nanoTDCR

TRIPLE-TO-DOUBLE COINCIDENCE RATIO LIQUID SCINTILLATION COUNTING SYSTEM (TDCR) and MCA

Model Numbers: TD9009 and TD9010

nanoTDCR Model Comparison

TD9009 vs TD9010

Feature	TD9009	TD9010
Signals from PMT	Yes	Yes
Negative signals from SiPM	Yes	Yes
Positive signals from SiPM	No	Yes
Overvoltage input protection	No	Yes
Input referred threshold range	+12.4 mV to -643 mV	+625mV to -625 mV
Input referred threshold adjustment step	10 μV	19 μV
SI traceable threshold calibration	Yes, new firmware	Yes
TTL and 5V CMOS tolerant IO - R,S,T	No	Yes

I. APPLICATIONS

- Liquid Scintillation Counting using PMT (TD9009, TD9010) or SiPM (TD9010).
- Radionuclide Metrology (TDCR method in LSC).
- Standardization and half-life measurement of short Lived Isotopes.
- Environmental Protection.
- Medical Radionuclides.
- Radon Measurement.
- Spectroscopy with organic or inorganic Scintillators.

II. FEATURES

- Four TDCR modules (coincidence and live time sets) operating in parallel - Parallel Multi-Measurements (PMM).
- TDCR Multi-Measurement Scaler (MMS) with up to 64 sequential runs of the PMM .
- MMS run time interval can be as short as 1 ms for short lived nuclide measurement.
- IDT - Independent (nanoTDCR) or CDT - Common (MAC3[*] equivalent) dead time extensions for each LS counting channel.
- Digitally controlled dead time extensions from 80 ns to 500 µs in 8 ns increments.
- Digitally selectable coincidence windows from 10 ns to 200 ns, 16 settings.
- Two coincidence windows and two dead time extensions for the PMM.
- Set of up to 64 counters and timers (combined) per MMS measurement run.
- Counter/timer depth 64 bits.
- Real timer and gated live timers operate at 125 MHz input frequency.
- Optional SI traceable timer frequency calibration.
- Timer frequency stability 15 ppm (max).
- UTC measurement time-stamp derived from NTP internet time servers.
- Digitally controlled PMT thresholds from +25mV to -1.3 V in increments of 20 µV.
- 4th PMT channel (gamma channel) with built-in PMT preamplifier.
- 4096-channel Multichannel Analyzer (MCA) using digital pulse processor (DPP).
- Separate MCA groups for the LS channels and the 4th PMT channel.
- Full featured coincidence/anticoincidence logic for TDCR and MCA measurements.
- State-of-the-art digital pulse processor with 16-bit low power ADC sampling at 125 MHz.
- Digitally synthesized triangular/trapezoidal pulse shapes.

- Pulse shape rise time from 50 ns to 16 µs.
- Adjustable flat top for all shapes 0 to 2 µs.
- Automatic MCA thresholds based on statistical noise estimation.
- Built-in and signal-interference free Digital Pulser for noise and base-line estimation.
- Two configurable digital outputs and one digital input/output.
- Trace Viewer (Mixed Signal Oscilloscope) with unique peak magnification feature.
- Battery-less backup of the measurements and the settings of the nanoTDCR.
- Interchangeable interface modules for either wired or wireless connectivity. Supports USB, Ethernet, WiFi, Bluetooth.
- Single mini USB I/O connector for all interfaces.
- Power source requirement 5 V/300 mA.
- Power consumption 1200 mW @ 25°C with USB interface.
- MCA Temperature Stability: Gain < 10 ppm/°C (± 5 ppm/°C), Base Line < 1 ppm/°C.
- Temperature Operating Range: 0 °C to +60 °C.
- Weight <135 g.
- Dimensions 3.6" x 1.5" x 1" (92 mm x 38 mm x 25 mm).
- Free ***labZY-TDCR*** software for TDCR and MCA data acquisition and configuration.

[*] J. Bouchard, P. Cassette, MAC3: an electronic module for the processing of pulses delivered by a three photomultiplier liquid scintillation counting system. Appl. Radiat. Isot. 52, 2000, 669–672

III. DESCRIPTION

The nanoTDCR is a radiation measurement device incorporating two highly-integrated systems. The first system is a Triple-To-Double Coincidence Ratio Liquid Scintillation Counting System (TDCR) and the second is a digital MCA. Both systems function independently of each other except when the MCA acquisition is in a coincidence/anticoincidence with the TDCR and vice versa.

Fig. 1 shows the block diagram of the nanoTDCR. There are three analog inputs (A,B and C) that accept anode signals from photo-electric multipliers (PMT) or silicon photo-multipliers SiPM (TD9010 only) of a TDCR counter. The input impedance of each of these inputs is 50Ω. The anode signal of each PMT or SiPM is amplified by a fast amplifier (FAMP) whose output is split in two. One branch is applied to a multiplexor (MUX) that feeds the MCA through an analog pre-filter (PRE-FILTER). The other branch drives a comparator (COMP) with a threshold that is set digitally by the labZY-TDCR software. The output of each comparator drives the TDCR counters.

The connector E of the nanoTDCR is the input to the 4th PMT channel. The 4th PMT channel has built in R-C preamplifier (PAMP) with an RC time constant of 512ns. The PAMP has hardware selectable sensitivity. Fig. 2 showst the sensitivity control of the PAMP. The selector switch is located under a cover on the bottom of the nanoTDCR enclosure. The selector has 8 position. The signal from PAMP is applied to the same multiplexor MUX as the amplified PMT signals A, B and C which allows spectrum acquisition by the MCA of the 4th PMT channel.

The CONTROLLER sets various parameters and controls the operation of the TDCR and the MCA. The communication with the external world (e.g. computer) is accomplished via a COMMUNICATION interface module. Logic I/O lines are used to provide direct control/access to/from various internal signal of the TDCR and the MCA.

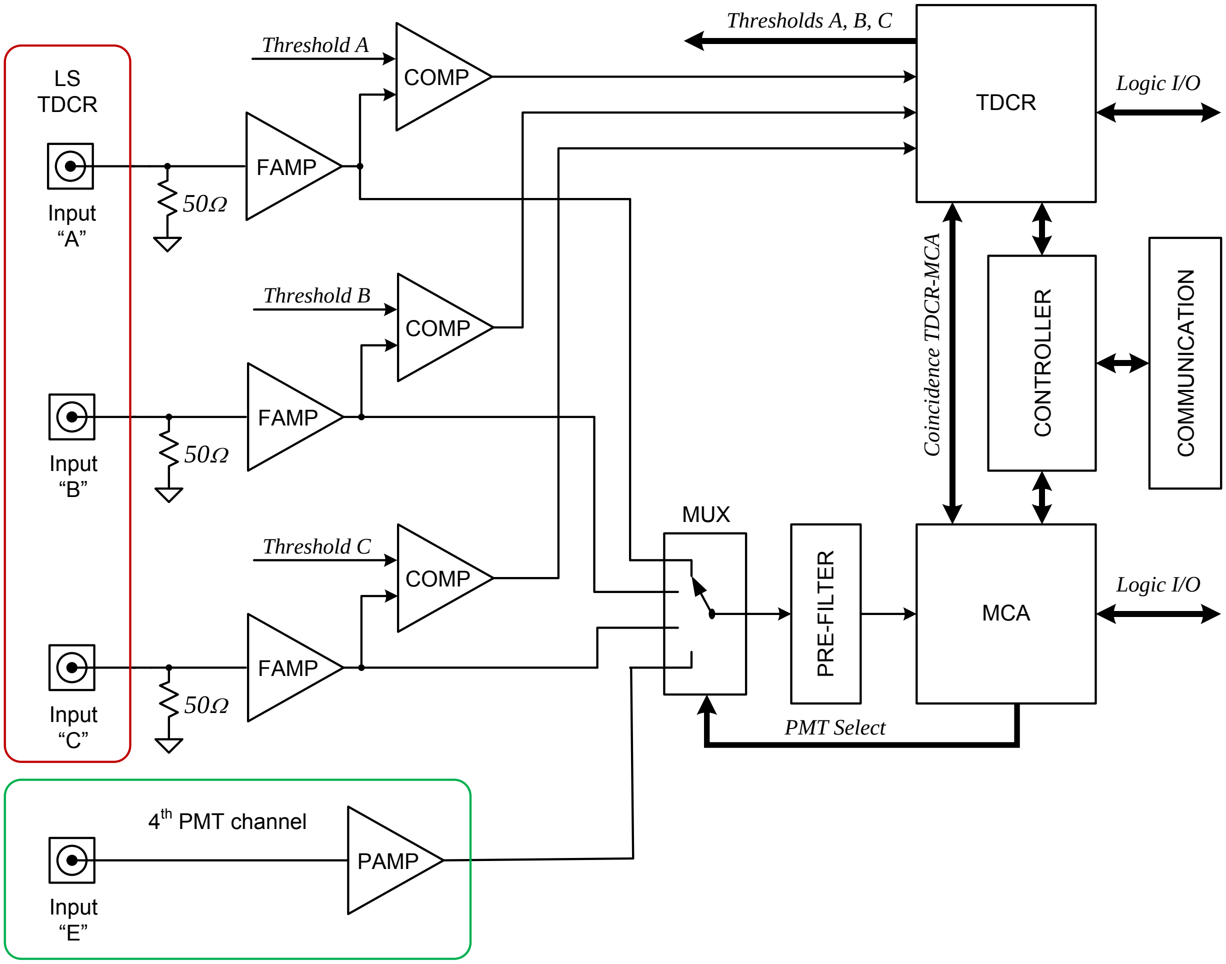


Fig. 1 Functional Block Diagram of the ***nanoTDCR***.

a) b)

Fig. 2 PAMP sensitivity selector a). The selector is under a small cover b) on the bottom side of the enclosure.

Fig. 3 shows the block diagram of the TDCR system. The PMM has 3 identical Extended Dead Time and Coincidence Pulse Generators. The Coincidence Unit and the Live Time Unit generate coincidence pulses and gated 125 MHz frequency for the live timers. The coincidence pulses and the live time frequency are counted by counters/timers in the MMS. MMS incorporates up to 64 counters/timers per measurement run. For each run four sets of coincidence data and live timers are counted. This is equivalent to use in parallel four traditional single channel TDCRs.

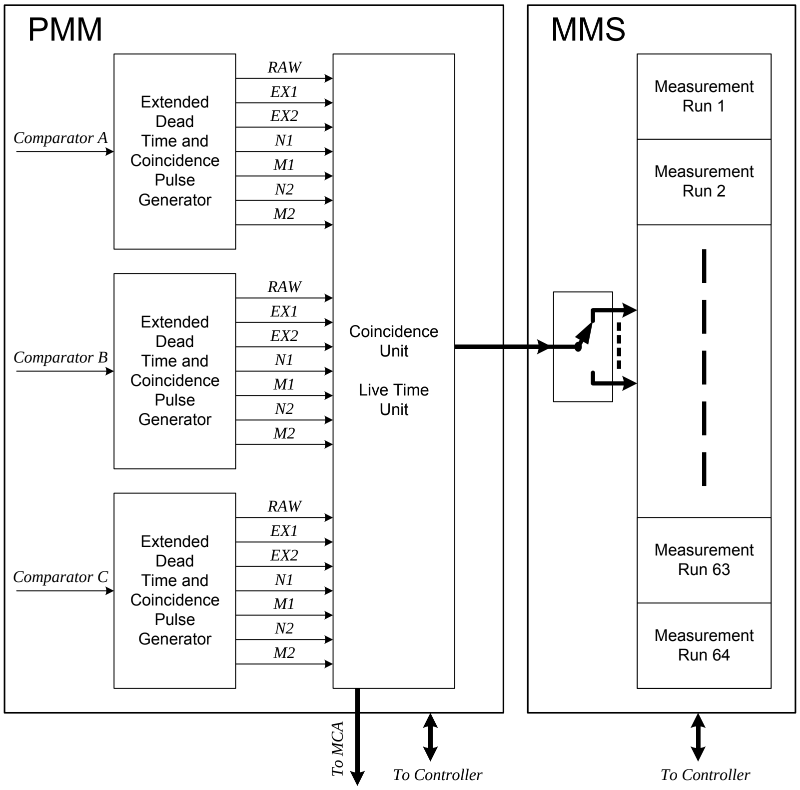


Fig. 3 Functional Block Diagram of the TDCR system.

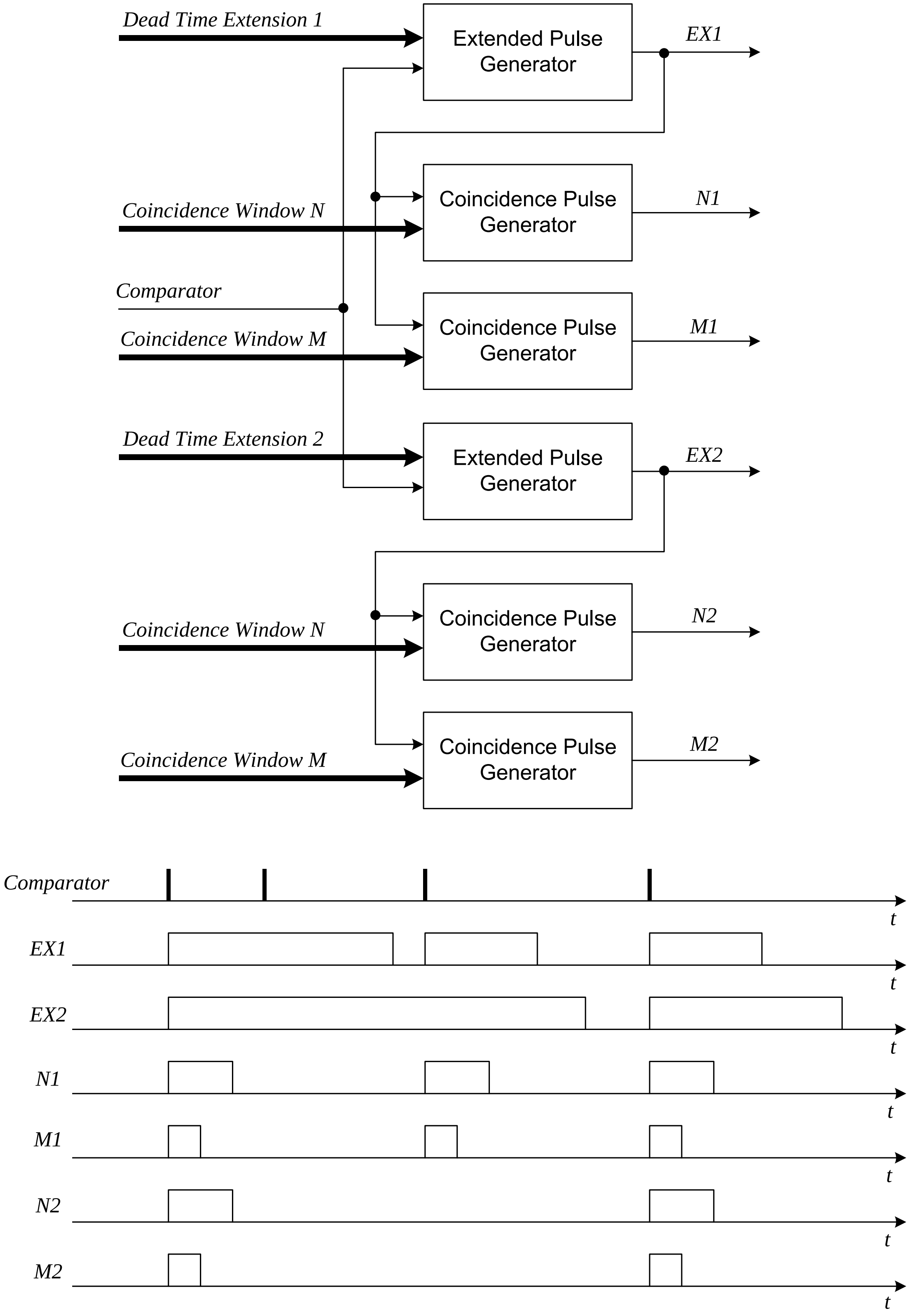
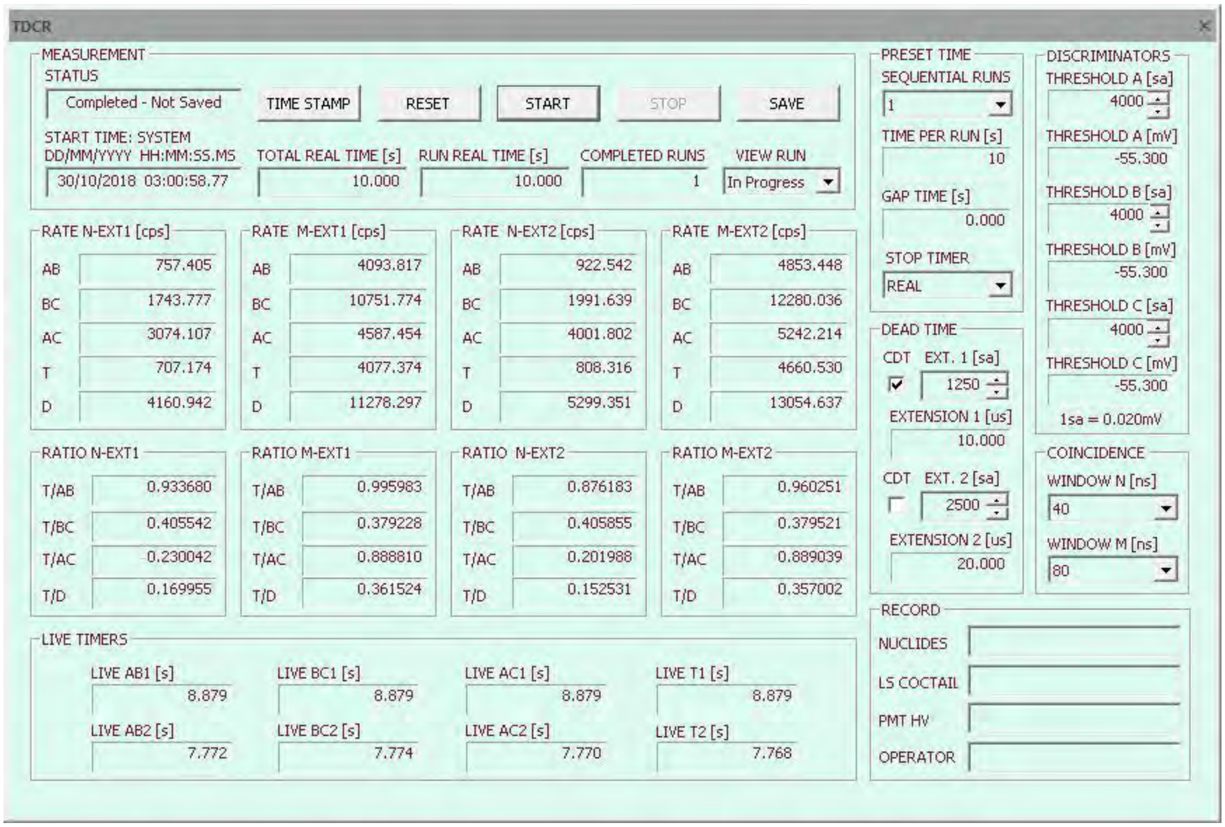


Fig. 4 Block and Timing Diagrams of the Independent Extended Dead Time and Coincidence Pulse Generator.

The salient feature of the nanoTDCR is the fully independent dead time extension and coincidence window generation for each PMT (SiPM). Fig. 4 shows the block diagram of the Extended Dead Time and Coincidence Pulse Generator. A single measurement run acquires counts and live time resulting from two dead time extensions (Extension 1 and Extension 2) and two coincidence windows (Window N and Window M). That is, four TDCR measurement are performed simultaneously. There are four sets of coincidence counts (counting rates) reported by the nanoTDCR for each measurement run. These are coincidence rates AB, BC, AC, D, and T. The four sets of these rates are defined by the following measurement parameter combinations: Extension 1 and Window N (N-EXT1), Extension 1 and Window M (M-EXT1), Extension 2 and Window N (N-EXT2), and Extension 2 and Window M (M-EXT2). Fig. 5 shows the labZY-TDCR software reporting the coincidence rates for each dead time extension - coincidence window set.



MEASUREMENT

STATUS: Completed - Not Saved

START TIME: SYSTEM DD/MM/YYYY HH:MM:SS.MS: 30/10/2018 03:00:58.77

TOTAL REAL TIME [s]: 10.000

RUN REAL TIME [s]: 10.000

COMPLETED RUNS: 1

VIEW RUN: In Progress

	RATE N-EXT1 [cps]	RATE M-EXT1 [cps]	RATE N-EXT2 [cps]	RATE M-EXT2 [cps]
AB	757.405	4093.817	922.542	4853.448
BC	1743.777	10751.774	1991.639	12280.036
AC	3074.107	4587.454	4001.802	5242.214
T	707.174	4077.374	808.316	4660.530
D	4160.942	11278.297	5299.351	13054.637

	RATIO N-EXT1	RATIO M-EXT1	RATIO N-EXT2	RATIO M-EXT2
T/AB	0.933680	0.995983	0.876183	0.960251
T/BC	0.405542	0.379228	0.405855	0.379521
T/AC	0.230042	0.888810	0.201988	0.889039
T/D	0.169955	0.361524	0.152531	0.357002

LIVE TIMERS

LIVE AB1 [s]	LIVE BC1 [s]	LIVE AC1 [s]	LIVE T1 [s]
8.879	8.879	8.879	8.879
LIVE AB2 [s]	**LIVE BC2 [s]**	**LIVE AC2 [s]**	**LIVE T2 [s]**
7.772	7.774	7.770	7.768

PRESET TIME

SEQUENTIAL RUNS: 1

TIME PER RUN [s]: 10

GAP TIME [s]: 0.000

STOP TIMER: REAL

DEAD TIME

CDT ☑ EXT. 1 [sa]: 1250

EXTENSION 1 [us]: 10.000

CDT ☐ EXT. 2 [sa]: 2500

EXTENSION 2 [us]: 20.000

DISCRIMINATORS

THRESHOLD A [sa]: 4000

THRESHOLD A [mV]: -55.300

THRESHOLD B [sa]: 4000

THRESHOLD B [mV]: -55.300

THRESHOLD C [sa]: 4000

THRESHOLD C [mV]: -55.300

1sa = 0.020mV

COINCIDENCE

WINDOW N [ns]: 40

WINDOW M [ns]: 80

RECORD

NUCLIDES:

LS COCTAIL:

PMT HV:

OPERATOR:

Fig. 5 labZY-TDCR software (Ver 6.42) - TDCR window, counting rates from external pulse generators.

Fig. 6 shows the block diagram of the MCA. The core technology of the MCA is an advanced Digital Pulse Processing (DPP) operating at 125 MHz. which is a result of more than 25 years of development and innovation. A unique feature of the MCA is the smart spectrum-size acquisition implementation which always stores the spectra in a 4k spectrum size (***hard size***). The labZY-TDCR software allows instant, distortion-free conversion of the ***hard size*** spectrum into smaller spectrum sizes (***soft size***) for display or data processing purposes. Spectra are always stored in files as hard size spectra (4k channels). The labZY-TDCR software allows exporting the ***soft size*** spectra for off-line analyses by applications that require spectra with sizes smaller than the ***hard size***.

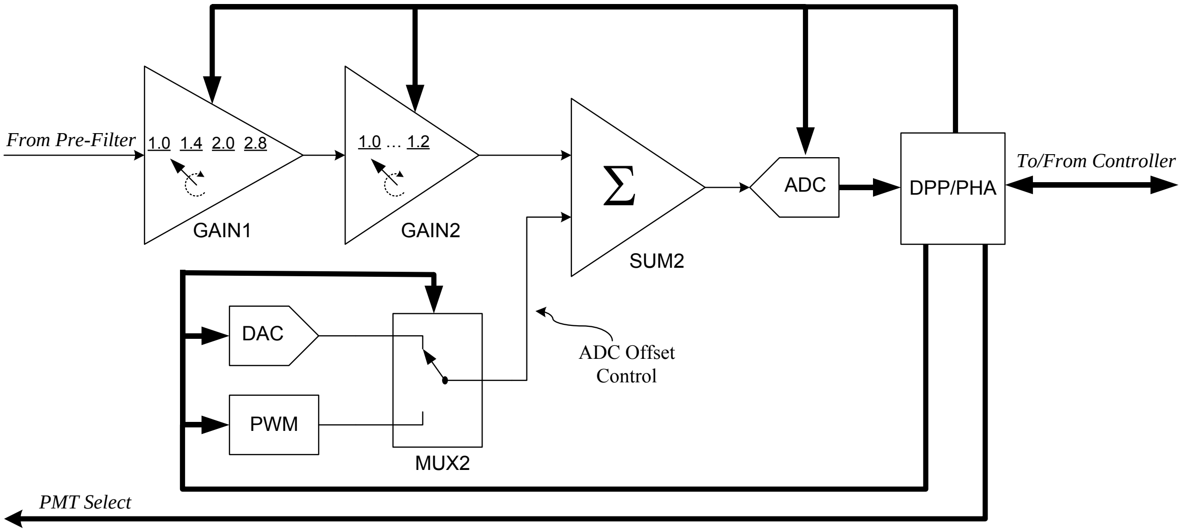


Fig. 6 Functional Block Diagram of the ***MCA.***

The DPP of the nanoTDCR employs advanced algorithms for pulse shaping. Multiple-pole unfolding technique allows the achieving of well-defined pulse shapes, which is essential for the accurate accounting for the pile-up losses. labZY's proprietary digital technique allows accurate incoming count rate (ICR) estimation, which is important for proper setting of the radiation measurement systems.

Another unique feature of the MCA system is the **Digital Pulser**. The Digital Pulser allows noise-free estimation of the intrinsic resolution (electronic noise). The Digital Pulser may also be used to verify the base line of the MCA. The Digital Pulser does not interfere with the signals from the PMTs.

The MCA can also be used in a PHA mode. In this mode the peak of the PRE_FILTER signal is detected, measured and counted in the spectrum histogram. The peak detection and measurement can be triggered by the TDCR comparator signals allowing instant coincidence of the recorded spectra with the corresponding PMT signals. The PHA mode can be used to accurate adjust the TDCR thresholds slightly below the single photon peak in the MCA spectrum. The low energy cut-off of the spectrum is directly proportional to the TDCR threshold when PHA mode is triggered by the TDCR system.

The MCA and the TDCR algorithms are in-system programmable and field upgradable which makes the nanoTDCR extremely flexible system. Functionality of the nanoTDCR can be changed by simply programming an FPGA design. The program process takes about one minute. labZY provides free standard FPGA designs that support TDCR functionality. Updates of the FPGA designs can be found at www.labzy.com.

IV. CONNECTIONS

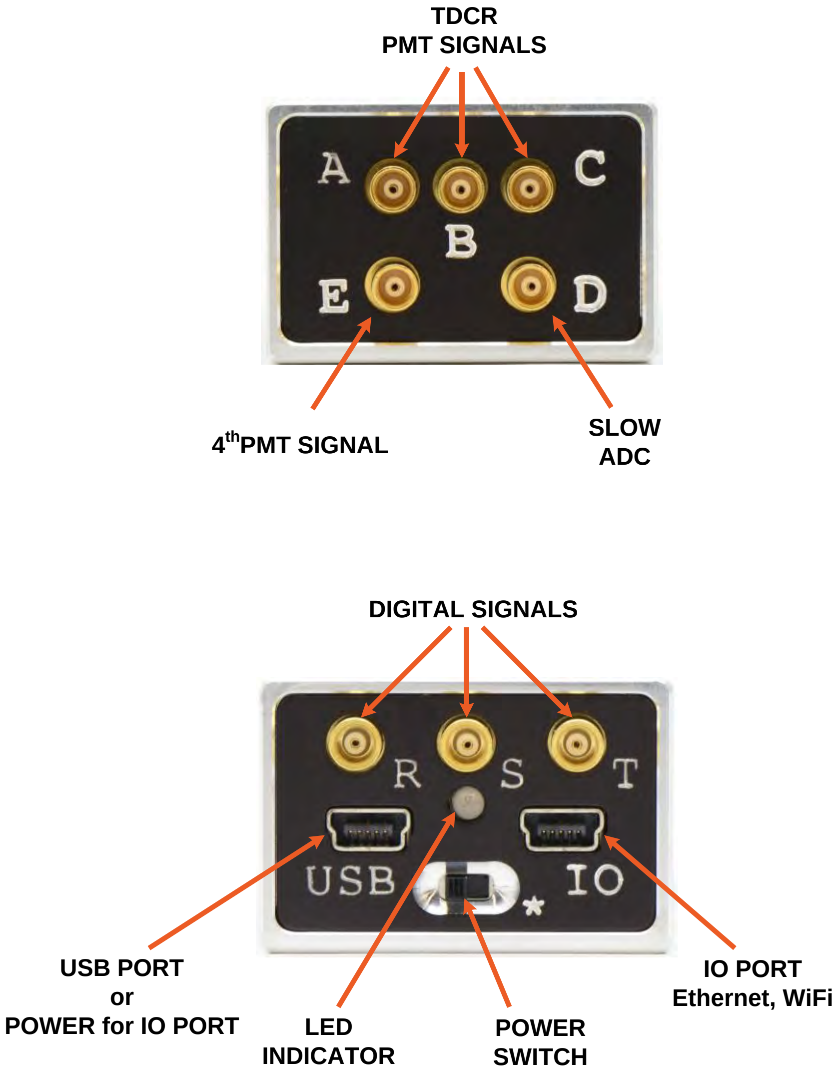


Fig. 7 nanoTDCR connectors and controls.

VI. INPUT SPECIFICATIONS

PMT (SiPM) Inputs A, B and C:

Input impedance: 50 Ω.

Operating Input Range TD9009: 0 to -4 V (Input current 0 to -80 mA).

Operating Input Range TD9010: -4 to +4 V (Input current 0 to ± 80 mA).

Signal Polarity: Negative TD9009, Negative or Positive TD9010 software selectable.

Absolute *Maximum Input Voltage*: ± 5.5 V.

Absolute Maximum Input Current: ± 90 mA.

Input Protection: ± 10 V@10ms TD9010 only.

NOTE: Exceeding the Absolute Maximum Specifications may damage permanently the nanoTDCR.

TDCR Discriminators A, B and C:

Voltage Range (TD 9009, DAC referred):	+24.7mV to -1.286 V, labZY-TDCR software prior to version 7.00.
Voltage Range (TD 9009, Input referred):	+12.35mV to -643 mV, labZY-TDCR software version 7.00 or later.
Voltage Range (TD 9010, Input referred):	+625mV to -625 mV, labZY-TDCR software version 7.00 or later.

Range Tolerance: ±5% (typ).

Discriminator Offset (Input referred): ±2 mV (typ).

Threshold Adjustment Step(±5%): 10 µV TD9009, 19 µV TD9010.

Threshold Temperature Drift: < ±5 µV /°C (typical), ±10 µV /°C (maximum)

Threshold Range Long Term Stability: < 50 ppm

Threshold Calibration Option: traceable to SI, orderable option

Threshold Re-Calibration Interval: 1 year

Input E:

Signals from PMT anode: AC or DC coupled

Preamplifier Time Constant: 520ns ±20%.

Charge Sensitivity:

8 position sensitivity selector (SEL = 0 to 7).

*SENSITIVITY = (8 - SEL)*3.2 fC/channel* ±5% @ gain of <u>1.00</u> and 2^{12} channels.

Charge Sensitivity at Gain >1: Charge Sensitivity @ Gain=1 divided by the gain.

Fine Gain: <u>1.00</u> to <u>1.20</u> in 65536 steps.

Maximum Input Offset Current: ±10µA.

Absolute Maximum Signal Voltage: ±5V.

Absolute Maximum DC Input Current: ± 20 mA.

NOTE: <u>Exceeding the Absolute Maximum Specifications may damage permanently the nanoTDCR</u>.

Input D:

Type: Analog Input 0 to +2.5V.

Function: Analog Input to a slow 12-bit ADC.

Important: Leave this input unconnected when not used.

Never apply pulse or high frequency signals to this input!

Input/Output R:

Type: Digital Input, 3.3V CMOS or Digital Output, 3.3V CMOS, Open Drain or Tristate.

Voltage Tolerance: 5V (TTL or CMOS) <u>TD9010</u> only.

Primary Input Function: Coincidence Logic Signal, 3.3V CMOS.

Secondary Input Function: 10 MHz Reference Clock, 3.3V CMOS.

Primary Output Function: TDCR channel A signals - software selectable.

Secondary Output Function: Internal 5 MHz Clock.

Custom Function: Per customer requirements.

Output Drive: DISABLED, PUSH-PULL, OPEN DRAIN; STRAIGHT or INVERTED.

Output S:

Type: Digital Output, 3.3V CMOS, Open Drain or Tristate.

Voltage Tolerance: 5V (TTL or CMOS) TD9010 only.

Primary Output Function: TDCR channel B signals - software selectable.

Secondary Output Function: Internal 10 MHz Reference Clock.

Default Output Driver: 3.3V CMOS.

Custom Function: Per customer requirements.

Output Drive: DISABLED, PUSH-PULL, OPEN DRAIN; STRAIGHT or INVERTED.

Output T:

Type: Digital Output, 3.3V CMOS, Open Drain or Tristate.

Voltage Tolerance: 5V (TTL or CMOS) TD9010 only.

Primary Output Function: TDCR channel C signals - software selectable.

Secondary Output Function: MCA Peak Detect Signal.

Default Output Driver: 3.3V CMOS.

Custom Function: Per customer requirements.

Output Drive: DISABLED, PUSH-PULL, OPEN DRAIN; STRAIGHT or INVERTED.

VII. TDCR SPECIFICATIONS

Extended Dead Time:

Type: Paralyzable.

Dead Time Extension Generation: generator for each PMT (SiPM), independent (IDT) from other TDCR channels or Common (CDT) for all TDCR channels - software selectable.

Range - Extension 1: 800 ns to 500 µs.

Increment Step - Extension 1: 8 ns.

Range - Extension 2: 800 ns to 500 µs.

Increment Step - Extension 2: 8 ns.

Coincidence Window:

Window N Selection: 10ns, 20ns, 30ns, 40ns, 50ns, 60ns, 70ns, 80ns, 90ns, 100ns, 110ns, 120ns, 140ns, 160ns, 180ns, 200ns.

Window M Selection: 10ns, 20ns, 30ns, 40ns, 50ns, 60ns, 70ns, 80ns, 90ns, 100ns, 110ns, 120ns, 140ns, 160ns, 180ns, 200ns.

Measurement Presets:

Sequential Runs per Measurement: 1 to 64.

Time per run: 1ms to $43\text{x}10^6$ s.

Time from end of a run to the start of the next run (GAP TIME): 0.1ms to $43\text{x}10^6$ s.

Stop Timers: Real or any of the available live timers.

Measurement Start Time Stamp: UTC, System (GMT), Local. The UTC time stamp requires internet connection and ability to connect to an internet time server. The System and Local time stamp are derived from the computer clock. The UTC time stamp has typical accuracy of less than 50ms.

Counters:

Bits per counter: 64.

Maximum number of counters per run: 64, shared with the timers.

Typical number per run: 48.

Coincidence Counters per PMM Group: AB, BC, AC, D and T (5 total).

Number of PMM Groups: 4.

Non-coincidence counters per PMT: RAW, Extended Pulses 1, Extended Pulses 2.

Timers:

Bits per timer: 64.

Internal Timer Resolution: 8 ns.

Reported Time Resolution: 1 ms.

Timer Accuracy (typ): ±2 ppm.

Timer Accuracy (worst case): ±15 ppm. (Includes variations due to initial tolerance, temperature and power supply voltage)

Maximum number of timers per run: 64, shared with the counters.

Typical number per run: 1 real and 14 live (15 total).

Coincidence Live Timers for Dead Time Extension 1: AB1, BC1, AC1, and T1 (4total).

Coincidence Live Timers for Dead Time Extension 2: AB2, BC2, AC2, and T2 (4total).

Non-coincidence Live Timers for Dead Time Extension 1: A1, B1, C1.

Non-coincidence Live Timers for Dead Time Extension 2: A2, B2, C2.

VIII. MCA SPECIFICATIONS - DPP MODE

Amplifier:

Coarse Gain: <u>1.00</u>, <u>1.41</u>, <u>2.00</u>, <u>2.83.</u>

Fine Gain: <u>1.00</u> to <u>1.20</u> in 65536 steps.

Gain Temperature Stability: < 10 ppm/°C (typical), 20 ppm/°C (maximum)

Digital Pulse Processor:

Sampling Period: 8ns (Sampling Frequency125 MHz).

Quantization: 16 bit, including offset and pile-up head room.

Primary Time Constant (Long TC) Cancelation: 120 ns to 4.1 µs, Adjustable in 1 ns increments.

Secondary Time Constant (Short TC) Cancelation: 1 ns to 255 ns. Adjustable in 1 ns increments.

Integral Nonlinearity: 0.006% (typ), 0.018% (max) over full scale.

Differential Nonlinearity: < 0.1% for typical high-resolution setup[#].

Peak Detection: labZY's proprietary digital constant-fraction timing algorithm.

Base Line Stabilizer: Digital, Gated High-Pass Filter with Software adjustable response.

Main Filter Digital Pulse Shape: Trapezoidal.

Main Filter Rise Time: 16 ns to 16 µs, adjustable in increments of 8 ns.

Main Filter Flat Top: 8 ns to 2 µs, adjustable in increments of 8 ns.

Fast Filter Digital Pulse Shape: Trapezoidal.

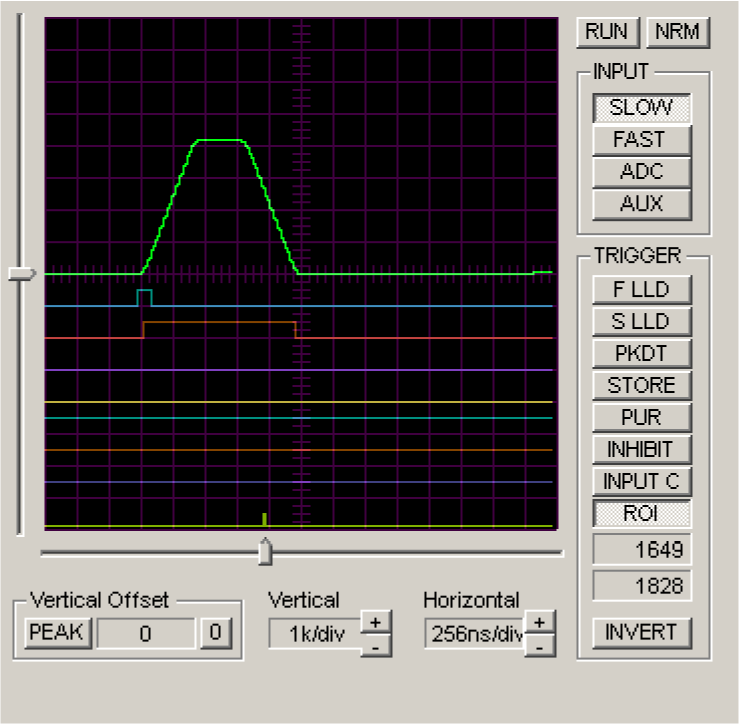
Fast Filter Rise Time: 8 ns to 8 µs, adjustable in increments of 8 ns.

Fast Filter Flat Top: 8 ns to 8 µs, adjustable in increments of 8 ns.

Digital MCA Thresholds (main and fast filters): Automatic or manual. Adjustment in increments of one ***hard size*** channel.

Base Line Temperature Stability: Digitally stabilized, not subject to temperature drift. For comparison purposes with analog systems < 1 ppm/°C

[#] Differential Nonlinearity depends not only on the quantization properties of the digitizer, but also upon the noise level of the signal. Reference: V.T. Jordanov and K.V. Jordanova, "Quantization Effects in Radiation Spectroscopy Based on Digital Pulse Processing ", Nuclear Science, IEEE Transactions on, Vol 59, Issue 4, pp 1282 - 1288, Aug. 2012.



Vertical Offset: 0

Vertical: 1k/div

Horizontal: 256ns/div

1649

1828

Fig. 8 Example: DPP synthesized trapezoidal pulse shape - trace viewer of labZY- TDCR software.

IX. MCA SPECIFICATIONS - PHA MODE

Amplifier:

Coarse Gain: 1.00, 1.41, 2.00, 2.83.

Fine Gain: 1.00 to 1.20 in 65536 steps.

Gain Temperature Stability: < 10 ppm/°C (typical), 20 ppm/°C (maximum)

Digital PHA Processor:

Sampling Period: 8 ns (Frequency125 MHz).

Quantization: 16 bit, including offset and pile-up head room.

Integral Nonlinearity: 0.006% (typ), 0.018% (max) over full scale.

Differential Nonlinearity: < 1%.

Base Line Temperature Stability: Digitally stabilized when using the internal BLR, not subject to temperature drift. For comparison purposes with analog systems < 1 ppm/°C.

Base Line Temperature Stability: Without the internal BLR < 25 ppm/°C.

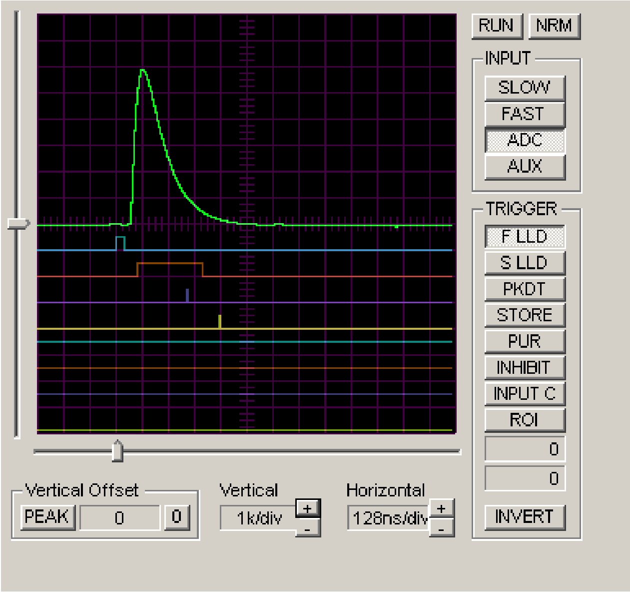
Peak Measurement: Real-time peak fitting.

Peak Detection: labZY's proprietary digital constant-fraction timing algorithm.

TDCR Triggered Peak Detection: Absolute peak above the threshold.

Base Line Stabilizer: Digital, Gated High-Pass Filter with Software adjustable response. Can be turned ON or OFF. Recommended setting ON.

ADC Offset: Automatic or manual. Recommended setting Automatic.



Vertical Offset 0 0

Vertical 1k/div

Horizontal 128ns/div

0

0

Fig. 9 Example: ADC pulse processed directly by PHA - Trace Viewer of labZY- TDCR software.

X. MCA SPECIFICATIONS - COMMON

Data Acquisition:

*Hardware Spectrum Size per PMT(SiPM)(**hard size**)*: 4096 channels (4k) using smart spectrum size technology. Hard size spectra are always recorded and stored in files.

Soft Spectrum Size per PMT(SiPM)(Soft Size): Instant, distortion free size conversion for display or data processing: 512, 780, 1024, 1489, 2048, 3276, 4096 channels. The soft size conversion does not cause destruction of the hard size spectra which allows an instant selection of any of the available soft sizes. A single acquisition allows display and/or data processing of the spectrum as any one of the soft spectrum sizes.

Counts per Channel: 4 bytes, 0 to 4.3 billion.

Time Measurement: Real and Live timers.

Preset Time: Real or Live.

Timer Resolution: 200 ns.

Timer Accuracy (typ): ± 2 ppm.

Timer Accuracy (worst case): ± 10 ppm. (Includes variations due to initial tolerance, temperature and power supply voltage)

Preset Time Resolution: 1s.

Maximum Preset Time: 43×10^6 s or 497 days.

Dead Time Correction Technique: Extended Paralyzable Dead Time.

ICR Estimation: Counting and correction for pile-up losses in either the fast channel or the main channel.

Pile-Up Rejection: Time between fast discriminator pulse and labZY's proprietary advanced fast discriminator pile-up detection.

Start Time Stamp Selection: UTC, System or Local.

Data Backup: Battery-less. Hard Size Spectrum and All Settings.

XI. COINCIDENCE

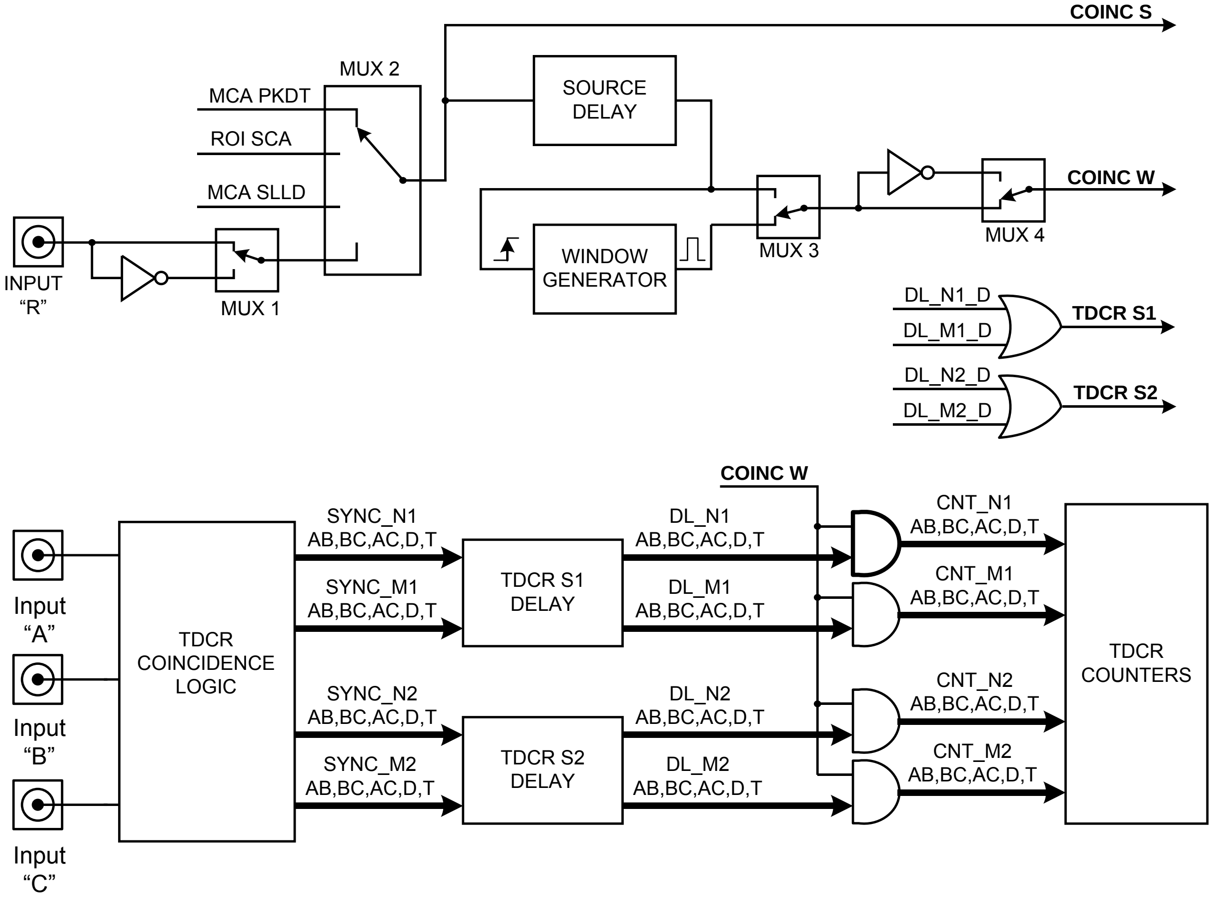


Fig. 10 Block Diagram of the nanoTDCR coincidence circuit - TDCR Coincidence.

TDCR Coincidence:

Coincidence Sources:

Internal: MCA Timing Peak Detector (MCA PKDT), ROI_SCA Timing Signal (ROI SCA), Low Level Discriminator of the main MCA shaper (MCA SLLD).

External: Input R.

Modes of Operation: Coincidence and Anti-Coincidence.

Coincidence Window Width:

Direct: Coincidence source (COINC S) width.

Window: 8 ns to 32.76 µs, in increments of 8 ns.

Window Trigger: Low to High Transition of the COINC S .

Counters Increment Delay (TDCR S1and TDCR S2): Adjustable 640 ns to 65.64 µs from the first arrival pulse at inputs A or B or C. Adjustment increment - 8 ns.

Coincidence Source Delay (Source Delay): Adjustable 8 ns to 130 µs, in increments of 8 ns.

TDCR S1and TDCR S2 Width: 8 ns.

MCA Coincidence:

Coincidence Sources:

Internal: TDCR discriminators A,B,C (TDCR A, TDCR B, TDCR C)

External: Input R.

Modes of Operation: Coincidence and Anti-Coincidence.

Coincidence Window Width:

Direct: Coincidence source (COINC S) width.

Window: 8 ns to 32.76 µs, in increments of 8 ns.

Window Trigger: Low to High Transition of the COINC S .

MCA Storage Delay (MCA STO): Adjustable 8 ns to 65 µs from the internal storage signal derived from the MCA PKDT at fixed latency delay. Adjustment increment 8 ns.

Coincidence Source Delay (Source Delay): Adjustable 8 ns to 130 µs, in increments of 8 ns.

MCA STO Width: 8 ns.

XII. GENERAL SPECIFICATIONS

Communication Interfaces:

Wired: USB (also power source), Ethernet.

Wireless: WiFi, Bluetooth.

Environmental:

Operating Temperature Range: Normal Temperature Range 0 °C to +80 °C

Power:

Power Supply: Required for all interfaces other than USB: 5 V @ 1 A.

Power Supply Voltage: +5 V ± 10%.

Operating Power (typ) : 1200 mW at 25°C and USB interface. 900 mW to 1.5 W over the full Extended Temperature Range.

Additional Power Requirements: Bluetooth Interface – 100 mW, WiFi Interface - 500 mW, RS-232 Interface – 50 mW, Ethernet Interface – 900 mW.

Mechanical:

Dimensions: 3.6" x 1.5" x 1" (92 mm x 38 mm x 25 mm).
Weight: 135 g.

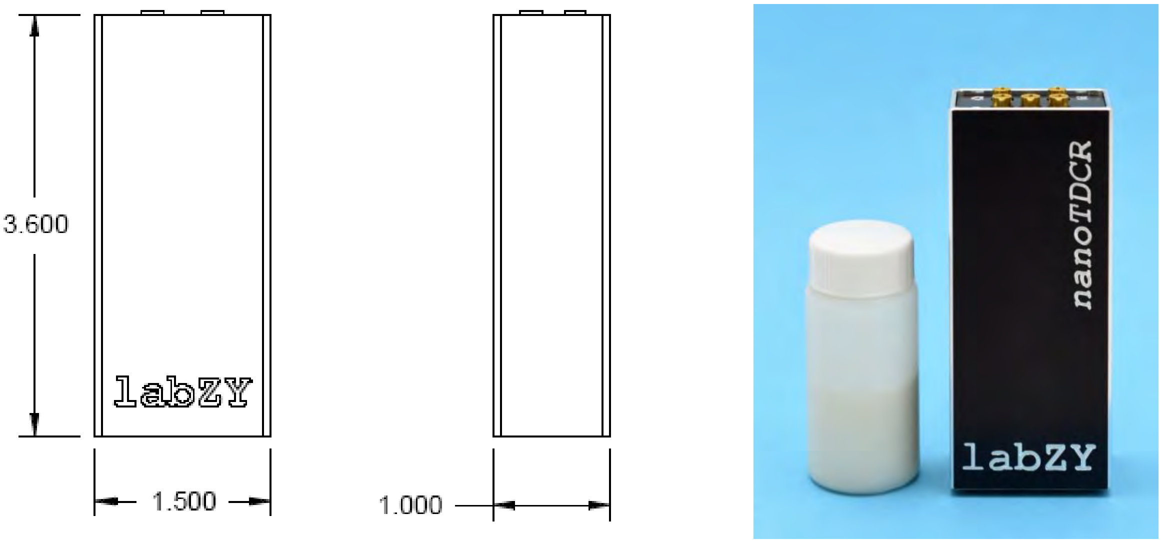


Fig. 11 nanoTDCR dimensions (inch).

XIII. TDCR APPLICATION INFORMATION

The nanoTDCR module can be directly connected to the anode outputs of a LS counter with 3 PMTs. The connection diagram of the nanoTDCR LS inputs is shown in Fig. 12 with details shown for input C. The detailed connection is similar for input A and B. Similar connection is used for the fourth scintillation detector input - input E.

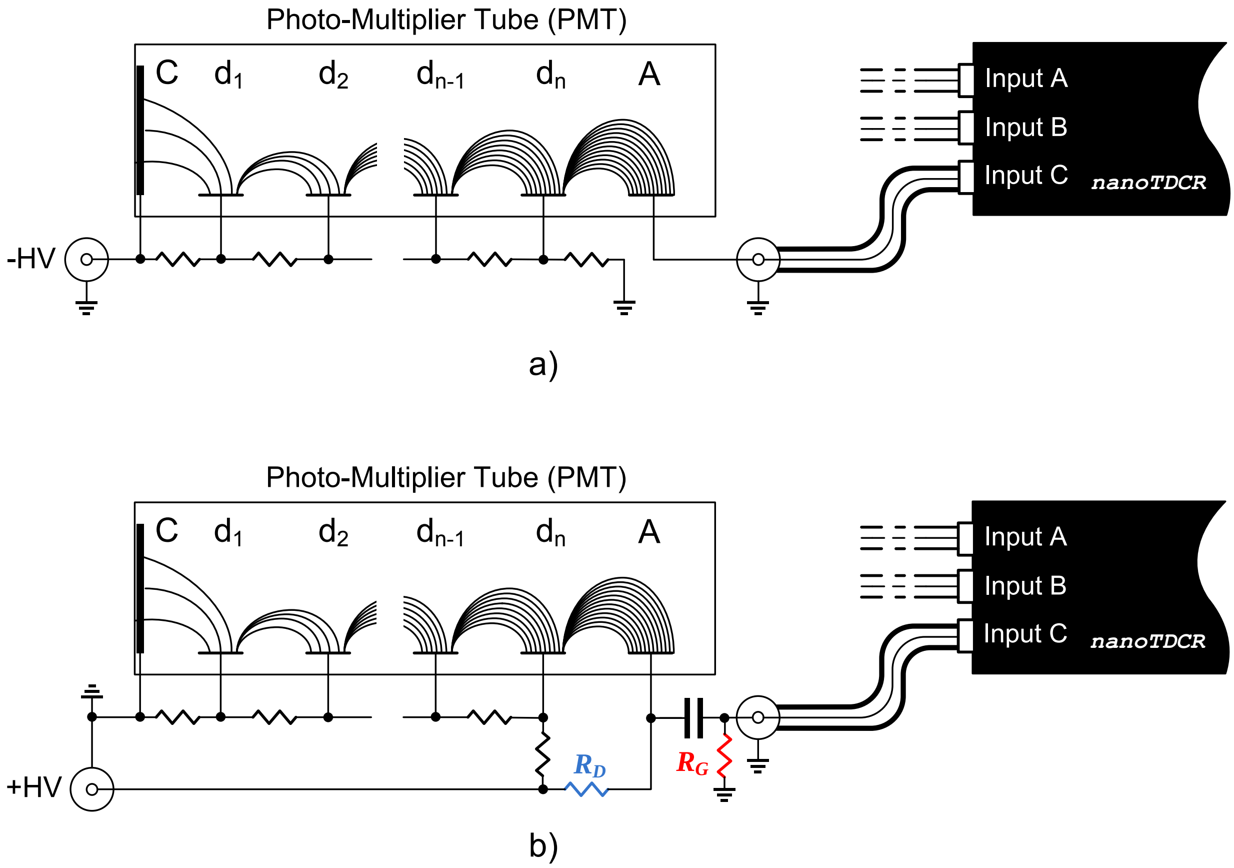
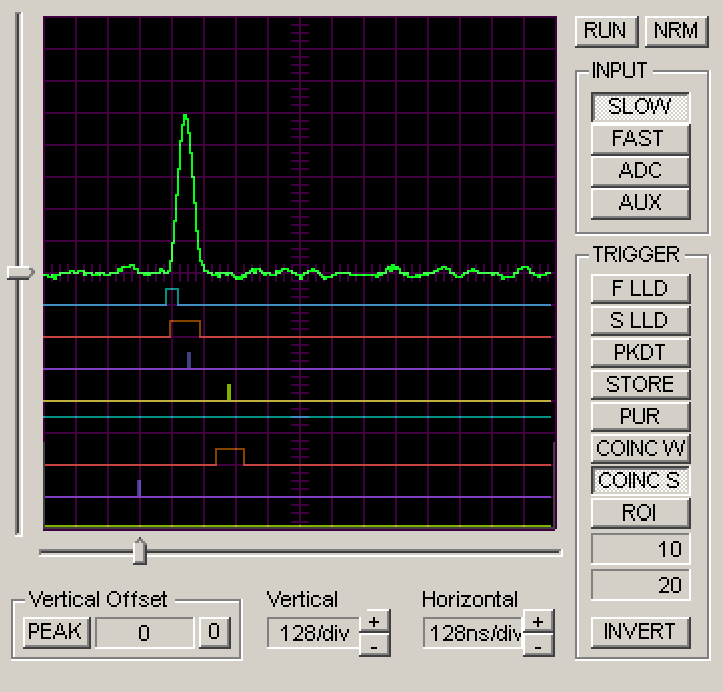


Fig. 12 Connection diagram of the nanoTDCR to a PMT (detail of Input C is shown): a) DC coupled (negative high voltage); b) AC coupled (positive high voltage). For optimum performance it is recommended to use a connection length of one meter or less.

To prevent damage to the nanoTDCR PMT Inputs it is recommended that a large (e.g. 100 kΩ) resistor R_G is installed and the resistor R_D must be selected as $R_D \geq \frac{+HV(V)}{0.08(A)}\,\Omega$.

The nanoTDCR has built-in all modules necessary for the implementation of the TDCR method. The acquisition software provides all the necessary information to calculate the detection efficiency from the global TDCR value (T/D) or from the 3 TDCR values (T/AB, T/BC and T/AC) for taking into account possible difference between the PMTs efficiencies. The main adjustment concerns the discriminators thresholds, which should be adjusted in the valley before the single electron response (SER). This adjustment is very important, as the TDCR model supposes, for the calculation of the global detection efficiency, that single photons could be detected by PMTs. The MCA of the nanoTDCR allows the precise adjustment of the 3 thresholds as described hereafter, as an example for channel B.

The PMT B signal is connected to the MCA. The MCA can be operated in either DPP or PHA mode. In DPP mode the acquisition is in coincidence with the B signal and delay between these two signals can be adjusted using the trace viewer window. Fig. 13 shows an example of the coincidence traces captured by the Trace Viewer of the labZY-TDCR software.



10

20

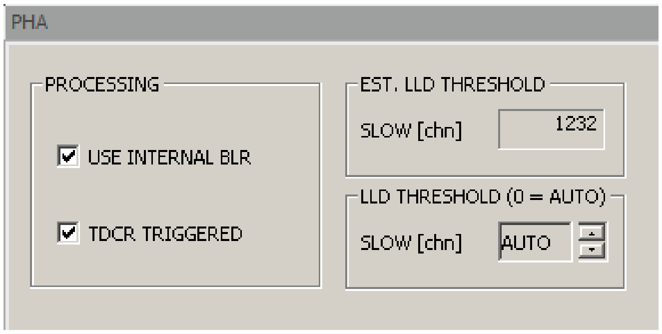
Vertical Offset: 0 0

Vertical: 128/div

Horizontal: 128ns/div

Fig.13 Example of PMT B SER pulse in coincidence with the discriminator signal of PMT B channel. Coincedence window (COINC W) genarated by the coincidence source (COINC S) is in coincidence with the memory store signal (STORE) of the MCA. The width of COINC W and the delay of the COINC _W relative to COINC S can be adjusted by the software in increments of 8 ns.

In PHA mode the peak detection is automatically in coincidence with the TDCR channel selected as input to the MCA when the TDCR TRIGGERED is selectedin the labz-TDCR software as shown in Fig.14.


PHA

PROCESSING

☑ USE INTERNAL BLR

☑ TDCR TRIGGERED

EST. LLD THRESHOLD

SLOW [chn] 1232

LLD THRESHOLD (0 = AUTO)

SLOW [chn] AUTO

Fig.14 Setting the PHA mode for automatic coincidence operation.

When the TDCR threshold is very low in PHA mode or when both the TDCR threshold and the MCA threshold in DPP mode are very low the SER spectrum shows a prominent noise counts. Fig. 15 illustrates a SER spectrum of PMT B with low threshold settings.

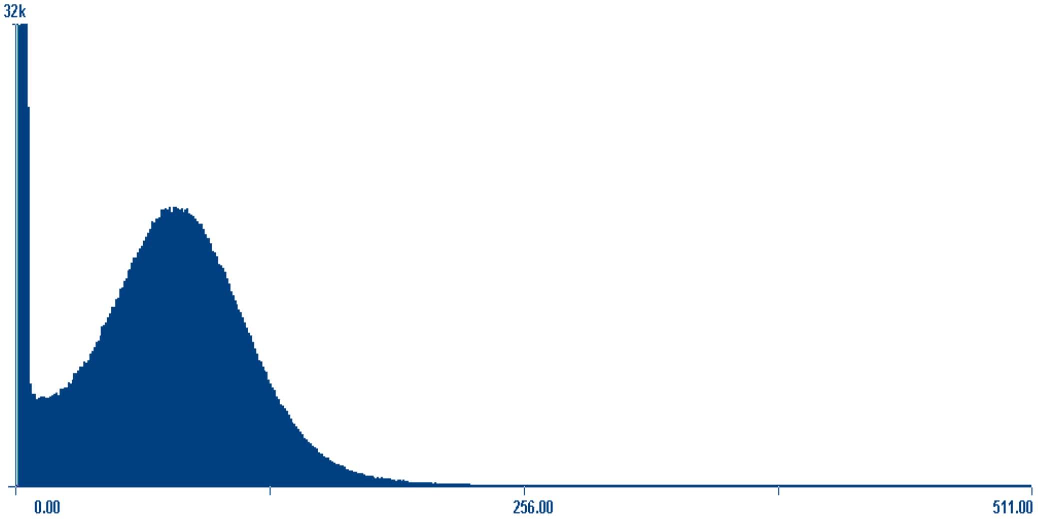


Fig.15 SER spectrum at low threshold settings.

The correct threshold adjustment is in the middle of the valley between the electronic noise (exponential shape starting from zero amplitude) and the Gaussian SER peak. If the threshold level is too high, pulses are lost and the results are biased. If the threshold is too low, the system could work but at the price of an excessive dead time, or could be completely frozen if the noise counting rate is saturating the extending type dead time unit. Fig. 16 shows a SER spectrum with proper adjustment of the TDCR discriminator threshold of PMT B channel.

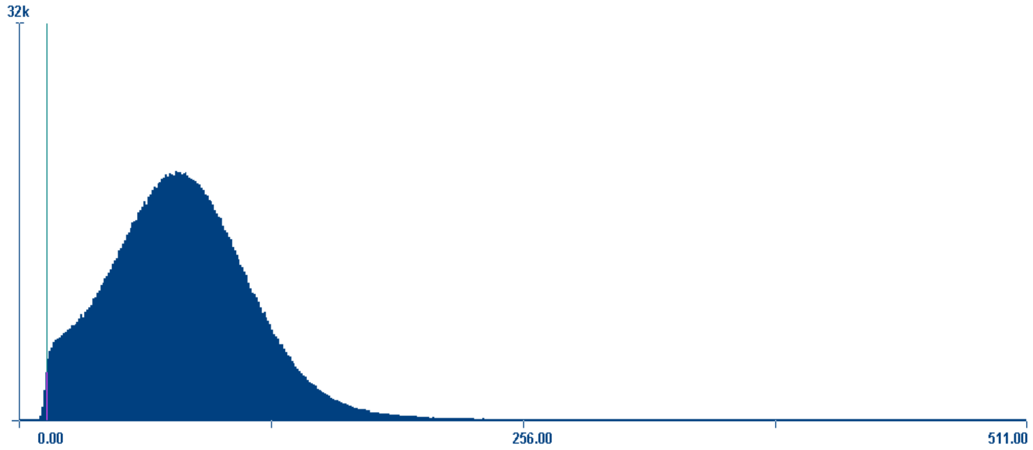


Fig.16 SER spectrum with properly adjusted discriminator threshold.

The others important adjustments concern the duration of the coincidence resolving time and the base duration of the dead time. As the system is able to make simultaneous acquisition with 2 coincidence resolving time and 2 dead times, it is equivalent to 4 TDCR acquisition systems in parallel. The duration of the coincidence resolving time depends on the energy or the radionuclide to be measured. For high energy beta radionuclides (say with maximum beta energy higher than 150 keV), the coincidence time is not critical and a value of 40 to 50 ns is optimal. Counting losses can be observed for shorter values and increasing the value could increase the accidental coincidence count rate. For low-energy beta radionuclide (e.g. tritium or ^{241}Pu) or low-energy electron-capture radionuclides (e.g. ^{55}Fe), the coincidence window can be increased up to 150 ns or even higher. This is a result of the intrinsic time spread of light emission when the mean number of photons is low.

The dead time system is necessary to protect against saturations and after pulses. The optimum duration depends on the size and technology of the PMTs used. For 51 mm diameter tubes (e.g. Burle 8850 or Hamamatsu R-331 tubes), a good value is about 50 µs. For compact PMTs (e.g. Hamamatsu R-7600), a shorter dead-time duration can be used, as the intrinsic after pulses of these tubes occurs during a shorter period. It was observed that old PMT have increasing after pulse rates, because of the contamination of the internal vacuum, and thus these tubes may require longer dead times. The possibility to use simultaneously two dead time duration is especially useful for the measurement of radionuclides with short half-life excited states of the daughter, or radioactive chains with short half-life radionuclide where some decays can occur during the dead-time caused by the parent radionuclide. Such situation occurs in the measurement of ^{222}Rn in equilibrium with its progeny (2). In this case, the detection efficiency is a function of the duration of the dead-time, and can be easily determined by analyzing measurement obtained using different dead time durations (e.g. 10 µs and 100 µs) and extrapolating to zero dead-time.

For the measurement of short lived radionuclides, the starting time of the measurement is critical and the traceability to UTC is directly provided using a NTP time server. The address of this server can be defined in the window of the nanoTDCR software, and it is recommended to use a local server (e.g. provided by the national metrology institute of your country), as the network system of some institutions does not allow the connection to external NTP servers.

The counting time (real or live time selectable) and the number of measurement repetitions must be defined in the acquisition software window. Even if this is statistically equivalent, it is better to e.g. repeat 10 times a 60 s acquisition than using a single 600 s measurement, as the former allows the calculation of the variances and covariances between the measured count rates, which are useful in the evaluation of counting uncertainties. Live time preset is especially useful for the measurement of high activity sources, where a defined counting statistics is expected. It must be stressed that, as the nanoTDCR system uses extending type dead times, the global acquisition dead-time can reach very high values when the counting rate exceeds several thousands counts per second.

Useful information on the measurement (Nuclide, LS cocktail, PMT HV and operator name) can be added in the nanoTDCR window and this information is saved in the acquisition file.

Exhaustive acquisition information can be saved in an ASCII file. This concerns the settlings, the count rates (single and coincident channels for each dead time and coincidence windows) and the live times of each single and coincident channels. A simple pre-processing software could be used to select the main quantities of interest in order to facilitate the measurement analysis.

XIV. MCA APPLICATION INFORMATION

MCA input signal

The shape of the pulse at the input of the MCA and digitized by the ADC is depicted in Fig. 17 trace c). This signal can be expressed as the convolution of two exponential pulses traces a) and b) in Fig. 17. The PRE-FILTER of the nanoTDCR shapes the PMT pulses with a LONG TC of the PMT exponential signals of about 120 ns. The SHORT TC is between 20 ns and 40 ns. The LONG TC and the SHORT TC should be adjusted to minimize the tailing and/or the undershoot of the digitally shaped pulses - slow and fast shapers. SHORT TC has more influence on the fast shaper of the DPP , while the LONG TC will affect both shapers. It is critical for counting rates to adjust these time constant properly. The SHAPER window of the labZY-TDCR software provide controls for these adjustment

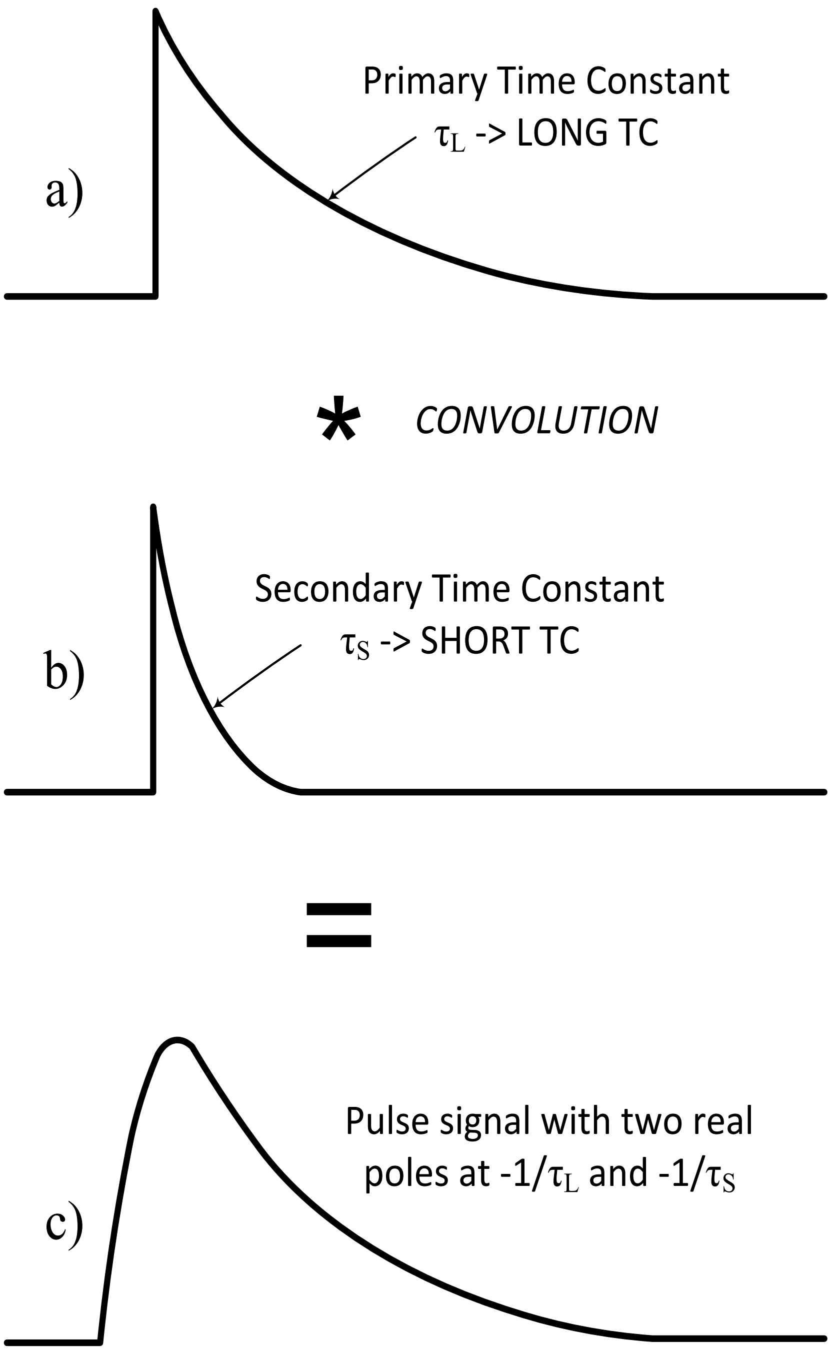


Fig.17 Pulse shapes at the input of the MCA.

The MCA system of the nanoTDCR can be used for spectroscopy with scintillation detectors coupled to PMTs and connected to Input E. Fig.17 shows a Cs-137 gamma spectrum obtained with the nanoTDCR in DPP mode. The peaking time of the DPP pulse is only 96 ns which would allow processing of detector interaction rates in the order of few million per second.

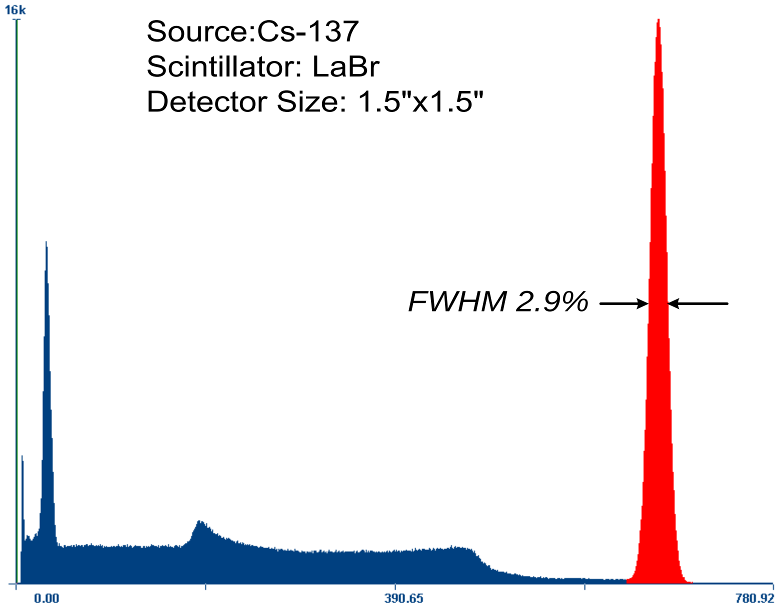


Fig.19 Example Cs-137 spectrum obtained with nanoTDCR in DPP mode.

Timing diagram of the coincidence circuit

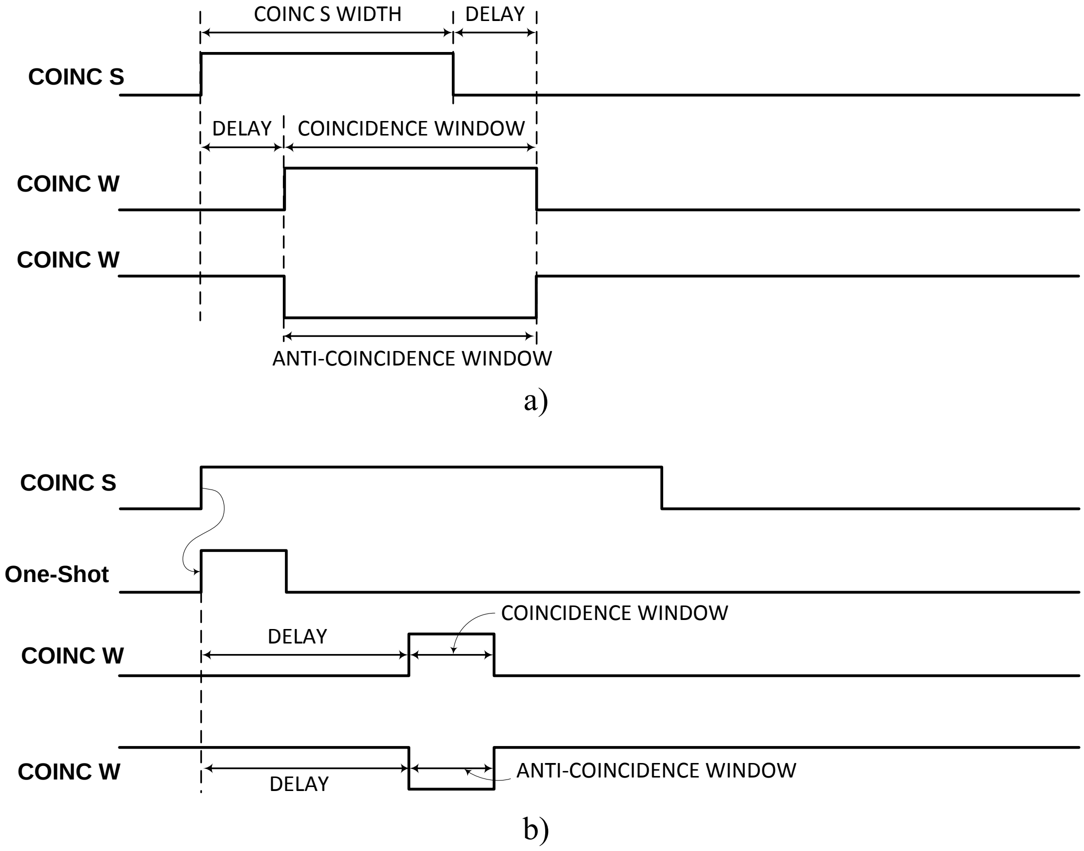


Fig. 19 Timing diagrams of the built-in coincidence circuit: a) Coincidence Source as direct coincidence/anti-coincidence signal, active high or anti-coincidence signal, active low; b) Window coincidence/anticoncidence.

FPGA Design Files

labZY provides standard FPGA designs that can be uploaded to the nanoTDCR using the configZY utility. Fig. 19 shows the naming specification of the FPGA design files.

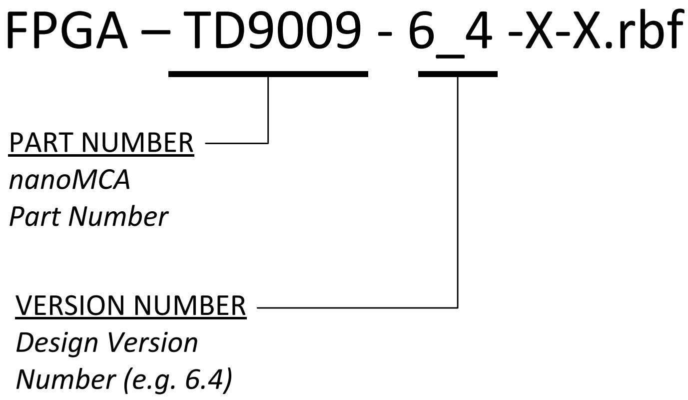


Fig.19 Naming specification of the FPGA design files. X-X labZY internal specifier.

XV. ORDERING INFORMATION

nanoTDCR 9009 Data Acquisition System Package

- One nanoTDCR Part Number: **TD9009**

Including the following accessories:

- One USB Cable, Part Number: NA0511
- Five BNC male to MCX male cables, Part Number: NA0512
- One Flash Drive with software and documentation

nanoTDCR 9010 Data Acquisition System Package

- One nanoTDCR Part Number: **TD9010**

Including the following accessories:

- One USB Cable, Part Number: NA0511
- Five BNC male to MCX male cables, Part Number: NA0512
- One Flash Drive with software and documentation

XVI. ACCESSORIES

BNC female to MCX male Adapter

Part Number NA0513

Length: 8cm

BNC male to MCX male Adapter

Part Numbers: NA0512, NA0514

Length: 100cm (NA0512), 40cm (NA0514)

USB Data Cable (3ft)

Part Number: NA0511-1

USB Data Cable (6ft)

Part Number: NA0511-2

USB Data Cable (15ft)

Part Number: NA0511-15

Bluetooth Interface Module

Part Number: NA0520

Ethernet Interface Module *nanoET*

Part Number: NA0523

WiFi Interface Module *nanoWF*

Part Number NA0521

***nanoWF* Extension Cable (30cm)**

Part Number: NA0511-E12

Power Adapter

(for use with *nanoET* and *nanoWF*)

Part Number: NA0510

Voltage: 110/240V Current: 1A