

Development of a graphical interface software for HRFlexToT

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Abstract: The HRFlexToT control software was designed to be used through command-line. In this project a graphical interface has been programmed in order to simplify the software configuration process. The interface has been programmed via PyQt libraries. It also includes a new feature to plot the data registered by the HRFlexToT board. Finally it's explained how to calibrate by the HRFlexToT acquisition system.

I. INTRODUCTION

The HRFlexToT is a 16-channel ASIC (application-specific integrated circuit, which means that is designed for a particular use rather than intended for general purposes) for SiPM anode readout designed for Positron Emission Tomography (PET) [1]. The SiPM (Silicon Phomultiplier) is a solid-state device based on Single-photon avalanche diode implemented on common silicon substrate. Nowadays this sensor is replacing the extensively use of the Photomultiplier Tube (PMT).

A very important application where SiPM provides a significant performance is medical imaging, in particular PET. PET is a molecular diagnosis technique that uses radioactive substances with a β^+ emission decay process. The main goal of PET is showing the cellular or molecular activity of the disease. During the PET imaging, a radio-tracer is injected into the body, which gets trapped within the tissues of interest. When the positron emitted by the radio-tracer meets with an electron both produce a pair of 511 keV gamma-rays as the result of their annihilation. The pair of photons travel approximately 180° from each other until they are reach the scintillator of the scanning device, and a near-simultaneous detection in a ring of detectors takes place. This technique allows to know where the annihilation took place, so it's possible to reconstruct the final image [2].

The HRFlexToT (High Resolution Flexible Time-over-Threshold) is a new version of the FlexToT ASIC [3] designed with an extended dynamic range suitable for readout of pixelated and monolithic scintillator chrystals in Time-of-Flight ToF PET applications [1, 4]. The ASIC can be easily controlled and configured by an FPGA and a USB connection to a computer.

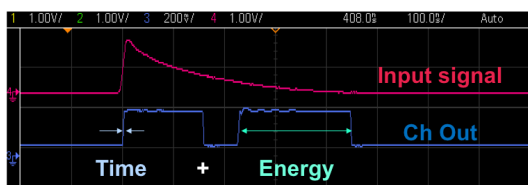


FIG. 1: Input signal and time+energy information in the channel output.

The ASIC generates two consecutive pulses encoding the arrival time (rising edge of the first pulse) and energy (width of the second pulse) of the detected photons, as shown in Figure 1. This information is readout by a Time to Digital converter (TDC) implemented in the FPGA and then sent to computer via USB. An aquisition board including the HRFlexToT ASIC, the FPGA, the USB and power control components is shown in FIGs 2 and 3. Lastly, note that this board only constains an ASIC, but several ASICs can be added in the same board.

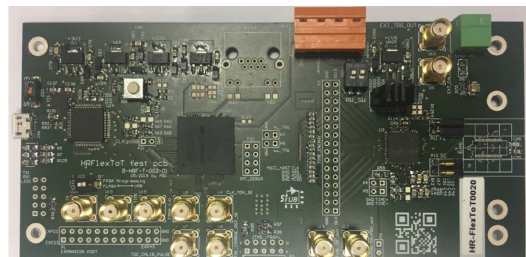


FIG. 2: Top side of the HRFlexToT board.

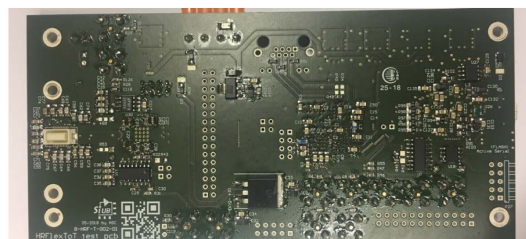


FIG. 3: Bottom side of the HRFlexToT board.

The HRFlexToT ASIC has been an inspiration to another ASIC, the FASTIC, which will be a candidate for the LHCb upgrade II calorimeter at CERN.

II. INTERFACE DEVELOPMENT

The configuration of the HRFlexToT is managed via command line. In order to set the configuration parameters of the software the user must write a line with the following syntax:

```
hrflectot config [parameters]
```

The list of parameters the user wants to set consists on the parameter code (usually preceded by - or --) followed by the value. Some parameters require more than one value to be set, such as the Fine Time Threshold (-t), and some of them may contain a list of values, each of them correspond to one of the channels of the ASIC. For example, the next statement:

```
hrflectot config -e 0 1 11 0 15 1 -i 1 0 2 1
--gain 3 --gain_rl 3
```

will enable the Energy Output (-e) at channels 0 and 15 and disable at 11, then the Time Output (-i) will be enabled at channel 2 and disabled at channel 1 and finally the coarse and fine gain (--gain and --gain_rl) will be set at the third level. Other parameters will remain unchanged.

This way for setting the configuration of the board is not comfortable at all. In this example a few parameters were changed, but the user might need to change several parameters of a given board. This might take a very huge command line. In order to simplify the software setup process and make it more intuitive and interactive, a graphical interface using QT libraries has been programmed. Moreover, this new interface enables to control several ASICs in the same environment.

QT is a free and open-source widget toolkit for creating graphical interfaces on various software and hardware platforms such as Linux, Windows, macOS or Android. In this case it has been used a Python binding of QT, PyQT, which is also a free software. It's included in many python installation packs.

The graphical interface has been focused into two functionalities: the HRFlexToT ASIC and FPGA configuration; and data acquisition and analysis. FIG. 4 shows a typical flow diagram that a user may follow while controlling the board. First of all the software settings can be customized, before the board is connected to the software. When the connection happens, the user may set the ASIC and FPGA configuration. Finally he can acquire data from the TDC and preview a plot of these data in the plot tab. During this process the user is able to save all settings, data and graphics.

In PyQt5 the window that has to be programmed is characterized by a python class, usually named as `MainWindow` or `ApplicationWindow`. In that class it has to be programmed all widgets we want to implement. PyQt allows to use multiple kinds of widgets such as Checkboxes, Buttons, Textboxes or Lists. Each widget is part of `PyQt5.QtWidgets`, the PyQt sublibrary for widgets. They are fixed into layouts, which they're already into other widgets. In our case the Main Window is divided in tabs (and subtabs if necessary), which contain these layouts.

A class for each tab has been designed to make the program more structured. These classes are `FPGA`, `Asic`,

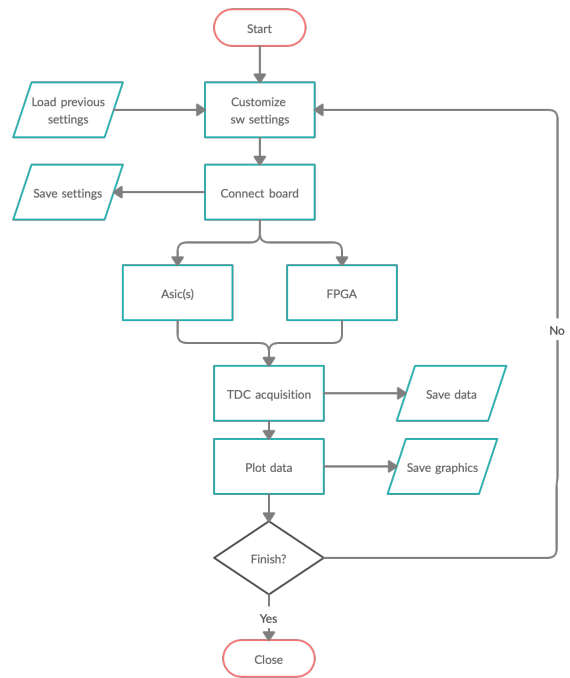


FIG. 4: Composition of the HRFlexToT graphical interface.

Plot, Histogram (similar to Plot) and Swsettings (software settings). These classes can be used in future PyQt5 interfaces with similar purposes.

A. Configuration

A new method has been introduced to configure the board from the interface. This new software works as follows: when the board is connected, a couple of temporary files are created. Note that the directory where these files are created can be modified in the software settings tab, the current directory is selected by default. One of these files controls the FPGA configuration, and another file control each of the ASICs in board (config files). Also it's possible to have the specifications from the board (board ID, number of ASICs...). Once the software detects a modification in a config file, it applies these changes into the board.

There's another file whose only function is to disconnect the board when the user finishes modifying the config files. The interface removes this state file when the user tries to disconnect the board or closes the window.

FIG 6 shows the config tab for the ASIC and FIG 7 for the FPGA. The user can control the FPGA and the ASIC when the board is connected to the interface (there's a button in the File menu to connect). Before that, the config tab remains disabled.

The user can load a set of config files (must be compressed in a zip file) clicking `File` → `Load setting file`. If the user changes any parameter of the FPGA

or ASIC window the interface updates the config files, then the software applies all changes to the board. The user can save the config files in a zip file at every moment. This process finishes when the user disconnects the board from the interface (from the File menu) or closes the window [5].

The location of the config files can be modified in the software settings tab. Other parameters that can be changed in this tab are: the board the user wants to connect (if more than one are connected), the Log Level and the Number of ASICs on the board (this can also be automatically detected).

B. TDC data acquisition

The information provided by the ASIC needs to be pre-processed with an FPGA before sending it to the computer for the data analysis. The spectrum can be plotted basing on the TDC (Time to Digital Converter) measure, which is the data given by the HRFlexToT, or it can be shown as an energy spectrum. The operation that must be done to perform this equivalence are explained in the next section.

C. Plotting

The interface is provided with a plot tab. Currently Dark Count Rate and Energy spectrum are available, but other plots may be added in the future. The Dark Count Rate is defined as the photons per unit of time that are detected in dark conditions. Photons are emitted in the electron-hole recombination in the SiPM anode, which were created due to thermal excitation. In the plot is represented the number of events registered in function of the value set as threshold. Since the energy distribution of these photons is exponential, it should be convenient

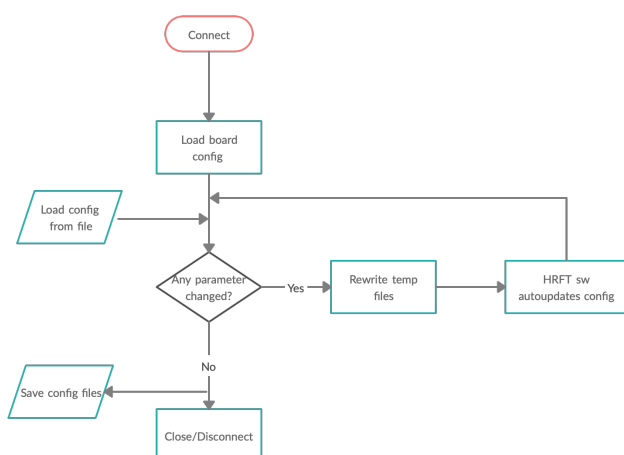


FIG. 5: Flow diagram of ASIC and FPGA classes.

to set the Y axis in logarithmic scale. Lastly, the software can represent the energy spectrum of a radiation source as an histogram.

As every channel gives its own data, users may choose which one they are interested to plot. Other settings related to the graphic can also be modified (log scale, bin width...). In FIG.9 there's a flow diagram that shows how the plot classes (DCR and spectrum) work. Graphics are made using the matplotlib python library, which has a class designed for PyQt. This class also provides a toolbar where the user can modify some graphical parameters of the plot, as the axes names or the margins of the figure. It's also possible to save the image in multiple formats.

III. ENERGY SPECTRUM CALIBRATION

The energy spectrum provided by the software is expressed as the width of the input signal in nanoseconds. Note that a silicon photomultiplier generates a secondary charge which is proportional to the energy of the incident particle. This charge is collected in the sensor. Its output is an exponential pulse whose width is related to the number of photons that hit the sensor microcells. The TDC function is to convert the binary pulse in the time domain (a pulse that encodes the energy in the width of a pulse) into a digital signal that can be sent to a computer. The energy encoded as the width still need to be converted into keV in order to properly analyse the energy spectrum of a radiation source. The calibration procedure is as follows.

The following equation shows the relation between the number of photons arriving to the detector (SiPM) and the number of fired microcells[6]

$$N_{photon}PDE = -N_{total} \ln \left(1 - \frac{N_{fired}}{N_{total}} \right) \quad (1)$$

where N_{photon} is the number of photons arriving to the sensor, PDE stands for Photon Detection Efficiency, N_{total} is the total number of microcells and N_{fired} is the

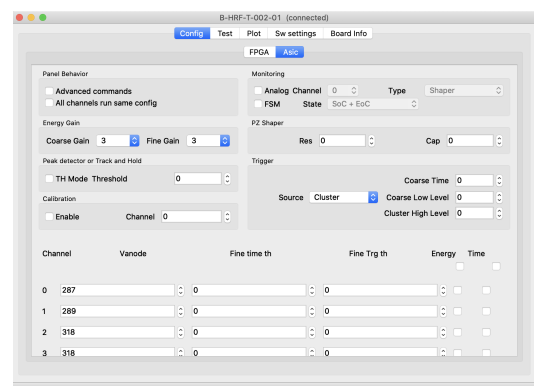


FIG. 6: Graphic appearance of the ASIC tab.

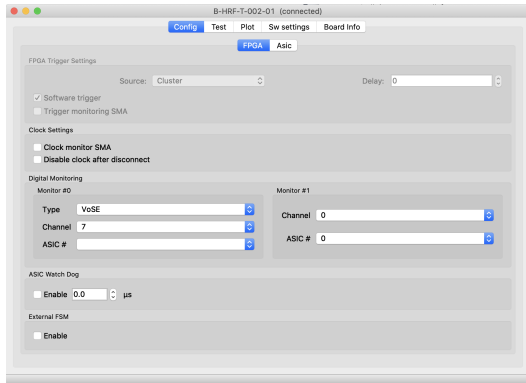


FIG. 7: Graphic appearance of the FPGA tab.

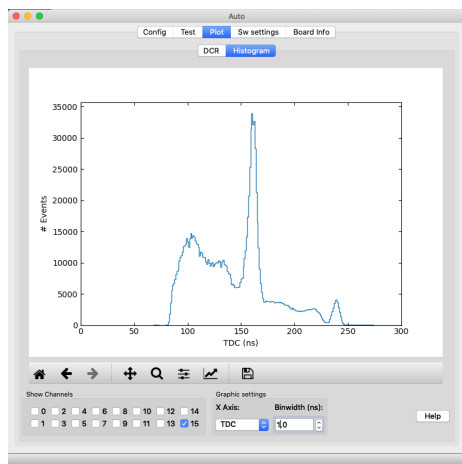


FIG. 8: Graphic appearance of the histogram subtab inside the plot tab.

number of fired microcells. The last term is directly related to the pulse width (TDC) by a calibration factor f [7]:

$$N_{fired} = TDCf \quad (2)$$

The calibration factor f is the inverse of the pulse width corresponding to a single microcell firing. This means that f is the energy gain (relation between photons and time width).

The calibration factor can be found if the energy ratio between two characteristic peaks of the spectrum is known. In this case it's used the ^{22}Na annihilation peak and the ^{22}Na gamma emission peak. Their energies are 511 keV and 1274 keV respectively. This ratio must be the same as the one in the detected photons for those peaks ($N_{photon}PDE$), since these magnitudes are assumed to be proportional:

$$\frac{E_1}{E_2} = \frac{N_{photon}PDE_1}{N_{photon}PDE_2} \quad (3)$$

The relationship between $N_{photon}PDE_i$ and TDC is in eq. (1).

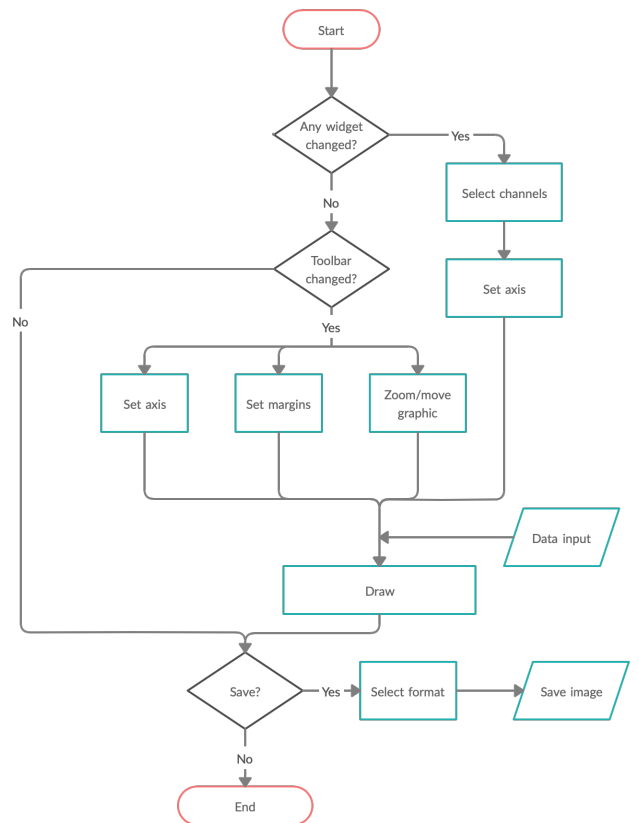


FIG. 9: Flow diagram of plot classes.

Once the calibration factor is found, the relation between the detected photons and the Energy E follows a lineal behaviour. Performing a linear regression one may find this relationship:

$$N_{photon}PDE = a + bE \quad (4)$$

where a and b are coefficients to be found via the linear regression. To find them it's convenient to use other peaks in the TDC spectrum, some of them are shown in table I [7].

Reference points	TDC (ns)	Energy (keV)
Na backscattering peak	100	170
Na Compton edge	125	340
Na annihilation peak	165	511
Na peak	239	1274

TABLE I: TDC using the HRFlexToT asic for characteristic peaks its energy correspondence.

After the calibration process has been performed, the energy spectrum remains as shown in FIG. 11. The parameters take the following values: $f = 13.834$, $a = 289.4$, $b = 6.791$.

Note that the annihilation peak is located at an energy of 490 keV but it had to be at 511 keV (electron rest

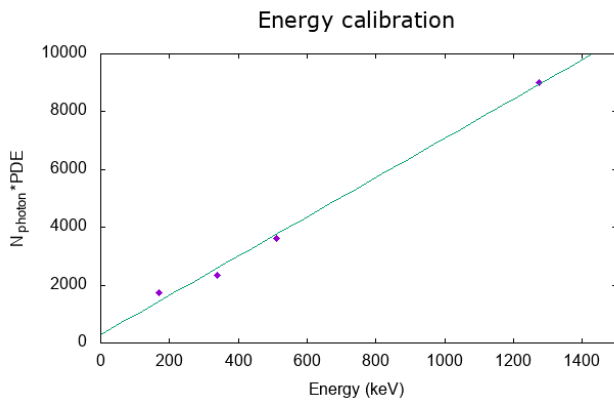


FIG. 10: Linear regression of data in table I, as explained in (4).

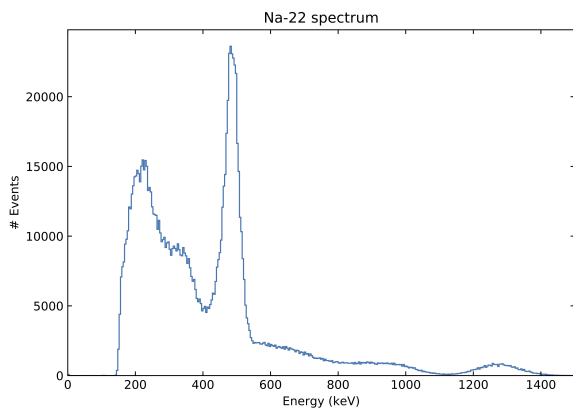


FIG. 11: ^{22}Na energy spectrum measured by the HRFlexToT.

mass). This deviation is related to the TDC-energy calibration. Usually backscattering and compton edge are not taken for calibration, since their peaks are not clear to find. As shown in FIG. 8 annihilation and gamma peaks are much more pronounced than the others. In order to do a better calibration of the spectrum other radio-isotopes must be studied, e.g. ^{60}Co or ^{137}Cs . Caesium has a gamma peak at 662 keV and cobalt has two

peaks at 1173 keV and 1333 keV [8].

IV. CONCLUSIONS

In this project it has been evidenced the importance of having an appropriate way to set and control any software. In complex softwares command-line is not comfortable at all and might be a major source of involuntary errors. Additionally, it has been incorporated a graphic toolbar where the user of HRFlexToT may plot the data acquired from the TDC. The control interface can have multiple boards connected via USB, each of them can have a variable number of Asics inside. The program reads their information so as to get access on their configuration.

The energy of an incident gamma photon is stored in the TDC width in time dimensions. The relationship between the TDC measure and the photon energy isn't even linear, so a calibration of the TDC signal has been made. The relationship between these magnitudes is known, but some parameters have been necessary to be determined. This calibration has been performed using gamma spectra of radioisotopes whose representative peaks are tabulated in the literature. In this project we've used the backscattering peak, compton edge, annihilation and gamma peak of Sodium-22. For a better calibration it should be noted that backscattering peak and compton edge must be avoided, since they provide a huge error as their peak isn't clear. Other radioactive sources should be considered in order to have an optimal calibration.

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- [6] https://www.hamamatsu.com/resources/pdf/ssd/e03_handbook_si_apd_mppc.pdf.
- [7] Tutorial on how to perform SPTR, Energy resolution and CTR measurements, available at SiUB website.
- [8] Due to COVID-19 shutdown of research facilities I wasn't able to test the HRFlexToT and I had to use old data that other group members provided to me.