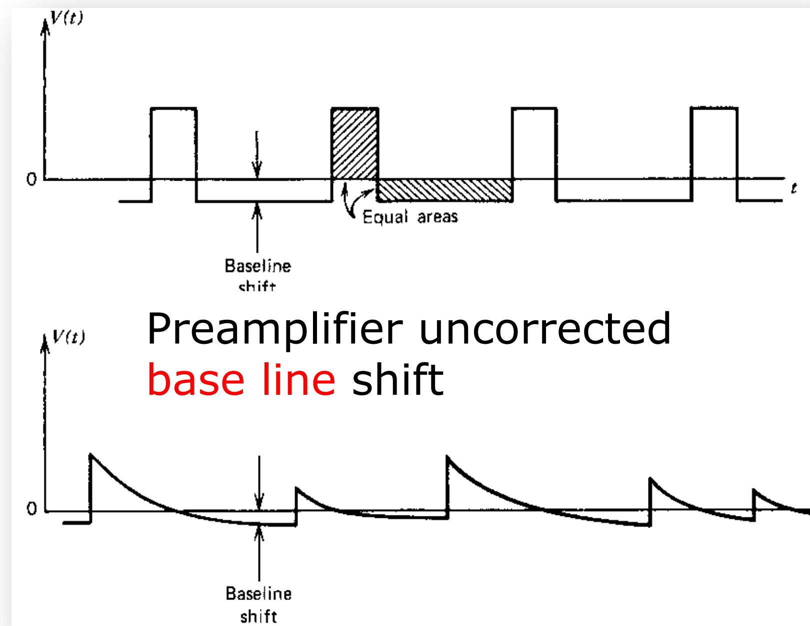
Avoid by reducing signal rate or width (pulse decay time)

Pole-Zero & Base Line Shift Distortions

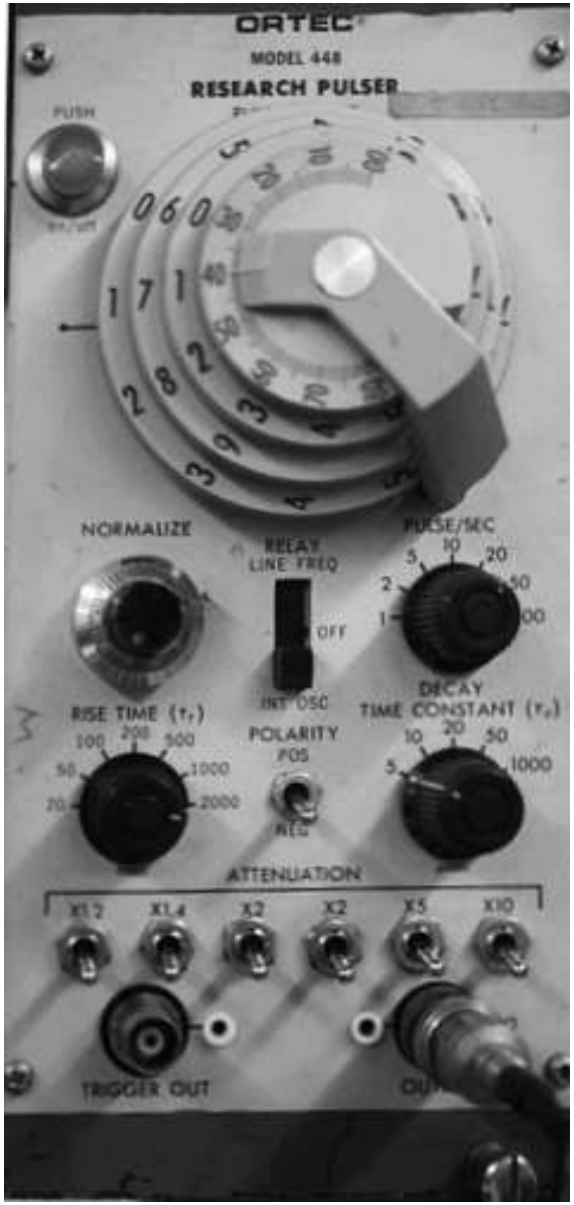




Blow-up of pulse under/over shoot



Test Modules: Precision Pulse Generators

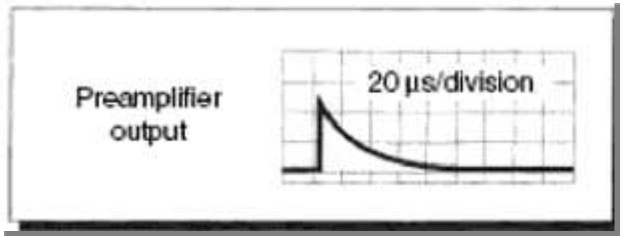


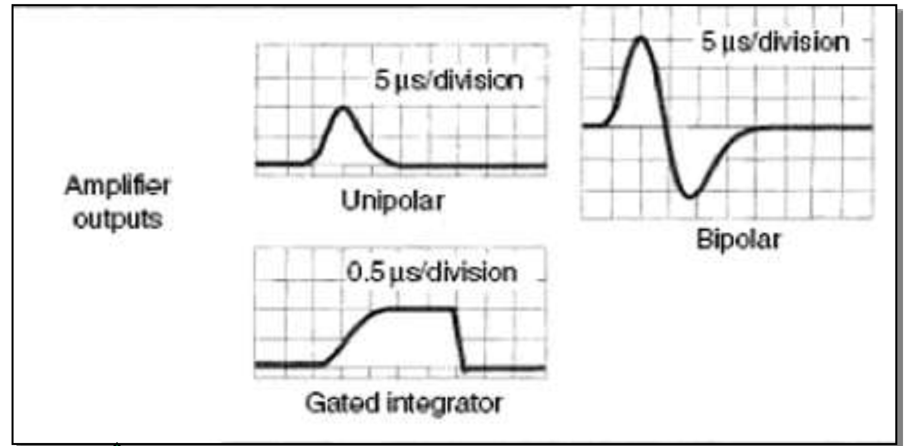
Tasks:
Simulate signals of physical events, controlled pulse shape, amplitude, timing, repetition rate

→ Adjust analog and logic electronics

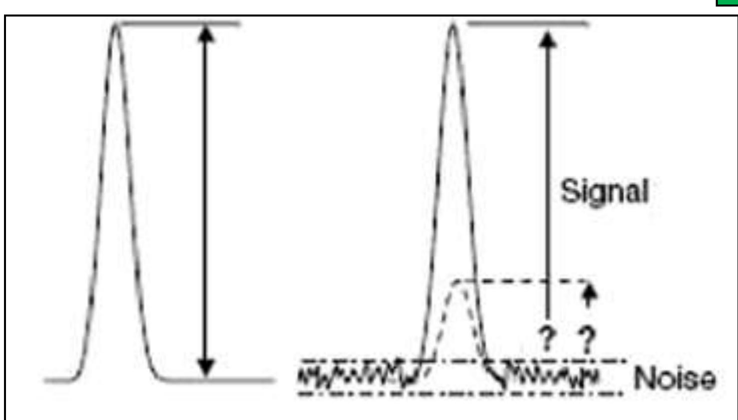
Analog Plus Digital Circuitry

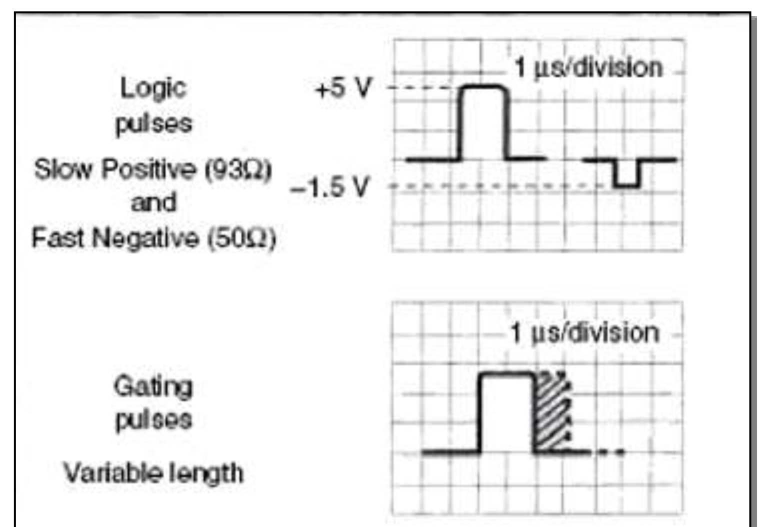
Analog (slow) circuit → proportional image detector output signal



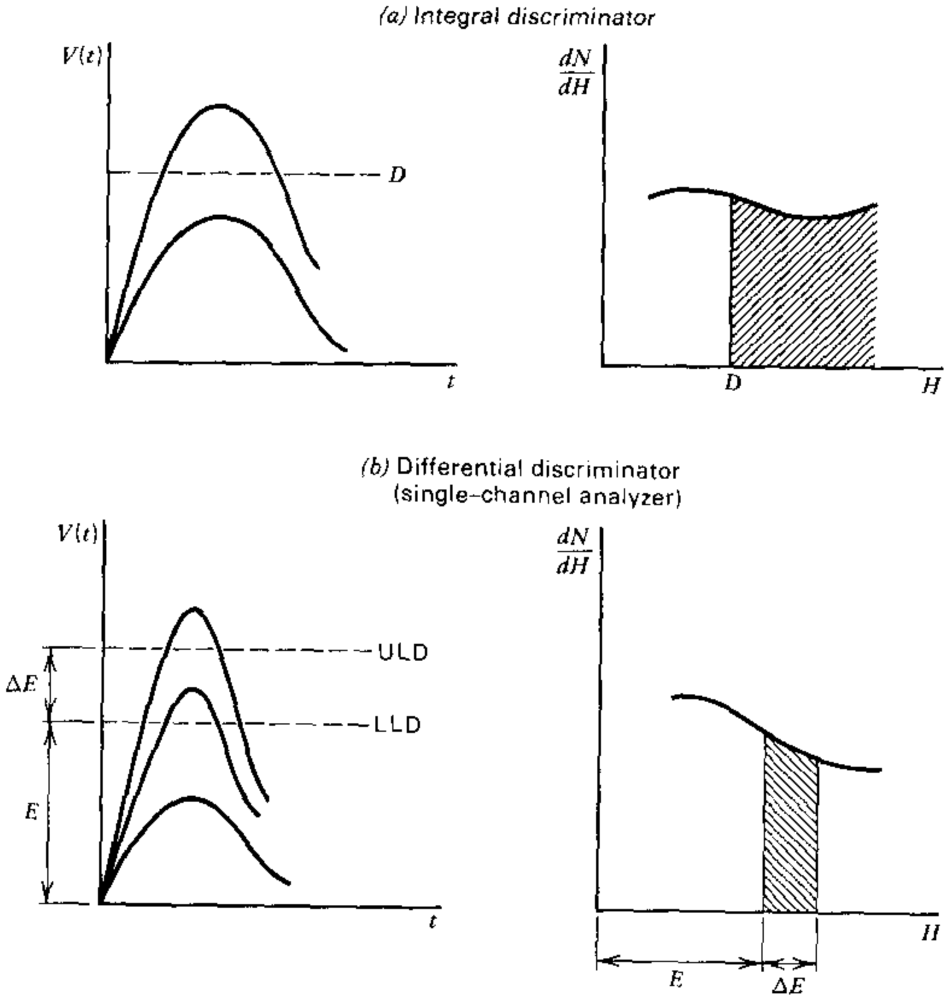


Digital (fast) circuit → yes/no information on signal presence

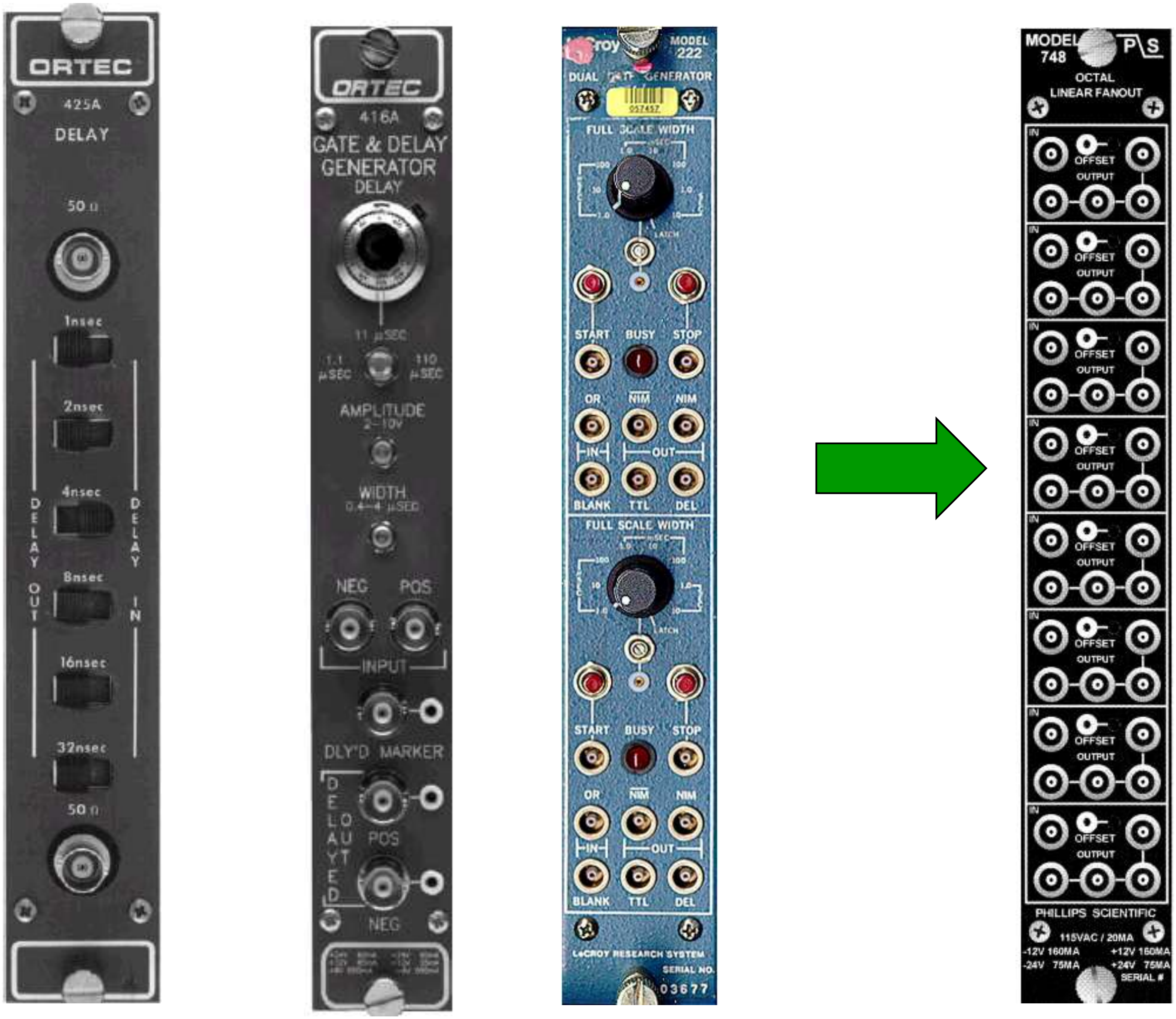




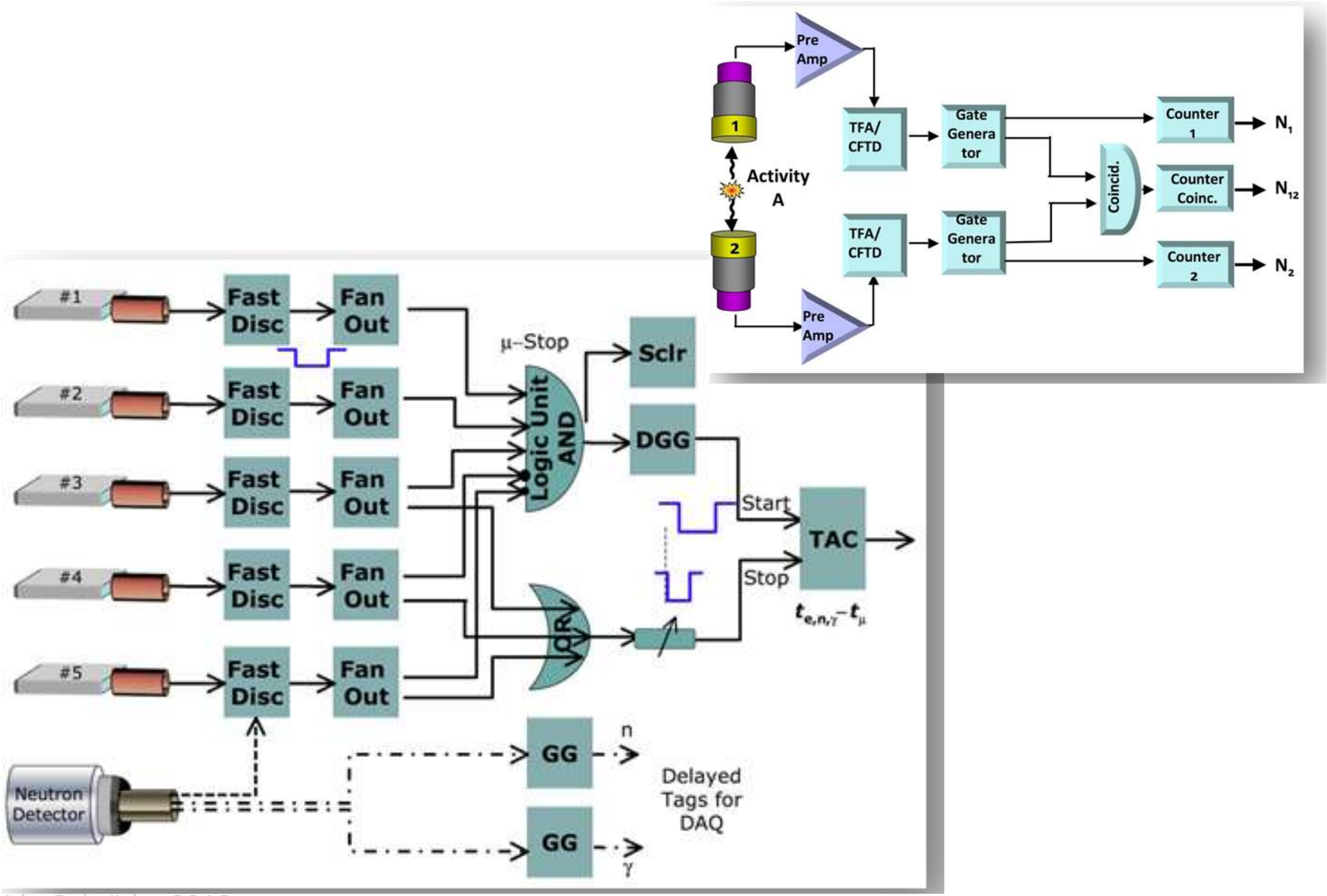
Single Channel Analyzer



Digital Pulse Shaping: Gate and Delay Generators

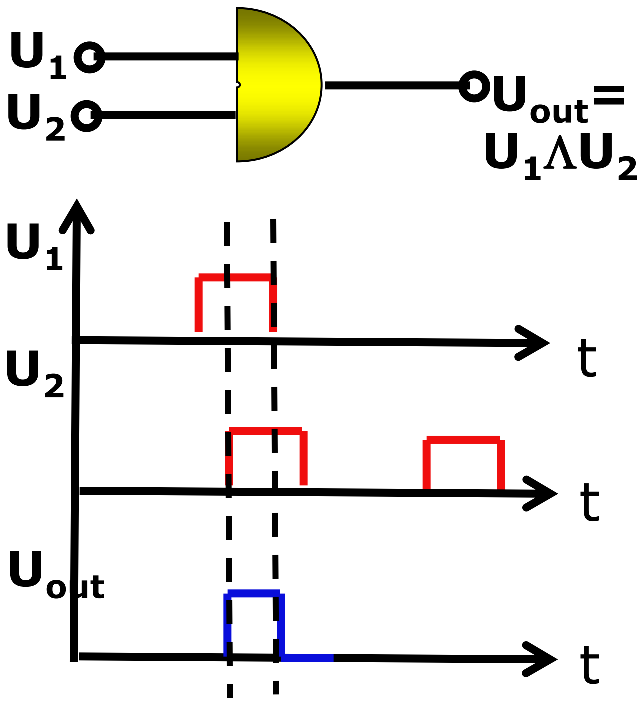


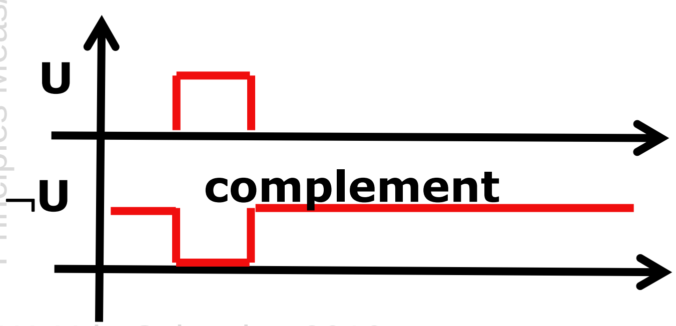
Digital Logic Circuits



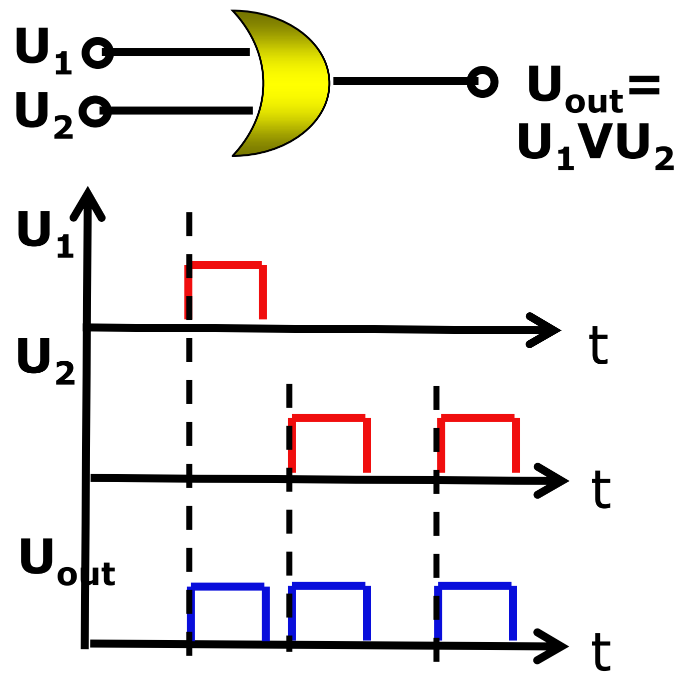
Logic Modules

Overlap Coincidence

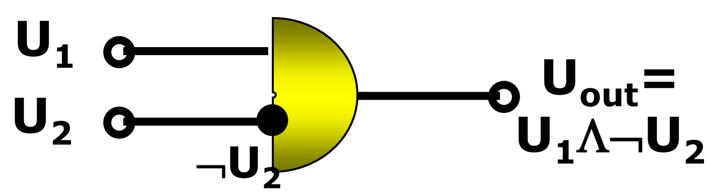




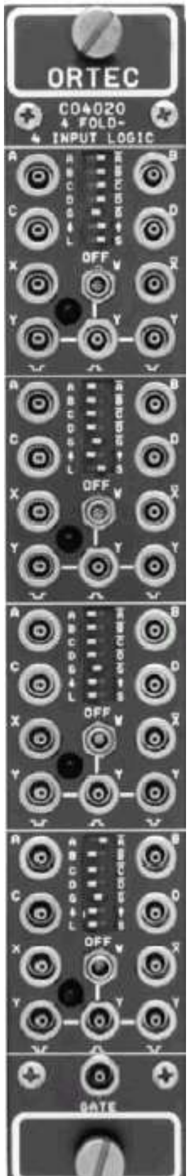
Or (inclusive)



For fast timing: use fast negative logic



Anti-Coincidence



Input Logic Switches (A/OFF/A↓ , B/OFF/B↓ , C/OFF/C↓ , D/OFF/D↓ , AND G/OFF/G↓) As defined in Fig. 1, these switches select variations of the following basic logic functions. In the OFF position, the state of that input is ignored. With switches set to the A, B, C, D, and G positions, the module performs the OR function at the X↓ output.

X = A + B + C + D + G

Setting the switches to the A↓ , B↓ , C↓ , D↓ , and G↓ positions provide the AND (coincidence) function at the X↓ output.

X↓ = A · B · C · D · G

Changing the G↓ switch to G implements the common-gate veto (anticoincidence).

X↓ = A · B · C · D · G↓

See Fig. 1 to determine other possible logic

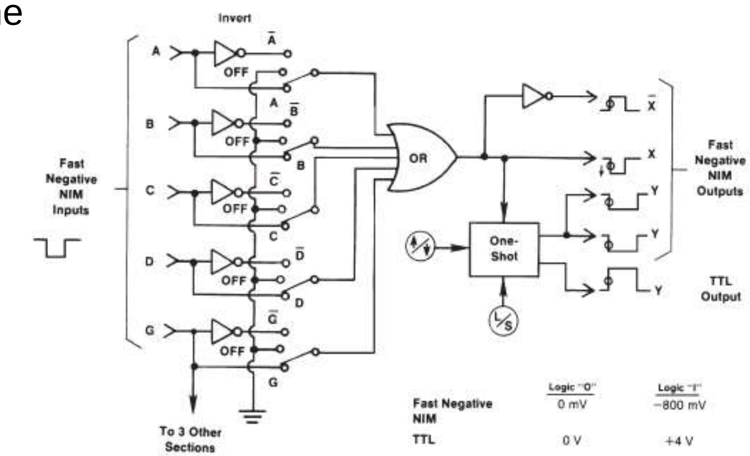
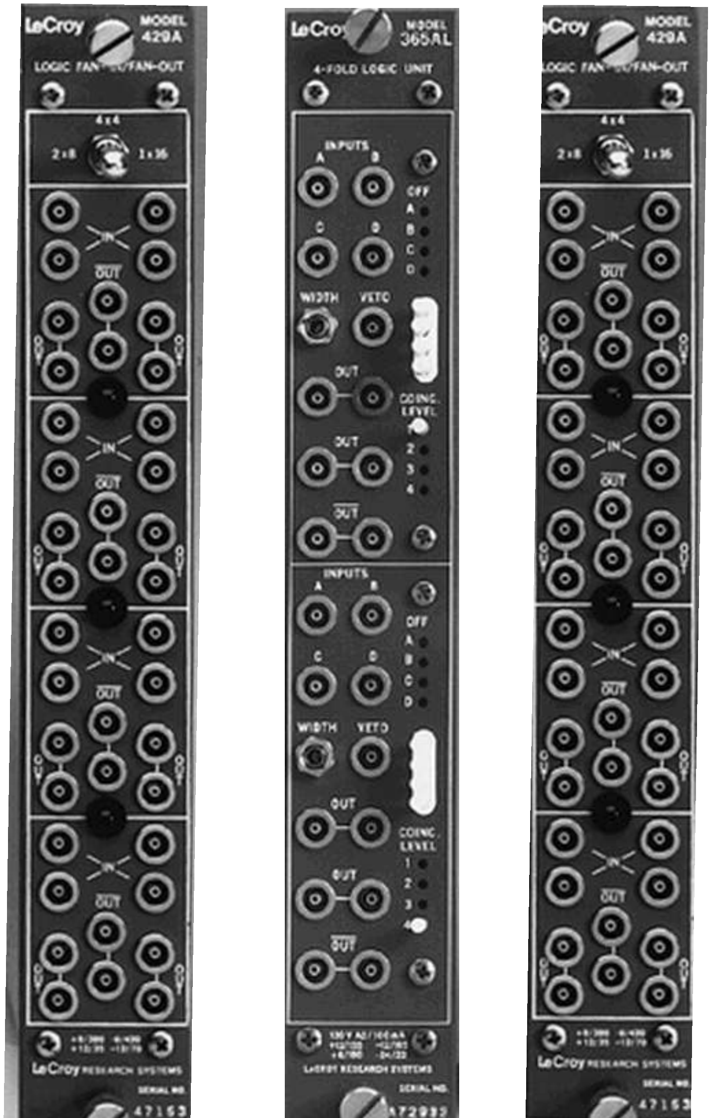
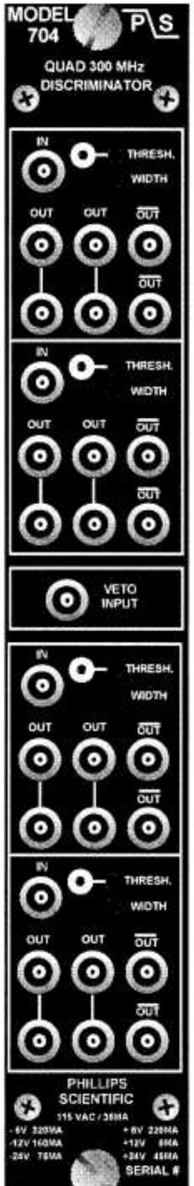
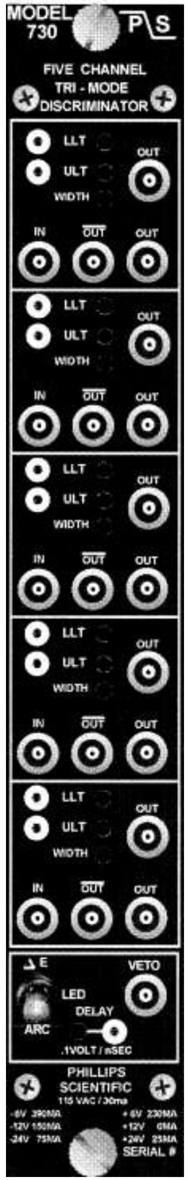
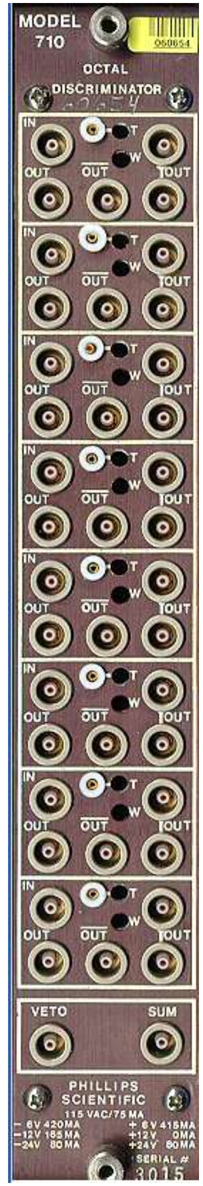


Fig. 1. Block Diagram of the Model CO4020 Logic Unit.

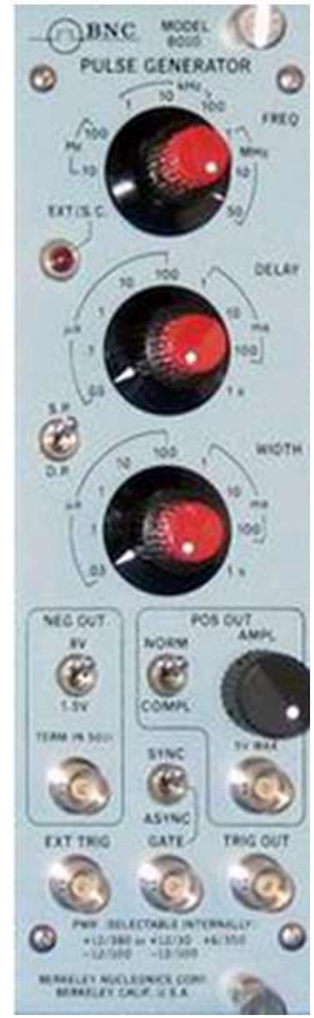

LeCroy
MODEL 429A
LOGIC FAN-IN/FAN-OUT
4x4
2x8
1x16
IN
OUT
MODEL 365AL
4-FOLD LOGIC UNIT
INPUTS
OFF
WIDTH
VETO
COINC. LEVEL
LeCroy RESEARCH SYSTEMS
SERIAL NO.

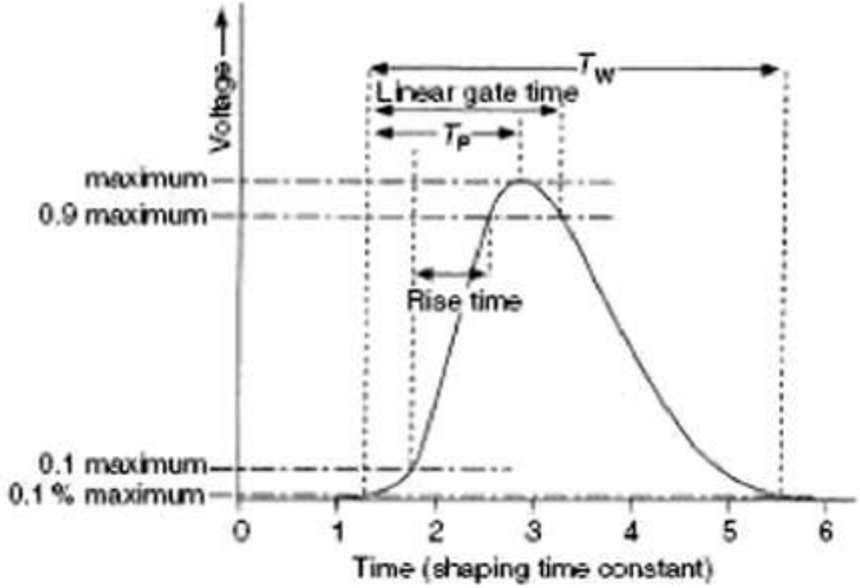

MODEL 704
P S
QUAD 300 MHz DISCRIMINATOR
IN
THRESH.
WIDTH
OUT
OUT
OUT
VETO INPUT
PHILLIPS SCIENTIFIC
SERIAL #


MODEL 730
P S
FIVE CHANNEL TRI - MODE DISCRIMINATOR
LLT
ULT
WIDTH
IN
OUT
OUT
VETO
LED
DELAY
ARC
.1VOLT / nSEC
PHILLIPS SCIENTIFIC
SERIAL #


MODEL 710
OCTAL DISCRIMINATOR
IN
OUT
T
W
VETO
SUM
PHILLIPS SCIENTIFIC
115 VAC/75 MA
SERIAL #

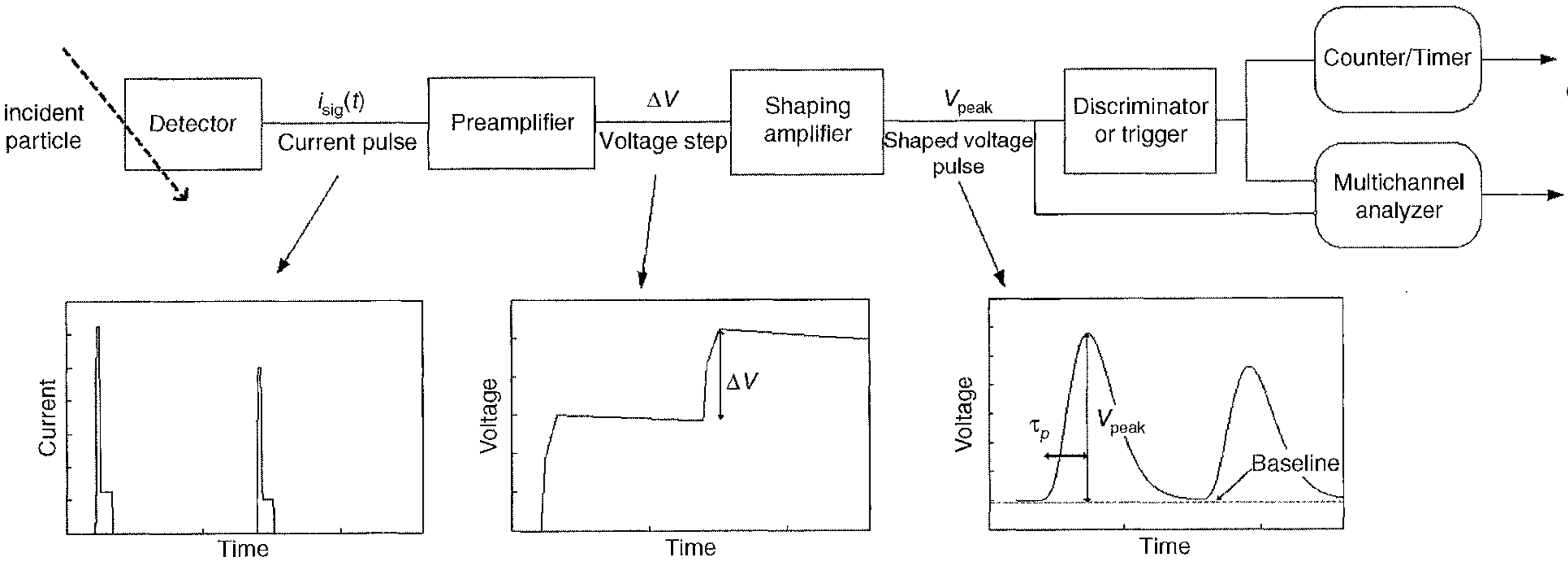

ORTEC
MODEL 448
RESEARCH PULSER
PUSH
NORMALIZE
RELAY
LINE FREQ
OFF
INT OSC
PULSE/SEC
RISE TIME
POLARITY
POS
DECAY
TIME CONSTANT
ATTENUATION
X1.2
X1.4
X2
X2
X5
X10
TRIGGER OUT

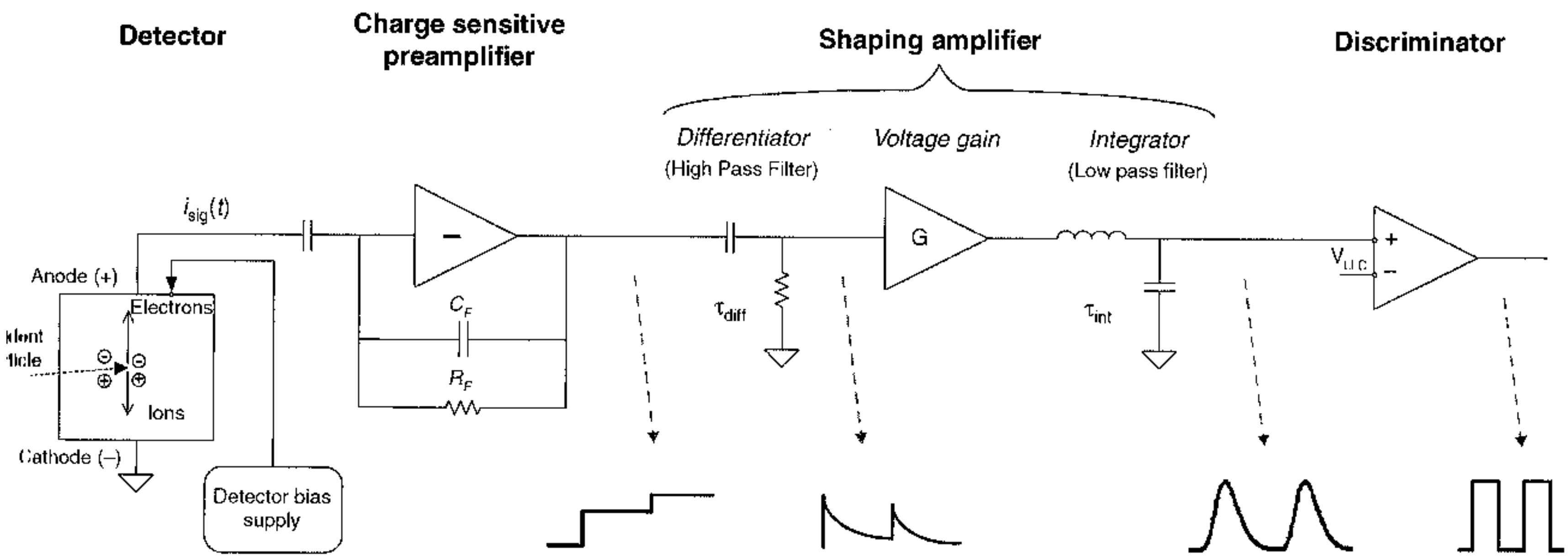

BNC
MODEL
PULSE GENERATOR
FREQ
DELAY
WIDTH
EXT/S.C.
NEG OUT
POS OUT
AMPL
NORM
COMPL
SYNC
ASYNC
EXT TRIG
GATE
TRIG OUT

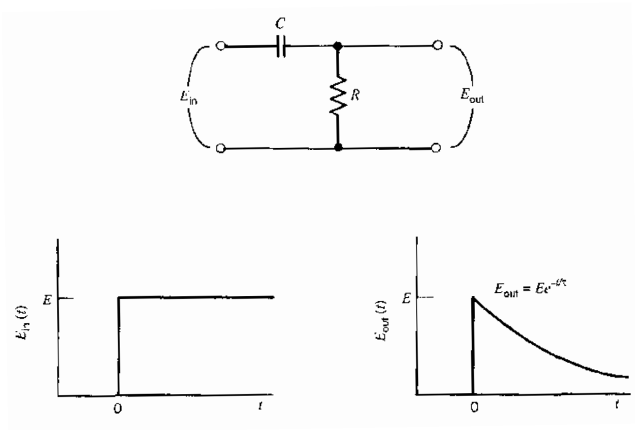


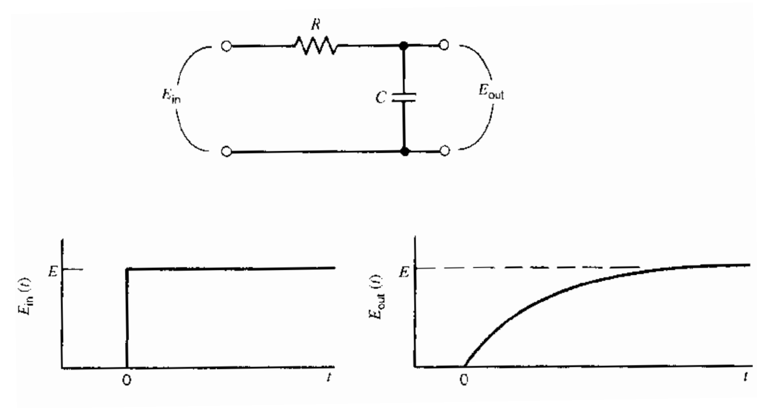
Measured timing factors for semi-Gaussian output pulses

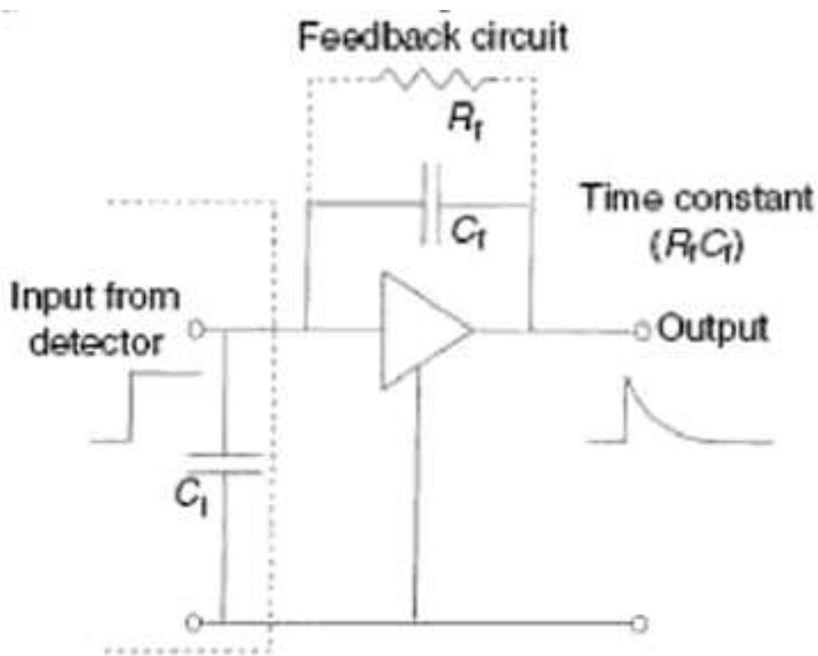
Factor	Time interval	Symbol	Time[a]
Rise time	0.1 to 0.9 of pulse maximum	—	1.26+0.05
Peaking time	threshold[b] to maximum	T_P	2.1+0.1
Linear gate time	threshold to 0.9 of max. beyond max.	T_{LG}	2.6+0.2
Width	threshold to threshold	T_W	5.6+0.5


incident
particle
Detector
$i_{sig}(t)$
Current pulse
Preamplifier
ΔV
Voltage step
Shaping
amplifier
V_{peak}
Shaped voltage
pulse
Discriminator
or trigger
Counter/Timer
Multichannel
analyzer
Current
Time
Voltage
ΔV
Time
Voltage
τ_p
V_{peak}
Baseline
Time

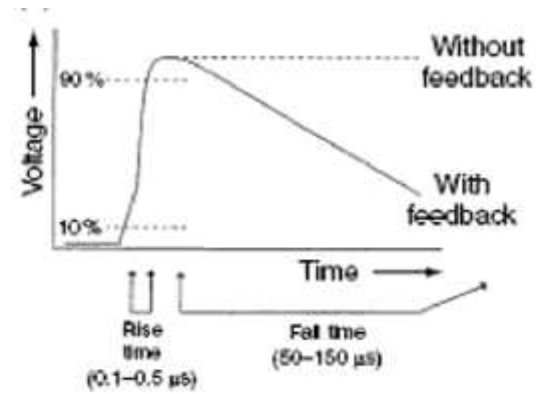

Detector
Charge sensitive preamplifier
Shaping amplifier
Discriminator
Differentiator
(High Pass Filter)
Voltage gain
Integrator
(Low pass filter)
$i_{sig}(t)$
Anode (+)
Electrons
Ions
Cathode (–)
Detector bias supply
C_F
R_F
τ_{diff}
G
τ_{int}


C
R
E_{in}
E_{out}
$E_{in}(t)$
E
0
t
$E_{out}(t)$
$E_{out} = Ee^{-t/\tau}$

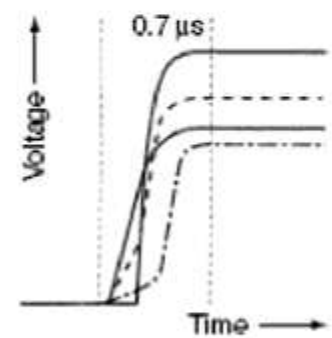

R
C
E_{in}
E_{out}
$E_{in}(t)$
$E_{out}(t)$
E
0
t



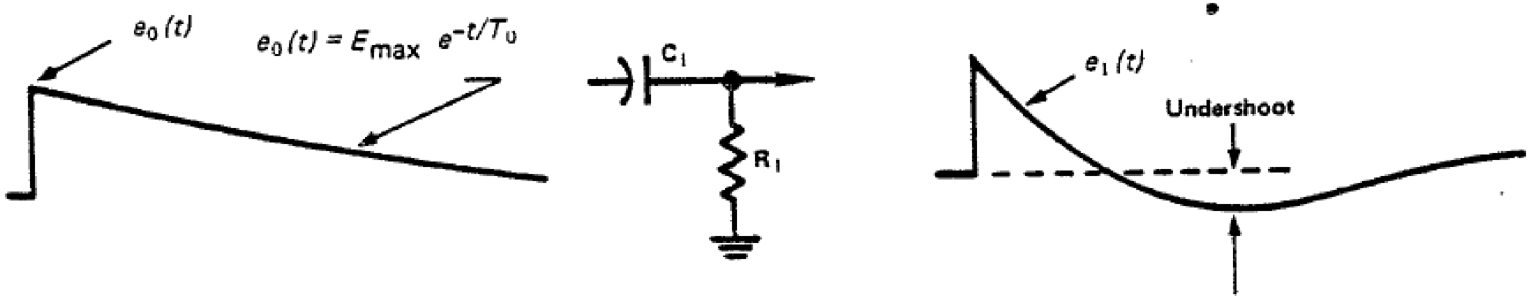
Feedback circuit
Rf
Cf
Time constant
(RfCf)
Input from
detector
Output
CI



Voltage
90 %
10 %
Without
feedback
With
feedback
Time
Rise
time
(0.1–0.5 µs)
Fall time
(50–150 µs)



0.7 µs
Voltage
Time



Charge loop output X First differentiate network = Differentiated pulse with undershoot

$$E_{max}\ e^{-t/T_0} \times G(t) = e_1(t)\ .$$

$$E_{max} \frac{1}{s + \frac{1}{T_0}} \times \frac{s}{s + \frac{1}{R_1 C_1}} = E_1(s) \text{ (Laplace transform).}$$

$$\frac{E_{max}}{T_0 - T_1} T_0\ e^{-t/T_0} - T_1\ e^{-t/T_0} = e_1(t), \text{ where } T_1 = R_1 C_1\ .$$

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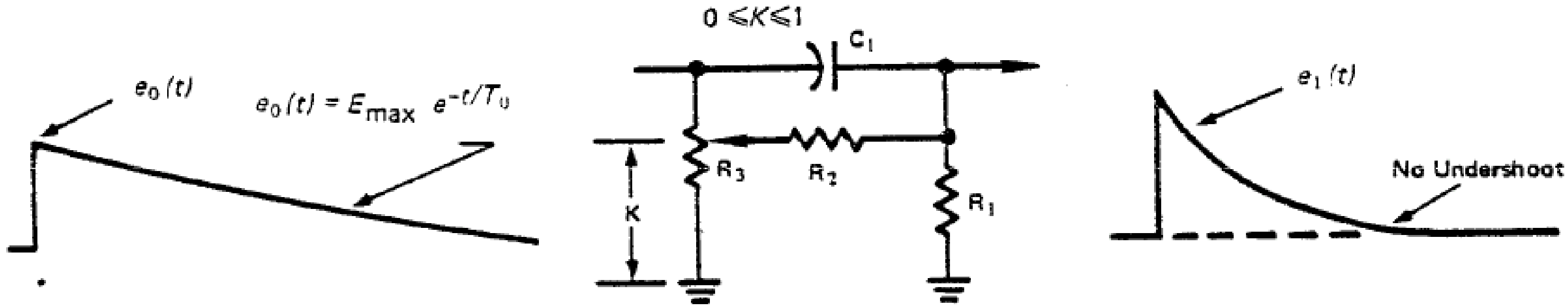


Charge loop output × Pole-zero cancelled differentiate network = Differentiated pulse without undershoot

$$E_{max}\, e^{-t/T_0} \times G(t) = e_1(t)\,.$$

$$E_{max}\, \frac{1}{s + \frac{1}{T_0}} \times \frac{s + \frac{K}{R_2 C_1}}{s + \frac{R_1 + R_2}{R_1 R_2 C_1}} = E_1(s). \text{ (Laplace transform).}$$

200410

Pole zero cancel by letting

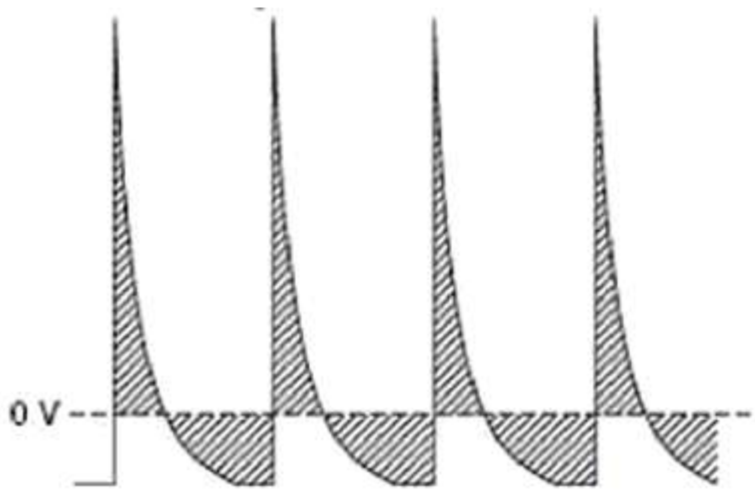
$$s + \frac{1}{T_0} = s + \frac{K}{R_2 C_1}\,.$$

or

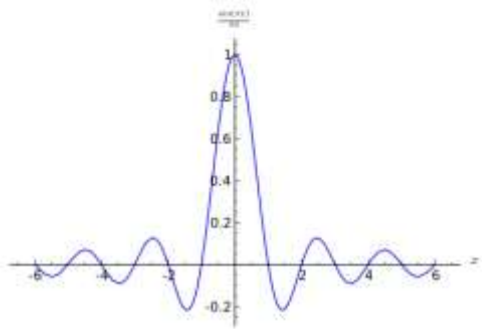
$$\frac{E_{max}}{s + \frac{R_1 + R_2}{R_1 R_2 C_1}} = \frac{E_{max}}{s + \frac{1}{R_p C_1}} = E_1(s), \text{ where } R_p = \frac{R_1 R_2}{R_1 + R_2}\,.$$

$$E_{max}\, e^{-t/R_p C_1} = e_1(t)\,.$$

Fig. 1.2. Differentiation in a Pole-Zero Cancelled Amplifier.

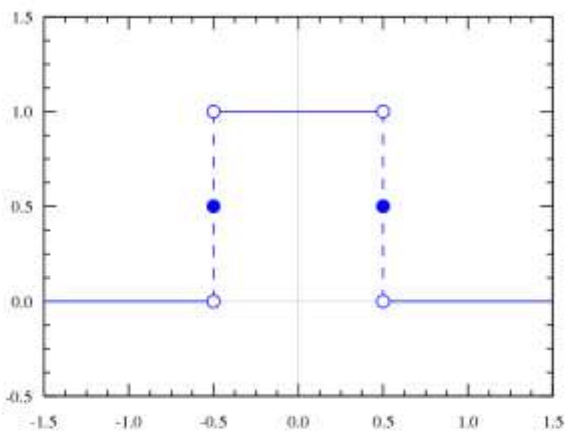

0 V

Time Dependent Electronic Signals



Function	Fourier transform unitary, ordinary frequency	Fourier transform unitary, angular frequency
$f(x)$	$\hat{f}(\xi) = \int_{-\infty}^{\infty} f(x) e^{-2\pi i x \xi}\, dx$	$\hat{f}(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{-i\omega x}\, dx$

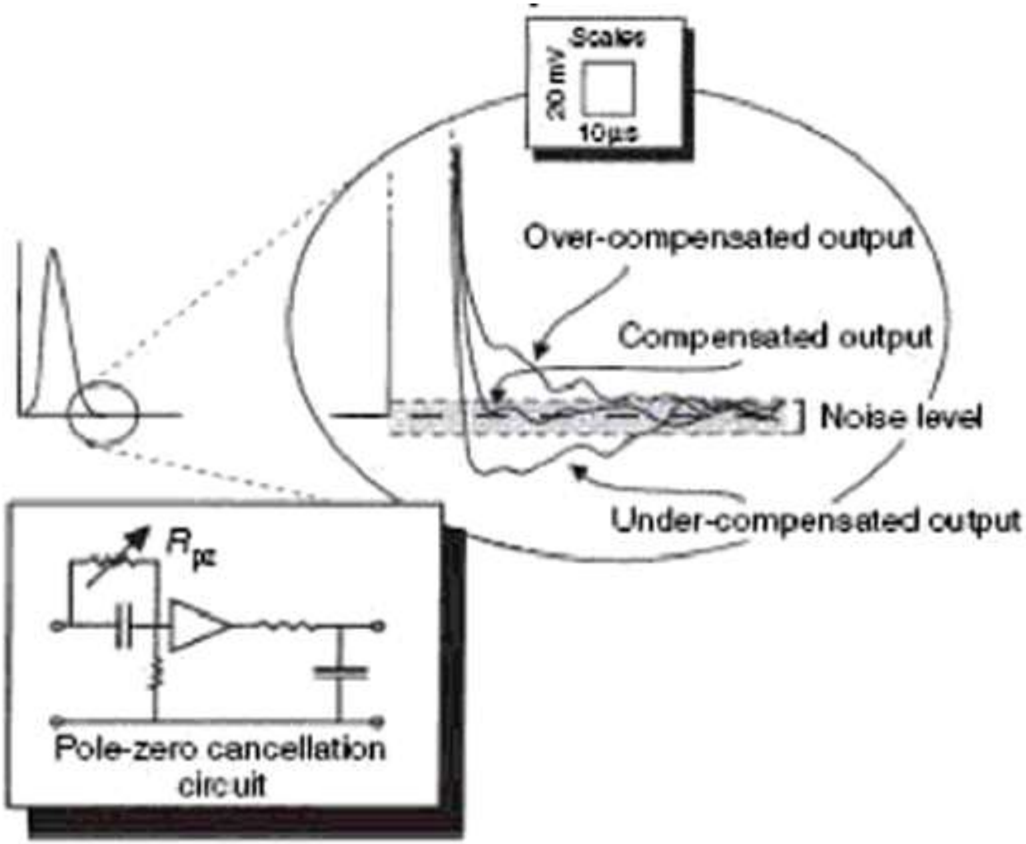
$$f(\varpi) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} g(t) e^{i\omega t} dt$$



$$\hat{f}(\omega) = \int_{\mathbb{R}^n} f(x) e^{-i\omega \cdot x}\, dx.$$

Under this convention, the inverse transform becomes:

$$f(x) = \frac{1}{(2\pi)^n} \int_{\mathbb{R}^n} \hat{f}(\omega) e^{i\omega \cdot x}\, d\omega.$$


Scales
20 mV
10µs
Over-compensated output
Compensated output
Noise level
Under-compensated output
R_{pz}
Pole-zero cancellation circuit