Dead time of the GM tube

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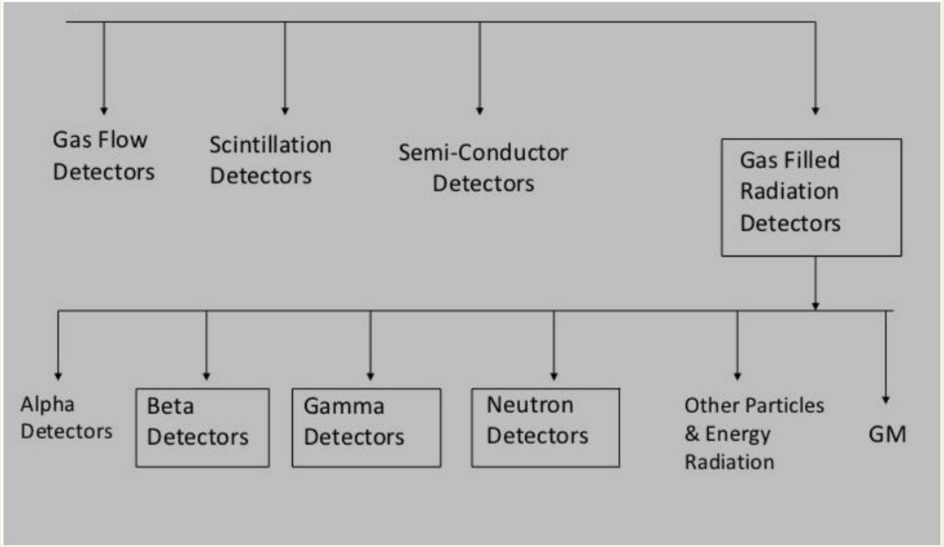
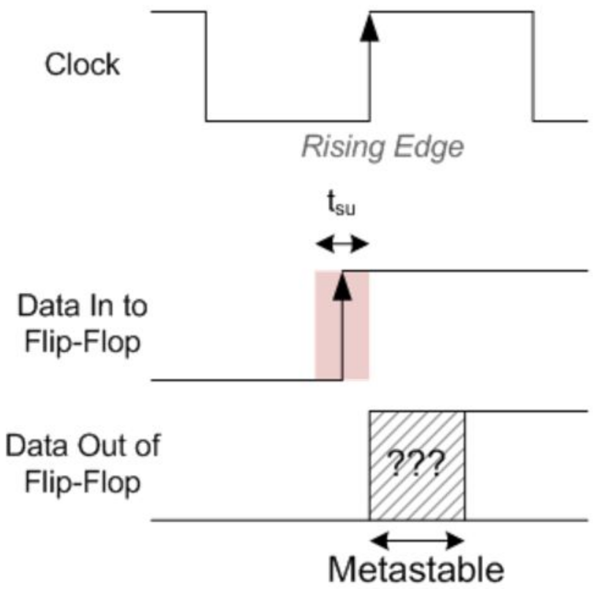
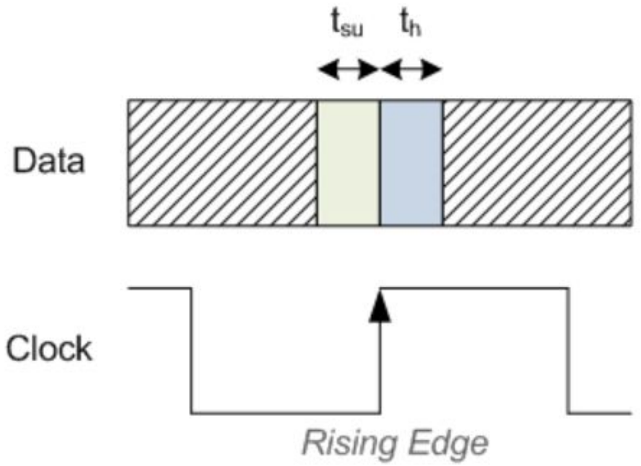
Types of Radiation Detectors

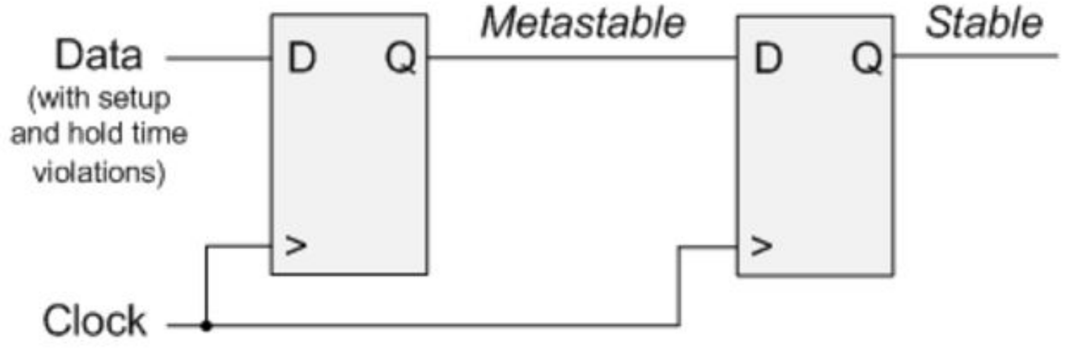
- Method based on the detection of free charge carriers by the ionization, i.e., ionization chamber, proportional counter, Geiger–Muller counter and semiconductor detectors.
- Method based visualization of the tracks of radiation, i.e., Wilson Cloud Chamber, Bubble Chamber, nuclear emulsion plates, spark chamber etc.
- Method based on light sensing, i.e., scintillation counter, cerenkov counter etc



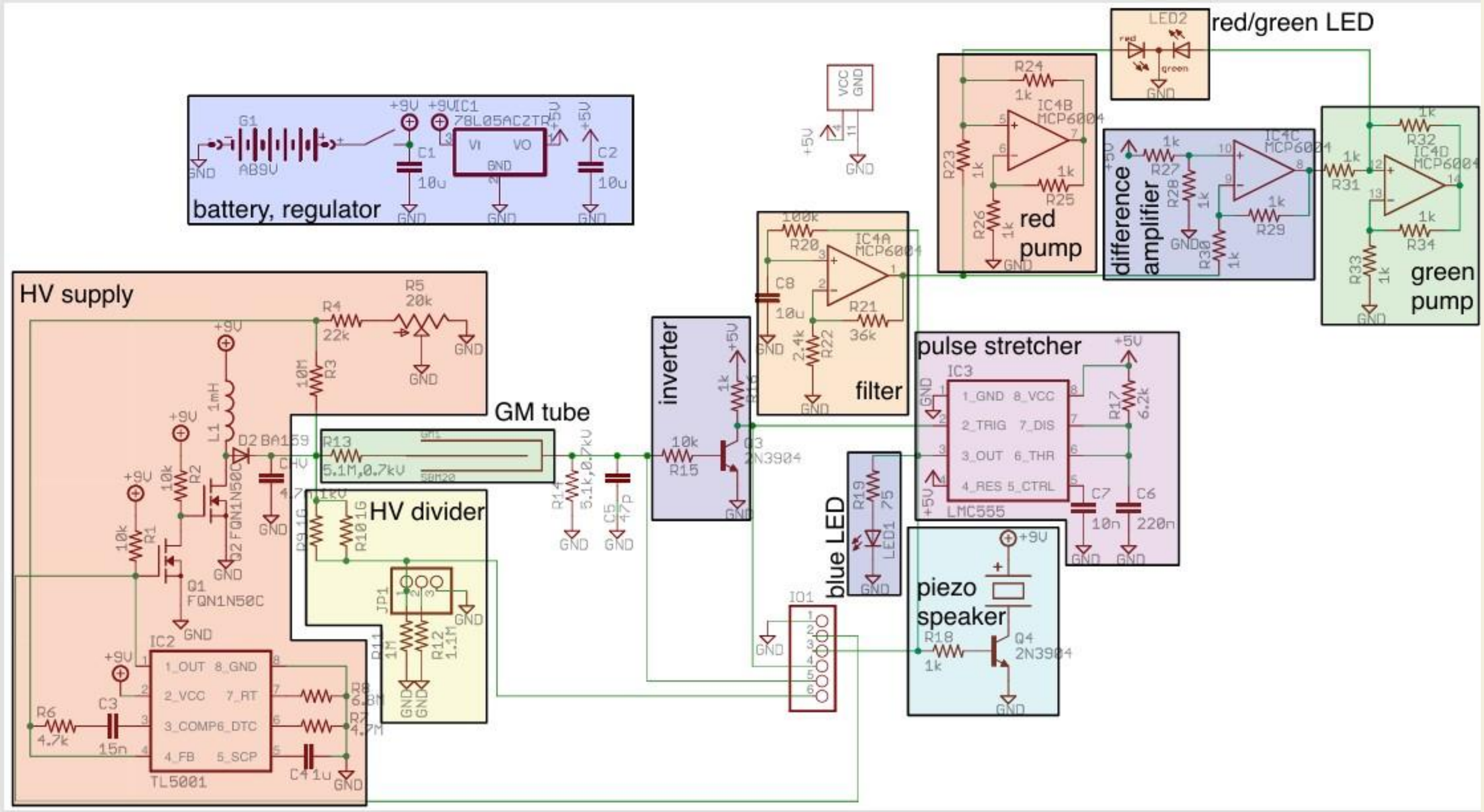
Appetizer

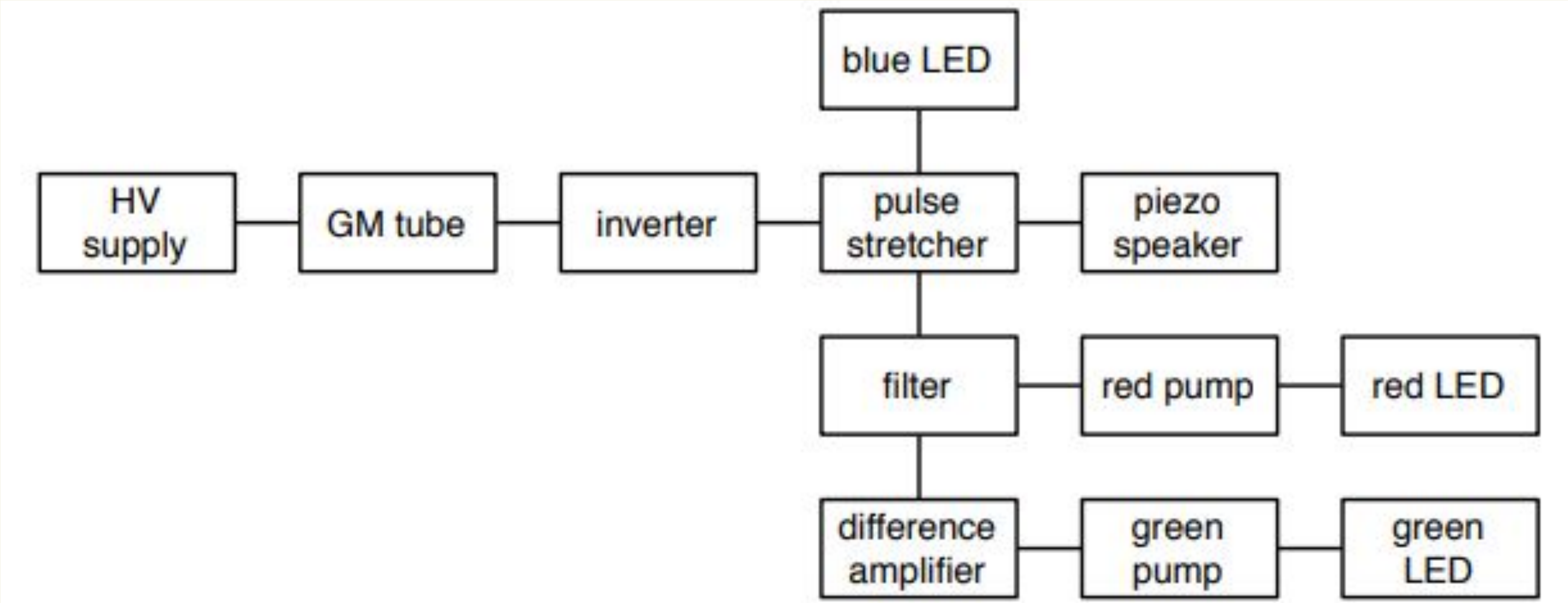






- **Sequential edge triggered circuits**


red/green LED
LED2
battery, regulator
G1
AB9V
IC1
78L05ACZTR
C1
10u
C2
10u
HV supply
R4
22k
R5
20k
R3
10M
L1 1mH
D2 BA159
Q2 FQN1N50C
Q1
FQN1N50C
R1
10k
R2
10k
IC2
TL5001
R6
4.7k
C3
15n
C4 1u
R8
6.8M
R7
4.7M
GM tube
R13
5.1M,0.7kV
SBM20
HV divider
R9 1G
R10 1G
JP1
R11
1M
R12
1.1M
R14
5.1k,0.7kV
C5
47p
inverter
R15
10k
R16
1k
Q3
2N3904
filter
IC4A
MCP6004
R20
100k
C8
10u
R21
36k
R22
2.4k
red
pump
IC4B
MCP6004
R23
1k
R24
1k
R25
1k
R26
1k
difference
amplifier
IC4C
MCP6004
R27
1k
R28
1k
R29
1k
R30
1k
green
pump
IC4D
MCP6004
R31
1k
R32
1k
R33
1k
R34
1k
pulse stretcher
IC3
LMC555
R17
6.2k
C7
10n
C6
220n
blue LED
R19
75
LED1
piezo
speaker
R18
1k
Q4
2N3904
IO1
VCC
GND
GND
+5V
+9V


blue LED
HV supply
GM tube
inverter
pulse stretcher
piezo speaker
filter
red pump
red LED
difference amplifier
green pump
green LED

HV supply Converts the 9 V battery voltage to the 400 V needed by the GM tube.

GM tube Detects ionizing radiation: emits a current pulse whenever an ionization event occurs inside the tube.

inverter Converts the current from the GM tube into an inverted voltage pulse.

pulse stretcher Converts the very short pulse from the inverter into a 1.5 ms pulse.

blue LED Flashes every time a pulse occurs.

piezo speaker Produces a click every time a pulse occurs.

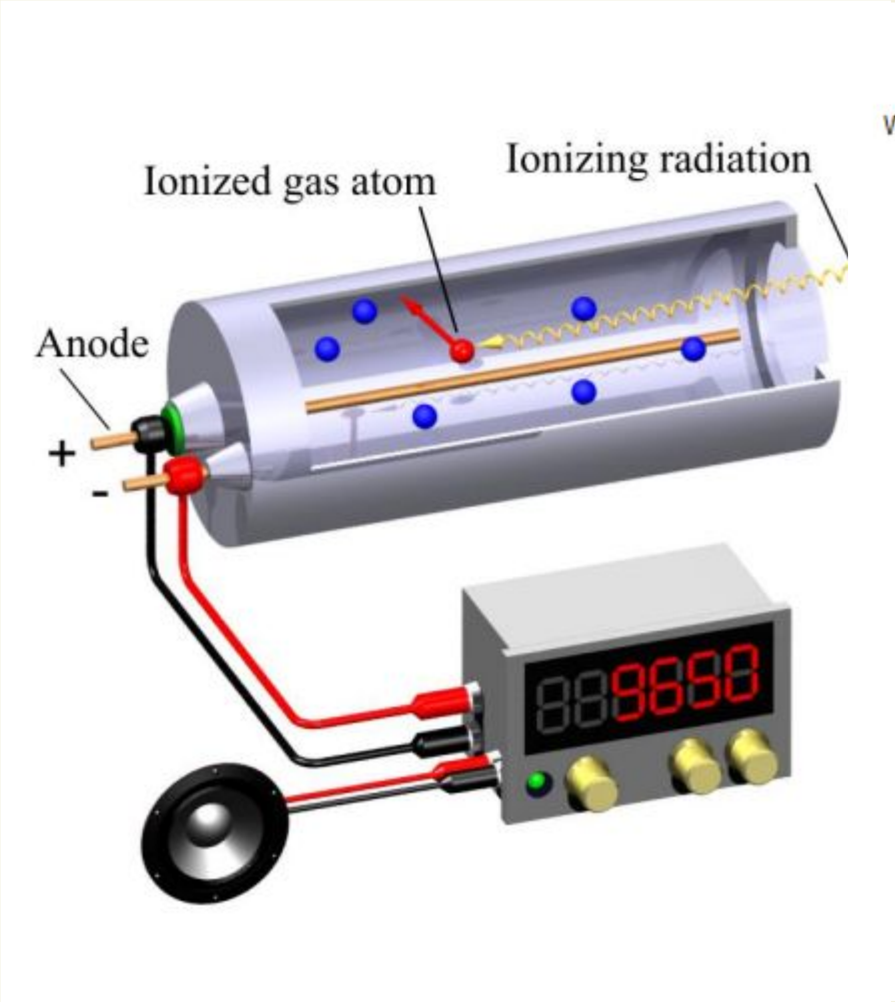
filter Accumulates charge from the pulses to produce a voltage roughly proportional to the count rate.

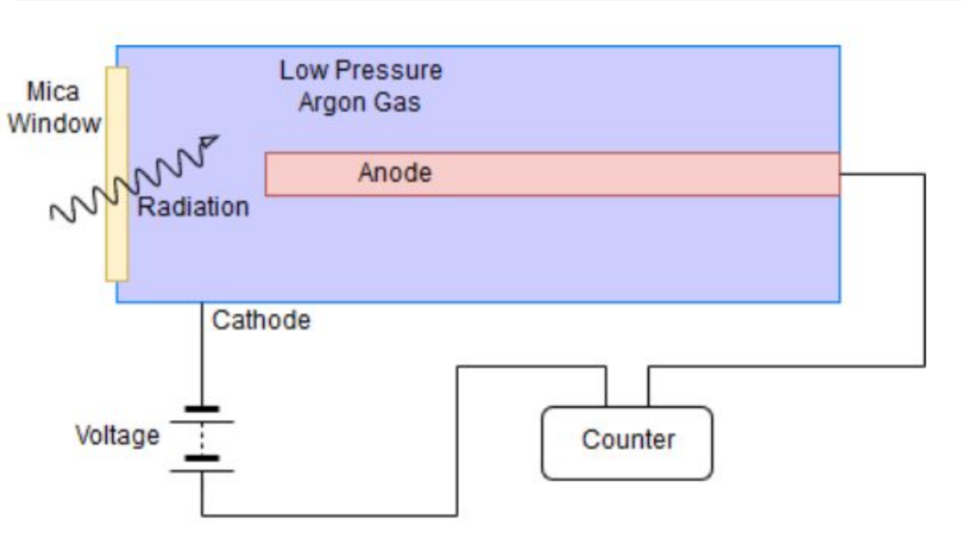
red/green LED Displays a visual indication of the count rate that continuously fades from green to orange to red as the rate increases.

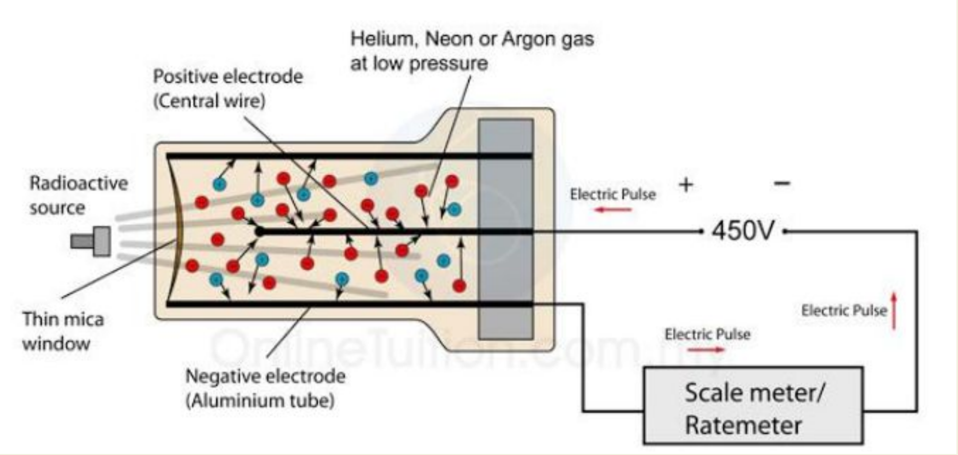
red pump Drives the red LED with a current proportional to the voltage from the filter.

difference amplifier Subtracts the filter voltage from a reference voltage to produce a signal that is goes down as the count rate goes up.

green pump Drives the green LED with a current proportional to the voltage from the difference amplifier.


Ionized gas atom
Ionizing radiation
Anode
+
-
889650


Mica
Window
Low Pressure
Argon Gas
Anode
Radiation
Cathode
Voltage
Counter

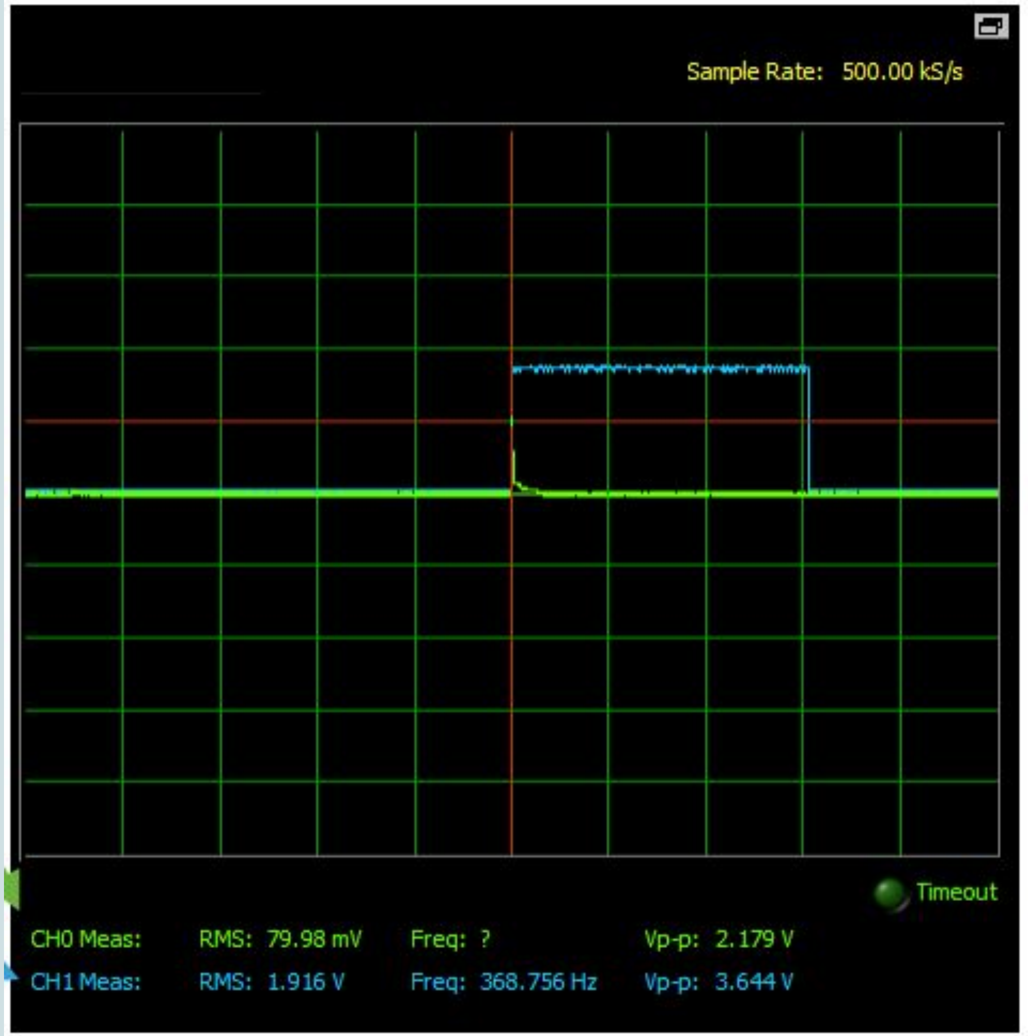

Helium, Neon or Argon gas
at low pressure
Positive electrode
(Central wire)
Radioactive
source
Electric Pulse
+
−
450V
Thin mica
window
Negative electrode
(Aluminium tube)
Electric Pulse
Electric Pulse
Scale meter/
Ratemeter

Inside a GM tube

- The Geiger-Müller tube is filled with an inert gas such as helium, neon, or argon at low pressure, to which a high voltage is applied.
- The tube briefly conducts electrical charge when a particle or photon of incident radiation makes the gas conductive by ionization .
- The ionization is considerably amplified within the tube and fed to the processing and display electronics
- When a charged particle or gamma-radiation enters the tube, the argon gas becomes ionized. This triggers a whole avalanche of ions between the electrodes.
- For a brief moment, the gas conducts and a pulse of current flows in the circuit

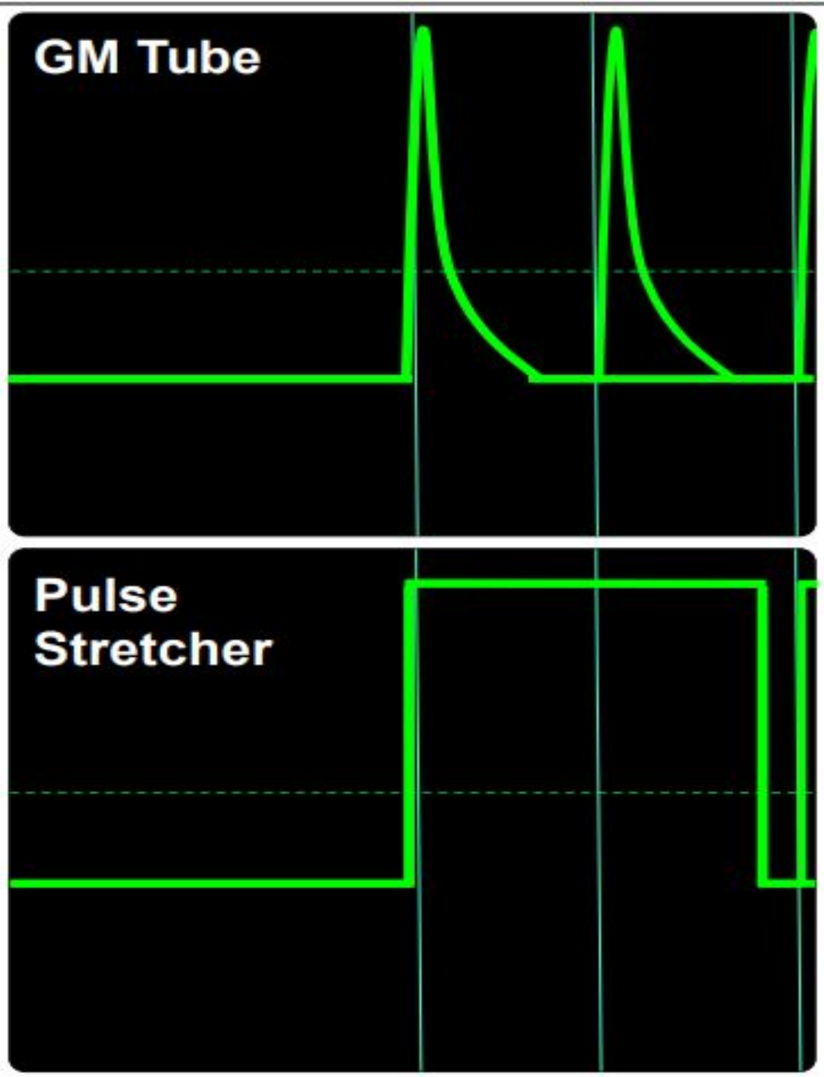
Pulse stretcher

- The output from the GM tube is very brief – if it were used to drive other circuit components directly, the effect would be nearly imperceptible. The pulse stretcher uses a very useful component known as a 555 timer to turn a short input pulse (of arbitrary shape and duration) into a square pulse.



Dead time in pulse stretcher

- During the time when the pulse is high, the circuit is designed to ignore any subsequent discharges
- This period can be considered a blackout period during which the pulses are processed
- Some pulses may need to be shaped or amplified, so the blackout time can be even bigger
- Some pulse stretchers use a threshold to ignore pulses below a certain voltage

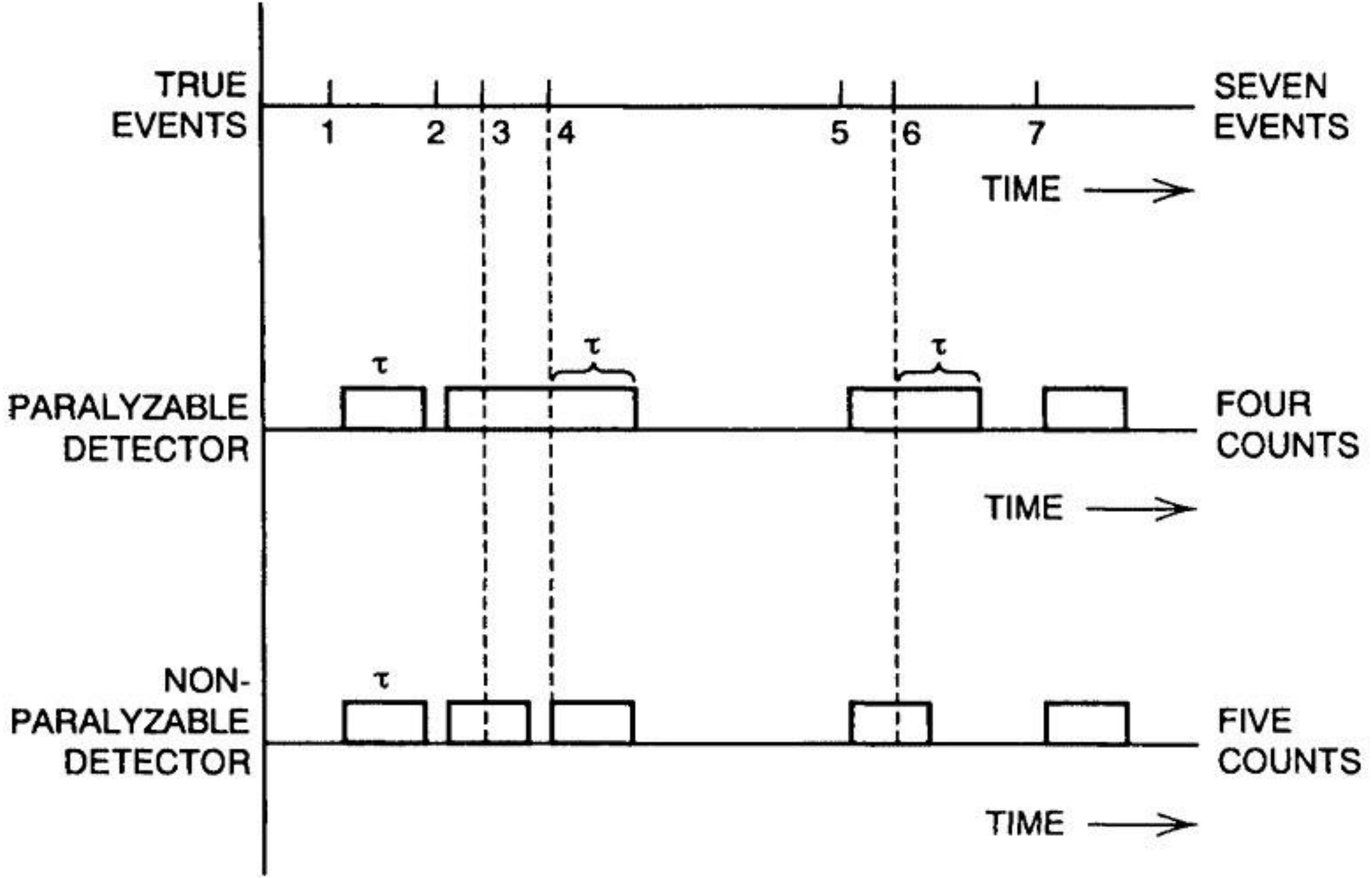


Basic definition

- An instrument that responds sequentially to individual events requires a certain minimum time to recover from one event before it is ready to respond to the next
- This interval, called the dead (or resolving) time, can be due to physical processes in the detector and to instrument electronics
- When a radioactive sample is counted, there is a possibility that two interactions in the detector will occur too close together in time to be registered as separate events

How to model dead time behaviour?

- Two models were proposed
- Following a count, a *paralyzable* detector is unable to provide a second response until a certain dead time τ has passed without another event occurring. Another event during τ causes the insensitive period to be restarted
- A *non paralyzable* detector, on the other hand, simply ignores other events if they occur during τ.


TRUE
EVENTS
1
2
3
4
5
6
7
SEVEN
EVENTS
TIME
τ
τ
τ
PARALYZABLE
DETECTOR
FOUR
COUNTS
TIME
τ
NON-
PARALYZABLE
DETECTOR
FIVE
COUNTS
TIME

- Such instruments thus actually count the number of intervals between events to which they respond, rather than the number of events themselves
- In practice, counting systems often exhibit behavior intermediate to the two extremes illustrated in the previous slide
- Dead time is one of the main limitations of GM tubes, especially if the ‘avalanche’ is too overwhelming for them.

Calculations

- For rt true events, the probability of the GM tube being ready to record is 1–rtт
- This probability is equal to the fraction of the detected count rate rc/rt
- We equate both sides, getting rc/rt=1–rtт
- Rearranging the equation, we get the expression on the right for a non paralyzable detector

$$r_t = \frac{r_c}{1 - r_c \tau} \qquad \text{(Nonparalyzable)}.$$

$$(r_c \tau \ll 1),$$

$$r_t \cong r_c(1 + r_c \tau).$$

A paralyzable detector is different…

- Only intervals longer than τ are registered
- We need the distribution of time intervals between successive random events that occur at the average rate rt
- The average number of events that take place in a time t is rt*t
- If an event occurs at time t = 0, then the probability that no events occur in time t immediately following that event is given by the Poisson term, P0 = exp(−rt*t)
- The probability that an event will occur in the next time interval dt is rt dt
- Therefore, given an event at time t = 0, the probability that the next event will occur between t and t + dt is:

$$P(t)\,\mathrm{d}t = r_t e^{-r_t t}\,\mathrm{d}t.$$

Calculations

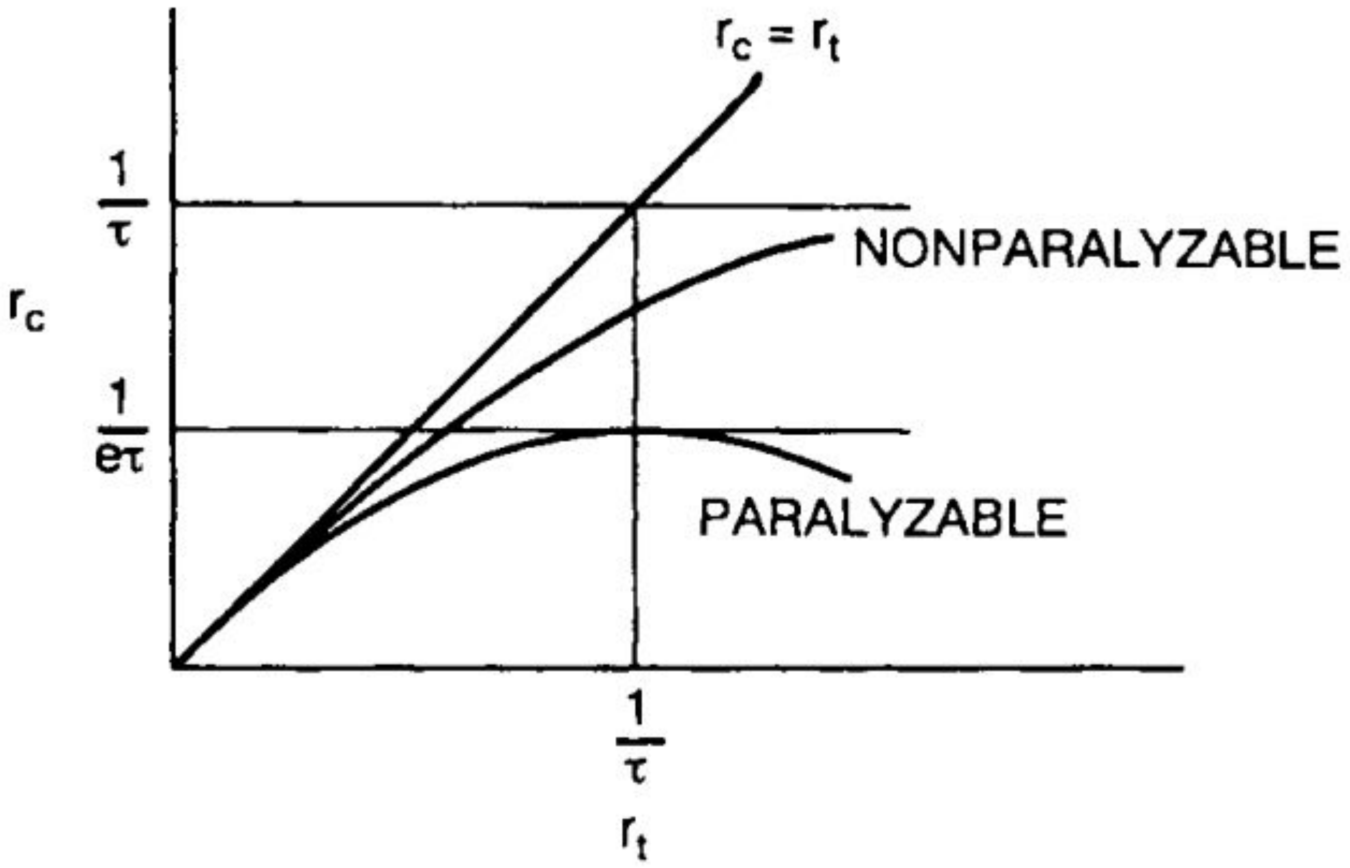
- The probability that a time interval larger than t will elapse is →→→
- This probability is equal to the fraction of the detected count rate rc/rt
- We equate both sides, getting rc/rt=exp(−rt*t)
- Rearranging the equation, we get the expression on the right for a paralyzable detector

$$\int_{\tau}^{\infty} r_t e^{-r_t t}\, dt = e^{-r_t \tau}.$$

$$r_c = r_t e^{-r_t \tau} \qquad \text{(Paralyzable).}$$

$$(r_t \tau \ll 1),$$

$$r_c = r_t(1 - r_t \tau).$$

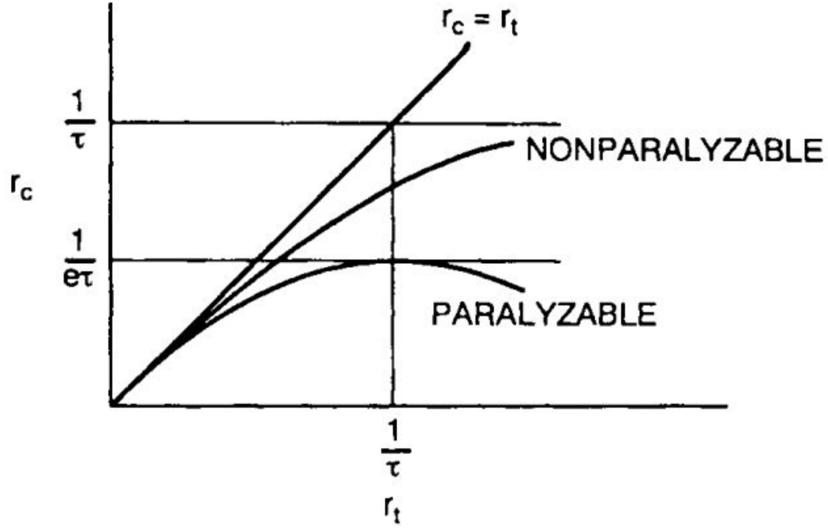

$r_c = r_t$
$\frac{1}{\tau}$
NONPARALYZABLE
r_c
$\frac{1}{e\tau}$
PARALYZABLE
$\frac{1}{\tau}$
r_t

More Calculations

- For the nonparalyzable model, as rt increases, rc approaches the asymptotic value 1/τ
- For the paralyzable model, the observed count rate goes through a maximum 1/eτ when rt = 1/τ
- With increasing event rates, the measured count rate with a paralyzable system will decrease beyond this maximum and approach zero, because of the decreasing opportunity to recover between events.

$$r_t = \frac{r_c}{1 - r_c \tau} \qquad \text{(Nonparalyzable).}$$

$$r_c = r_t e^{-r_t \tau} \qquad \text{(Paralyzable).}$$



Example

- A counting system has a dead time of 1.7 μs. If a count rate of 9×104 s−1 is observed, what is the true event rate if the counter is (a) nonparalyzable or (b) paralyzable?
- (a)

$$r_t = \frac{9 \times 10^4\ \mathrm{s}^{-1}}{1 - (9 \times 10^4\ \mathrm{s}^{-1})(1.7 \times 10^{-6}\ \mathrm{s})} = 1.06 \times 10^5\ \mathrm{s}^{-1}.$$

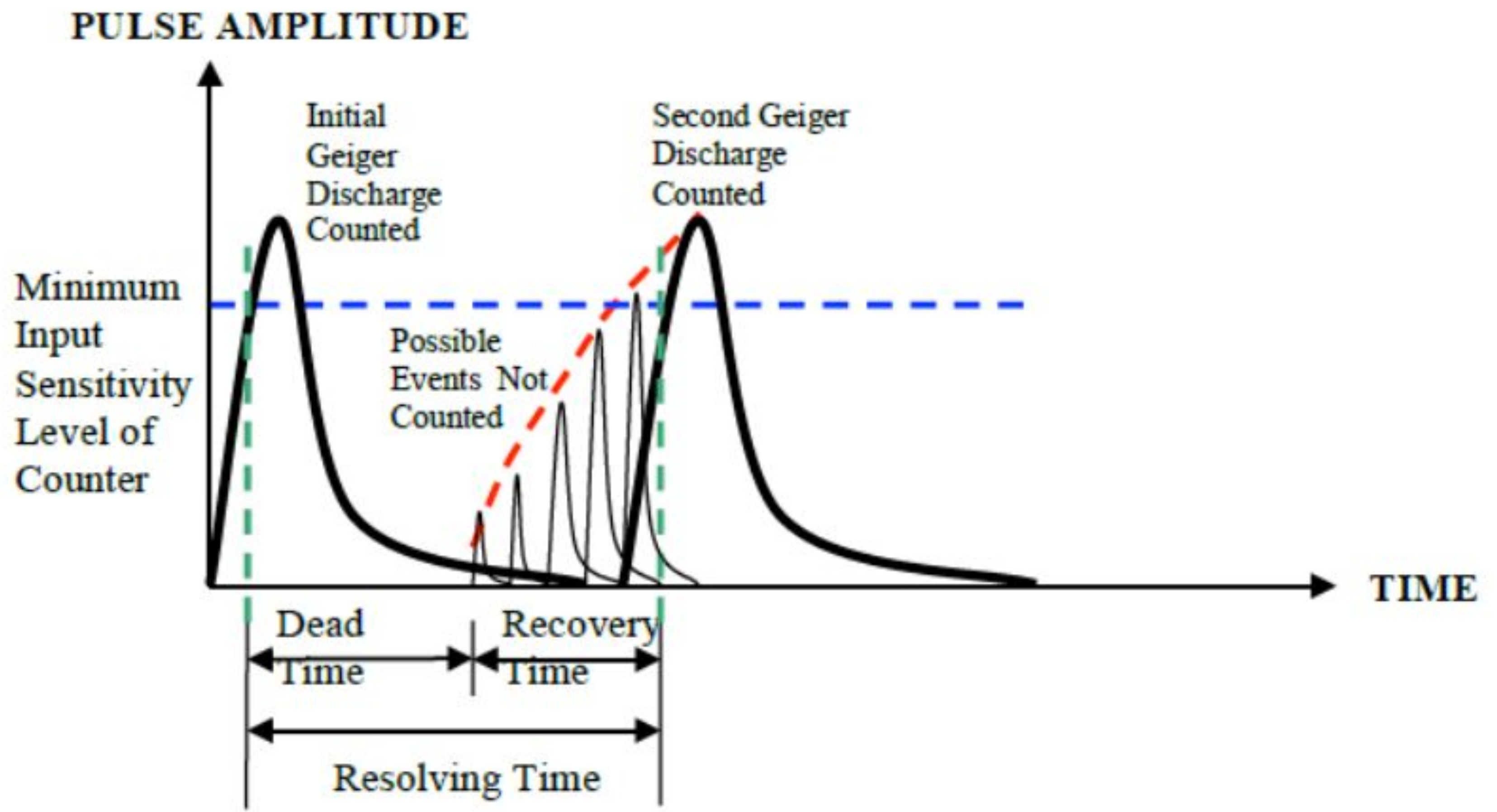
- (b)

$$9 \times 10^4 = r_t e^{-1.7 \times 10^{-6} r_t}. \rightarrow 1.7 \times 10^{-6} r_t = \ln \frac{r_t}{9 \times 10^4}.$$

Solving by iteration

$$1.7 \times 10^{-6} r_t = \ln \frac{r_t}{9 \times 10^4}.$$

- We try the solution rt = 1.06×10^5 s–1 here. The lefthand side then has the value 0.180, compared with the smaller value on the right-hand side, 0.164
- Since the paralyzable counter misses more events than the nonparalyzable, rt should be larger now than in part (a)
- Trying rt = 1.10×10^5 s–1 gives 0.187 on the LHS compared with the larger 0.201 on the right. Thus, equality is satisfied by a value of rt between these two trial values. Further refinement yields the solution rt = 1.08 × 10^5 s–1
- Since this solution is close to the result for the nonparalyzable counter, we expect the second solution to be at a higher event rate.
- For rt = 10^–6 s–1, the LHS and RHS give, respectively, 1.70 and 2.41. For rt = 10^7 s–1, the results are 17.0 and 4.71. Therefore, the solution is between these two values of rt. One finds rt = 1.75 × 10^6 s–1.


PULSE AMPLITUDE
Initial Geiger Discharge Counted
Second Geiger Discharge Counted
Minimum Input Sensitivity Level of Counter
Possible Events Not Counted
TIME
Dead Time
Recovery Time
Resolving Time

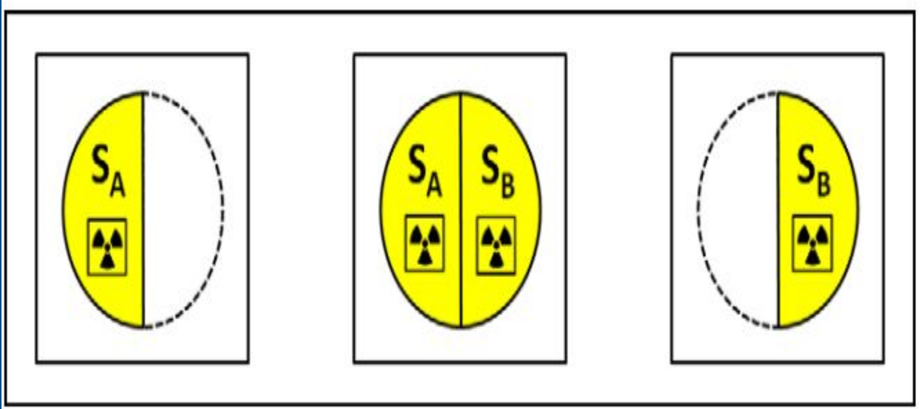
- Geiger–Muller tubes exhibit Dead Time effects due to the recombination time of the internal gas ions after the occurrence of an ionizing event
- The counter discharge occurs very close to the wire, and the negative particles, usually electrons, are collected very rapidly
- The positive ions move relatively slowly, so that as the discharge proceeds a positively charged sheath forms around the wire. This has the effect of reducing the field around the wire to a value below that corresponding to the threshold voltage, and the discharge ceases
- If another ionizing event triggers the counter at this stage, a pulse smaller than normal is obtained, as the full voltage across the counter is not operative.
- However, if the positive ions reach the cathode before the next particle arrives, the pulse will be of full size.

Dead time vs Recovery time

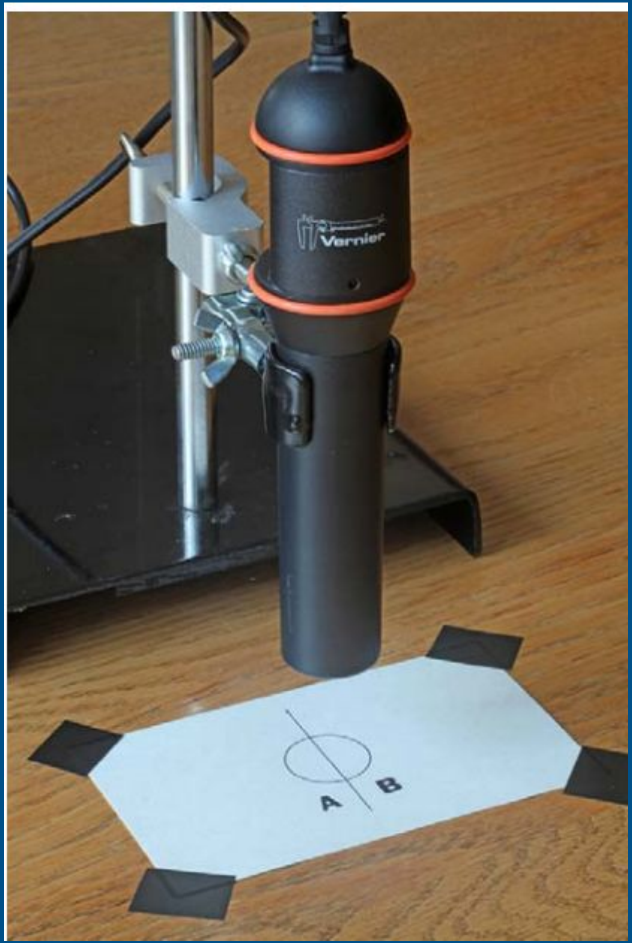
- Physically, the deadtime is the time required for the positive ions to travel far enough from the wire to permit the resumption of Geiger action, and the recovery time is the time required for the positive ions to reach the counter wall
- The resolving time is the addition of dead time and recovery time
- During dead time, GM tube is completely unresponsive
- During recovery time, GM tube is partially responsive, and smaller pulses are generated that may or may not be detected
- Resolving time is the minimum time interval by which two pulses must be separated to be detected as separate pulses by the counter

Experimental Procedure

The two-source method


S_A
S_A S_B
S_B


USNRC/State License Exempt Quantity
A
FEB 2013
Tl-204 / 5 u Ci / 3.78 yrs
Radioactive Material
SpectrumTechniques
USNRC/State License Exempt Quantity
B
Tl-204 / 5 u Ci / 3.78 yrs
Radioactive Material
SpectrumTechniques
Blank Disk


Vernier
A
B

Since $N_s = N_1 + N_2$

$$N_s = \frac{n_1}{(1-n_1 t)} + \frac{n_2}{(1-n_2 t)} \qquad (5)$$

From (4) we have

$$n_s = \frac{N_s}{(1+N_s t)} \qquad (6)$$

Substituting (5) into (6), we obtain after manipulating:

$$n_s = \frac{n_1 + n_2 - 2n_1 n_2 t}{(1-n_1 n_2 t^2)} \qquad (7)$$

Normally $n_1 n_2$t2<<1, we can approximate eq (7) to

$$n_s = n_1 + n_2 - 2n_1 n_2 t \qquad (8)$$

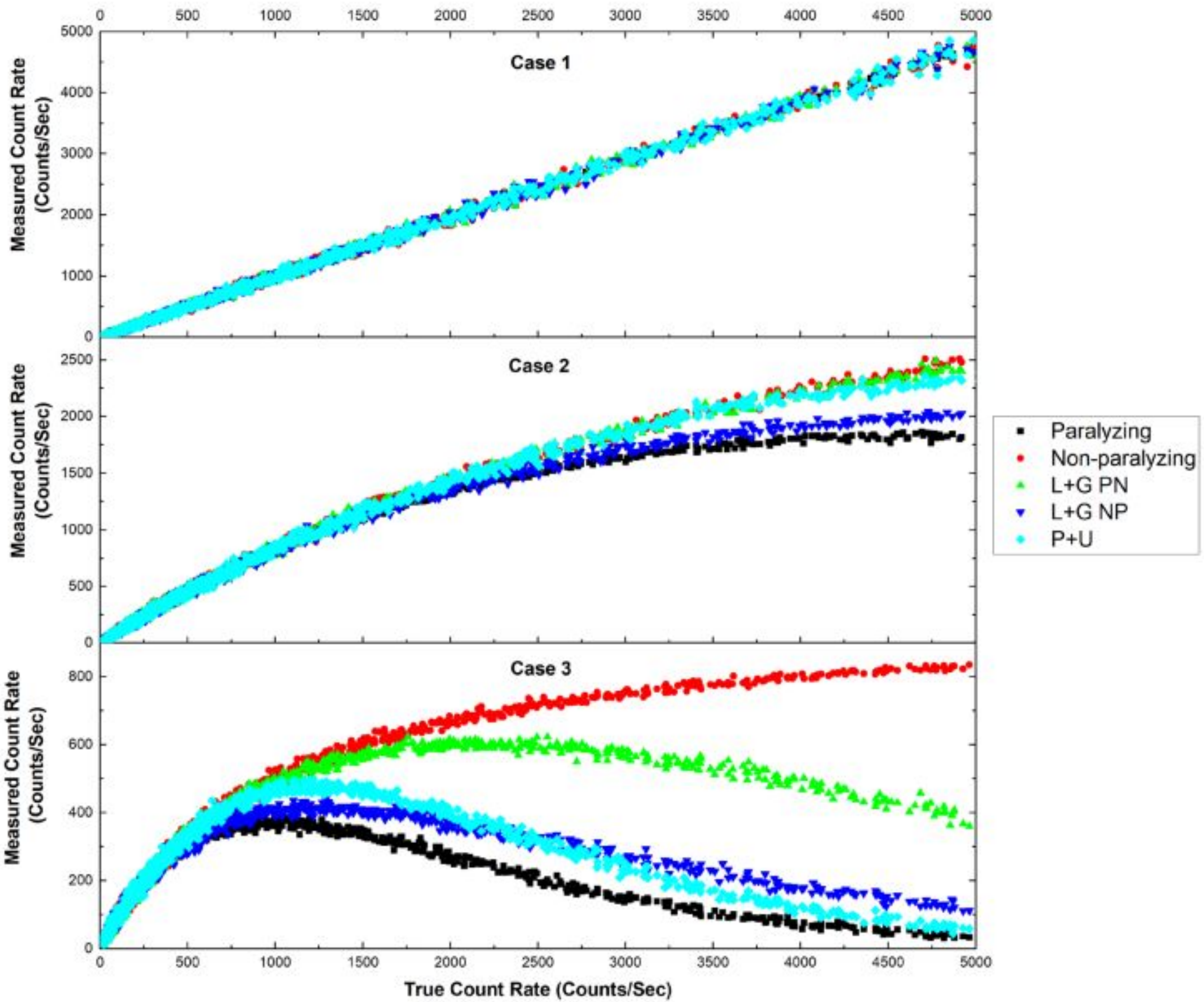
which yields

$$t = \frac{n_1 + n_2 - n_s}{2n_1 n_2} \qquad (9)$$

$$N_1 = \frac{n_1}{(1-n_1 t)} \qquad (2)$$

$$N_2 = \frac{n_2}{(1-n_2 t)} \qquad (3)$$

$$N_s = \frac{n_s}{(1-n_s t)} \qquad (4)$$



Case 1
Case 2
Case 3
Measured Count Rate (Counts/Sec)
True Count Rate (Counts/Sec)
Paralyzing
Non-paralyzing
L+G PN
L+G NP
P+U

Negative dead time

- Primarily due to errors in the measurement process
- The radioactive source is not properly aligned with the detector, leading to inconsistent count rates
- If count rate not corrected for background, you may end up with a negative value for the dead time
- Weak sources have relatively larger fluctuations in count rates, which can lead to an inaccurate dead time
- Faulty or malfunctioning electronic components could produce inconsistent pulses, leading again to an inconsistent count rate

Some improvements

- Add a halogen gas or organic vapour that increases the speed of the quenching mechanism and stops the ionization avalanche faster
- Use an external quenching circuit to implement electronic quenching
- Due to the dependence of dead time on the operating voltage, choose your operating voltage wisely, preferably one in the middle of the plateau
- Use advanced electronics to optimize the processing of the signal, such that the generated pulse can be narrower, reducing the electronic dead time
- Optimize the geometry of the GM tube such the anode is not completely covered by the positively charged cloud
- Make sure the source has a robust setup such that the alignment between the source and detector is unchanged throughout the experiment

Thank you