rev. 0 - 16/02/2016

DT4800

Micro Digital Detector Emulator

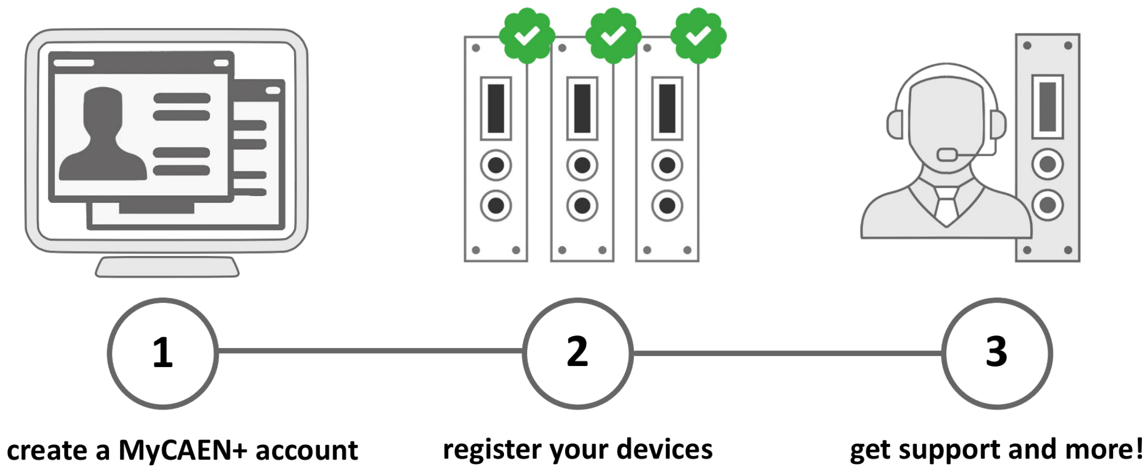
CAEN
Tools for Discovery

User Manual
UM5094

Register your device

Register your device to your **MyCAEN+** account and get access to our customer services, such as notification for new firmware or software upgrade, tracking service procedures or open a ticket for assistance. **MyCAEN+** accounts have a dedicated support service for their registered products. A set of basic information can be shared with the operator, speeding up the troubleshooting process and improving the efficiency of the support interactions.

MyCAEN+ dashboard is designed to offer you a direct access to all our after sales services. Registration is totally free, to create an account go to https://www.caen.it/become-mycaenplus-user and fill the registration form with your data.



https://www.caen.it/become-mycaenplus-user/

Purpose of this Manual

This User Manual contains the full description of the DT4800 Digital Detector Emulator firmware and software GUI. The description is compliant with DT4800 Digital Detector Emulator firmware release **6,** and software release **1.7.0.0** For future release compatibility please check the firmware and software revision history files.

Change Document Record

Date	Revision	Changes
16 February 2016	00	Initial release

Symbols, Abbreviated Terms and Notation

TDC	Time-to-Digital Converter
ADC	Analog-to-Digital Converter
DAQ	Data Acquisition
DPP	Digital Pulse Processing
MCA	Multi-Channel Analyzer
DDE	Digital Detector Emulator
QDC	Charge-to-Digital Converter
USB	Universal Serial Bus

Reference Documents

[RD1] FPGA-Optimised Uniform Random Number Generators Using LUTs and Shift Registers, David B. Thomas and Wayne Luk

[RD2] UM2088 – DPHA User Manual

CAEN S.p.A.
Via Vetraia, 11 55049 Viareggio (LU) - ITALY
Tel. +39.0584.388.398 Fax +39.0584.388.959
info@caen.it
www.caen.it

MADE IN ITALY : We stress the fact that all the boards are made in Italy because in this globalized world, where getting the lowest possible price for products sometimes translates into poor pay and working conditions for the people who make them, at least you know that who made your board was reasonably paid and worked in a safe environment. (this obviously applies only to the boards marked "MADE IN ITALY", we cannot attest to the manufacturing process of "third party" boards).

Index

List of Figures

List of Tables

1 Introduction

The massive evolution of digital processors for radiation measurements has highlighted the extreme convenience to develop techniques for emulating the detection and acquisition systems. The process of debugging of systems as digital pulse processors, pulse discriminators, Time-to-Digital/Amplitude converters, etc, requires an ever-increasing effort of processing algorithms that are becoming more and more complex. The possibility to generate test vectors that are the as similar as possible to the actual data produced by the experiment, both in the software simulation and at the hardware level can extremely reduce the R&D projects time.

All of this can be summarized in the need to generate an electrical signal with completely controlled characteristics that is compliant to the real output of a radiation detection setup. Although the use of a source and a detector is always the best way to generate a reliable data set, it involves considerable disadvantages, especially during preliminary feasibility studies. The use of the source inherently involves a risk for the health of the experimenters, and in addition requires labs equipped in accordance with the regulations in term of use of radioactive substances.
Moreover, the emission spectrum depends on the nature of the source, e.g. the polarization of an X-ray tube or the process of decay. The statistical distribution of the events is Poissonian and usually the user can only control the rate, and has no control on the statists. The spectrum of noise and the pulse shape are issues on which the experimenter can hardly affect. Furthermore, the natural emission process is not repeatable and therefore it is not possible to evaluate the behavior of different implementations of the processing system on a set of equal data.

It is common practice to use electronic instruments to generate analog signals with similar features to real experiment. There are instruments able to generate exponential signals with fixed amplitude and Poissonian temporal distribution, that can emulate effects such as pile up. However they cannot modulate the amplitudes of generated signals according to a generic spectrum of emission.
To overcome this problem hardware tools, called arbitrary waveform generators, have been developed. These instruments can generate long sequences of events at high rate (up to 1 GSPS), which have been synthetized off-line using simulation tools (e.g. MatLab). At present the most efficient tools have 1 Gword memory which means about a signal one second long before a repetition or about 10 millions of counts. Obviously this is not enough for a good statistics of a complex spectrum.

We therefore developed, in collaboration with Nuclear Instruments SrL, a single channel digital instrument for emulating radiation detection systems. The processor is initialized with a reference pulse shape, and statistic distribution of amplitude and time. According to this information, the device generates a stream of events that can be also selectively summed together simulating the pile-up phenomenon. At each pulse can be superimposed noise arbitrarily generated and baseline deviation.

DT4800-DDE is therefore the only synthesizer of random pulses that is also an emulator of radiation detector signals with the possibility to configure the energy and time distribution. The stream of emulated signals becomes a statistical sequence of pulses, reflecting the programmed input features. The DT4800 Digital Detector Emulator is able to emulate radiation source.

Main Functionalities

The main features of the DT4800 Digital Detector System are:

- Emulator/Pulser operation mode
- Energy spectrum emulation
- Time spectrum emulation
- Pile-up emulation
- Noise emulation
- Continuous reset emulation
- Windows software for full system management
- USB 2.0 connection
- DLL for automation of emulation process
- Import/Export in CSV format of spectra

The description of this User Manual is compliant with the following products:

Board Models	Description	Product Code
DT4800	DT4800 - Single Channel Compact DT4800 Digital Detector Emulator	WDT4800XAAA

Tab. 1.1: Ordering Options.

2 Technical Specifications

Energy emulation features	• Single line (16384 selectable levels) • Spectrum emulation (16384 bins with 14 bit resolution) • ± 5.6 V output range, high impedence; ± 2.8 V, 50 Ω termination • 14 bit D/A converter
Time emulation features	• Constant rate emulation • Poisson distribution • Up to 1MCPS, both in constant and statistical emulation • Integrator circuit emulation without pile-up limitation • 20 ns to 1 ms exponential decay time
Signal shape	• Exponential Digital RC Emulator • Up to two separate shapes mixed on the same channel with independent statistics
Noise emulation	• White noise emulation (Gaussian) • Random Walk (baseline drift)
Digital I/O	• 1-input and 1-output programmable • Trigger out • Trigger in
Software and interface	• Windows-based control software • USB 2.0 and Ethernet interfaces

Tab. 2.1: Technical Specifications.

3 Power Requirements

The module is powered by the external AC/DC stabilized power supply provided with the DT4800 and included in the delivered kit. Please, use only the power supply shipped with this instrument and certified for the country of use.

Input: 100-240 VAC , 47-63 Hz; Output: 5.0 V, 3.3 A .

All I/O digital gates are LVCMOS compliant. The dynamic range of the analog outputs is 2.8 V @ 50 Ω output impedance and 5.6 V @ high impedance.

Fig. 3.1: AC/DC power supply provided with the DT4800 kit.

4 Panel Description

Front Panel Device

The DT4800 front panel is as in the following picture. Numbered labels are explained in the table.

Fig. 4.1 DT4800 Front Panel.

Number	Description
1	Power Led
2	GPO: Trigger Output
3	GPI: External trigger
4	Analog Output Channel
5	Green LED – Analog output channel power on status OFF: channel output disabled ON: channel output enabled

Tab. 4.1 DT4800 Front Panel Description.

⚠ CAUTION. All I/O gates are LVCMOS compliant. The dynamic range of the analog outputs is 2.8 V @ 50 Ω output impedance and 5.6 V @ high impedance.

Back Panel Device

The DT4800 back panel is as in the following picture. Numbered labels are explained in the table.

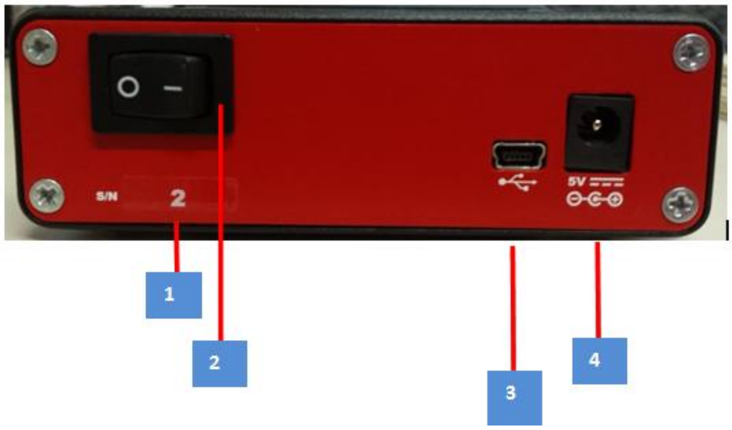


Fig. 4.2 DT4800 Back Panel.

Number	Description
1	Serial number
2	ON/OFF switcher
3	Mini USB Interface Connector
4	Power Supply Connector (+5 V central terminal positive)

Tab. 4.2 DT4800 Back Panel Description.

5 Hardware Architecture

Overview

The hardware structure of the emulator is shown in **Fig. 5.1**. The core of the system is a FPGA device Spartan 6 LX-150 that contains all the logic resources necessary for the emulation. The instrument requires a permanent connection via USB/Ethernet to the host PC, on which software allows to program all the operating settings of the instrument.

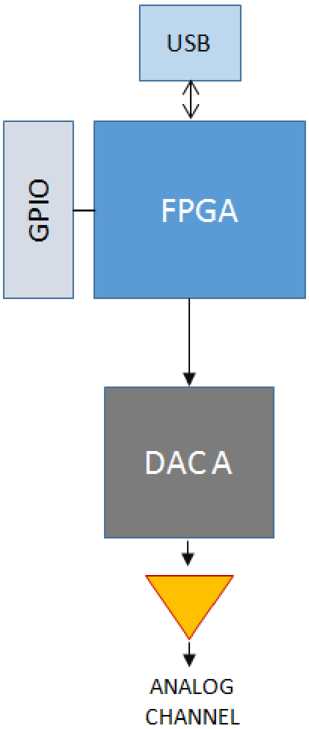


Fig. 5.1: The hardware architecture of the DT4800 Digital Detector Emulator

The FPGA is interconnected through two bus LVDS to a 14-bit DACs, which generate the analog signals. Specific output stages convert the differential current signal from the DACs into single-ended voltage signals that are made available for the user. The power supply is a crucial point in the system. In fact, the digital circuits require high currents that are supplied by switching power architectures.
The analog section of the system requires very pure power supplies with ripple below 1 mV. Moreover, the system is powered by a single +5 V source while the analog section needs both positive and negative voltage levels.

Analog Outputs

The analog stage has been designed to be at the same time at low noise and at high dynamic. We therefore used AD8045 amplifiers that allow to achieve a noise level of 820 uV rms with rise time of 18 ns or noise level of 200 uV rms with rise time of 30 ns.
The filter sequence in the analog output stage is shown in **Fig. 5.2** . The filter, called “output” filter in the GUI interface, can be added by the user.

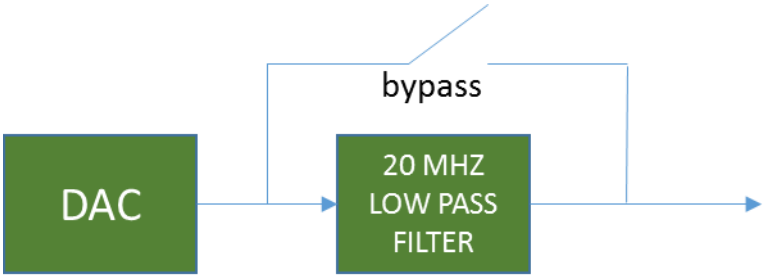


Fig. 5.2 Filter on the Digital Detector analog output stage.

Feature	Value	
Dynamic	± 2 V	
Linearity	10 ppm	
Rise Time	No Filter	20 MHz Low Pass Filter
	20 ns	30 ns

Tab. 5.1 Analog output stage performances.

The filter has a single-pole at 20 MHz and acts as an anti-aliasing filter directly connected to the DAC output. By slowing down the signal before the amplification stage, it makes the operational amplifiers not to be affected by slew-rate limitation during the rise-time. If this filter is enabled, the rise time increases to 30 ns. The effect of the filter is visible in **Fig. 5.3** .

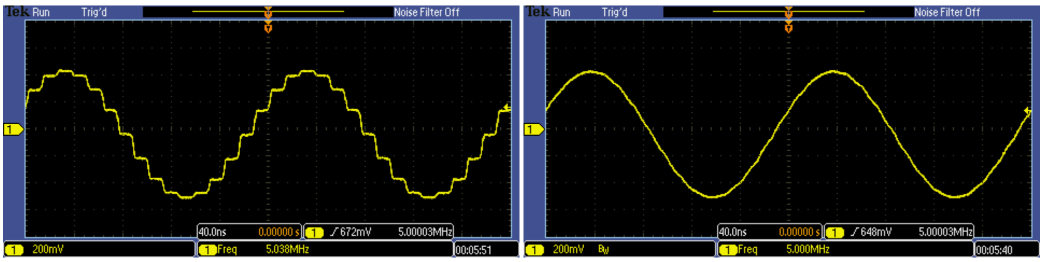


Fig. 5.3 Signal output before (on the left) and after (on the right) the 20 MHz.

The analog output is designed to generate a signal amplitude of ± 2.8Vpp, with 50 Ω termination. It is possible to terminate it with high impedance, having a final amplitude of ± 5.6Vpp. In this case it is possible to have multiple signal reflections, if the signal edge is sharp. It is strongly recommended to enable the filter when using high impedance.

Digital I/O

The digital I/O functionalities can be set from the software GUI (refer to **Chapter** 8 for the complete list of functionalities).
The digital outputs provide LVCMOS 0-3.3 V signals, as the inputs can receive signals with amplitude 0-3.3V. Inputs and outputs are protected with anti-ESD diodes.

6 Firmware Architecture Overview

The hardware of the DT4800 Digital Detector Emulator slightly differs from a classic arbitrary function generator. The great innovation is the ensemble of algorithms that allow the synthesis of digital signals in real-time with specific controlled characteristics. The number of operations that enables the real-time emulation of signal the closest as possible to reality is really huge. The emulator is able to generate each sample of the stream at the rate of 100 Msamples/s, taking into account the emission spectrum, the statistic of emission and therefore also the pile-up between the events, the shape of the signal, the contributions of noise, the fluctuations of the baseline, the shaping of the conditioning electronics.

The hardware is from 100 to 10,000 times faster than the equivalent software that we have developed in Matlab to characterize the system. To be able to accelerate as much as possible the calculation, the spatial distribution of the processing resources into the FPGA device has been deeply exploited. **Fig. 6.1** shows the structure of the firmware.

An algorithm for getting the first order statistical characteristics of a random process from a histogram of events has been devised and implemented. The algorithm returns the statistical distribution of amplitudes and occurrence times of the events. The generator of occurrence times acts as the trigger for the output of the signal shape, whose amplitude is scaled according to the sorted amplitude value.

The shape generated by the DT4800 emulates a real analog pulser with no limits on the generation of piled-up events. It can only emulate exponential shapes.

White noise and generic disturbances can be emulated as well. The device can also emulate the random walk of the baseline.

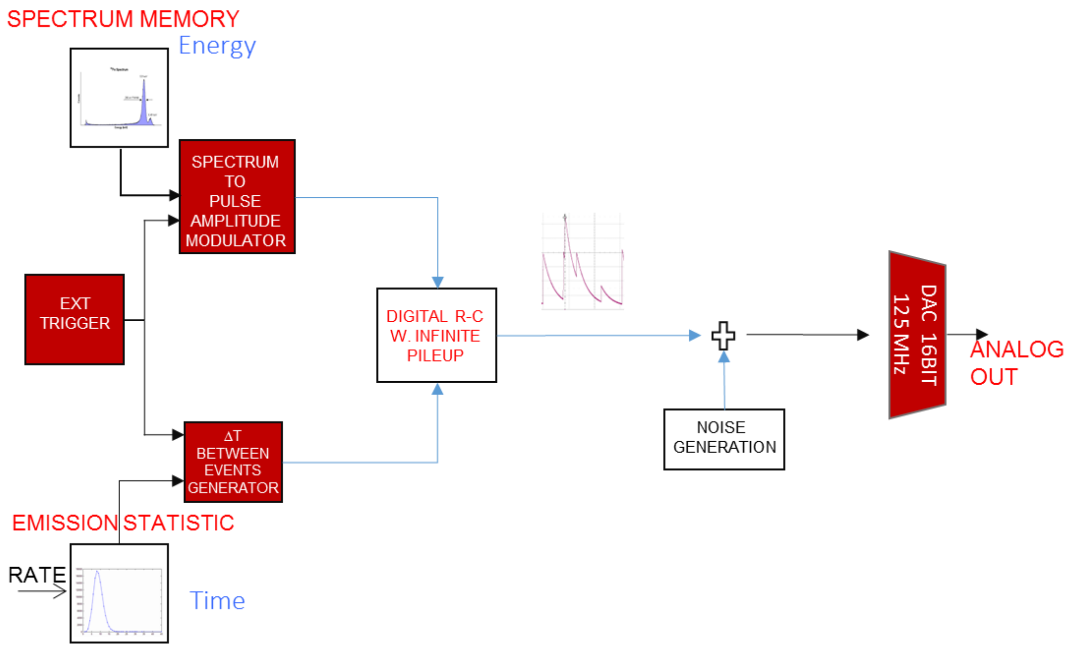
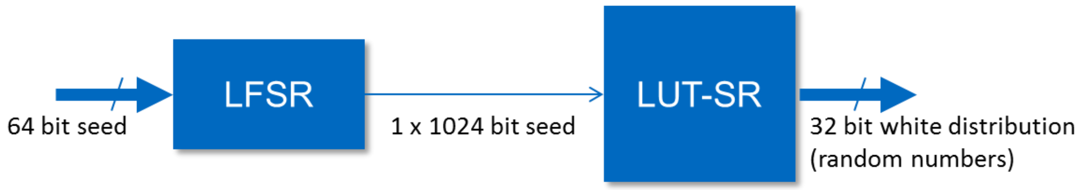


Fig. 6.1 DT4800 Digital Detector Emulator firmware architecture.

Random Number Generation

The emulation process is based on the generation of pseudo-random sequences that statistically reproduce the input programmed features. For example the user can set the desired energy spectrum; then the device will convert the spectrum into a sequence of numbers representing the pulse amplitudes. A very good source of pseudo-random numbers is required in order to have very long sequences, with no pattern and artefact. This will ensure that the emulator output is as close as possible to a real output. Moreover a pseudo-random generator allows to reproduce many times the same sequence, or to generate any times a statistically independent sequence. The seed used as a starting point for the pseudo-random generator is a 64 bit number.
The structure of the number generation is shown in the following figure.



The use of a simple Linear-Feedback Shift Register (LFSR) allows to generate pseudo-random sequences with statistical properties that limits the good result of the emulation. For this reason the LFSR are used to program a 32 bit LookUp Table-Shift Register (LUT-SR) generator that generates numbers with very small auto-correlation. The LUT-SR has a very long period, up to 2^{1024} clock cycles. Refer to **[RD1]** for further details about this method.

From Custom Distributions to a Set of Values

In emulating a radioactive source, a primary task is to generate the energy values following a user-defined energy spectrum and the Poisson distribution of the pulse occurrence times.
Those distributions have to be converted into a stream of values, whose probability distribution follows the input spectra. Being a statistical variable x described by a density probability distribution f(x), it can be modelled by the cascade of a generator of uniformly distributed random numbers and the transform function F(x). In this way, the quality of the generated statistic values depends only on the uniform number generator, which can be used for every emulated source, characterized only by F(x). Therefore from a white spectrum it is possible to get any kind of spectrum.
In order to explain how the algorithm works, let us consider that the energy spectrum is a histogram composed by 16 energy bins, from E0 up to E15, with a maximum dynamic range (DR) equal to 16. The bin width is the spectrum resolution, while the DR is the maximum height of each histogram column. Of course, the higher is the number of bins and the DR, the better is the represented spectrum. However, increasing the accuracy of the spectrum is simply a matter of the number of bits that can be used and this is not a problem with modern digital devices.
Each column of the histogram can be thought as composed by a number of small squares; if a generic bin x is twice higher than a bin y means that there is twice the probability for an event to have energy E_x rather than energy E_y. In fact, the height of the column of the bin x represents the density probability that the event has energy between E_{x-1} and E_{x+1}. The product of the column value by the bin width returns the probability. The ratio of the probabilities that an event has energy in a certain interval rather than in another one is simply the ratio between the corresponding areas below the density probability curve.
With reference to **Fig. 6.2** , each square of each column is sequentially numbered. Consider the simplified case in which the total number of squares under the curve is a power of 2, e.g. 2^5=32. Using 5 bit in the random number generator, all the 32 numbers can be obtained with the same probability, i.e. the random numbers map completely the area under the spectrum curve. Every time a random number is generated, the algorithm searches the number in the spectrum area and, when finds it, delivers the bin number n thus indicating the corresponding energy value En. If we consider again a generic x bin two times higher than a y bin, it is easy to see that, since the random numbers with equal probability map all the squares, there is twice the probability that the random number picks up a square in x rather than in y column, which means that generated pulses with Ex energy are twice those with Ey energy.
In practice, an array is loaded with the cumulative energy spectrum Hc(Ex) that is computed from energy spectrum H(E)

$$H_C(E_X) = \int_0^{E_x} H(E)dE$$

In this way, only one memory cell per bin is required. Using the cumulative spectrum, it is still possible to identify the bin that contains the generated random number by means of an extension of the described algorithm. For instance (see **Fig. 6.2**Fig. 6.2), if the random number is 18, it is easy to see that it belongs to the memory cell number 10: in fact, the cell number 10 contains a number that is higher than 18 (20), while the previous cell contains a number that is lower (16); this means that bin number 10 contains the squares that go from 16 to 19, exactly the range in which 18 belongs. So the output energy value correspondent to the random number 18 is 10.

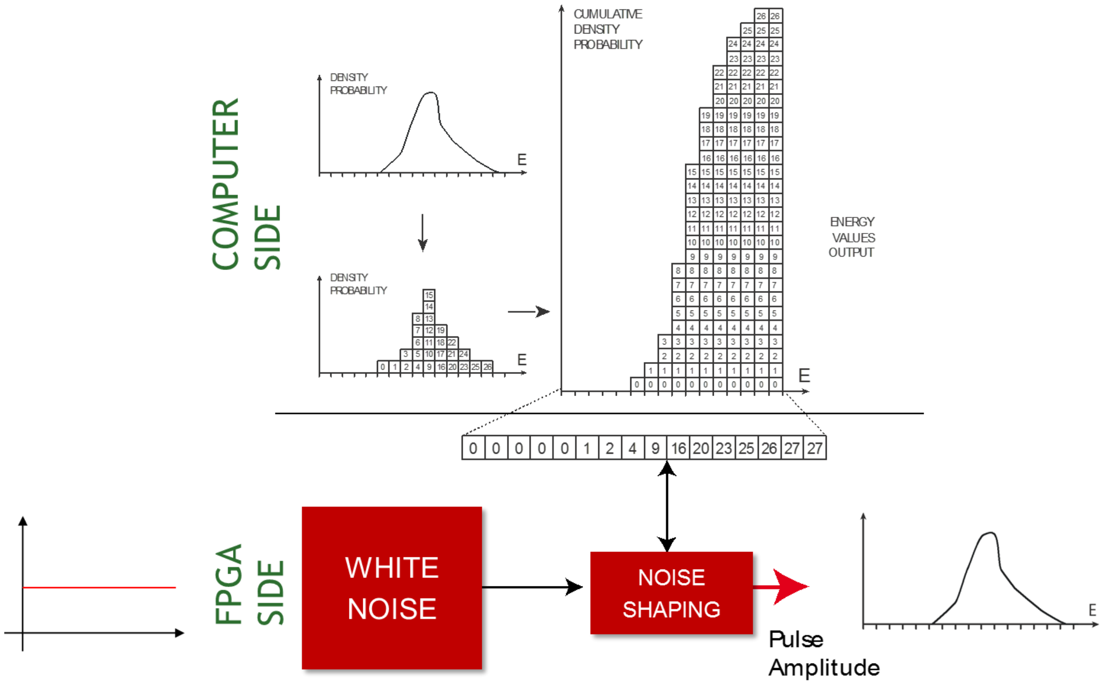


Fig. 6.2 Emulation of a spectrum.

Energy Datapath

The energy of a pulse represents the area under the pulse, and for a constant shape it is proportional to the pulse amplitude itself.
The emulator has two ways to modulate the energy, as shown in the following figure.

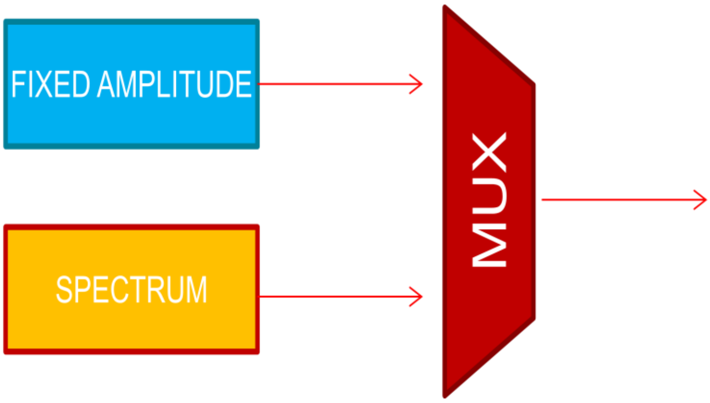


Fig. 6.3 The two ways to emulate the energy.

The "fixed energy" mode generates pulses with the same amplitude, while the "spectrum" mode generates pseudo-random sequences of values that follow the programmed input energy spectrum. The "spectrum" data-path uses the algorithm explained in the previous section. **Fig. 6.4** shows an example of generation of a set of amplitudes starting from an energy spectrum.

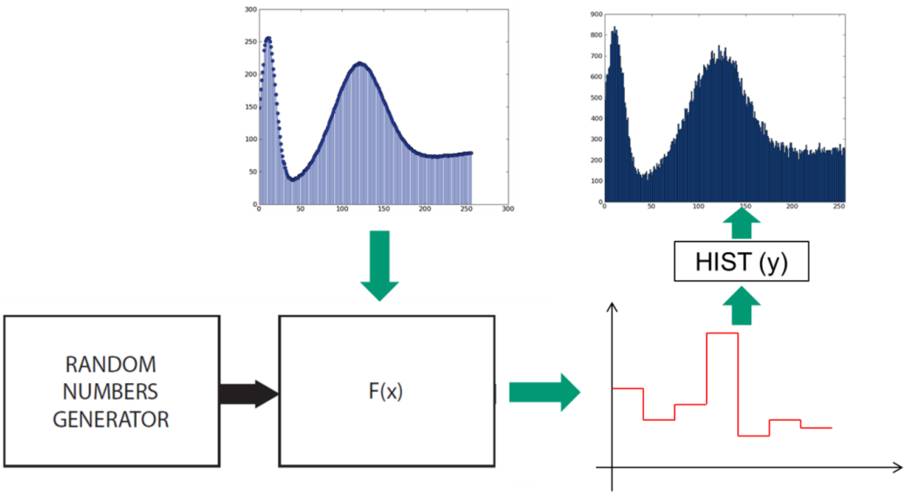
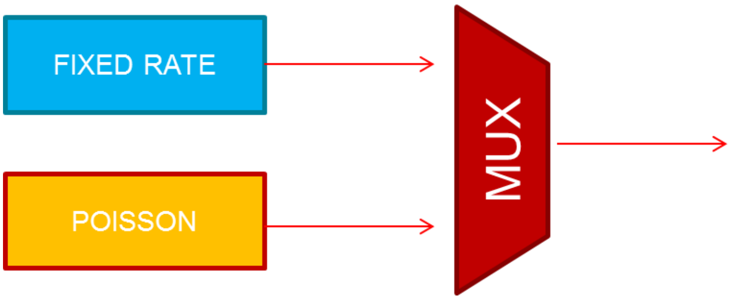


Fig. 6.4 Conversion of a programmed energy spectrum into an amplitude sequence. Evaluating the histogram on the output vector user gets the same input spectrum.

Timebase Datapath

It is possible to generate the time of occurrence of a pulse in two ways, as shown in the following figure: "fixed rate" and "Poisson" distribution.



The Poisson distribution is obtained through the Bernoulli Trials method. Repeated independent trials in which there can be only two outcomes are called Bernoulli trials. Bernoulli trials lead to the binomial distribution. If the number of trials is large, then the probability of k success in n trials can be approximated by the Poisson distribution.
The generation process of Poissonian events is shown in **Fig. 6.5**. For each clock cycle the device generates a pseudo-random number. If this number is greater than α = rate/f_{clk}, then the event is generated.

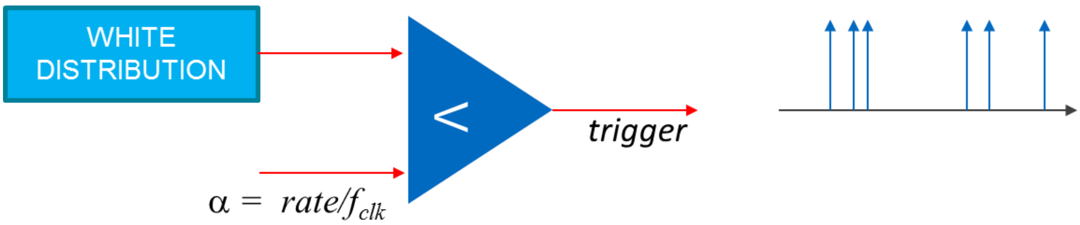


Fig. 6.5 Generation of Poisson distributed events using the Bernoulli Trails method.

The emulator can work also with an external trigger put into the digital input connector. The external trigger is sampled with a precision of 8 ns, and it then enables the event generation.

Shape Datapath

The emulator allows the shape generation on the basis of the following diagram.

Digital RC

The “Digital RC” is based on two first order IIR (Infinite Impulse Response) filters that emulate the behaviour of a classical analog pulser. It allows the emulation of exponential only shapes, with no limitation on the signal rate, and on the length of the exponential tails. The only limitation comes from the saturation of the analog stage; otherwise this method would give infinite piled-up events.

In **Fig. 6.6** it is shown the implementation of the Digital RC option. Delta-like pulses are fed into the first IIR filter. The decay time of the first filter sets the pulse decay time. The second IIR filter then emulates the rise rime; it has a pole at the *rise_time/0.35* frequency. **Fig. 6.7** shows the typical analog output for the Digital RC option.

Note: Being the emulation of a real RC-RC, the output signal amplitude might depend on the rise and fall time values too.

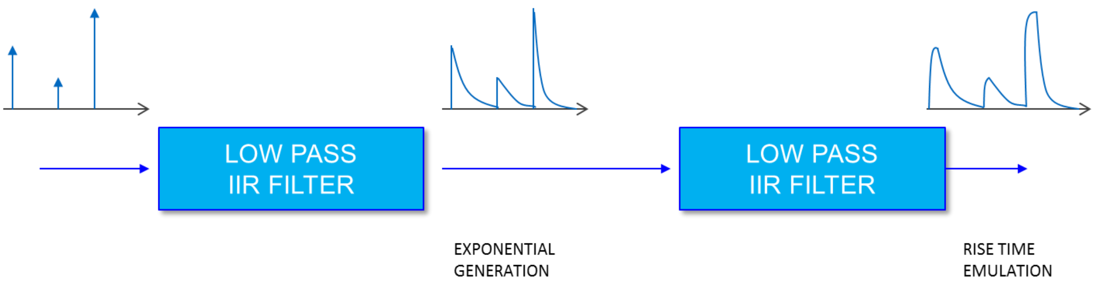


Fig. 6.6 Digital RC structure.

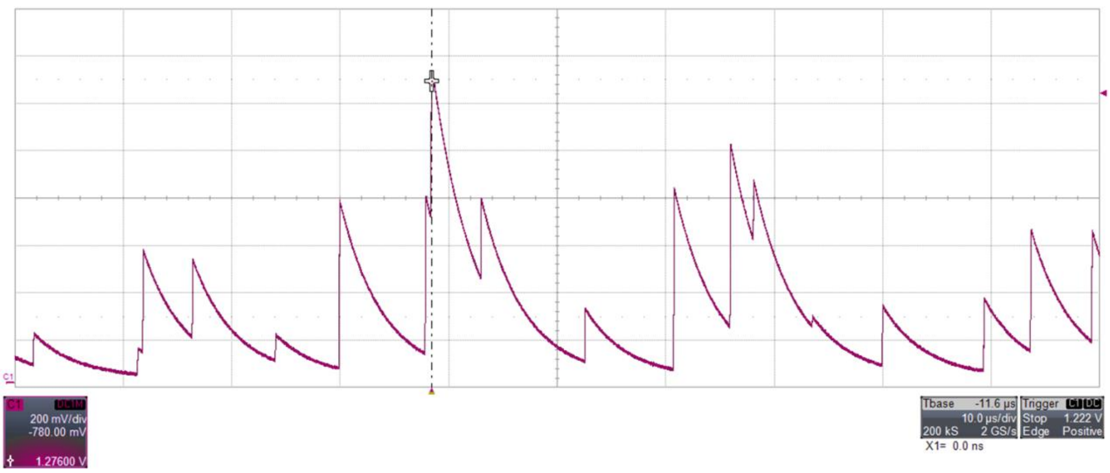


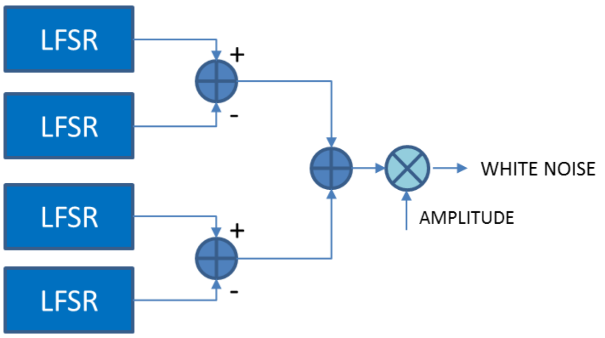
Fig. 6.7 Typical Digital RC analog output.

Noise Emulation

The DT4800 Digital Detector Emulator allows the emulation of different types of noise. The user can program the spectral features and the amplitude modulation independently.

White Noise

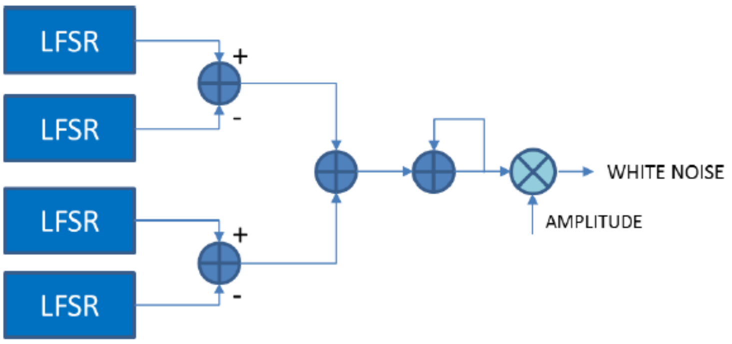
The emulated white noise is a wideband noise white noise with a constant spectral density (up to 62.5MHz) and a Gaussian distribution of amplitudes.



The white noise is generated as RND1-RND2+RND3-RND4, where RND*n* is the random number generated by the LFSR generator *n*. The noise spectrum approximate well a real white noise up to 62.5 MHz (limitation due to the DAC frequency) if neither the anti-alias, nor the output filter are applied. If they are applied then the white noise band decreases up to 20 MHz.

Random Walk

Very low speed baseline drift approximate as the integral of a Gaussian white noise



7 Getting Started

Scope of the Chapter

This chapter is intended to provide a quick guide of the DT4800 Emulator Software, in order to manage the first practical use of the DT4800 Digital Detector Emulator.

System Overview

The DT4800 Digital Detector Emulator system proposed in the chapter consists of the following products:

- DT4800, 1-channel with standard firmware revision **6**.
- Digital Detector Emulator software GUI release **1.7.0.0**, running on the host station.

Hardware Setup

The getting start demo proposed in this Chapter makes use of the DT4800 connected via Mini USB to a computer equipped with Microsoft Windows 10 Professional 64-bit OS. The DT4800 Digital Detector Emulator driver and software are properly installed in the work station (see the next section). The analog output of DT4800 is sent to the CAEN Desktop Digitizer DT5724 with DPP-PHA firmware. The DT5724 readout is monitored through the DPP-PHA Control Software (or MC2A Control Software), running on the host station. Refer to **[RD2]** for more information about the DPP-PHA Control Software installation and practical usage. Alternatively it is possible to use one of the CAEN Digitizers with DPP firmware installed, as the 751 or 720 families, or an oscilloscope.

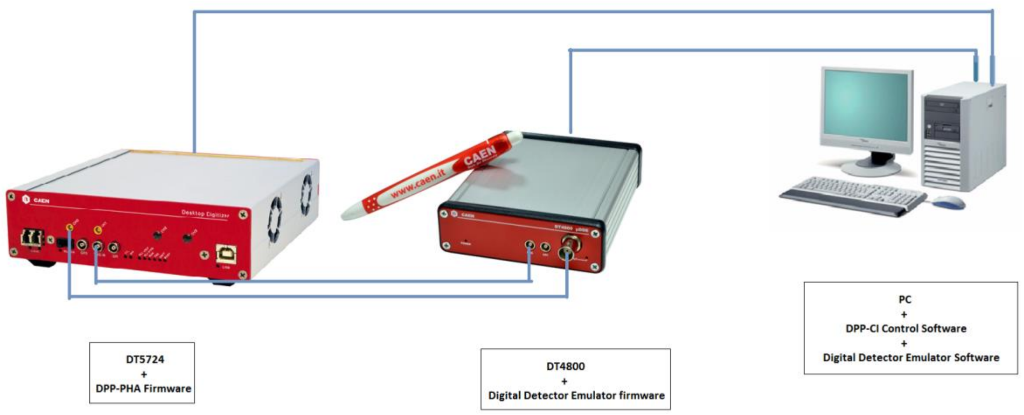


Fig. 7.1: The hardware setup including the Digital Detector Emulator DT4800 and the DT5724 used for the practical application.

Software and Drivers

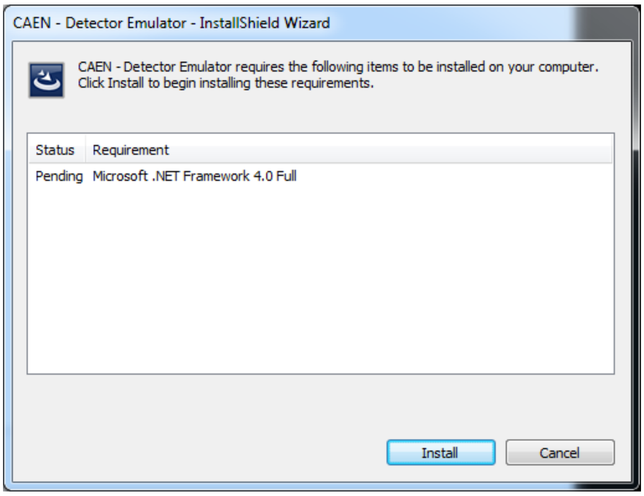
The DT4800 Digital Detector Emulator Software is compliant with Windows 7, 8 and 10 OS, both 32 and 64 bit.

- ✓ SOFTWARE
  - **DT4800 Digital Detector Emulator Software** for Windows OS.

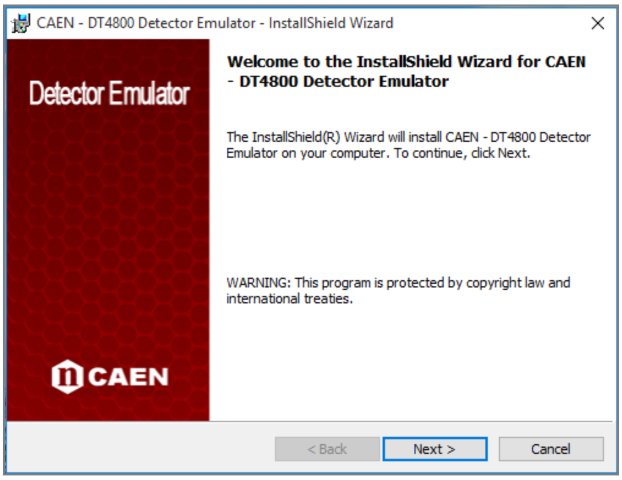
    Download the standalone **DT4800 Digital Detector Emulator Software 1.7.0.0** full installation package on CAEN website in the 'Download' area of the DT4800 Digital Detector Emulator page (**login is required before the download**).

    Unpack the **installation package**, login as administrator, **launch** the **setup file.**

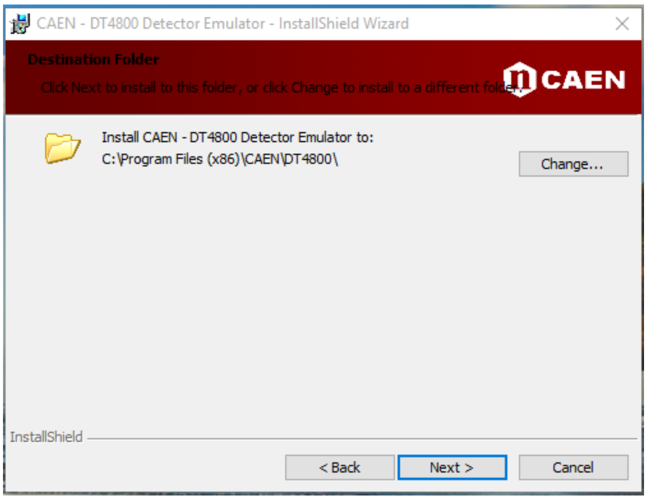
    If Microsoft .NET is not already installed, the setup will ask you to install it. The operation may take some minutes.



Complete the **Installation wizard.**

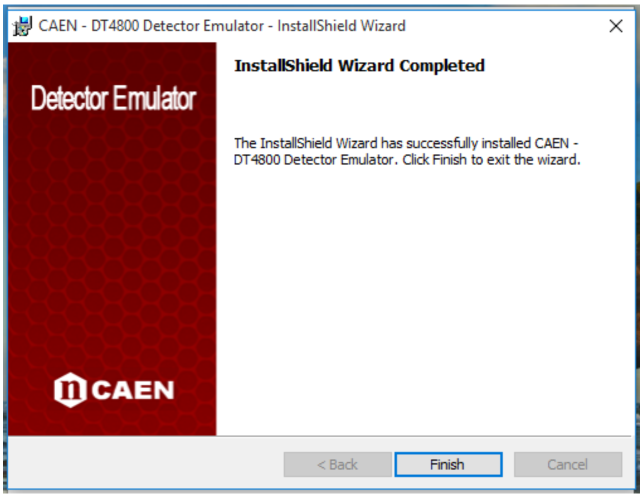


Select the **destination folder**



The setup will create a Desktop icon.

Launch the program when the setup is completed.



See Section **Installation** for requirements and special cases.

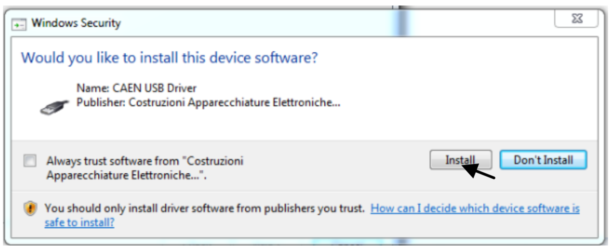
- ✓ DRIVERS
  - ○ **USB 2.0 (Mini USB)** Windows driver.

How to install the driver (Windows)

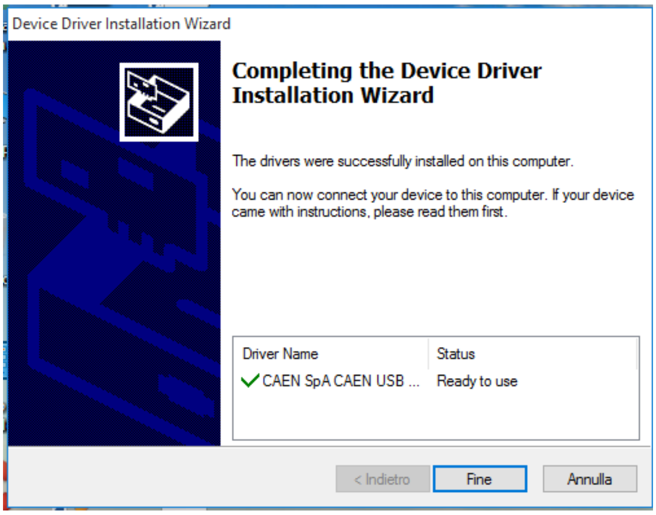
Power ON the DT4800 Digital Detector Emulator. The device starting may last about 30 seconds. When the front panel LED is ON, the device is ready for use.

Connect the emulator to a USB port (please, avoid to use a USB Hub).

Wait for Windows to install the drivers through **Windows Update.**



Check the correct installation



Firmware

The DT4800 Digital Detector Emulator Software works with the **DT4800 Digital Detector Emulator Firmware**. **<u>The firmware is already installed into the device</u>**.

✓ **<u>How to upgrade the firmware</u>**

Download the **DT4800 Digital Detector Emulator Firmware** (.BIN) on CAEN website in the 'Download' area of the DT4800 Digital Detector Emulator page.

Open the DT4800 Digital Detector Emulator **Software.**

Under "Hardware", **select** "Firmware Upgrade".

You can **download** the firmware from web, **browse and select** the .BIN file, and finally **program** the FPGA.

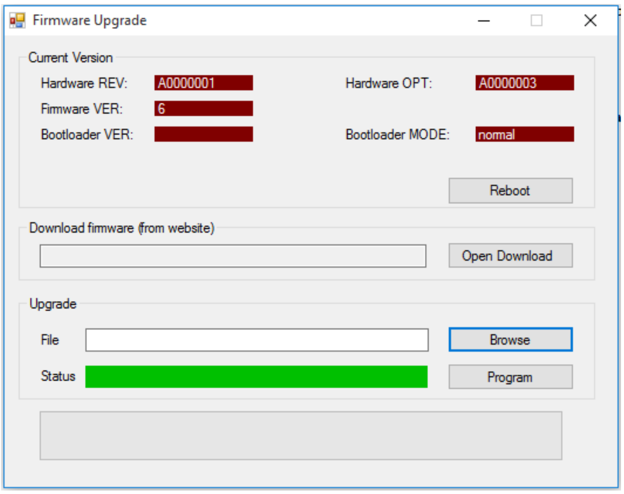


Fig. 7.2 Firmware Upgrade window.

When the firmware is successfully upgraded, **restart** the emulator software.

Note: The FPGA programming can take some minutes. The green bar shows the upgrade status. Please, **wait until the end of the firmware upgrade**.

Practical Use

The following step-by-step procedure shows how to use the DT4800 Digital Detector Emulator Software and how to get a simple output signal.

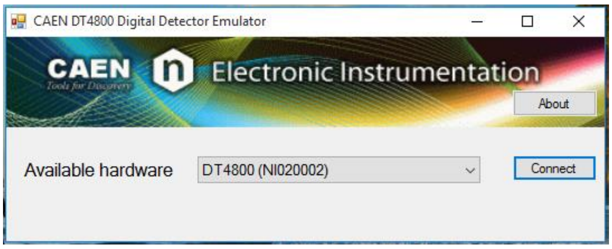
1. **Check that the whole hardware in your setup is properly connected and powered on.**
2. Download the **examples.zip** file from the 'Download' section of the DT4800 Digital Detector Emulator from CAEN web site.
3. **Run the software.**

   Run the **DT4800 Digital Detector Emulator Software GUI**, according one of the following options:

   - The **Desktop icon**
   - The **Quick Launch icon**
   - The **.exe file** in the main folder from the installation path on your host

4. **Connect to the emulator**

   Select the DT4800 Digital Detector Emulator checkbox and press **'CONNECT'**



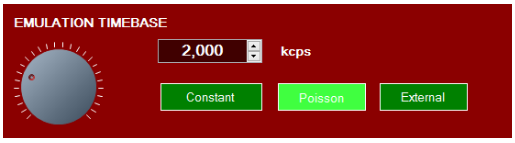
5. **GUI**

The **CAEN DT4800 Digital Detector Emulator Software interface**, is a simple GUI that allows the user to setup a signal in a very straightforward way.

The Software Interface generates exponential shape analog output, with as many piled-up events as half of the DAC frequency.

The user can set the analog output signal rate, the amplitude, the rise and fall time of the exponential shape, the white noise contribution as well as the Random walk noise.

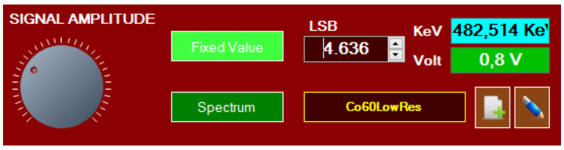
Action 1: set the **RATE** to **"Poisson"**, and change the **rate value** to 2 kHz



Note: You can **change the rate value** by either moving the knob pointer or by writing the value in the box.

Note: After typing the value of a parameter in a box menu, press **"Enter"** to activate the setting.

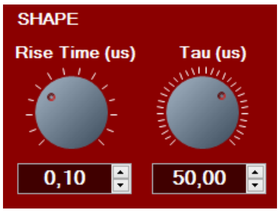
Action 2: set the **AMPLITUDE** to **"Fixed Value"**, and change the **amplitude value** to 0.8 V.



Note: You can **change the amplitude value** by either moving the knob pointer, by writing the value in the LSB box, or by writing the desired value in Volts in the *green box*.

Note: After typing the value of a parameter in a box menu, press **"Enter"** to activate the setting.

Action 3: set the SHAPE parameters. "Rise Time" = 0.10 us, and "Fall Time" = 50.00 us.



Note: You can **change the shape values** by either moving the knob pointer or by writing the value in the underlying box.

Note: If you set the Rise Time = 0.00 you are asking for the best the device can provide, i.e. about 7ns (due to the DAC sampling).

Action 4: Enable channel OUTPUT. The front panel LED will be ON.

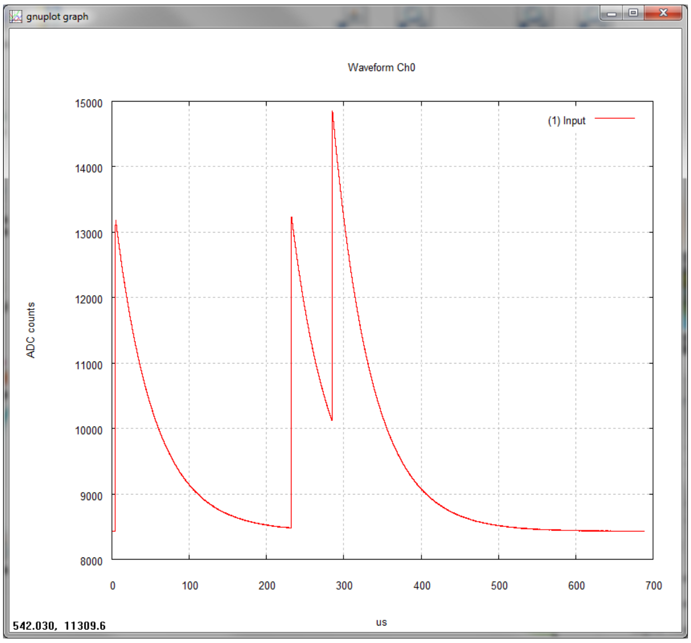
6. Check the analog output on the the DT5724 with DPP-PHA firmware installed

For the particular example of this chapter we are making use of a DT5724 with proper DPP-PHA. The DT4800-Digital Detector Emulator settings chosen in the previous step are consistent with a signal coming from a pre-amplifier device, compliant with the DPP-PHA firmware itself. The DPP-PHA Control Software must be properly installed in the host PC. Please refer to the DPHA User Manual for any details about the DPP-PHA settings.

Note: The same test can be performed with any other CAEN digitizer with proper DPP or Standard firmware. Be aware that the standard firmware allows to check the waveform output only, as the DPP allows to check both the waveform and the spectrum (see the next step). In that case please set the signal parameters accordingly.

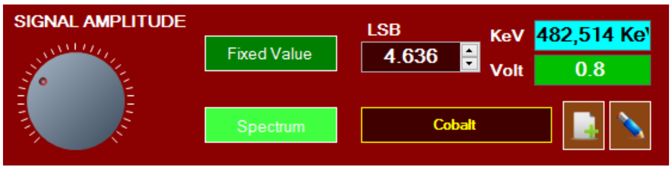
Note: You can use an oscilloscope as well to check the waveform output. Use 50 Ω termination.

The oscilloscope plot of the DT5724 should appear as in the following picture.

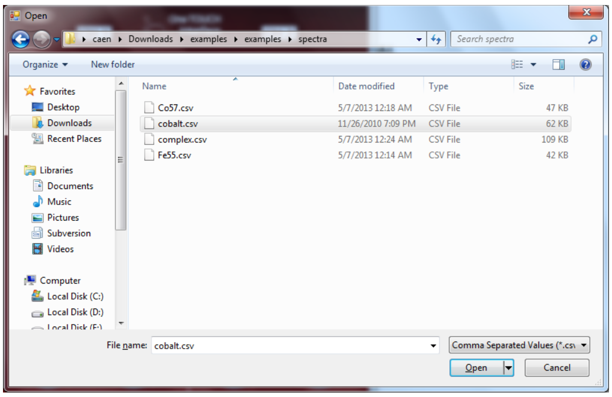


7. Enable the spectrum amplitude generation

Action 1: Change the **AMPLITUDE** settings by choosing **"Spectrum"**

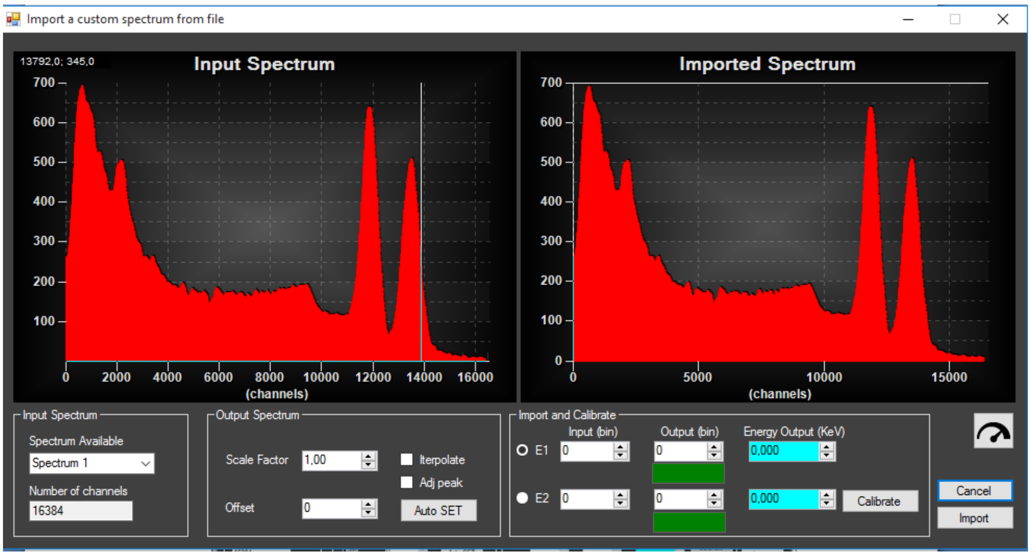


Action 2: Browse and select a **spectrum file** on your computer.
We provide you some examples. Unzip the downloaded "examples.zip" folder and look for the .csv files inside the "spectra" folder. Select the "cobalt.csv" file.

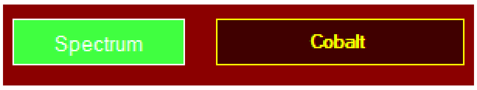


Note: accepted file formats are: .csv (comma separated values), .dat (CAEN spectrum files), .spectrum (digital detector emulator internal spectrum format), .xml (ANSI N42.42)

Action 3: Import the spectrum into the Detector Emulator. Click **"Import"** to import the spectrum.

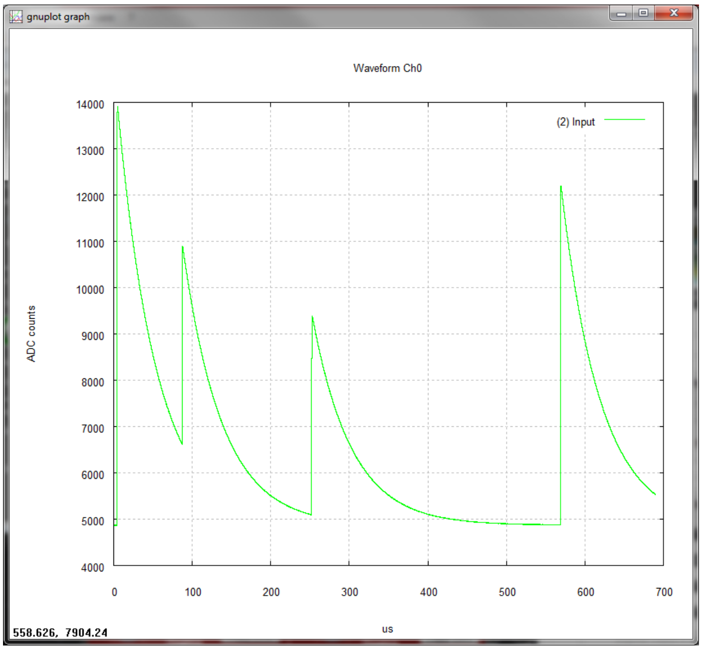


The spectrum file name should appear into the DT4800 Control Software Interface.

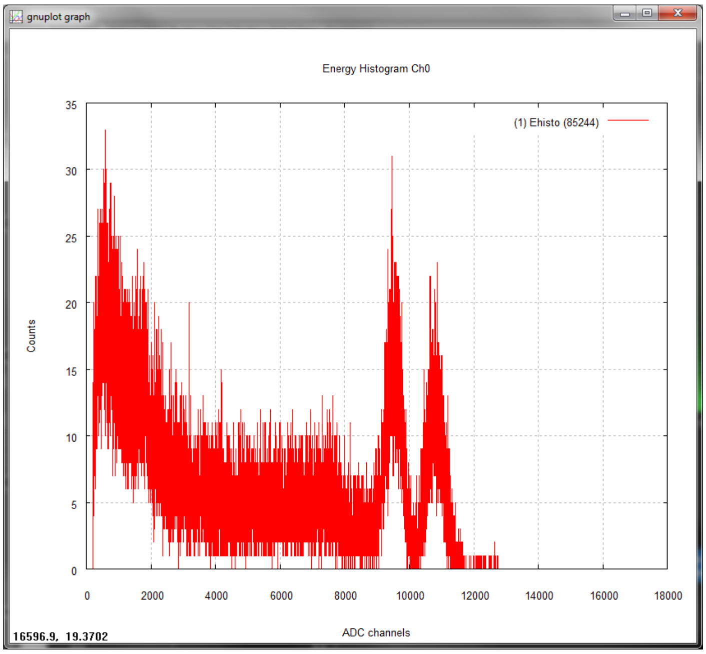


8. Check the Spectrum Generation with the DT5724

In the oscilloscope mode of the DPP-PHA software you should see the signal amplitude modulated with the input spectrum.



If you switch to the Histogram acquisition mode you should see something like in the following figure.



8 Software Interface

Introduction

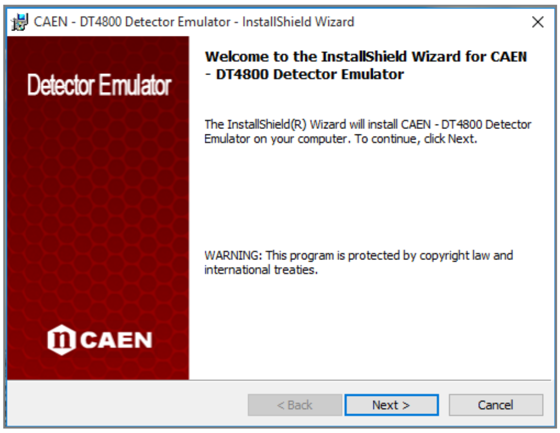
The DT4800 Digital Detector Emulator software allows to manage the communication and to set the parameters for the signal generation. This chapter is intended to give to the user a complete description of all the functionalities of the emulator that can be set through the software interface.

Installation

The DT4800 Digital Detector Emulator Software is compliant with Windows 7, 8 and 10 OS, both 32 and 64 bit.

Download the standalone DT4800 Digital Detector Emulator Software revision **1.7.0.0** full installation package on CAEN website in the “Software/Firmware” area of the Digital Detector Emulator page (login is required before the download).

Unpack the installation package, login as administrator, launch the setup file, and complete the Installation wizard. See Section **Software and Drivers** for further details.

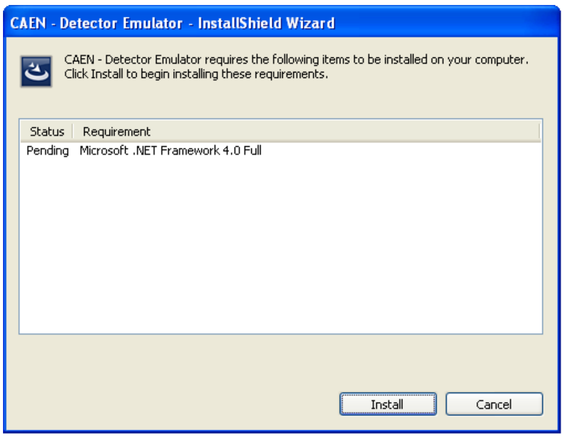


Note: If the driver installation fails, you can install them manually from the ‘Drivers’ folder in the CAEN DT4800 Digital Detector Emulator installation folder.

The setup automatically creates a link on the PC Desktop.

Requirements

The software requires Microsoft .NET 4.0 or higher. If the framework is not available on the machine, the Detector Emularor setup will install the framework. Click on **“Install”** if this message appears:



Program Execution

You can run the program in three ways:

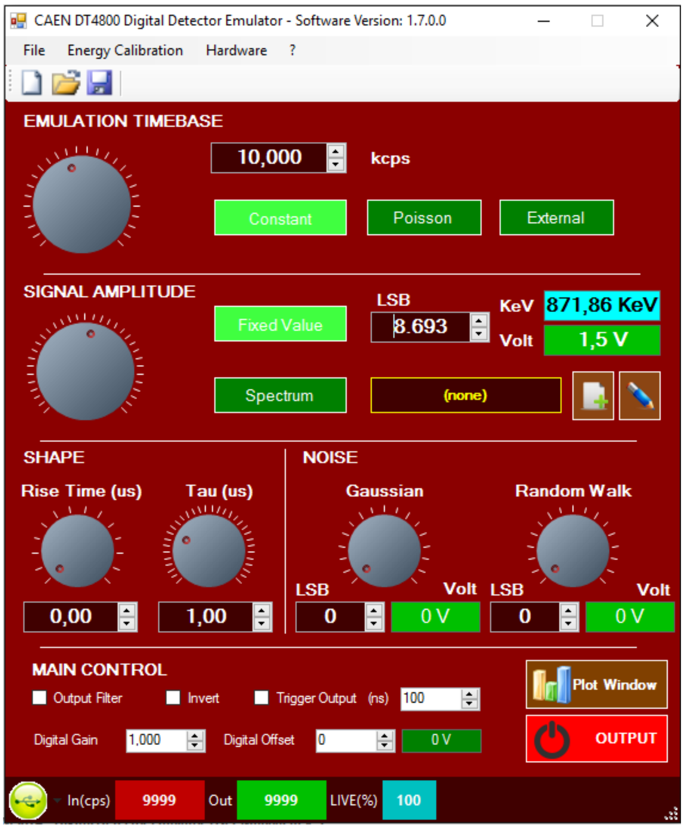
- The **Desktop icon** of the program
- The **Quick Launch** icon if the program
- The **.exe file** in the installation path on your PC.

When the program is opened, it automatically lists the available Emulator connected to the system bus via USB.

Note: Before upgrading the software uninstall the previous version through the function: "Uninstall a Program" of the Windows "Control Panel".

User Interface

The Software interface is particularly indicated for quickly setting the instrument. Customers that are used to manage with a classical pulser may find this interface quite familiar. The GUI Interface enables the generation of analog output according to the method described in **Digital RC Section**. The user can set the analog output signal rate, the amplitude, the rise and fall time of the exponential shape, and the noise contributions.



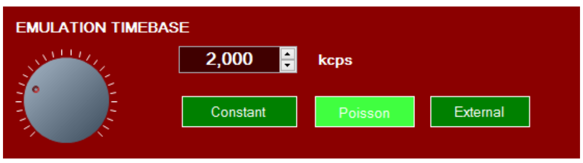
The main parameters for the signal generation can be set either through the virtual knob, the LSB box, or the green box. Considering the main GUI, the lower side of the display is dedicated to the following informations:

	The button is red when the emulator in not connected or the connection has been lost. When the device is correctly connected this button is green. Click here if you want to connect or disconnect the device.
In(cps):	is the ideal number of events that should be generated in accordance with the programmed statistic.
Out(cps):	is the number of events actually generated that takes into account possible limitations due to pile-up or saturation of the output analog stage.
Live(%):	is the ratio between the number of pulses that should be generated and the number of events actually generated (IN/OUT).

Frequency

The user can choose among two internal options, “constant rate” and “Poisson distribution” (random), or use and external frequency source.

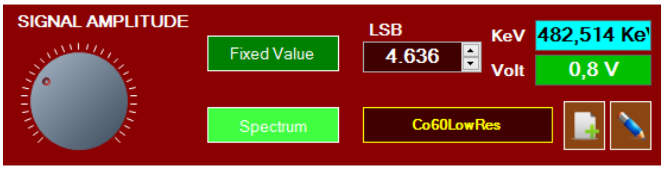
It is possible to set the rate value (in kHz) either moving the knob pointer or by writing the value in the adjacent box.



Amplitude

It is possible to choose among a "Fixed Value" of amplitude, or the load a file with the spectrum samples.

The amplitude value can be set by either moving the knob pointer, or by writing the value in the LSB box, or by writing the desired value in Volts in the green box.



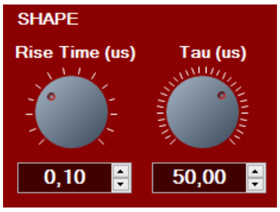
For details about the available file formats please refer to the **Accepted File Formats Section**.

Note: Whenever you write a value click **ENTER** to validate it.

When the "Spectrum" option is enabled, the software opens a folder browser that allows the user to select a file. The spectrum name is then shown on the yellow box. Users can load a new spectrum by clicking on the yellow box.

Shape

The Software Interface allows to generate exponential shapes only. The user can set the "Rise Time" and the "Tau"(i.e decay time) in µs. Values can be changed by either moving the knob pointer or by writing the value in the underlying box.

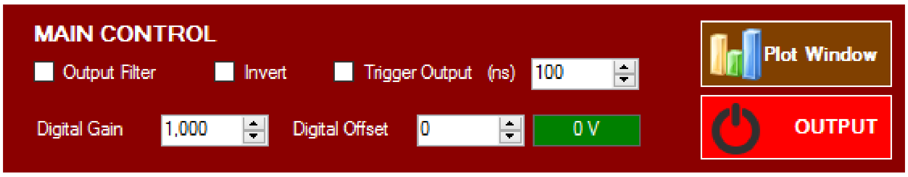


Note: If you set the Rise Time = 0.00 you are asking for the best the device can provide, i.e. about 6-8 ns (due to the DAC clock).

Noise

The noise box allows the user to add a white noise to the output signal. The user can set the sigma of the Gaussian distribution of the noise amplitude by either moving the knob pointer, or by writing the value in the underlying box, or by writing the desired value in Volts in the green box.
The user can also add a baseline drift to the output signal by using the "Random Walk" option. The value can be set by either moving the knob pointer, or by writing the value in the underlying box, or by writing the desired value in Volts in the green box.

Main Control



Output filter. Insert an LC 7th order filter (analog Bessel filter) on the output. The can reduce the output noise by a factor of 5 and it can improve the signal shape. Rise time increases from 7ns to 16ns.

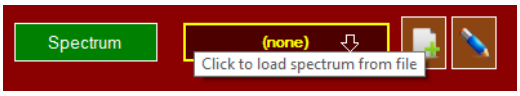
Invert. If selected the polarity of the output is changed.

Digital Gain. Digital amplification of the output signal between 0 and 2. It is applied at the end of the processing chain, therefore the whole output is multiplied by the digital gain, including the offset.

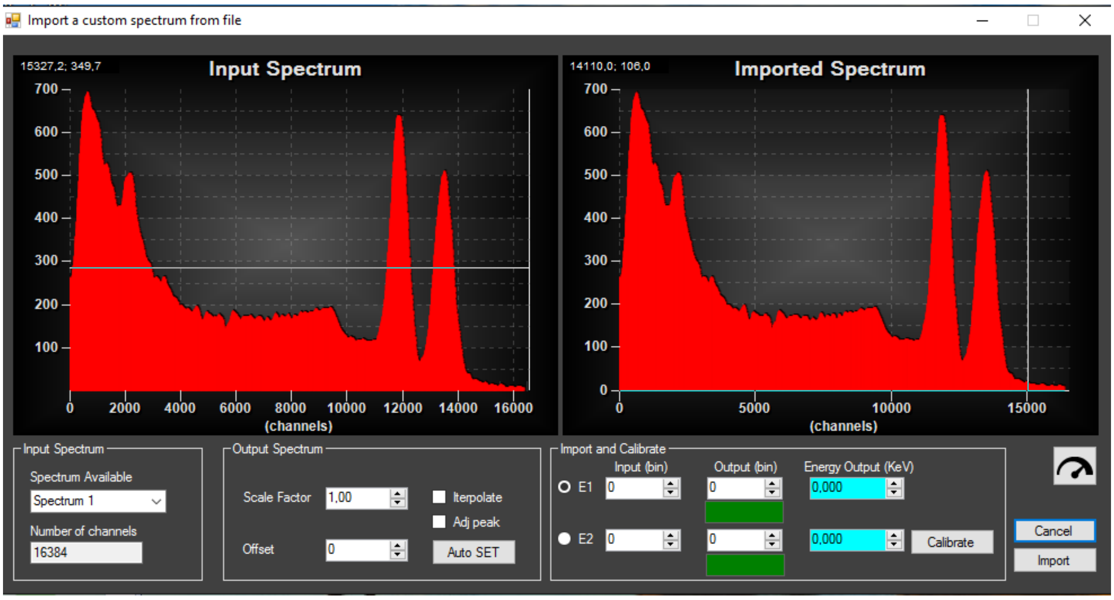
Digital Offset. Reference offset expressed as a fraction of 216 levels of quantization, i.e. between -2.2 V and +2.2 V. The offset is applied before the gain stage.

Trigger Output: Enable the output of the internal trigger. It is also possible change the widths in the range [20;1000]ns.

Import an Energy Spectrum from File



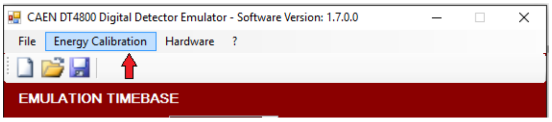
After selecting the spectrum file to be imported, the GUI opens the ”Import a custom spectrum from file”, that allows to upload the spectrum, to make preliminary operations on the spectrum itself, and to make the calibration.



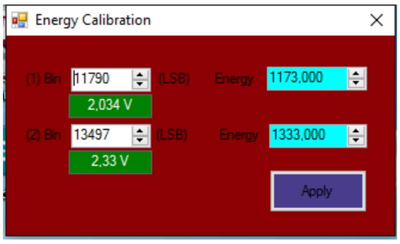
The **“Input Spectrum”** is the spectrum as got from file.
The **“Imported Spectrum”** is the spectrum as imported by the device. Some operations can be made on the input spectrum; the plot “imported spectrum” allows to see in real-time the effect of those operations.
“Spectrum Available” works for multipleANSI N42.42 spectra, where it is possible to select the desired spectrum.
“Number of channels” corresponds to the number of channels of the DAC device, 16384.
Under the **“Output Spectrum”** box, it is possible to set a **“Scale factor”** and an **“Offset”** values. The first allows to rebin the x-axis of the spectrum. The second allows to set an offset of the x-axis (in number of channels).
The tool allows to adjust the dynamic of the input spectrum to the resolution of 16384 bins of the instrument.
By checking the **“Interpolate”** button, the scaling is performed by means of a linear interpolation, otherwise each new bin is created on the basis of the nearest value of the bin on the left. The function of **“Adj Peak”** sets the highest peak of the input spectrum at the value 65535.
It is also possible to calibrate the instrument through the box **“Calibrate”**. Refer to **Section How to Calibrate in Energy (KeV)** for more details.
Press “**Import**” to import the selected spectrum.

How to Calibrate in Energy (KeV)

The device can be calibrated in energy (KeV). Press "Energy Calibration" to visualize the calibration parameters or to set a new energy calibration.

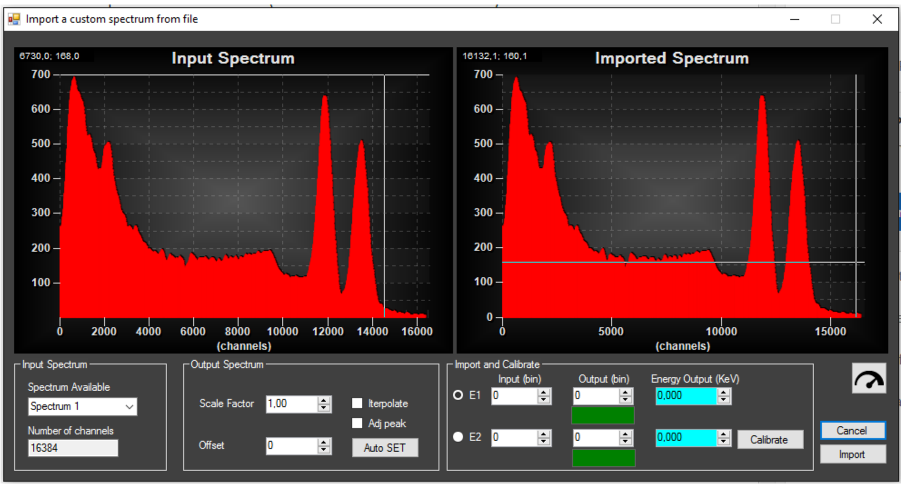


All plots can be then visualized in KeV, and the user can set the output energy directly in energy value, according to the physical source that wants to emulate.

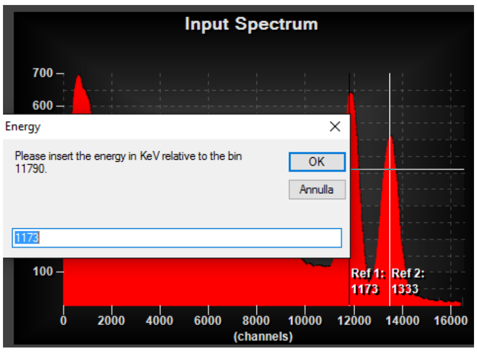


The user can put two reference values (either in LSB counts, or in Volts), and assign to them the desired value in energy (KeV). Press "Apply" to set the calibration.

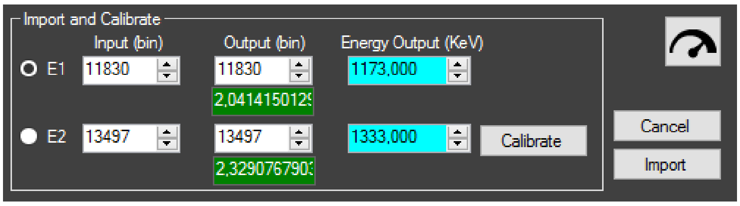
It is also possible to calibrate the instrument through the box **"Import"** and **"Calibrate"** in the "Import a custom spectrum from file" mode, when the spectrum is imported at the first time.



If a spectrum has been previously loaded (see the **Import an Energy Spectrum from File Section**), than it appears in the input spectrum window allowing the user to calibrate it. In the example above we want to calibrate a Cobalt spectrum. Double click on one of the two peaks. The software asks for the energy to be associated to that peak.



"Ref1" marker appears in the plot. Make double click on the second peak to assign the second energy value.
Values assigned into the spectrum are reported in the table of the main settings.



allows to change between the first and the second value of energy for calibration.

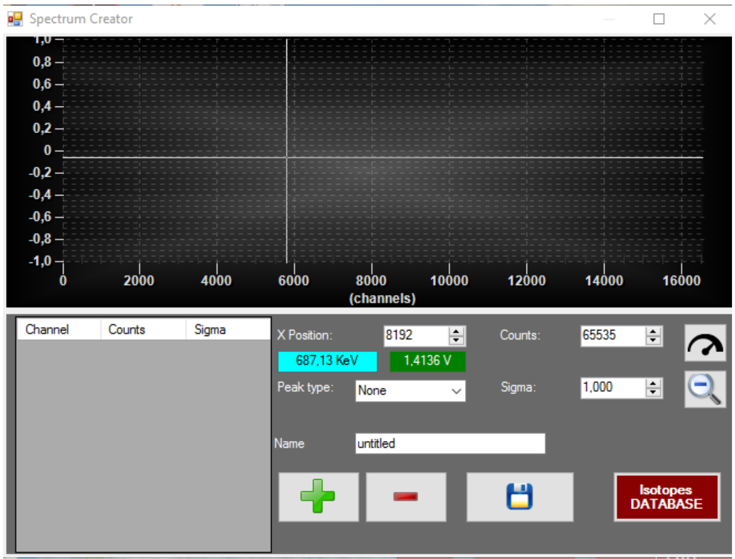

the scale of the Imported Spectrum can be swapped between ADC channels, Voltage and Energy, by preserving the calibration itself.
Press “**Calibrate**” to apply the calibration, “**Cancel**” to cancel the calibration.

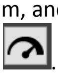
The user can calibrate the instrument also though the “Isotopes Database” tool. For further details see the **Generate an Energy Spectrum with Isotopes Database Section**.

How to Generate an Energy Spectrum with the Internal Tool

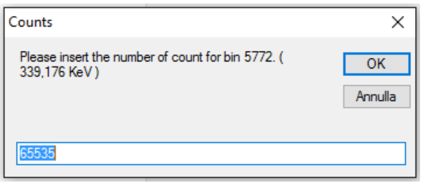
The instrument allows to generate a custom spectrum by adding specific lines and setting their width. It is also possible to select the radioactive lines of specific elements of the periodic table.

Click as shown above to open the Emulator Spectrum Creator window.

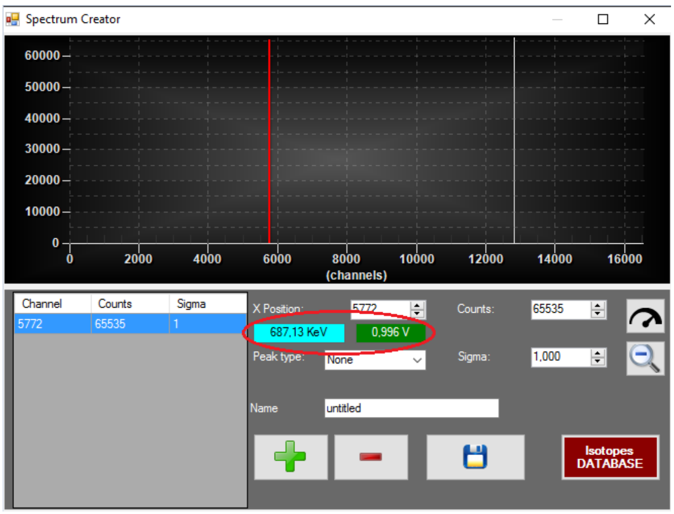


Point the cursor on the diagram, and double click to add a line. The x-axis is in counts unit, but the scale can be changed in Volt and keV units through .

In the pop-up write the corresponding value of height. 65535 is the maximum value allowed.



Alternatively you can write the value of KeV and Volt in the cyan and green box respectively.



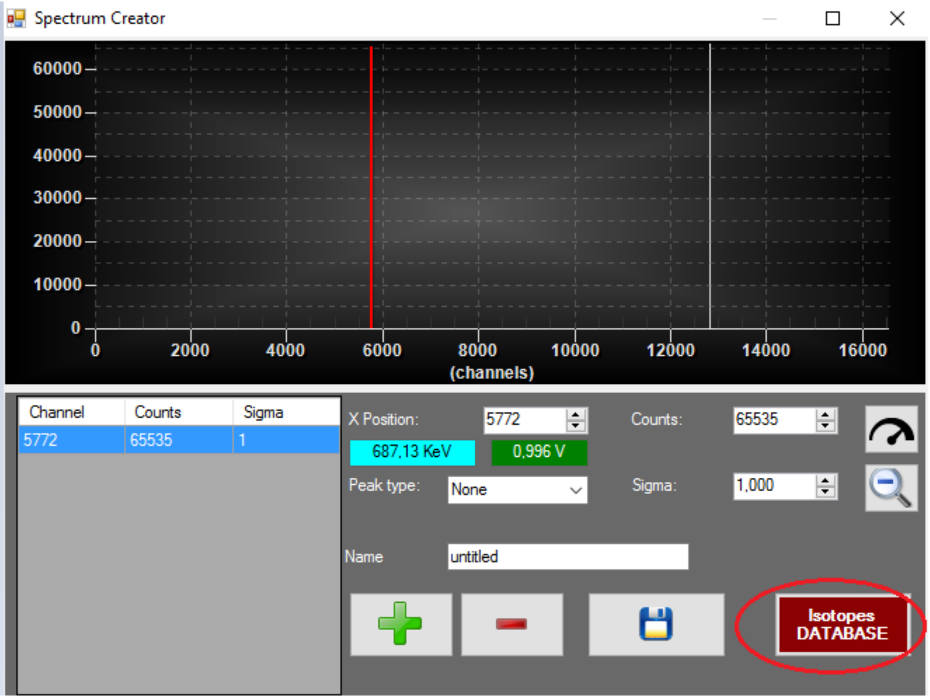
Select the **"Peak type"** between **"Gaussian"** and **"Rectangular"**. The **"Sigma"** value corresponds to the classical sigma of the Gaussian function in the first case, and to the width of the rectangular in the second. It is expressed in counts unit.

The ('+') sign allows to add more lines, as the ('–') sign to delete them.
The tool allows to **"Save"** the spectrum in its internal file format .spectrum. Specify the file **"Name"** before saving. A browser is then open to select the destination folder.

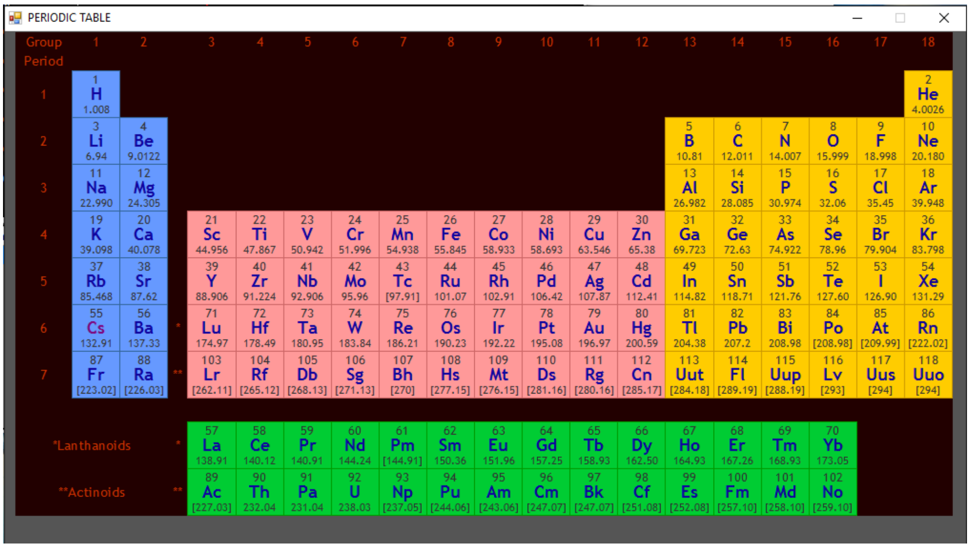
The spectrum is represented on a scale with maximum resolution of 14 bits, compatible with the Emulator resolution.

Generate an Energy Spectrum with Isotopes Database

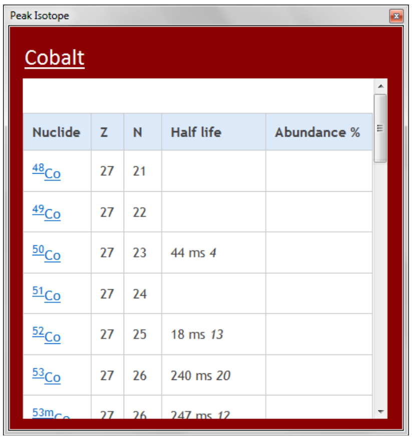
From the Spectrum Creator select “Isotopes DATABASE”



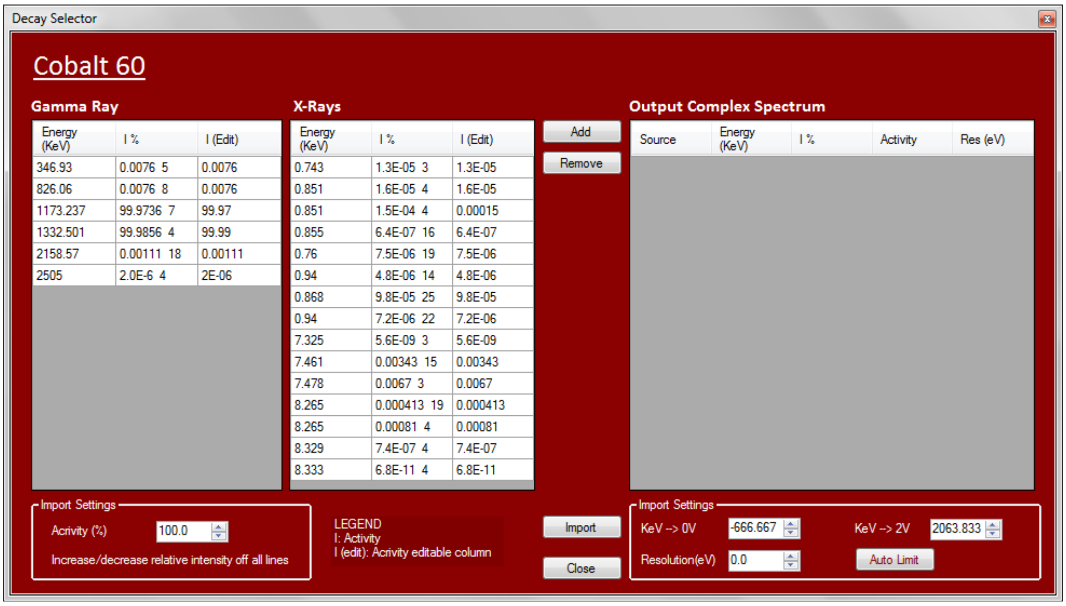
Select from the periodic table one of the element you want to add into the spectrum, as for example the Cobalt (Co).



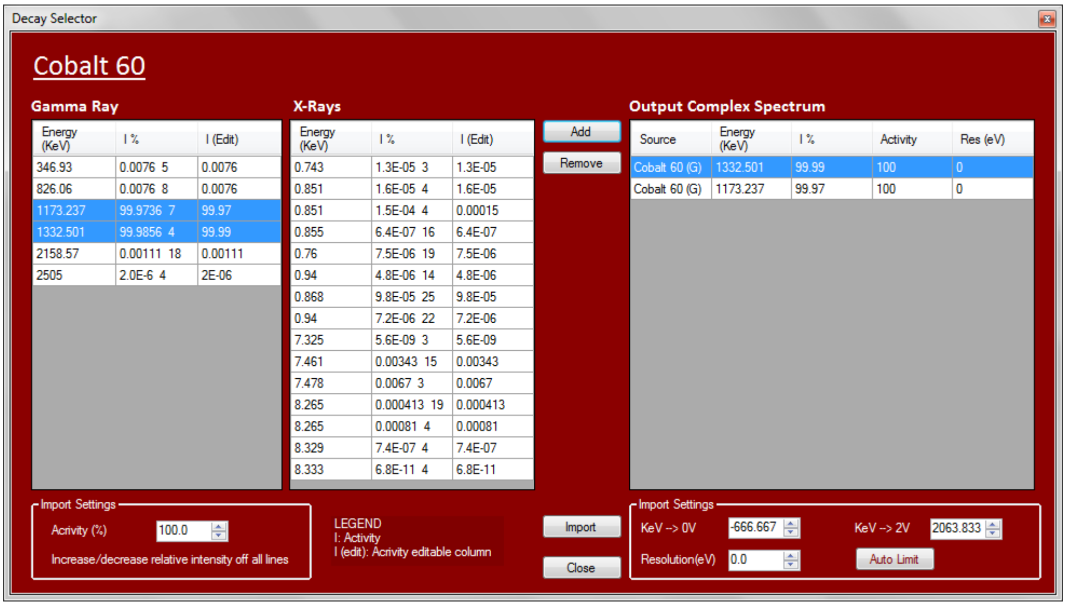
The list of isotopes will then appear.



Scroll the bar up to the radioactive ^{60}Co, and click on the name to open the "Decay Selector" Window.



The Decay Selector shows on the first column the list of ^{60}Co emitted "Gamma Ray", on the second the list of "X-Ray" lines. The user can select the desired lines and add them to the output spectrum. For example select the 1173 and 1332 keV Gamma Ray lines, and click "Add". Click "Remove" to remove undesired lines from the output spectrum.



X-Rays

Energy (KeV)	I %	I (Edit)
0.556	0.037 10	0.037
0.637	0.028 7	0.028
0.637	0.25 6	0.25
0.64	0.0022 6	0.0022

The column **I %** represents the relative intensity of the line of the isotope. The column "**I (Edit)**" allows the user to edit the activity (relative cps) of the selected line.

Output Complex Spectrum

Source	Energy (KeV)	I %	Activity	Res (eV)
Cobalt 60 (G)	1332.501	99.99	100	0
Cobalt 60 (G)	1173.237	99.97	100	0

Columns Activity and Res (eV) can be edited also from the "Output Complex Spectrum" tab

The user should make sure that the selected lines are in the calibrated range of energy of the DT4800 Digital Detector Emulator. The energy calibration is performed by setting the energy in keV unit corresponding to 0 V, the energy corresponding to the full scale of 2 V to fit the dynamic of the output spectrum. Changing those values will automatically re-calibrate the device.

Press "**Auto Limit**" to find the best calibration for the designed spectrum.

Set the desired Gaussian resolution in eV unit for all lines of the spectrum. A resolution equal to 0 eV corresponds to mono-energetic lines.

Note: The resolution can be set both from the "**Decay Selector**" and the "**Spectrum Creator**" window.

This "**Import Settings**" box allows to select the relative activity of the current isotopes when a complex mixture of isotopes is selected. The activity value acts to all the lines of the current isotope.

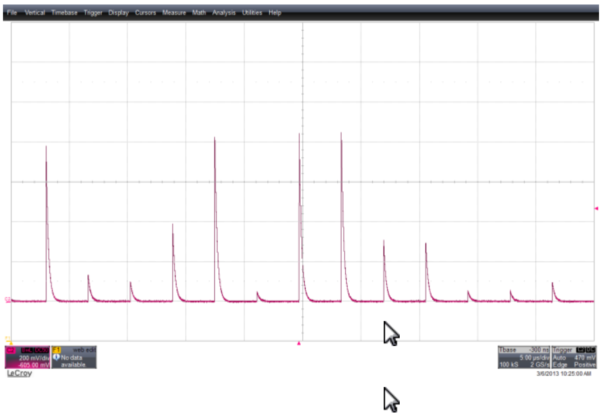
Click "**Import**" to import the spectrum with the desired settings, or "**Close**" to cancel it.

How to Modify a Spectrum

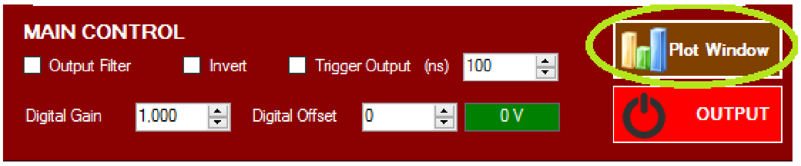
Select “Edit” in the Spectrum mode.

If the spectrum has been previously loaded from file, the “Import a custom spectrum from file” will appear; otherwise the “Spectrum Creator” allows to modify the custom spectrum.

The picture below shows a screenshot of the output of the emulator initialized as in the example above with the spectrum of the isotope ^{60}Co.



Display Area

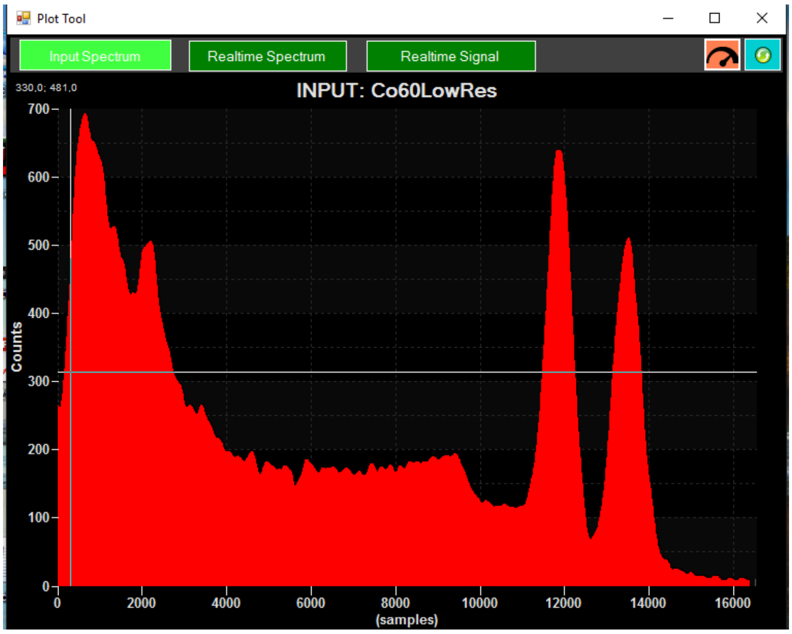


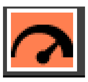
The **"Plot Window"** of the GUI gives a complete Realtime graphical overview of the operating status of the Emulator. It contains three tabs:

- Programmed Spectrum
- Realtime Spectrum
- Realtime Signal

Input Spectrum

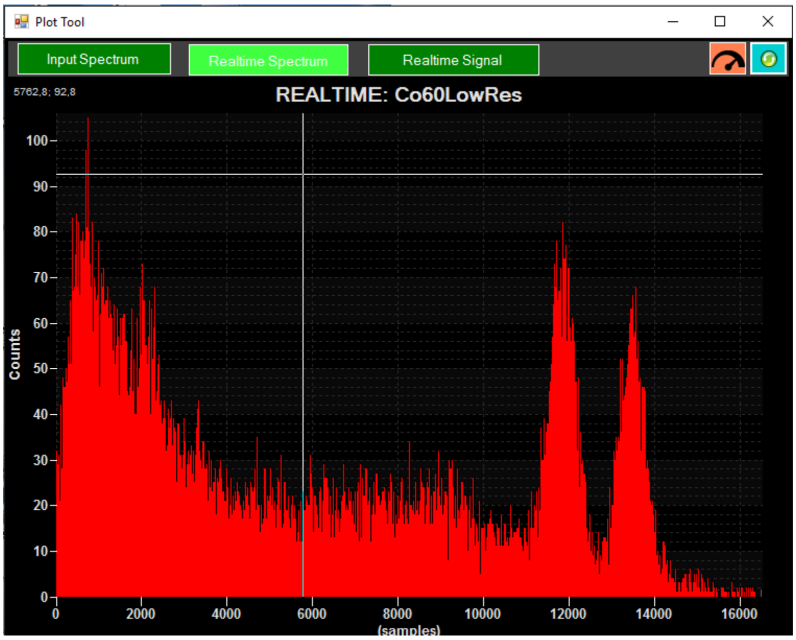
The **"Input Spectrum"** tab shows the programmed spectrum

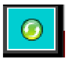


The button  allows to convert the spectrum Channels in Voltage and KeV.

Realtime Spectrum

The **"Realtime Spectrum"** tab shows a real-time view of the generated spectrum.
In the following example a Cobalt 60 spectrum has been loaded.

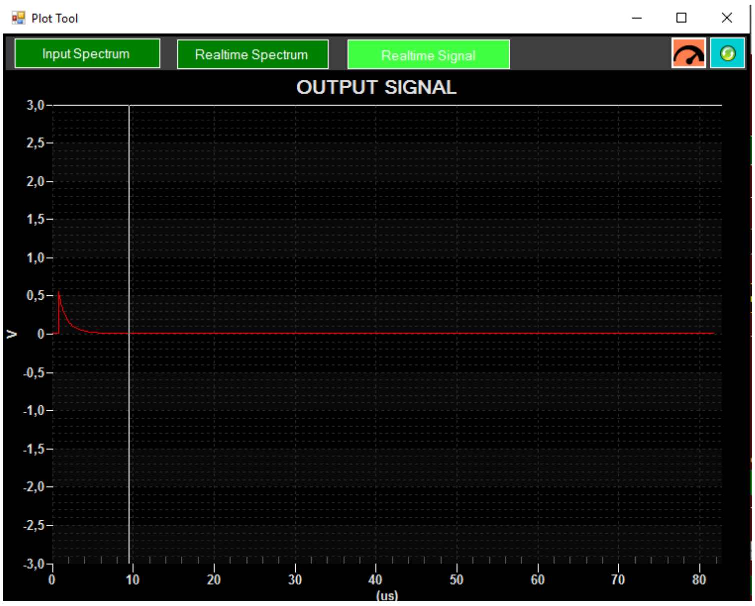


Use  to reset the spectrum.

Use  to swap between digital and physical units.

Realtime Signal

The **"Realtime Signal"** tab shows the shape preview. It works as a real oscilloscope. Moreover it is possible to change the scales by using the button 



Accepted File Formats

The accepted file formats are the following:

- **Comma Separated Values (.csv)**. This file format can be used for any kind of settings of the device. For the energy spectrum only the user can choose also one of the following file formats:
- **CAEN digitizer files (.dat)**. The histogram data is written in the following format:

  Number_of_sample_#1 Energy_value_#1
  Number_of_sample_#2 Energy_value_#2
  ……..
- **Spectrum files (.spectrum)**. This is the internal spectrum file format. Any spectrum created by the GUI will have this file format.
- **ANSI N42.42 (.xml)**. This is the standard ANSI N42.42 file format.

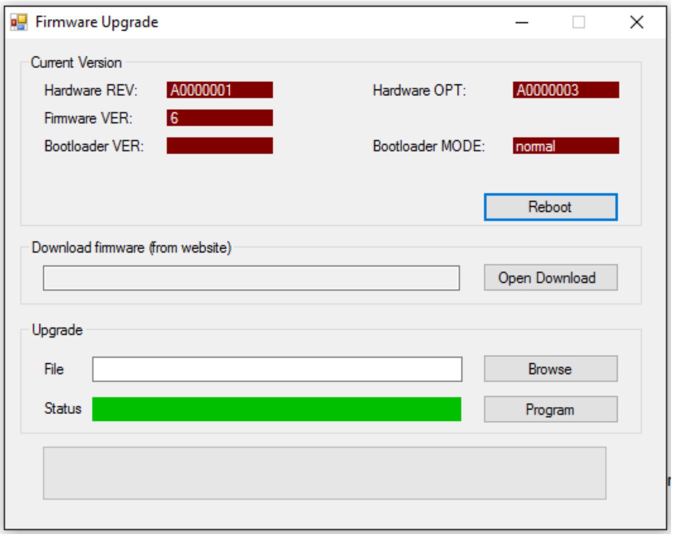
In the next section we are going to see in details the .csv file format.

Spectrum (.csv)

The values are organized in column format. Each value begins a new paragraph
Value #1
Value #2
Value #3
Value #4
Value #5
Value #6
……..
The values represent the probability and are quantized to 16 bits (from 0 to 65535). The number of bins is equal to 16384 (14 bits). If a lower number of bins is inserted, the remaining samples are automatically set to zero.

9 System Recovery and Update

The system recovery and update procedure is fully automatic and it does not need any human attendance.
Even if the DT4800 Digital Detector Emulator firmware is corrupted, the instruments automatically enters the 'Firmware Upgrade' procedure, and the user can restore the firmware. If the procedure has to be aborted during execution, there should be no consequences for the instrument.



Operatively, the configuration consists of three steps.

Boot loader mode entrance. After running the procedure through "Program", the instrument is busy for 20'' and it responds changing the status of the 'Bootloader MODE' in Boot loader.

Erasing FLASH. The system FLASH is erased.

Programming. The FLASH is initialized with the new firmware and the process is verified in real-time.

The update procedure is terminated with the re-start of the Emulator.

In case of problem or doubt please contact CAEN support at the following mail addresses:

- support.nuclear@caen.it
  (for questions about the hardware)
- support.computing@caen.it
  (for questions about software and libraries)

10 Application Examples

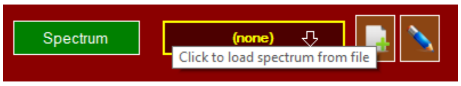
Setting Up a Remote Experiment

The device can be used with the CAEN digital MCAs as DT5770 to characterize a measurement system (detector and preamplifier) and to reproduce it to fine adjust its settings.
It is also possible use the DT4800 with the DT5720A digitizer that is present in all the CAEN educational set-ups.
It is required to:

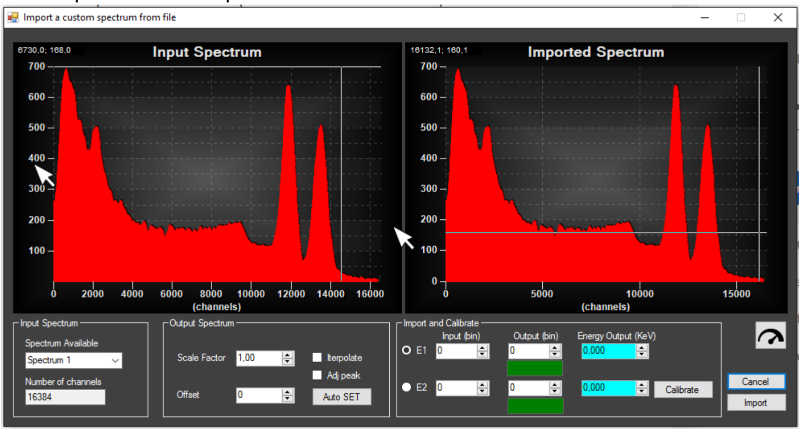
- Acquire a stream of pulses from detector and get the mean shape;
- Measure the energy spectrum through the digitizer;
- Measure the signal baseline through an oscilloscope, or the digitizer itself;
- Acquire the noise shape;
- Perform a noise characterization through spectrum analyser.

That information allows to uniquely configure the DT4800 Digital Detector Emulator.

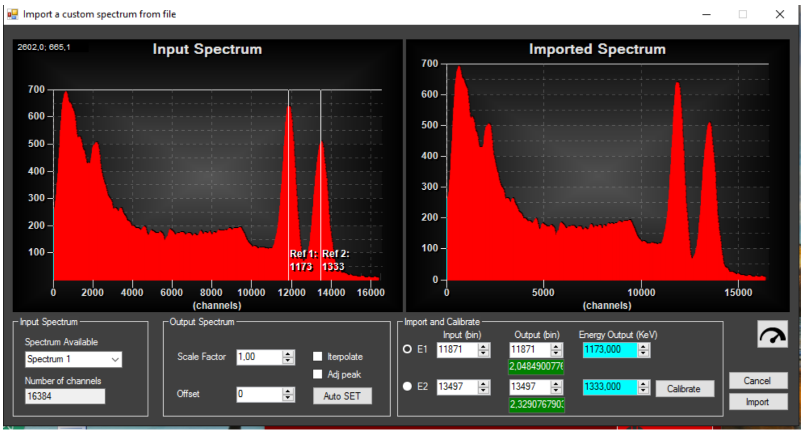
1. **Load the energy spectrum** file as saved from the DT5770 (or DT5720A).
   Select "Spectrum" in the "Signal Amplitude" section of the User Interface and select the desired file from the browser.



The "Import a custom spectrum from file" comes out.

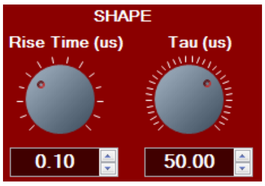


It is possible to calibrate the spectrum. In this example we are using the Cobalt60 energy spectrum.
Double click on the first peak and write the corresponding energy value in KeV. Repeat the same procedure for the second peak.
The user can also insert the corresponding value of Volt for the two peaks.
Click on "Calibrate" to calibrate the instrument.

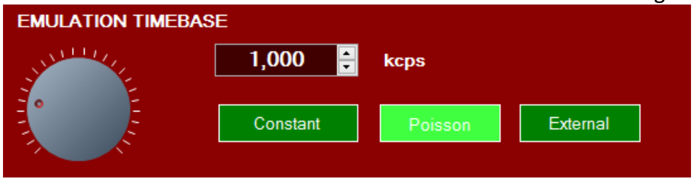


Click on "Import" to import the spectrum.

2. **Define the signal shape**.
   Set the rising time and tau of the exponential shape.



3. Set the **Time distribution**.
   For a radioactive source select “Poisson distribution”. Set the average time value in kcps units.



4. Enable the channel output

   Click on 

in the “**Main Control**” to enable the output channel. When the channel is activated the button color is red 

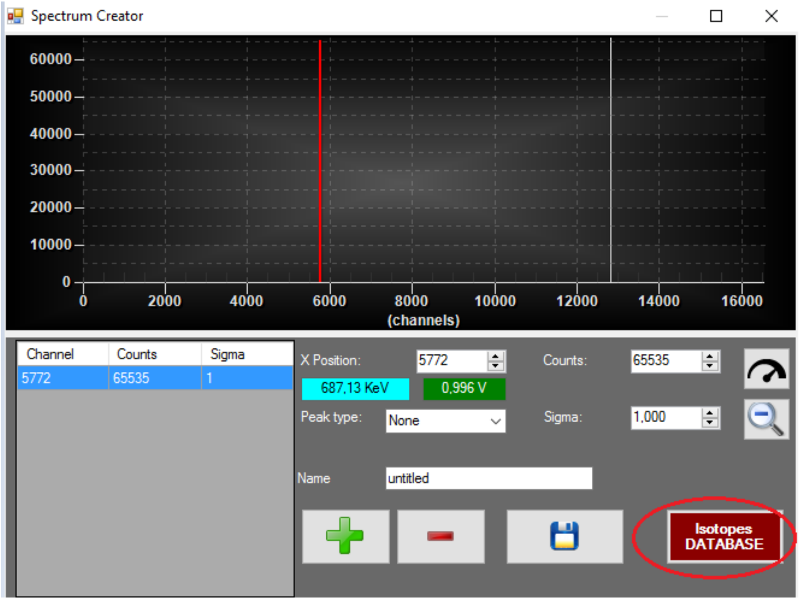
.

Generating Artificial Spectra With Isotopes Database

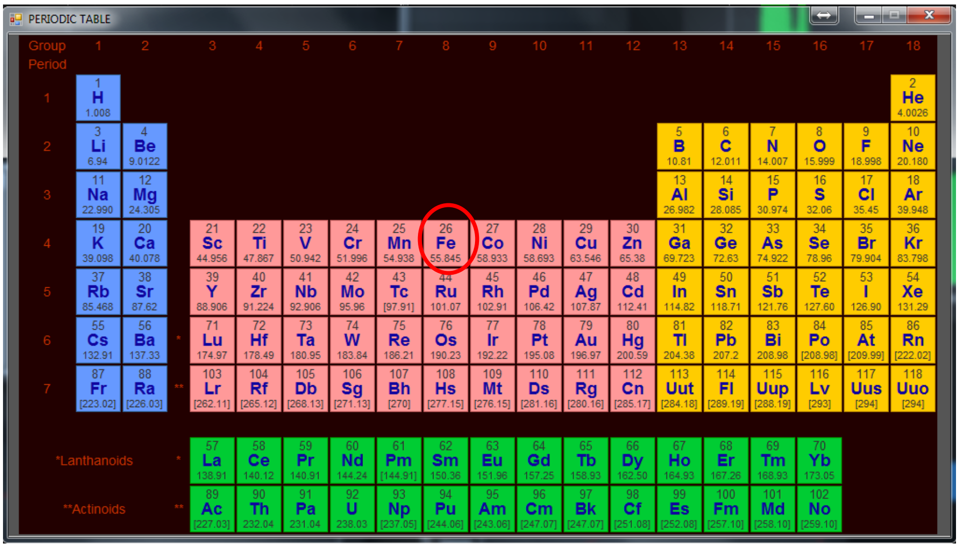
The software emulator comes with a database of common isotopes. In the following section we are going to describe how to create an artificial spectrum of the ^{55}Fe isotope.

1. Click on "Spectrum" in "Amplitude Section" and click  to create a new spectrum;

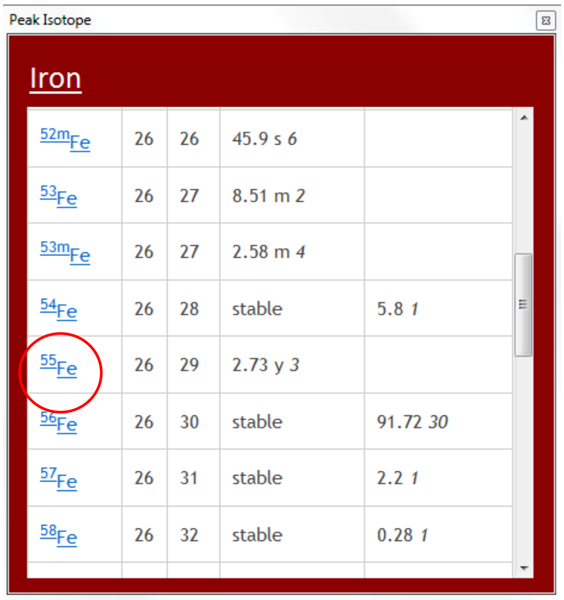
2. From the "Spectrum Editor" window select "Isotopes DATABASE"



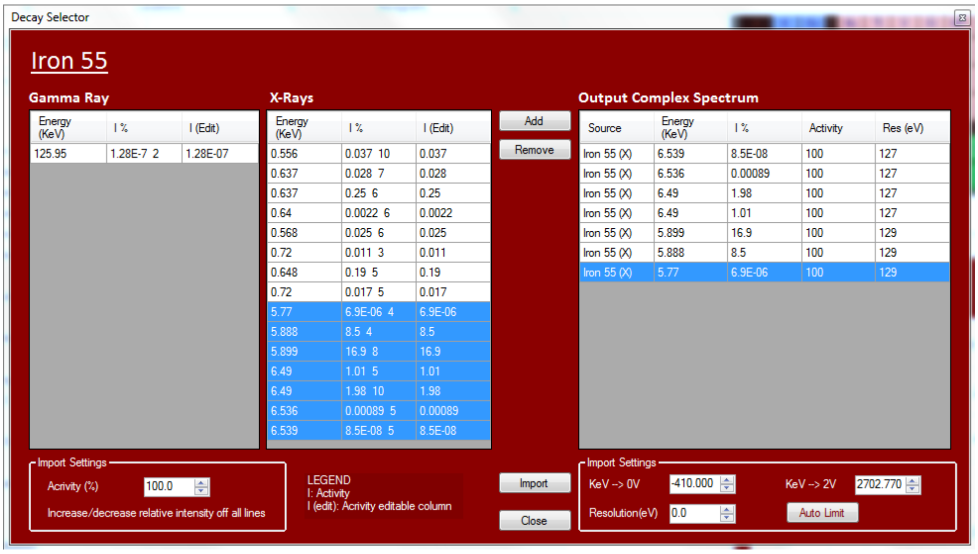
3. Select the Iron from the "Period Table";



4. Select the ^{55}Fe isotope from the list on the left;



5. Select the specific radioactive lines that you want to add in your spectrum, as for example the X-rays in the range of 5-6 KeV. Click "Add" to add the selected lines on the spectrum

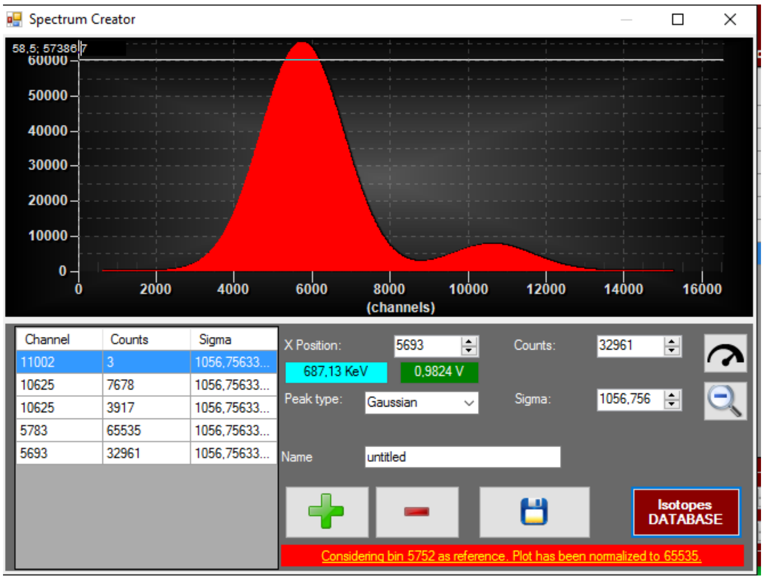


6. Write the resolution value on the "Res (eV)" column. For example we can set a resolution of 127 eV for the 6 KeV lines, and a resolution of 129 eV for the 5 KeV lines. Click on the each cell and write the desired value. If you want to set the same value for all lines write it on the "Resolution (eV)" box under "Import Settings" on the right.

7. Calibrate the instrument writing the values in energy corresponding to 0 V and 2 V. We can write 1 KeV for 0 V, and 10 KeV for 2 V.

Note: If the device is already calibrated, the new calibration will override the old one.

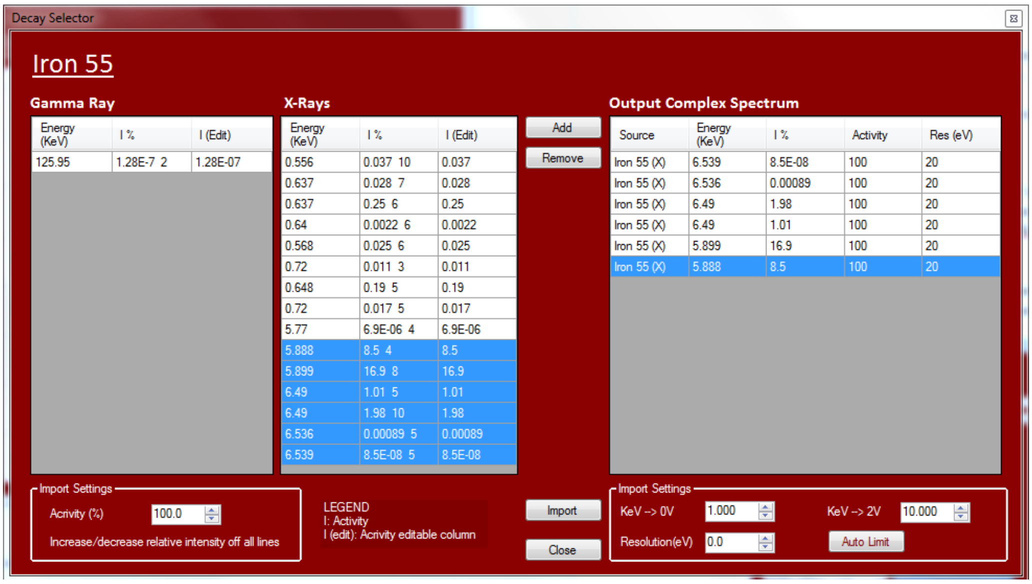
8. Press "Import" to import the spectrum. A preview will appear in the "Spectrum Creator" window.



9. Write a "Name" and press "Save" to save and load the spectrum file.

Consider the case you want to create a composite spectrum adding lines from the ^{52}Mn and ^{55}Fe. Set the Mn activity equal to twice the Fe activity.

1. Import the Fe lines as before



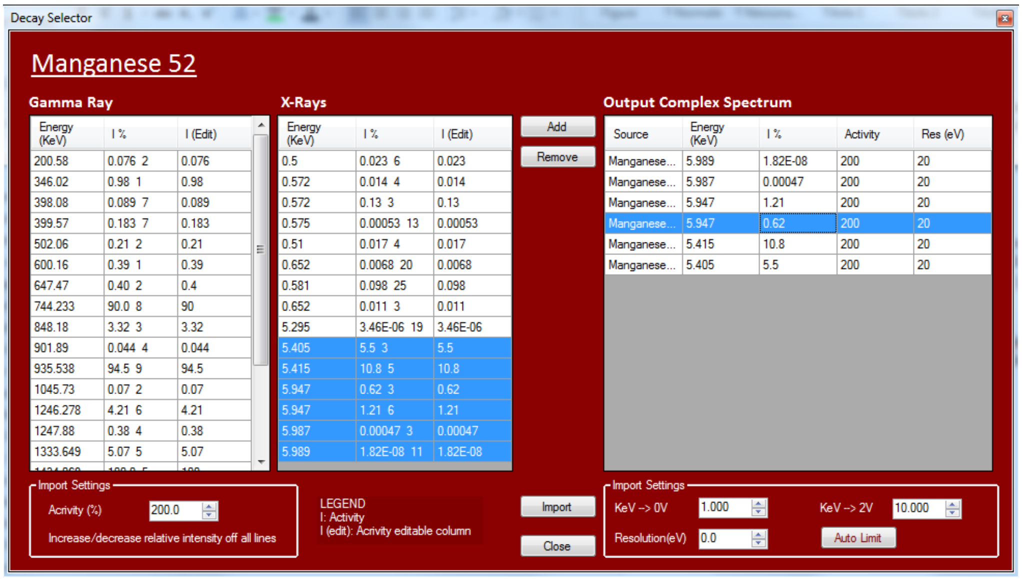
2. Set 20 eV of resolution for all lines.

3. Set the calibration point: 1 KeV for 0 V, and 10 KeV for 2 V.

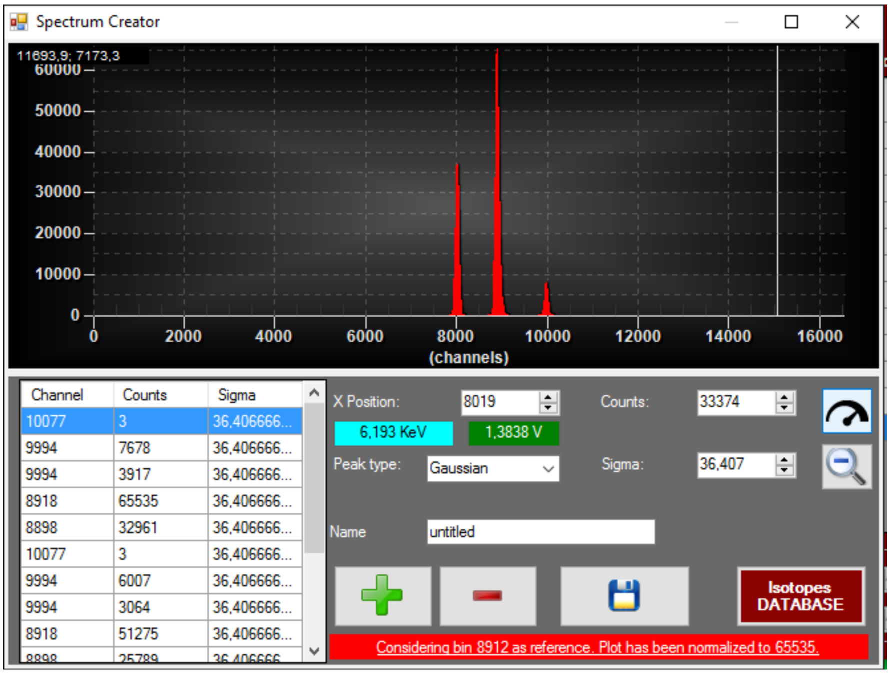
4. Press "Import".

5. Then add the Mn lines. Select the X-rays lines as in the following picture. Write in the left box "Import Settings" an activity of 200 % (to set a double activity than the Iron). Click "Add" to add the lines with the modified activity.

Note: You can modify the activity also writing the desired value in the specific cell of the "Output Complex Spectrum".



6. Press "Import". The "Spectrum Editor" window will appear as follows.



11 Technical Support

CAEN makes available the technical support of its specialists at the e-mail addresses below:

support.nuclear@caen.it
(for questions about the hardware)

support.computing@caen.it
(for questions about software and libraries)

CAEN GmbH
Brunnenweg 9
64331 Weiterstadt
Germany
Tel. +49 (0)212 254 4077
Mobile +49 (0)151 16 548 484
info@caen-de.com
www.caen-de.com

CAEN Technologies, Inc.
1 Edgewater Street - Suite 101
Staten Island, NY 10305
USA
Phone: +1 (718) 981-0401
Fax: +1 (718) 556-9185
info@caentechnologies.com
www.caentechnologies.com

CAEN S.p.A.
Via Vetraia 11
55049 - Viareggio
Italy
Phone +39 0584 388 398
Fax +39 0584 388 959
info@caen.it
www.caen.it

CAENspa INDIA Private Limited
B205, BLDG42, B Wing,
Azad Nagar Sangam CHS,
Mhada Layout, Azad Nagar, Andheri (W)
Mumbai, Mumbai City,
Maharashtra, India, 400053
info@caen-india.in
www.caen-india.in