User's Manual

Digital Gamma Finder (DGF)

Pixie-500 Express

Version 3.30, December 2014

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1 Overview

The Digital Gamma Finder (DGF) family of digital pulse processors features unique capabilities for measuring both the amplitude and shape of pulses in nuclear spectroscopy applications. The DGF architecture was originally developed for use with arrays of multi-segmented HPGe gamma-ray detectors, but has since been applied to an ever broadening range of applications.

The DGF Pixie-500 Express is a 4-channel all-digital waveform acquisition and spectrometer card based on the CompactPCI/PXI Express (PXIe) standard for fast data readout to the host. It combines spectroscopy with waveform capture and on-line pulse shape analysis. The Pixie-500 Express accepts signals from virtually any radiation detector with exponentially decaying pulses. Incoming signals are digitized by 14-bit 500 MSPS ADCs. Waveforms of up to 8.0 μs in length for each event can be captured in a first level FIFO, and stored in 256 MB of on-board SDRAM memory organized as a fast FIFO with DMA readout to the host PC. The waveforms are available for onboard pulse shape analysis, which can be customized by adding user functions to the core processing code. Waveforms, timestamps, and the results of the pulse shape analysis can be read out by the host system for further off-line processing. Pulse heights are calculated to 16-bit precision and can be binned into spectra with up to 32K channels. The Pixie-500 Express supports coincidence spectroscopy and can recognize complex hit patterns.

Data readout rates through the CompactPCI/PXI Express backplane to the host computer can reach up to 800 MB/s (theoretical max for x4 connection). Multiple modules can be read out in parallel with a suitable chassis and host PC. The PXI backplane is also used to distribute clocks and trigger signals between several Pixie-500 Express modules for group operation. With a large variety of CompactPCI/PXI Express processor, controller or I/O modules being commercially available, complete data acquisition and processing systems can be built in a small form factor. Sooner or later there will even be hard drives with >10 GB/s write capability to take full advantage of the Pixie-500 Express readout bandwidth.

1.1 Features

- Designed for high precision γ-ray spectroscopy with fast radiation detectors, e.g. scintillator/PMT combinations (NaI, $LaBr_3$, etc) and many others.
- 14 bit, 500 MHz ADC resulting in energy resolutions close to HPGe capabilities.
- Simultaneous amplitude measurement and pulse shape analysis for each channel.
- Programmable gain (high/low) and input offset.
- Programmable pileup inspection criteria include trigger filter parameters, threshold, and rejection criteria.
- Triggered synchronous waveform acquisition across channels, modules and crates.
- Supports x4 PCIe data transfers (<= 800 Mbytes/second).

1.2 Specifications

Front Panel I/O	
Signal Input (4x)	4 analog inputs. Selectable input impedance: 50Ω and 2kΩ, ±2V pulsed, ±2V DC. Switch selectable input attenuation 1:8 and 1:1 for either impedance setting.
Logic Input/Output	General Purpose I/O connected to programmable logic: 1 MMCX coaxial connector and 1 high density 10-pin connector (single ended or differential)
Backplane I/O	
Clock Input/Output	Distributed 10 and 100 MHz clocks on PXIe backplane.
Triggers	Wired-or bussed trigger on PXIe backplane for synchronous event acquisition.
Synchronization	Wired-or SYNC signal distributed through PXIe backplane to synchronize timers and run start/stop to 50ns.
Veto	Global logic level to suppress event triggering.
Data Interface	
PCI Express	x4 connection to host PC. Theoretical bandwidth 800 MB/s per slot Actual bandwidth: ~450 MB/s
Digital Controls	
Gain	Analog switched gain of 1.0 or 2.9 Digital gain adjustment of up to ±10% in 15ppm steps.
Offset	DC offset adjustment from –2.5V to +2.5V, in 65535 steps.
Shaping	Digital trapezoidal filter. Rise time and flat top set independently in small steps.
Trigger	Digital trapezoidal trigger filter with adjustable threshold. Rise time and flat top set independently.
Data Outputs	
Spectrum	1024-32768 bins per channel, 32 bit deep (4.2 billion counts/bin). Additional memory for sum spectrum for clover detectors.
Statistics	Real time, live time, filter and gate dead time, input and throughput counts.
Event data	Pulse height (energy), timestamps, pulse shape analysis results, waveform data and ancillary data like hit patterns.

2 Setting Up

2.1 Installation

2.1.1 Hardware Setup

The Pixie-500 Express modules can be operated in any standard 3U PXIe chassis. The total system bandwidth will depend on the architecture of the chassis and controller – for maximum bandwidth each slot should have an x4 connection (1 GB/s) and the controller should be capable of 1 GB/s times the number of slots[1].

A PXIe controller (embdded PC or bridge to desktop/laptop) must be placed in the system slot of your chassis. Place the Pixie-500 Express modules into any peripheral PXIe or PXIe/PXI hybrid slot with the chassis still powered down, then power up the chassis (Pixie-500 Express modules are not hot swappable). If using a remote controller, be sure to boot the host computer *after* powering up the chassis[2].

2.1.2 Drivers and Software

System Requirements: The Pixie software is supported on Windows 7 and still compatible to Windows XP and Vista. Restrictions apply to the 64 bit version of Windows 7[3]. Please contact XIA for details on operating Pixie-500 Express modules with Linux.

When the host computer is powered up the first time after installing the controller and Pixie-500 Express modules in the chassis, it will detect new hardware and try to find drivers for it. (A Pixie-500 Express module will be detected as a new device every time it is installed in a new slot.) While there is no required order of installation of the driver software, the following sequence is recommended (users with embedded host computer skip to step 4):

1. If you have a remote controller, first install the driver software for the controller itself. Otherwise, skip to step 4.
   Unless directed otherwise by the manufacturer of the controller, this can be done with or without the controller and Pixie-500 Express modules installed in the host computer and/or chassis. If the modules are installed, ignore attempts by Windows to install drivers until step 7.
   NI controllers come with a multi-CD package called “Device Driver Reference CD”. For simplicity it is recommended to install the software on these CDs in the default configuration.
2. Unless already installed, power down the host computer, install the controller in both the host computer and chassis, and power up the system again (chassis first).

[1] Fast data rates will avoid or reduce dead times associated with data readout from module to host PC, but will only matter at high count rates. Lower speed connections still work well for applications with lower data transfer requirements.

[2] In some systems, “scan for hardware changes” in the Windows device manager may detect and install a remote chassis when the PC was booted first.

[3] At the time of writing, these restrictions are: Support for 64bit Windows is still under development.

3. Windows will detect new hardware (the controller) and should find the drivers automatically. Verify in Window's device manager that the controller is properly installed and has no "resource conflicts".
4. Install Igor Pro, version 6.2 or higher
5. Install the Pixie-500 Express software provided by XIA (see section 2.2.3)
6. Unless already installed, power down the host computer and install the Pixie-500 Express modules in the chassis. Check the input switch settings for the appropriate signal termination: 50 Ω or 2 kΩ (see section 10.1 for details). Then power up the system again (chassis first).
7. Windows will detect new hardware (the Pixie-500 Express modules) and should find the drivers automatically. If not, direct it to the "drivers" directory in the Pixie-500 Express software distribution installed in step 5. Verify in Window's device manager that the modules are properly installed as "Pixie500e" under Jungo devices and have no "resource conflicts".

2.1.3 Pixie User Interface

The Pixie Viewer, XIA's graphical user interface to set up and run the Pixie-500 Express modules (as well as other members of the Pixie family), is based on WaveMetrics' IGOR Pro. To run the Pixie Viewer, you have to have IGOR Version 5.0 or higher installed on your computer. By default, IGOR Pro will be installed at C:\Program Files\WaveMetrics\IGOR Pro Folder.

The CD-ROM with the Pixie-500 Express software distribution contains the installation program (for version XXX)

Pixie-500e_XXX_setup.exe

Follow the instructions shown on the screen to install the software to the default folder selected by the installation program, or to a custom folder. This folder will contain the IGOR control program (Pixie.pxp), online help files and 8 subfolders (Configuration, Doc, Drivers, DSP, Firmware, MCA, PixieClib, and PulseShape). Make sure you keep this folder organization intact, as the IGOR program and future updates rely on this. Feel free, however, to add folders and subfolders at your convenience.

For the latest version of the Pixie Viewer software, go to support.xia.com and search for "Pixie release".

2.2 Getting Started

To start the Pixie Viewer, double-click on the file "Pixie.pxp" in the installation folder. After IGOR loaded the Pixie Viewer, the START UP[4] panel should be prominently displayed in the middle of the desktop.

In the panel, first select the chassis type and number N of Pixie modules in the system. Then specify the serial numbers of the modules – this allows addressing the modules from 0-N independent of the physical slot.

[4] In the following, SMALL CAPS are used for panel names; *italic* font is used for buttons and controls.

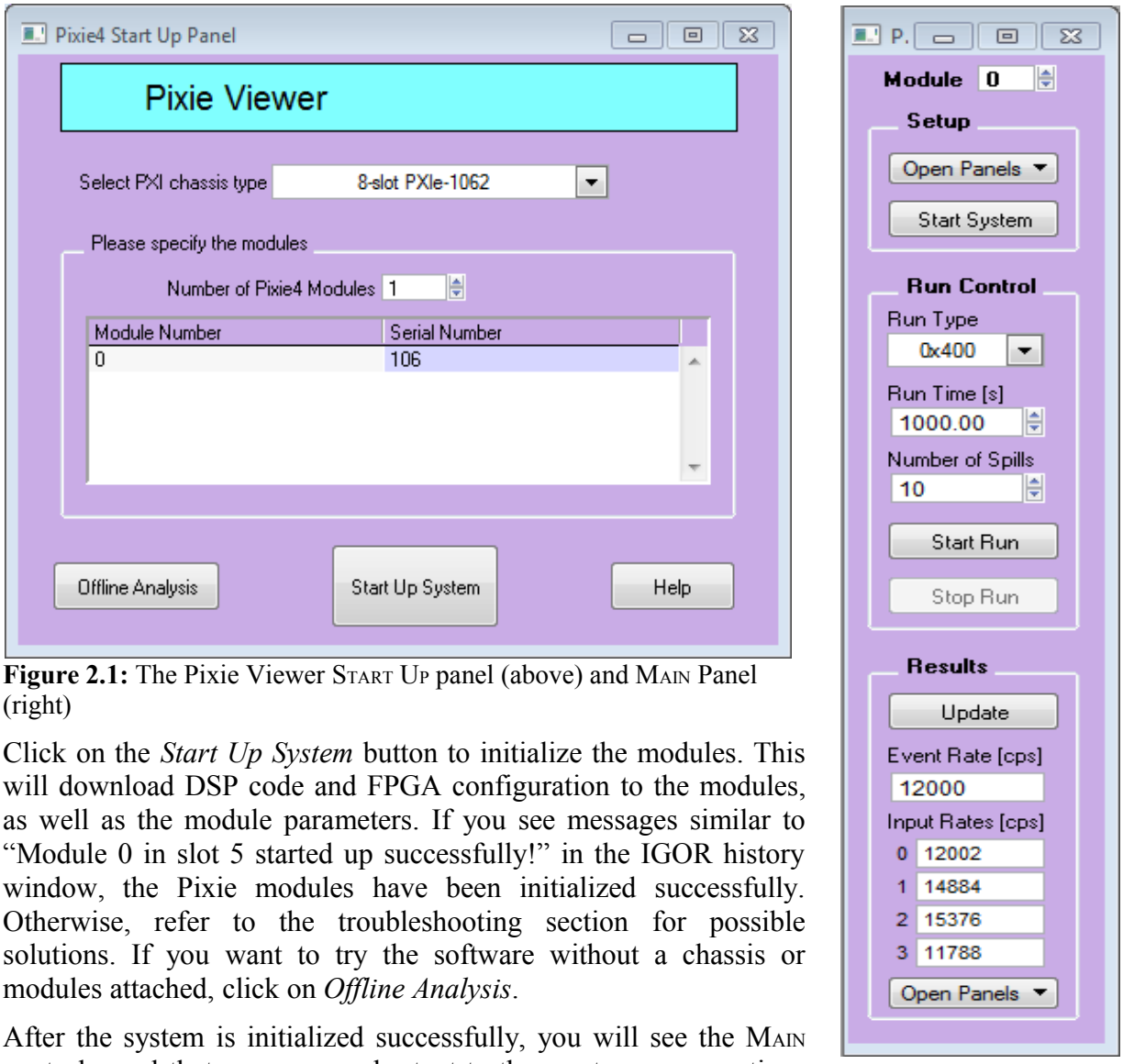


Figure 2.1: The Pixie Viewer START UP panel (above) and MAIN Panel (right)

Click on the *Start Up System* button to initialize the modules. This will download DSP code and FPGA configuration to the modules, as well as the module parameters. If you see messages similar to "Module 0 in slot 5 started up successfully!" in the IGOR history window, the Pixie modules have been initialized successfully. Otherwise, refer to the troubleshooting section for possible solutions. If you want to try the software without a chassis or modules attached, click on *Offline Analysis*.

After the system is initialized successfully, you will see the MAIN control panel that serves as a shortcut to the most common actions and from which all other panels are called. Its controls are organized in three groups: Setup, Run Control, and Results.

In the Setup group, the *Start System* button opens the START UP panel in case you need to reboot the modules. The *Open Panels* popup menu leads to four panels where parameters and acquisition options are entered. They are described in more detail in section 3 and in the online help. To get started, select *Parameter Setup*, which will open (or bring to front) the PARAMETER SETUP panel shown in Figure 2.2. For most of the actions the Pixie Viewer interacts with one Pixie module at a time. The number of that module is displayed at the top of the MAIN panel and the top right of the PARAMETER SETUP panel. Proceed with the steps below to configure your system.

Note: The *More/Less* button next to the *Help* button on the bottom of the PARAMETER SETUP panel can be used to hide some controls. This may be helpful to first-time Pixie users who only want to focus on the most essential settings.

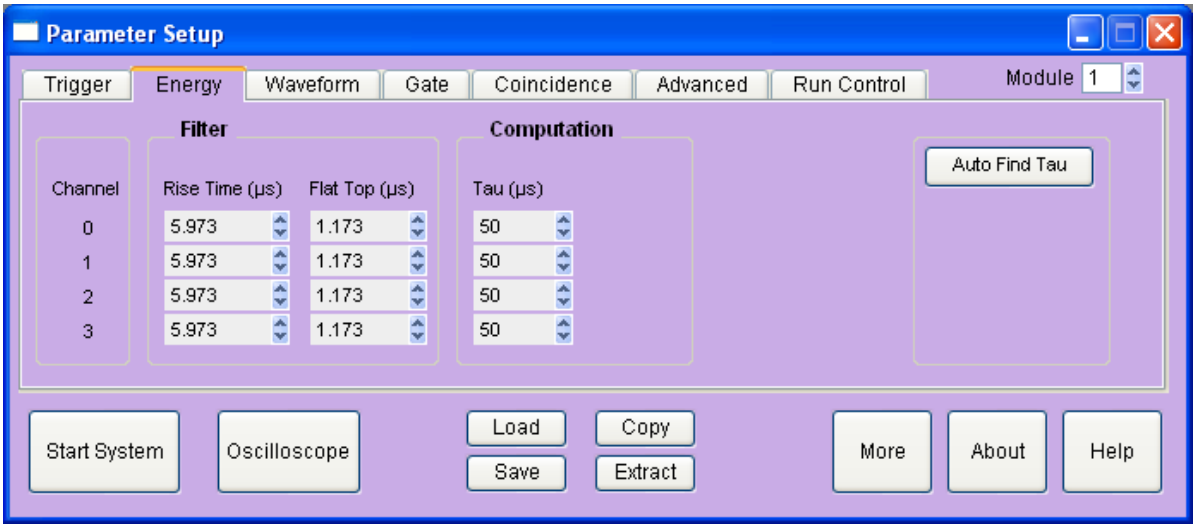


Figure 2.2: The PARAMETER SETUP Panel, *Energy* tab shown

For an initial setup, go through the following steps:

1. If not already visible, open the PARAMETER SETUP panel by selecting *Parameter Setup* from the *Open Panel* popup menu in the MAIN panel.
2. At the bottom of the PARAMETER SETUP panel, click on the *Oscilloscope* button. This opens a graph that shows the untriggered signal input. (Fig.2.3)
   In the OSCILLOSCOPE panel, click *Refresh* to update the display. The pulses should fall in the display range (0-16K). If no pulses are visible or if they are cut off at the upper or lower range of the display, click *Adjust Offsets* to automatically set the DC offset. If the pulse amplitude is too large to fall in the display range, decrease the *Gain*. If the pulses have falling leading edges, toggle the *Invert* checkbox.

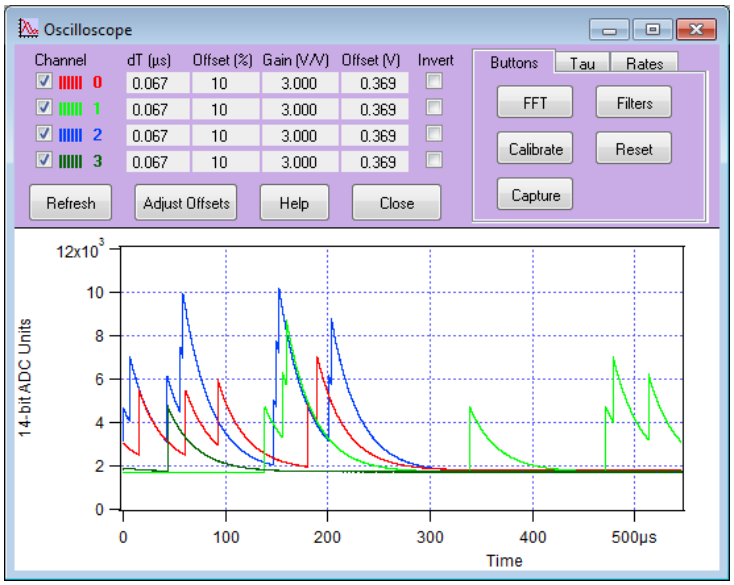


Figure 2.3: OSCILLOSCOPE panel.

3. In the *Energy* tab of the PARAMETER SETUP panel, input an estimated preamplifier exponential RC decay time for *Tau*, and then click on *Auto Find Tau* to determine the actual Tau value for all channels of the current module. You can also enter a known good Tau value directly in the *Tau* control field, or use the controls in the OSCILLOSCOPE to manually fit Tau for a pulse.
4. Save the modified parameter settings to file. To do so, click on the *Save* button at the bottom of the PARAMETER SETUP panel to open a save file dialog. Create a new file name to avoid overwriting the default settings file.
5. Save the Igor experiment using *File -> Save Experiment As* from the top menu. This saves the current state of the interface with all open panels and the settings for file paths and slot numbers (the settings independent of module parameters).
6. Click on the *Run Control* tab, set *Run Type* to "0x301 MCA Mode", *Poll time* to 1 second, and *Run time* to 30 seconds or so, then click on the *Start Run* button. A spinning wheel will appear occasionally in the lower left corner of the screen as long as the system is waiting for the run to finish. If you click the *Update* button in the MAIN panel, the count rates displayed in the Results group are updated.
7. After the run is complete, select *MCA Spectrum* from the *Open Panels* popup menu in the Results group of the MAIN panel. The MCA SPECTRUM graph shows the MCA histograms for all four channels. You can deselect other channels while working on only one channel. After defining a range in the spectrum with the cursors and setting the fit option to *fit peaks between cursors*, you can apply a Gauss fit to the spectrum by selecting the channels to be fit in the *Fit* popup menu. You can alternatively enter the fit limits using the *Min* and *Max* fields in the table or by specifying a *Range* around the tallest peak or the peak with the highest energy. To scale the spectrum in keV, enter the appropriate ratio in the field *keV/bin*.

At this stage, you may not be able to get a spectrum with good energy resolutions. You may need to adjust some settings such as energy filter rise time and flat top as described in section 3.5.

3 Navigating the Pixie Viewer

3.1 Overview

The Pixie Viewer consists of a number of graphs and control panels, linked together by the MAIN control panel. The Viewer comes up in exactly the same state as it was when last saved to file using *File->Save Experiment*. This preserves settings such as the file paths and the slot numbers entered in the START UP panel. However, the Pixie module itself loses all programming when it is switched off. When the Pixie module is switched on again, all programmable components need code and configuration files to be downloaded to the module. Clicking on the *Start Up System* button in the START UP panel performs this download. Below we describe the concepts and principles of using the Pixie Viewer. Detailed information on the individual controls can be found in the Online Help for each panel. The operating concepts are described in sections 4-7.

The controls in the MAIN control panel are organized in three groups: Setup, Run Control, and Results. In the Setup and Results groups, popup menus lead to the panels and graphs indicated in Figure 3.1.

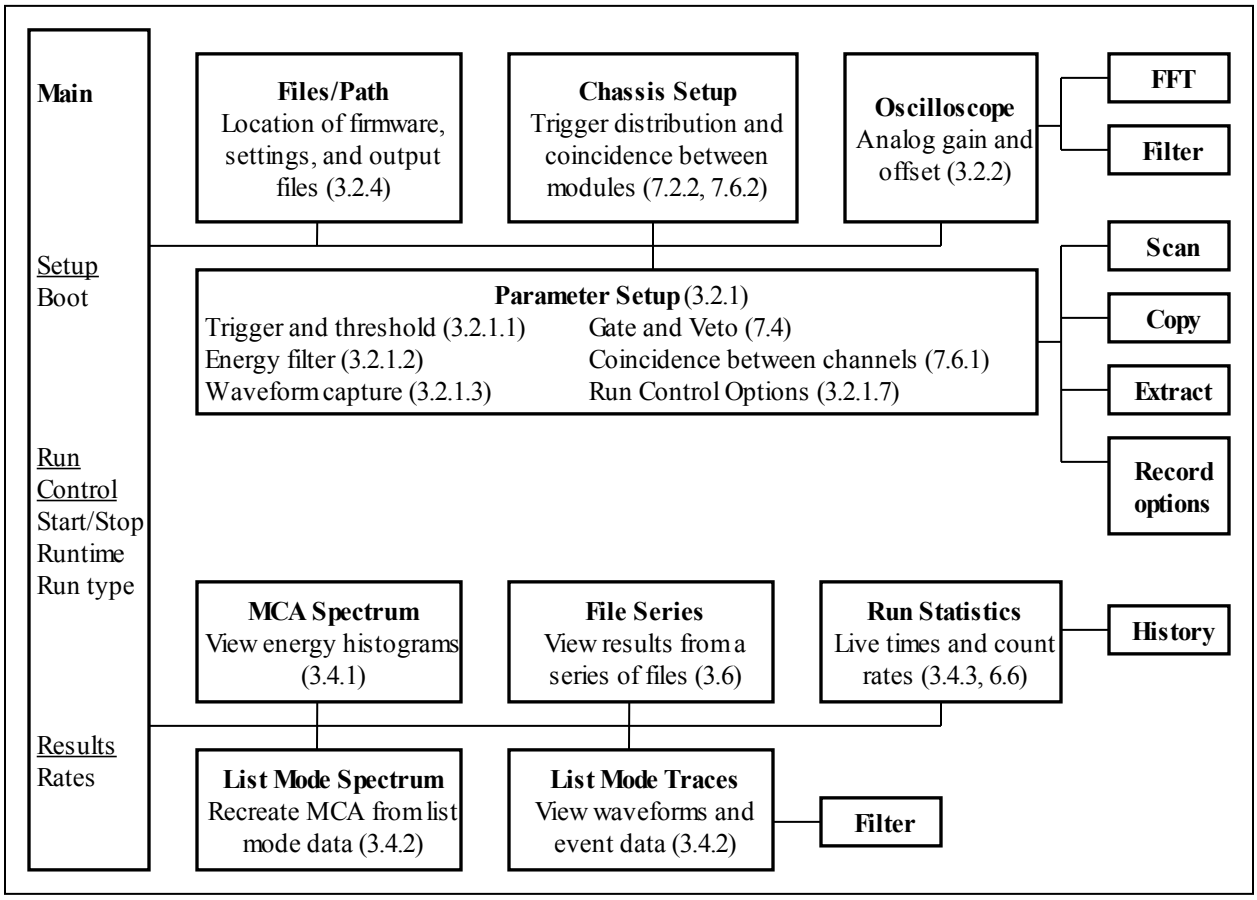


Figure 3.1: Block diagram of the major panels in the Pixie Viewer. Numbers in brackets point to the corresponding section in the user manual. All panels are described in detail in the online help.

3.2 Setup Group

In the setup group, there is a button to open the START UP panel, which is used to boot the modules. The *Open Panels* popup menu leads to one of the following panels: PARAMETER SETUP, OSCILLOSCOPE, CHASSIS SETUP, FILES/PATHS

3.2.1 PARAMETER SETUP Panel

The PARAMETER SETUP panel is divided into 7 tabs, summarized below. Settings for all four channels of a module are shown in the same tab. At the upper right is a control to select the module to address. At the bottom of the panel is a *More* button, which will make all advanced panel controls visible as well.

The Pixie spectometer being a digital system, all parameter settings are stored in a settings file. This file is separate from the Igor experiment file, to allow saving and restoring different settings for different detectors and applications. Parameter files are saved and loaded with the corresponding buttons at the bottom of the PARAMETER SETUP panel. After loading a settings file, the settings are automatically downloaded to the module. At module initialization, the settings are automatically read and applied to the Pixie module from the last saved settings file.

In addition there are buttons to copy settings between channels and modules, and to extract settings from a settings file. Two large buttons at the lower left duplicate the buttons to call the START UP panel and the OSCILLOSCOPE.

3.2.1.1 Trigger Tab

The *Trigger* tab contains controls to set the trigger filter parameters and the trigger *threshold*, together with checkboxes to enable or disable trigger, to control trigger distribution (see section 7.2.1), and to set time stamping options for each channel. Except for the threshold, the trigger settings have rarely to be changed from their default values.

The threshold value corresponds to ¼ of the pulse height in ADC steps, e.g. with a threshold of 20, triggers are issued for pulses above 80 ADC steps. This relation is true if the trigger filter *rise time* is large compared to the pulse rise time and small compared to the pulse decay time. A pulse shape not meeting these conditions has the effect of raising the effective threshold. For a modeled behavior of the trigger, you can open displays from the OSCILLOSCOPE and the LIST MODE TRACES panels that show trigger filter and threshold computed from acquired waveforms using the current settings. The threshold value is scaled with the trigger filter *rise time*, therefore it is not limited to integer numbers.

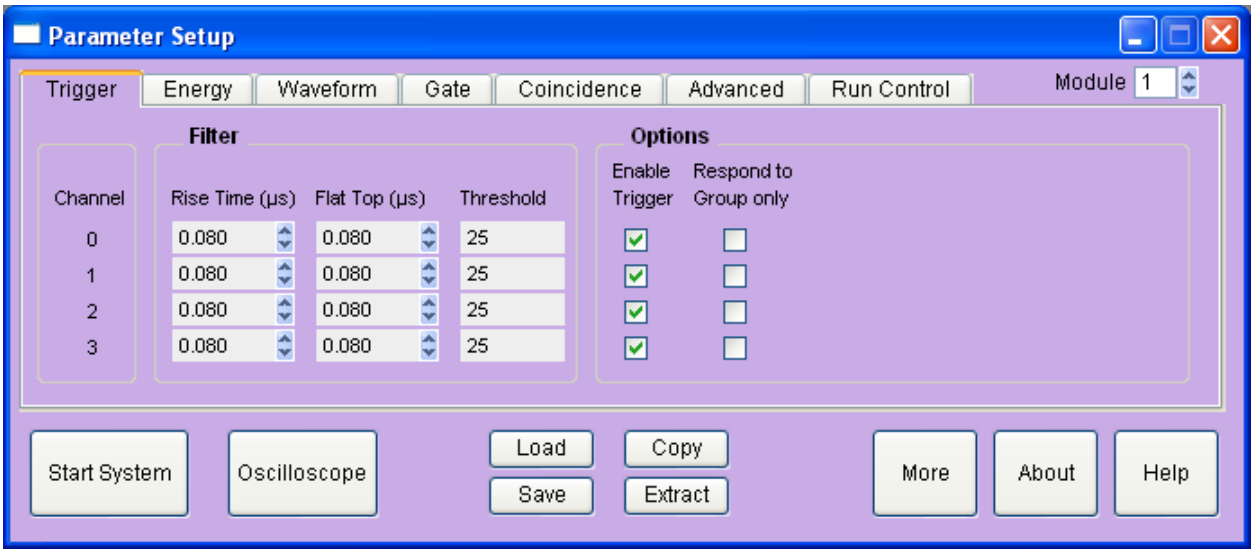


Figure 3.2: The *Trigger* tab of the PARAMETER SETUP panel.

3.2.1.2 Energy Tab

The E*nergy* tab contains the settings for the energy filter and the subsequent computation. These settings are most important for obtaining the best possible energy resolution with a Pixie system. The energy filter *rise time* (or peaking time) essentially sets the tradeoff between throughput and resolution: longer filter *rise times* generally improve the resolution (up to a certain optimum) but reduce the throughput because more time is required to measure each pulse. The pulse decay time *Tau* is used to compensate for the decay of a previous pulse in the computation of the pulse height. You can enter a known good value, or click on *Auto Find Tau* to let the Pixie Viewer determine the best value.

The advanced controls in this tab contain functions to modify the energy computation and to acquire a series of measurements with varying filter settings and decay times to find the best settings. For a detailed description of the filter operation, see section 6.

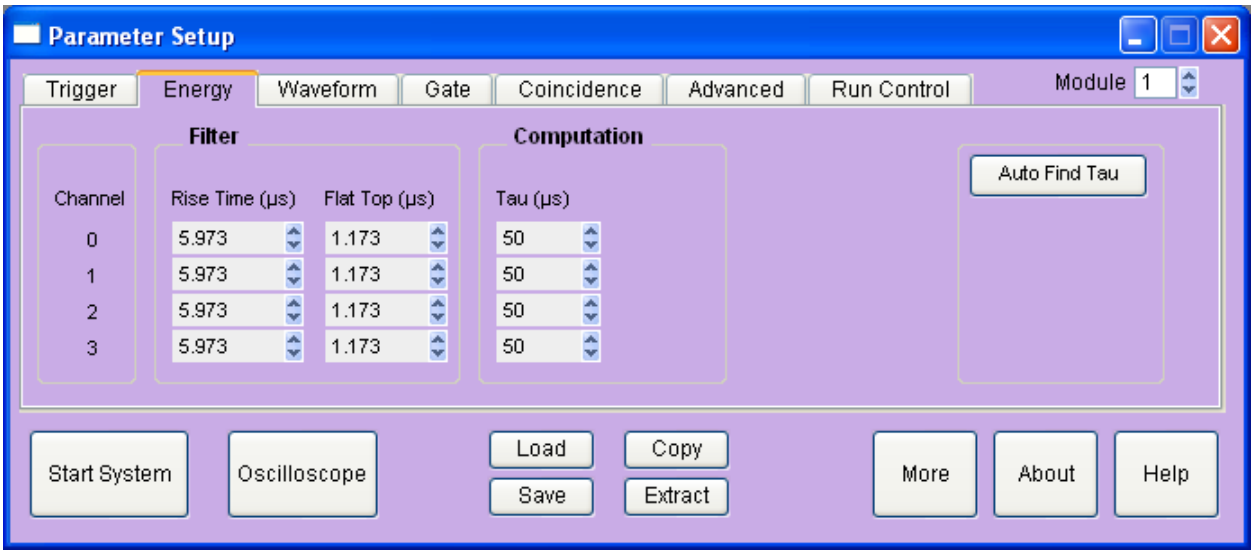


Figure 3.3: The *Energy* tab of the PARAMETER SETUP Panel.

3.2.1.3 Waveform Tab

The *Waveform* tab contains the controls to set the length and pre-trigger delay of the waveforms to be acquired. Advanced options include parameters for online pulse shape analysis

3.2.1.4 Gate Tab

The *Gate* tab contains the controls to set the window for gating acquisition with external signals. We define VETO as a signal distributed to all modules and channels, but each channel is individually enabled to require or ignore this signal. VETO is active during the validation of a pulse (after pileup inspection), an energy filter rise time plus flat top after the rising edge. With suitable external logic, the decision to veto a pulse can be made from information obtained at the rising edge of the pulse (e.g. multiplicity from several channels) and therefore this function is also called Global First Level Trigger (GFLT).

For a detailed description of the VETO operation, see section 7.4.

3.2.1.5 Coincidence Tab

The *Coincidence* tab contains the controls to set the acceptable hit pattern, and the coincidence window after validation during which channels can contribute to the hit pattern. There is a checkbox for each possible hit pattern. For example, if the checkbox with pattern 0100 is checked, events with a hit in channel 2 and no others are accepted. Selecting multiple checkboxes accepts combinations of hit patterns, e.g. any event with exactly one channel hit.

For a detailed description of the coincidence operation, see section 7.2.1. Controls for coincidences between modules are located in the CHASSIS SETUP Panel and described in section 7.2.2.

3.2.1.6 Advanced Tab

The A*dvanced* tab contains the controls for modifying the pileup inspection, histogram accumulation, baseline measurements, and ADC calibration. The ADC used on the Pixie-500 Express actually consists of two ADC cores on a single IC, which need to be calibrated for matched gain, offset and phase. Normally, these calibration settings are read from the module's non-volatile memory at boot time, but sometimes, for example at temperature changes, it may be required to recalibrate the cores. An indication of mismatch are systematic offsets between odd and even samples. These controls are repeated in the OSCILLOSCOPE panel.

3.2.1.7 Run Control Tab

The *Run Control* tab defines the settings for data acquisition. The “Run Type” popup menu selects MCA or list mode runs, see section 4 for a detailed description. In addition, there are controls

- to set the run time (length of data acquisition as measured by Igor),
- to set the polling time (period for checking if list mode data is available for readout and/or run time is reached),
- to specify the data file name (a *base name* plus 4-digit *run number* that can be made to increment automatically), and

- to specify the number of spills in list mode runs. (In list mode runs, data is accumulated in on-board memory until full, at which time it is read out by the host PC. We call each such readout a spill. The number of spills thus sets the amount of data to collect.)

The *Start Run* and *Stop Run* buttons from the MAIN control panel are duplicated here as well.

Advanced options include settings for synchronizing acquisition between modules, controls to set a timeout for each spill, the number of events per spill, and the spill readout mode, and a button to open a panel with advance record options.

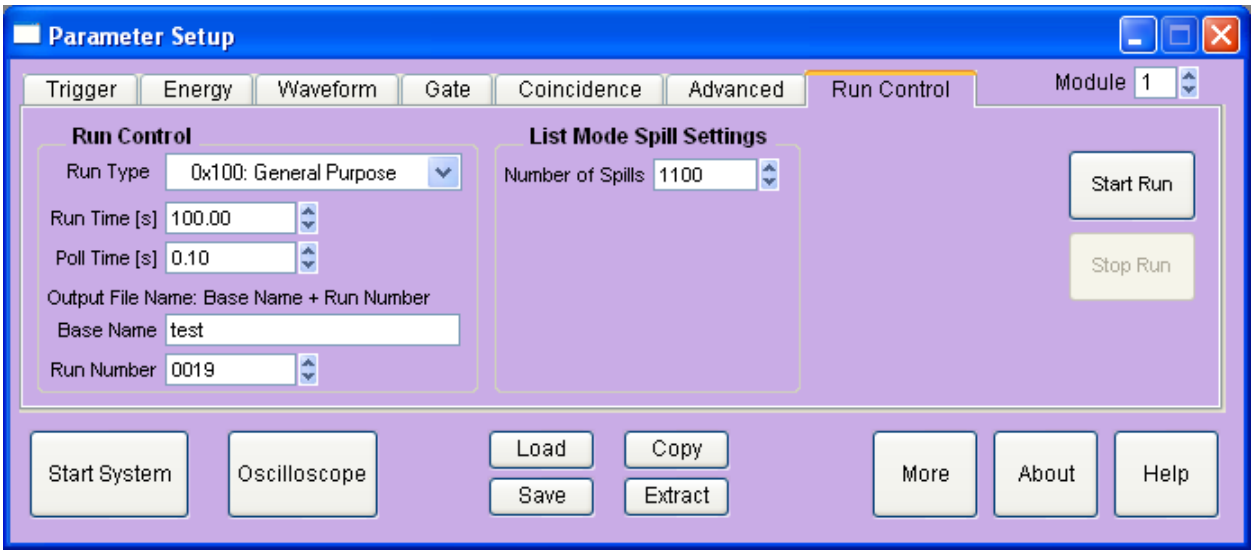


Figure 3.4: The *Run Control* tab of the PARAMETER SETUP Panel.

3.2.2 OSCILLOSCOPE

As mentioned in section 2.3, the OSCILLOSCOPE (Figure 2.3) is used to view untriggered traces as they appear at the ADC input and to set all parameters relating to the analog gain and offset. There are controls titled

- *dT [us],* which sets the time between samples in the oscilloscope (there are always 8192 samples in the oscilloscope window),
- *Offset [%],* which sets the target DC-offset level for automatic adjustment,
- *Gain (V/V),* which sets the analog gain before digitization, and
- *Offset (V),* which directly sets the offset voltage.

The traces from different channels are not acquired synchronously but one after the other. Therefore even if coincident signals are connected to the Pixie-500 Express inputs, the OSCILLOSCOPE will show unrelated pulses for each channel.

There are also buttons and controls to

- open a display of the *FFT* of the input signal, which is useful to diagnose noise sources
- open a display of the waveforms of the trigger *filter* and energy filter computed from the traces in the oscilloscope
- repeat the action of the *Refresh* button until a pulse is *captured*. This is useful for low count rates.
- *Fit* the pulses in the OSCILLOSCOPE with an exponential decay function to determine the decay time Tau, and to *accept* the fit value for the module settings.

- View the current input count rate and the current fraction of time the signal is out of range. These values are updated in the DSP every ~2-3ms independent of whether a run is in progress or not. Their precision is in the order of 5-10%, or 50 cps.
- *Calibrate* the ADC gain and offset matching of its two cores. Calibrations are reset at every power cycle or reboot of the module, or by clicking the *Reset* button. The process started with this button will measure the mismatch, then modify the gain and offset match in an iterative process.

3.2.3 FILES/PATHS

The firmware files, DSP files and settings files are defined in the FILES/PATHS panel. Changes will take effect at the next reboot, e.g. when clicking the *Start Up System* button in this panel or in the START UP panel. There is also a button to set the files and paths to the default, relative to the "home path" of the file Pixie.pxp.

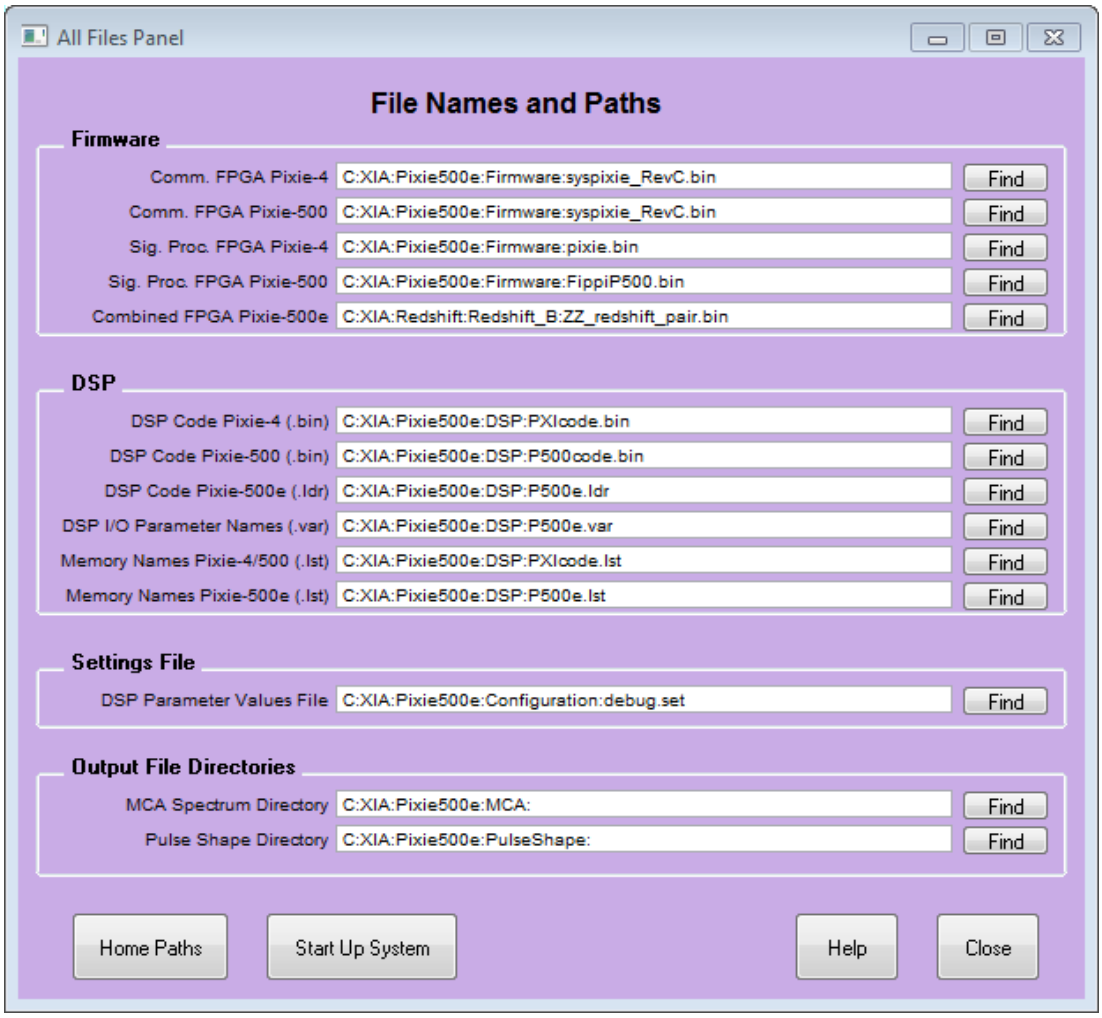


Figure 3.5: The FILES/PATHS Panel.

3.2.4 Chassis Setup

The Chassis Setup panel is used to set parameters that affect the system as a whole. Examples are trigger distribution between modules, coincidence settings between modules, and the operation of the Pixie-500 Express's front panel input. See sections 7.2.2 and 7.6.2 for details.

3.3 Run Control Group

The Run Control group in the Main control panel has the most essential controls to start and stop runs, and to define or monitor the run time and the number of spills. For more options, use the *Run Control* tab of the Parameter Setup panel.

3.4 Results Group

The Results group of the Main control panel displays the count rates of the current or most recent run. Click *Update* to refresh these numbers.

The popup menu *Open Panels* leads to panels to view the output data from the data acquisition in detail. These panels are the MCA Spectrum display, the List Mode Traces display, the List Mode Spectrum display, the Run Statistics, and a panel to display results from a series of files.

3.4.1 MCA Spectrum

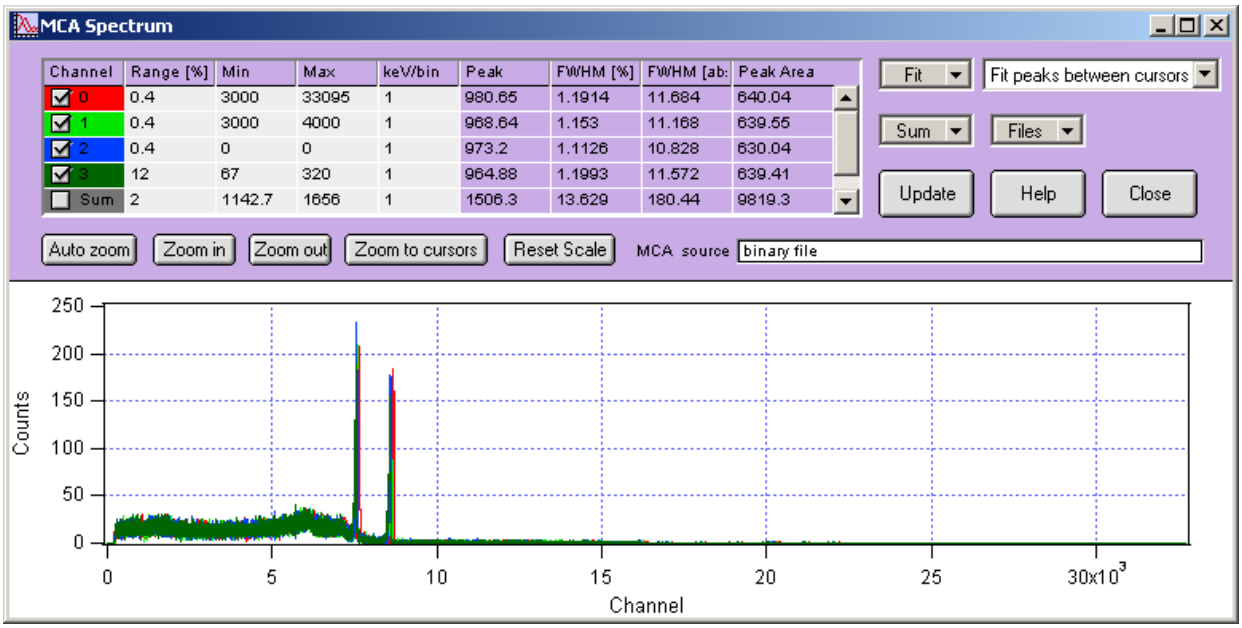


Figure 3.6: The MCA Spectrum display.

The MCA Spectrum display shows the spectra accumulated in on-board memory or from a .mca file saved at the end of a run. Spectrum analysis is limited to fitting peaks with a Gaussian and computing the peak resolution. There are several options to define the fit range, as described in the online help. Spectra can be saved as text files for import into other applications.

3.4.2 List Mode Traces and List Mode Spectrum

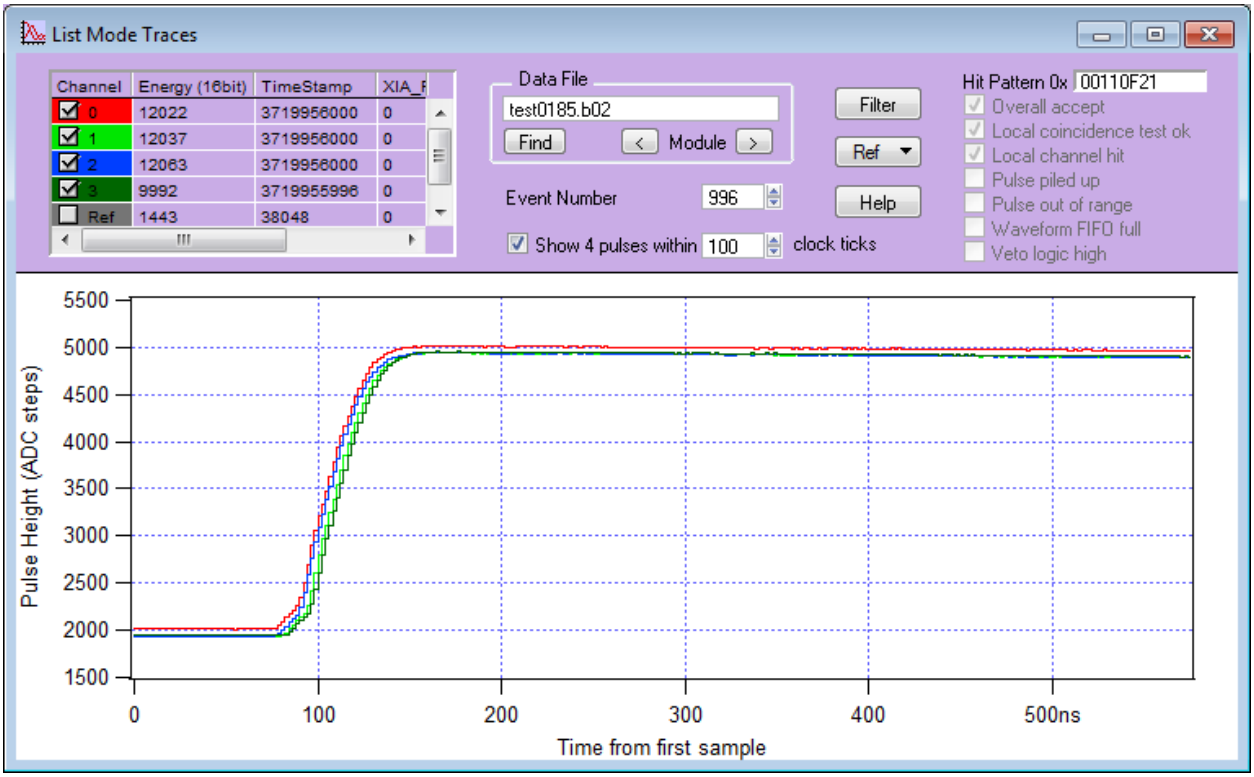


Figure 3.7: The List Mode Traces display.

The List Mode Traces display shows the data from the binary list mode files (.bin or .b##[5]). If waveforms were collected, they are shown in the graph section of the panel. Event and channel header information – energy, time stamps, and hit patterns as described in section 4.1.2 – are shown in the fields above the graph section. Key information bit of the hit pattern are decoded in checkboxes below the hexadecimal value. After specifying a data file with the *Find* button, you can select an event to view by entering its number in the *Event Number* field. In the binary file, events are stored as single-channel records. To display data from coincident pulses in multiple channels, check the box *Show 4 pulses* and enter a coincidence window in clock ticks. You will have to increment the *Event Number* up to 4 times to get new data. The waveform from the current event is displayed in bold. Arrow buttons allow changing of both module number and file name at the same time.

The *Ref* popup menu allows one of the current 4 channels to be saved for comparison; check the corresponding box in the table to add its waveform to the plot.

[5]For multi-module runs, select the appropriate file b## for module ##.

The button *Digital Filters* opens a new plot that shows the response of the trigger filter and energy filter computed from the list mode waveforms. This plot is more precise than the related graph opened from the OSCILLOSCOPE since it uses the same full rate data, same as the filters implemented in the module, not the reduced rate sampled at the OSCILLOSCOPE'S *dT*. However, unless long list mode traces are acquired or energy filters are short, there may not be sufficient data to compute the energy filter properly.

The LIST MODE SPECTRUM display is a plot similar to the MCA SPECTRUM, but it is computed from the energies saved in the list mode data file. Since energies are stored there in full 16 bit precision, binning can be made finer than in the MCA SPECTRUM, which is limited to 32K bins. See the online help for a detailed description of the controls. Note that invalid events will have energy=0, which causes a large spike in the first bin of the spectrum. Set *Emin* to a nonzero value to hide this feature.

3.4.3 RUN STATISTICS

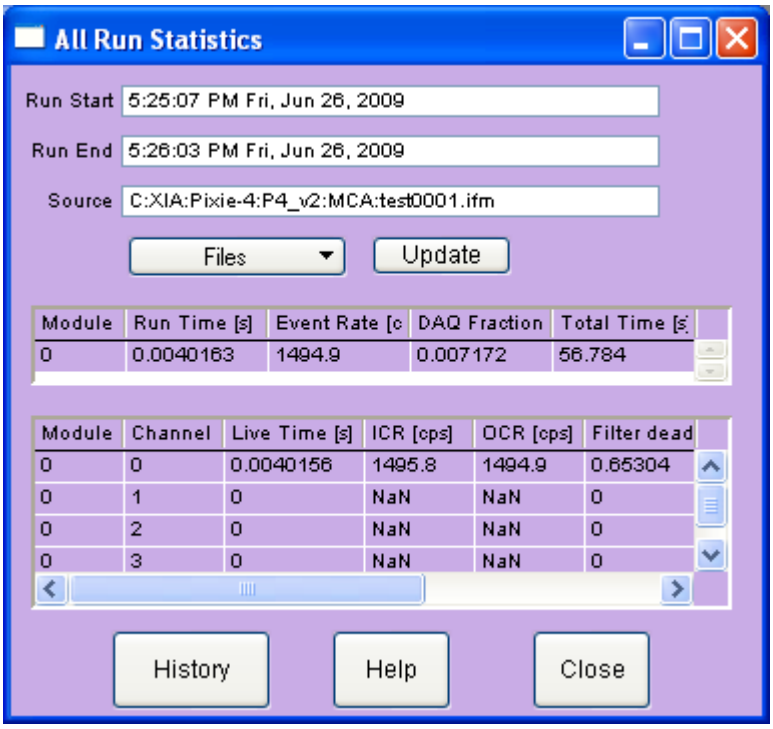


Figure 3.8: The RUN STATISTICS panel.

The RUN STATISTICS panel shows the live times and count rates measured by the Pixie-500 Express. The numbers can be updated by clicking the *Update* button and read from or save to *Files*. For a detailed description of the definition of these values, see section 6.6.

3.4.4 FILE SERIES

See section 3.6 for a more detailed description

3.5 Optimizing Parameters

Optimization of the Pixie-500 Express's run parameters for best resolution depends on the individual systems and usually requires some degree of experimentation. The Pixie Viewer includes several diagnostic tools and settings options to assist the user, as described below.

3.5.1 Noise

For a quick analysis of the electronic noise in the system, you can view a Fourier transform of the incoming signal by selecting OSCILLOSCOPE → *FFT*. The graph shows the FFT of the untriggered input sigal of the OSCILLOSCOPE. By adjusting the *dT* control in the OSCILLOSCOPE and clicking the *Refresh* button, you can investigate different frequency ranges. For best results, remove any source from the detector and only regard traces without actual events. If you find sharp lines in the 10 kHz to 1 MHz region you may need to find the cause for this and remove it. If you click on the *Apply Filter* button, you can see the effect of the energy filter simulated on the noise spectrum.

3.5.2 Energy Filter Parameters

The main parameter to optimize energy resolution is the energy filter rise time. Generally, longer rise times result in better resolution, but reduce the throughput. Optimization should begin with scanning the rise time through the available range. Try 2µs, 4µs, 8µs, 11.2µs, take a run of 60s or so for each and note changes in energy resolution. Then fine tune the rise time.

The flat top usually needs only small adjustments. For a typical coaxial Ge-detector we suggest to use a flat top of 1.2µs. For a small detector (20% efficiency) a flat top of 0.8µs is a good choice. For larger detectors flat tops of 1.2µs and 1.6µs will be more appropriate. In general the flat top needs to be wide enough to accommodate the longest typical signal rise time from the detector. It then needs to be wider by one filter clock cycle than that minimum, but at least 3 filter clock cycles. Note that a filter clock cycle ranges from 0.026 to 0.853µs, depending on the filter range, so that it is not possible to have a very short flat top together with a very long filter rise time.

The Pixie Viewer provides a tool to create a file series where the energy filter parameters are modified for each file in the series. See section 3.6 for more details.

3.5.3 Threshold and Trigger Filter Parameters

In general, the trigger threshold should be set as low as possible for best resolution. If too low, the input count rate will go up dramatically and "noise peaks" will appear at the low energy end of the spectrum. If the threshold is too high, especially at high count rates, low energy events below the threshold can pass the pile-up inspector and pile up with larger events. This increases the measured energy and thus leads to exponential tails on the (ideally Gaussian) peaks in the spectrum. Ideally, the threshold should be set such that the noise peaks just disappear.

The settings of the trigger filter have only minor effect on the resolution. However, changing the trigger conditions might have some effect on certain undesirable peak shapes. A longer trigger rise time allows the threshold to be lowered more, since the noise is averaged over longer periods. This can help to remove tails on the peaks. A long trigger flat top will help to trigger better on slow rising pulses and thus result in a sharper cut off at the threshold in the spectrum.

3.5.4 Decay Time

The preamplifier decay time τ is used to correct the energy of a pulse sitting on the falling slope of a previous pulse. The calculations assume a simple exponential decay with one decay constant. A precise value of τ is especially important at high count rates where pulses overlap more frequently. If τ is off the optimum, peaks in the spectrum will broaden, and if τ is very wrong, the spectrum will be significantly blurred.

The first and usually sufficiently precise estimate of τ can be obtained from the *Auto Find* routine in the *Energy* tab of the PARAMETER SETUP panel. Measure the decay time several times and settle on the average value.

Fine tuning of τ can be achieved by exploring small variations around the fit value (±2-3%). This is best done at high count rates, as the effect on the resolution is more pronounced. The value of τ found through this way is also valid for low count rates. Manually enter τ , take a short run, and note the value of τ that gives the best resolution.

Pixie users can also use the fit routines in the OSCILLOSCOPE to manually find the decay time through exponentially fitting the untriggered input signals. Another tool is to create a file series where τ is modified for each file in the series. See section 3.6 for more details.

3.5.5 Baselines and ADC calibration

Between detector pulses, the Pixie module continuously measures baselines, which is ultimately used to correct for the DC offset. Multiple baseline measurements can be averaged to reduce noise, and a threshold can be set to exclude the occasional bad measurement from the average. The controls to set these parameters are located in the *Advanced* tab of the PARAMETER SETUP panel. The optimum values depend on the detector used; but usually the defaults are good estimates and resolutions only improve slightly with manual fine tuning.

The 500 MHz ADC used on the Pixie-500 Express is actually a combination of two 250 MHz ADC cores on a single IC. For best performance, the two cores have to be calibrated to match in gain, offset and phase. Default ADC calibration values are stored on an on-board EEPROM and are applied to the ADCs at boot time. It may happen that the default values are not suitable, e.g. due to significant temperature drifts. This would manifest itself as a distinct offset between even and odd samples in the waveforms. In such a case, the ADCs can be recalibrated with a routine called from a button in the *Advanced* tab of the PARAMETER SETUP panel.

3.6 File Series

3.6.1 File Series to break up long data acquisition runs

When taking long data acquisitions, it may be beneficial to break up the run into smaller sub runs. This helps to save data in case of power failure or system crashes, since only the most recent sub run is lost. Also list mode files tend to get large and unwieldy for analysis in longer runs, and 32bit operating systems may impose a 4 GB limit.

The Pixie Viewer thus has a method to create a series of files at specified intervals. In the DATA RECORD OPTIONS panel, opened with the *Record* button in the *Run Control* tab of the PARAMETER SETUP panel, there is a checkbox named *New files every*, followed by a control field to enter a

spill (or time) interval N. If checked and a run is started, every N spills (or, in MCA runs, every N seconds) the data file is closed, spectra, settings and statistics are saved, and then a new run is started. This is equivalent to manually clicking first the Stop Run button and then the Start Run button. It is recommended to enable the automatic increment and auto-store options as shown in Figure 3.9 as well.

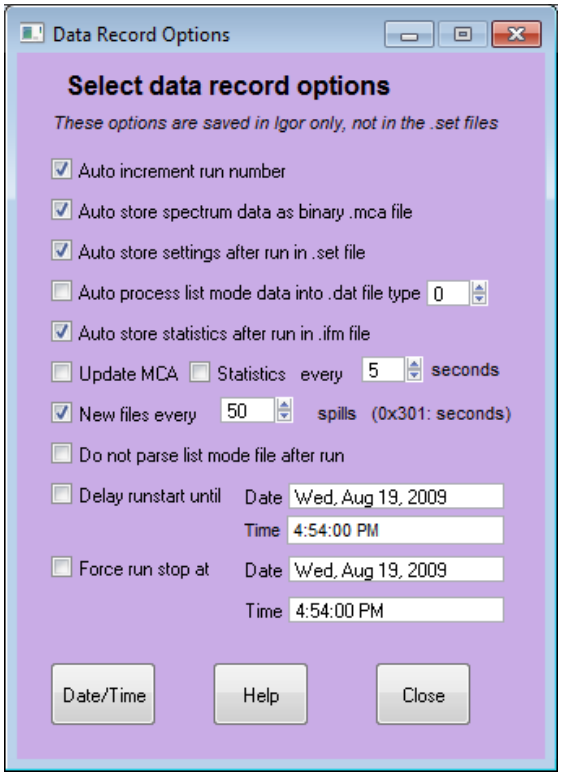


Figure 3.9: The DATA RECORD OPTIONS panel with checkboxes set to acquire a series of files.

For fastest polling (Igor stops completely), a dedicated function to acquire a file series can be called from the Igor command line by typing

Pixie_RepeatDMA("") <Enter>

This function will create a series of list mode files with incrementing run numbers, without stopping acquisition between files. Run statistics and spectra are *only* saved at the end of the run into files with the first run number. Press <ESC> to stop this run; Igor will not respond to anything else.

3.6.2 File Series to scan filter parameters

With some modifications, the mechanism to create file series described in section 3.6.1 can also be used to scan through a range of energy filter or decay time settings. This is equivalent to starting an MCA run with initial settings, stopping the run, incrementing the energy filter rise time, restarting the run, and so on. The file series will thus contain spectra for a whole range of settings, which can be analyzed manually or with the routine described in section 3.6.3.

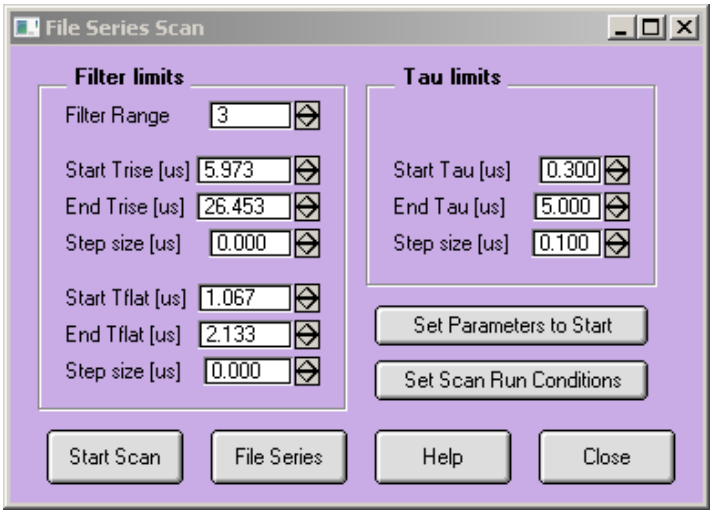


Figure 3.10: The FILE SERIES SCAN panel to acquire a series of files in which energy filter parameters and Tau are varied within user defined limits.

To set up such a parameter scan, open the FILE SERIES SCAN panel (PARAMETER SETUP -> *Energy* tab -> *Scan Settings*) shown in Figure 3.10. A control field named *Filter Rang*e is repeated from the *Energy* tab. In three groups of controls, you can set the start, end, and step size for varying the energy filter *rise time*, the energy filter *flat top*, and *Tau*. If the *step size* is zero, that parameter will not be varied.

Two buttons assist in setting up the initial conditions: *Set Parameters to Start* sets the current values of the energy filter and Tau to the start value defined in the File Series Scan panel. If you omit to click this button, the file series will begin with the current value; this is useful to resume a file series. *Set Scan Run Conditions* will set the checkboxes in the DATA RECORD OPTIONS panel to the values required for the scan, and set the run time to the total time required (interval N in the DATA RECORD OPTIONS panel times the number of settings).

At the bottom of the panel, the button *Start Scan* starts the file series. This is a different button from the standard *Start Run* button, because it is starting a run which is modifying parameters. All the updates during a run work the same as in a standard run, though; and the run can be stopped with the standard *Stop Run* button. When the run is complete, click on the *File Series* button to open the panel described in section 3.6.3

3.6.3 File Series Analysis

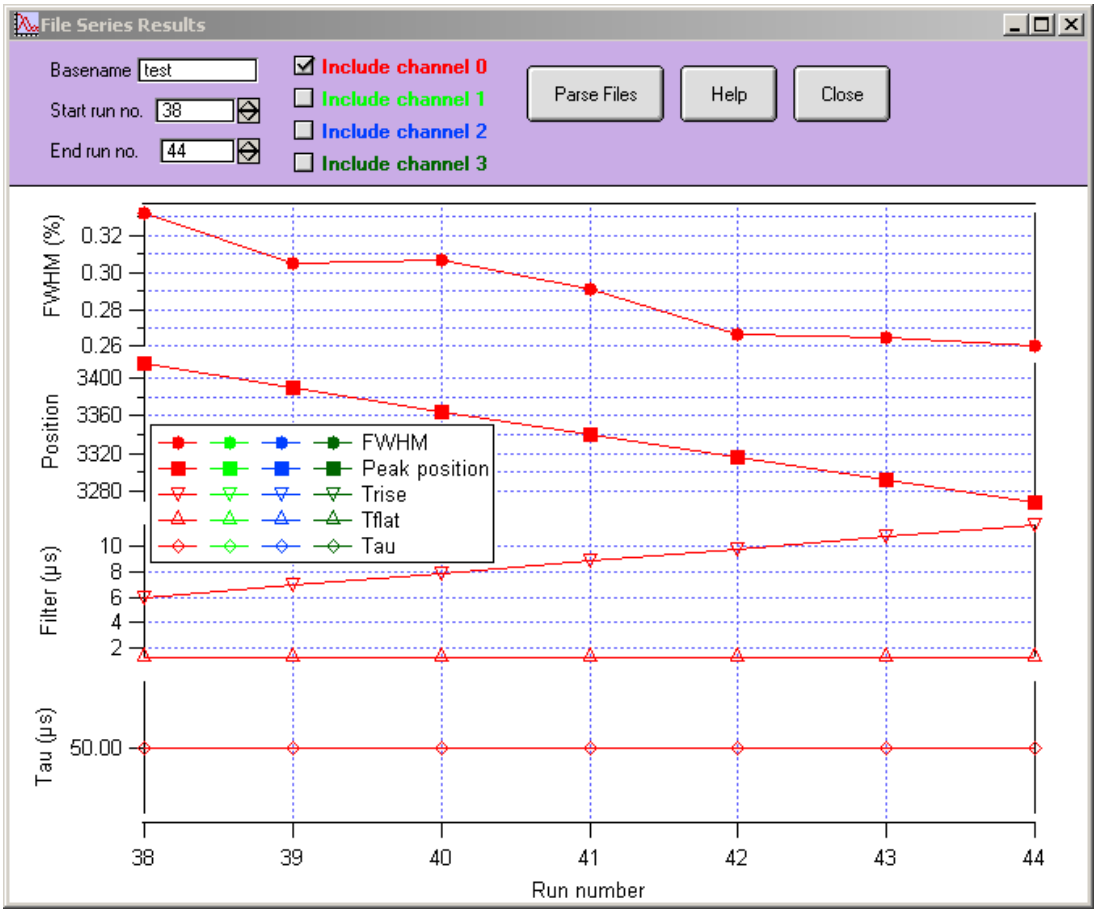


Figure 3.11: The FILE SERIES RESULTS plot to analyze a series of files from a parameter scan.

To analyze a series of .mca files, you can use the FILE SERIES RESULTS panel. Enter the base name and the start and end run numbers of the series, then click *Parse Files*. Start and end are inclusive, i.e. for start = 1 and end =13, the parsing covers files base0001-base0013. An .ifm file is required to read the values for Tau and the filter settings. The parsing routine reads the spectra and fits peaks with the options set in the MCA SPECTRUM. Thus make sure the fit range is set appropriately. In the plot, the peak position and resolution is plotted as a function of run number, together with the filter settings and tau for each channel selected.

4 Data Runs and Data Structures

4.1 Run Types

There are two major run types: MCA runs and List mode runs. MCA runs only collect spectra and run statistics, List mode runs acquire data on an event-by event basis, but also collect spectra and run statistics. List mode runs come in several variants (see below), storing different amounts of data per event.

The output data are stored in three different memory blocks. The MCA block resides in a dedicated spectrum memory. List mode data is stored in 256 MB of SDRAM organized as a FIFO. Run statistics are kept in local memory by the on-board FPGA.

4.1.1 MCA Runs

If only energy spectra are of interest, an MCA run should be used. For each event, this type of run collects the data necessary to calculate pulse heights (energies) only. The energy values are used to increment the MCA spectrum. The run continues until the host computer stops data acquisition, either by reaching the run time set in the Pixie Viewer, or by a manual stop from the user (the module does not stop by itself).

There is no data transferred between the Pixie module and the host PC, except for the occasional manual update of MCA spectra and run statistics. By design, the MCA memory does not "fill up" – each event simply increments a bin in the spectrum[6].

4.1.2 List Mode Runs

If, on the other hand, data should be collected on an event-by-event basis, including energies, time stamps, pulse shape analysis values, and wave forms, a list mode run should be used. In list mode, pulse heights are still histogrammed into MCA spectra, e.g. for monitoring purposes. The list mode data is continuously transferred from the Pixie module to the host PC.

List mode runs halt data acquisition either when a preset time is reached, or when a preset number of "spills" have been collected, as determined by the Pixie Viewer. A spill here means 2 MB of data read from the SDRAM FIFO. Unlike the Pixie-4 or Pixie-500, the Pixie-500 Express never stops the acquisition for data readout. List mode data is buffered in the SDRAM FIFO, and read by the host PC on one end while being written by the firmware on the other end. Given the data bandwidth of the PXIe interface, it is rather unlikely for the SDRAM to fill up, except for situations with very high rates and very long waveforms. (If the SDRAM actually does fill up, data acquisition is *paused* but as soon as the host frees up SDRAM memory by reading and storing data to disk, the acquisition continues. The red light on the module's front panel indicates such a condition.)

When the Pixie Viewer ends the data acquisition, there may be data in the SDRAM that has not yet been stored to file. The readout thus continues for a short while after the DSP stops collecting

[6]Rollovers from 2^{32} to 0 may happen for extremely long runs and/or extremely high count rates

new data, adding one or more spills to the file. The preset number of spills is therefore to be understood as a *minimum* request.

4.1.2.1 Pulse Shape Analysis

Pulse shape analysis comes in several varieties, executing algorithms by XIA (enabled by selecting options in the standard firmware/software) or algorithms programmed by users as plug-in code for the DSP. In the current firmware/software, the following algorithms are available from XIA:

- Accumulation of 2 sums (baseline subtracted) near the rising edge of the pulse.
- Capture of amplitude (maximum minus baseline) near the rising edge of the pulse.
- Computation of the ratio of the 2 sums

Please contact XIA for details.

4.1.2.2 Compressed Data Formats

The output data of list mode runs can be reduced by using one of the compressed formats described below. The key differences are that as less data is recorded for each event, there is room for more events in the SDRAM FIFO, less time is spent per event to read out data to the host computer, and data files are smaller. Further compressed data formats are under development.

Table 4.1: Summary of run types and data formats.

Run Type	Output data	DSP Variables	Files created
MCA Mode	Spectra in MCA memory	RUNTASK = 0x301	. mca binary spectra .set binary settings (optional) .ifm ASCII run statistics etc (optional)
List Mode (standard)	Energies, time stamps, PSA values, and wave forms in List mode memory. Spectra in MCA memory	RUNTASK = 0x400 (CHANHEADLEN = 32)	.b## binary list mode data . mca binary spectra (optional) .set binary settings (optional) .ifm ASCII run statistics etc (optional)
List Mode (text, no traces)	Energies, time stamps, PSA values in List mode memory. Spectra in MCA memory	RUNTASK = 0x401 (CHANHEADLEN = 32)	_m#.dt3 ASCII list mode data . mca binary spectra (optional) .set binary settings (optional) .ifm ASCII run statistics etc (optional)

For Runtask 0x401, since no waveforms are recorded in the output file, waveforms are *not* acquired internally even if the tracelengths are set to a nonzero value. Pulse shape analysis implemented in the FPGA operates on the incoming data stream and creates valid values.

4.2 Output Data Structures

4.2.1 MCA Histogram Data

The MCA memory currently uses 32K words (32-bit deep) per channel, i.e. total 128K words. The memory can be read out via the PCIe data bus at any time, though not at the full burst rate. If spectra of less than 32K length are requested, only part of the 32K will be filled with data.

The total MCA memory size on the Pixie-500 Express is 512K words. It can be reorganized for special applications (e.g., 2D spectra or channel sum spectra).

If enabled, the histogram data is automatically read and saved to file at the end of the run. The file has the extension .mca.

4.2.2 List Mode Data

The list mode data in the SDRAM FIFO consists of a series of single channel data records. For each module, the host readout process creates an individual file for these records. The extension of these files is .b## (## = 2 digit module number) in runtype 0x400 and _m#.dt3 (# = 1-2 digit module number) in runtype 0x401. The records can be written by the DSP in a number of formats. User code should access the data in the file header to navigate through the data. The file should only be read when the run has ended.

4.2.2.1 Binary files in Runtask 0x400

The data organization of one .b## file is as follows. The file always starts with a file header of length BUFHEADLEN. Currently, BUFHEADLEN is 32, and the 32 words (16 bit) are:

Table 4.2: File header data format, total 32 words (16bit)

Word #	Variable	Description
0	BlkSize	Block size (16-bit words)
1	ModNum	Module number
2	RunFormat	Format descriptor = RunTask
3	ChanHeadLen	Channel Header Length
4	CoincPat	Coincidence pattern
5	CoincWin	Coincidence window
6	MaxCombTraceLen	Maximum length of traces from all 4 channels (in blocks)
7	unused	reserved
8	TraceLength0	Length of traces from channel 0 (in blocks)
9	TraceLength1	Length of traces from channel 1 (in blocks)
10	TraceLength2	Length of traces from channel 2 (in blocks)
11	TraceLength3	Length of traces from channel 3 (in blocks)
12--31	unused	reserved

Following the file header, the single channel event records are stored in sequential order. Each event starts out with an channel header of length ChanHeadLen. Currently, ChanHeadLen=32, and the 32 words (16 bit) are:

Table 4.3: Channel header data format.

Word #	Variable	Description
0	EvtPattern	Hit pattern.
1	EvtInfo	Event status flags.
2	NumTraceBlks	Number of blocks of Trace data to follow the header
3	NumTraceBlksPrev	Number of blocks of Trace data in previous record (for parsing back)
4	TrigTimeLO	Trigger time, low word
5	TrigTimeMI	Trigger time, middle word
6	TrigTimeHI	Trigger time, high word
7	TrigTimeX	Trigger time, extra 8 bits
8	Energy	Pulse Height
9	ChanNo	Channel number
10	User PSA Value	Result of User specific pulse shape analysis
11	XIA PSA Value	Result of standard XIA pulse shape analysis
12--15	Extended PSA Values	
16--31	reserved	

The hit pattern is a bit mask, which tells which channels were captured within the specified coincidence window plus some additional status information, as listed in table 4.4. The channel header may be followed by waveform data. An offline analysis program can recognize this by reading the number of waveform blocks from the NumTraceBlks word. The block size is defined in the file header.

Table 4.4: Event Pattern and Event Info bit description.

Bit #	Description
EvtPattern	
0..3	If set, indicates that data for channel 0..3 have been recorded
4..7	4: Logic level of FRONT panel input 5: Result of LOCAL acceptance test 6: Logic level of backplane STATUS line, 7: Logic level of backplane TOKEN line (= result of global coincidence test), see section 7
8..11	If set, indicates that channel 0..3 has been hit in this event (i.e. if zero, energy reported is invalid or only an estimate)
12..15	reserved
EvtInfo	
0	Coincidence test result
1	Logic level of backplane VETO line
2	If set, indicates event is piled up
3	If set, indicates waveform FIFO full
4	If set, indicates this channel was hit (else the event was recorded based on distributed trigger)
5..15	reserved

4.2.2.2 ACSII files in Runtask 0x401

The .dt3 files created in runtask 0x401 list energies, channel numbers, 48 bit time stamps, and 6 PSA values as tab delimited values, one event per line. This is the same format as created with the AutoProcessListModeData option set to 3. See below for an example

```
Module:     0
Run Type:   1025
Run Start Time (s) :    33.912160
Event Channel     TimeStamp   Energy      RT    Apeak Bsum  Q0    Q1    PSAval
0   0   16956079848   2876   4369   8738   808   1361  2434  0
1   0   16956109724   899   4369   8738   739   628  65466  65535
…
```

Meanings:

Energy	Pulse Height
RT	unused, reserved for rise time (PSA variant)
Apeak	peak amplitude (PSA variant)
Bsum	pre-trigger baseline sum (PSA variant)
Q0	first sum on rising edge of pulse (PSA variant)
Q1	second sum on rising edge of pulse (PSA variant)
PSAval	DSP computed ratio of Q sums (PSA variant)

4.2.3 Reconstruction of List Mode Time Stamps

In the Pixie-500 Express, there is a 56-bit time counter that is reset to zero at boot time or at a run start with the "synchronize clocks" option selected. It is incremented at a rate of 125 MHz by 4 ticks, so that the unit of the LSB is 2ns. Hence, the 56-bit word can span a time interval of over 800 days before rolling over.

The full 56 bit time stamp is recorded in every channel header. Compressed data formats may store less bits in the future.

5 Hardware Description

The Pixie-500 Express is a 4-channel unit designed for gamma-ray spectroscopy and waveform capturing. It incorporates four functional building blocks, which we describe below. This section concentrates on the functionality aspect. Technical specification can be found in section 1.2. Figure 5.1 shows the functional block diagram of the Pixie-500 Express.

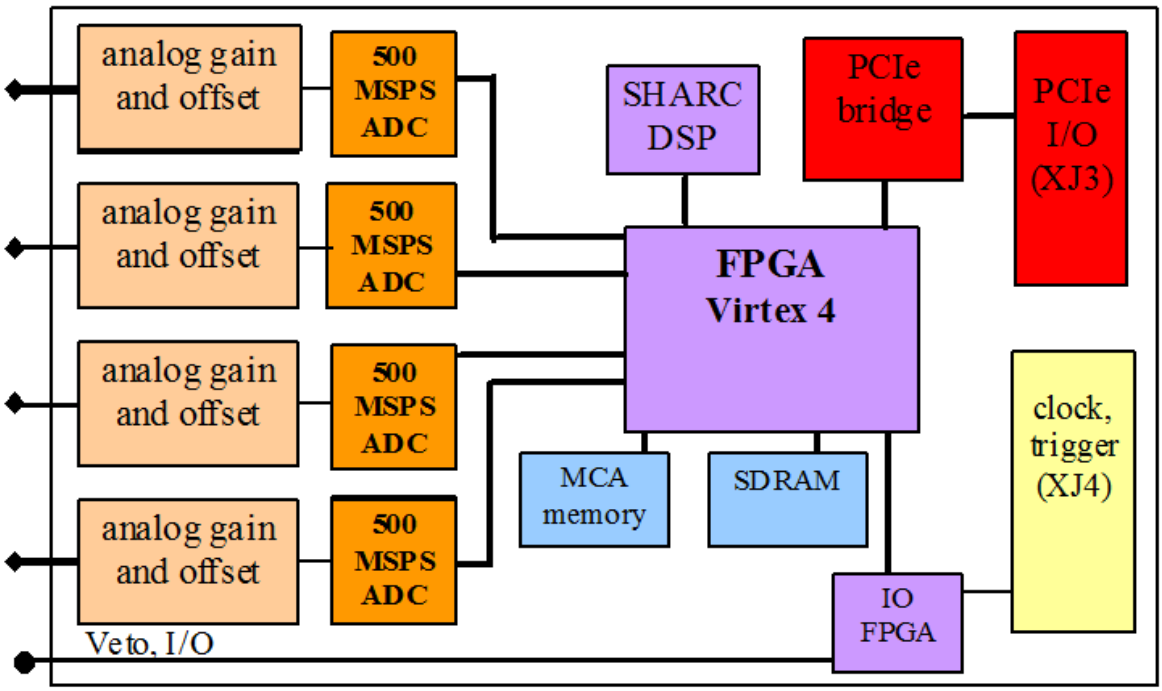


Figure 5.1: Functional block diagram of the Pixie-500 Express front-end data acquisition and signal processing card.

5.1 Analog Signal Conditioning

Each analog input has its own signal conditioning unit. The task of this circuitry is to adapt the incoming signals, which are DC coupled, to the input voltage range of the ADC, which spans 2 V. Input signals are adjusted for offsets, and there is a computer-controlled gain stage of switched relays. A fine tuning of the gain is achieved by multiplying the calculated energy values with digital gain factors in the digital signal processor (DSP). Four options of termination and attenuation are selected by manual switches at the front end of the module.

The ADC is not a peak sensing ADC, but acts as a waveform digitizer. In order to avoid aliasing, we remove the high frequency components from the incoming signal prior to feeding it into the ADC. The anti-aliasing filter, an active Sallen-Key filter, cuts off sharply at the Nyquist frequency, namely half the ADC sampling frequency.

Though the Pixie-500 Express can work with many different signal forms, best performance is to be expected when sending the output from a charge integrating preamplifier directly to the Pixie-500 Express without any further shaping.

5.2 Pulse Processing

Real time pulse processing is implemented in a field programmable gate array (FPGA) which also incorporates FIFO memory for each channel. The data stream from the ADCs is sent to these units at the full ADC sampling rate. While modern FPGAs can capture high speed data streams, internal processing is limited by the complexity of the logic. Therefore, the FPGA on the Pixie-500 Express internally "de-serializes" each channel's 14-bit, 500 MHz data stream into a 56-bit, 125 MHz data stream for processing. Using a pipelined architecture, the signals are processed at this high rate, without the help of the on-board DSP.

The processing applies digital filtering to perform essentially the same action as a shaping amplifier. The important difference is in the type of filter used. In a digital application it is easy to implement finite impulse response filters, and we use a trapezoidal filter. The flat top will typically cover the rise time of the incoming signal and makes the pulse height measurement less sensitive to variations of the signal shape.

The first two processing elements in the FPGA are thus a fast filter for triggering and a slow filter for pulse height (energy) measurements. For a detailed description, see section 6. These filters run continuously. Triggers are issued at each detected rising edge, latch time stamps, and are used for the other processes. The energy filter sums are latched the appropriate time after each trigger.

A third processing element is a pileup inspector. This logic ensures that if a second pulse is detected too soon after the first, so that it would corrupt the first pulse height measurement, both pulses are flagged as piled up. The pileup inspector is, however, not very effective in detecting pulse pileup on the rising edge of the first pulse, i.e. in general pulses must be separated by their rise time to be effectively recognized as different pulses. Therefore, for high count rate applications, the pulse rise times should be as short as possible, to minimize the occurrence of pileup peaks in the resulting spectra.

The fourth processing component is the FIFO memory, which is organized in two blocks. A smaller delay FIFO (2K samples) buffers ADC data to position captured waveforms appropriately for the user defined pre-trigger delay. A larger storage FIFO (8K samples) captures waveforms of the user defined trace length.

Up to 16 events and 8K samples of waveforms are buffered in the FPGA. For each event, a complete set of time stamps, energy filter sums, pileup inspection flags, coincidence information and waveforms are stored. Waveforms from closely following events may overlap, i.e. the same ADC data is stored once but read twice for subsequent events. User defined acceptance settings specify if an event is considered valid (e.g. only accept events without pileup).

The last processing element are a number of counters that keep run statistics such as live time, filter dead time, number of triggers, and so on.

5.3 Digital Signal Processor (DSP) and Event Building

The pulse processing described above runs independently in every channel of the Pixie module. On a module-wide level, additional logic is implemented to distribute triggers and apply a coincidence test. See section 7 for details. The result of the coincidence test is fed back to every processing channel.

The DSP manages the flow of channel data into the SDRAM buffer. Whenever a channel has an event in its buffer, the DSP will read the raw data from the FPGA and based on the event status flags determine if the event is to be recorded. (At this point, there is also the option of executing customized user DSP code to modify results and the acceptance decision.) If the event is acceptable, the DSP computes the pulse height in a few floating point operations, and includes it in the event header data sent to the SDRAM. The captured waveform data is normally not touched by the DSP; the DSP only enables a direct FPGA-internal transfer from the channel processing block to the SDRAM interface block, at a rate of 1GByte/s.

The DSP also controls the overall operation of the Pixie-500 Express. The host computer communicates with the DSP via the PCIe interface. Reading and writing data to DSP memory does only temporarily pause its operation, and can occur even while a measurement is underway. The host sets variables in the DSP memory and if necessary calls DSP functions to apply them to the FPGA. Through this mechanism all gain and offset DACs are set and the filter settings are applied to the FPGA. The FPGA then processes the data without support from the DSP, once it has received the filter settings.

In this scheme, the greatest processing power is located in the FPGA, processing the incoming waveforms from the ADCs in real time and producing, for each valid a event, a small set of distilled data from which pulse heights and arrival times can be reconstructed. The computational load for the DSP is much reduced, as it has to react only on an event-by-event basis and has to work with only a small set of numbers for each event.

5.4 PCI Express Interface

The PCI Express (PCIe) interface through which the host communicates with the Pixie-500 Express is implemented in a PCIe endpoint IC which is linked to the FPGA by a local bus. At this time, the interface does not issue interrupt requests to the host computer (but it may do so in the future). Instead, for example to determine the run status, the host has to poll a Control and Status Register (CSR) in the FPGA.

The FPGA links the PCIe IC with the DSP and the on-board memory. The host can read out the memory without interrupting the operation of the DSP. This allows updates of the MCA spectrum or list mode data while a run is in progress.

A dedicated I/O FPGA distributes triggers and coincidence signals to other modules using the PXI backplane connections and the front panel connectors.

6 Theory of Operation

6.1 Digital Filters for γ-ray Detectors

Energy dispersive detectors, which include such solid state detectors as Si(Li), HPGe, HgI_2, CdTe and CZT detectors, are generally operated with charge sensitive preamplifiers as shown in Figure 6.1 (a). Here the detector D is biased by voltage source V and connected to the input of preamplifier A which has feedback capacitor C_f and feedback resistor R_f.

The output of the preamplifier following the absorption of an γ-ray of energy E_x in detector D is shown in Figure 6.1 (b) as a step of amplitude V_x (on a longer time scale, the step will decay exponentially back to the baseline, see section 6.3). When the γ-ray is absorbed in the detector material it releases an electric charge $Q_x = E_x/\varepsilon$, where ε is a material constant. Q_x is integrated onto C_f, to produce the voltage $V_x = Q_x/C_f = E_x/(\varepsilon C_f)$. Measuring the energy E_x of the γ-ray therefore requires a measurement of the voltage step V_x in the presence of the amplifier noise σ, as indicated in Figure 6.1 (b).

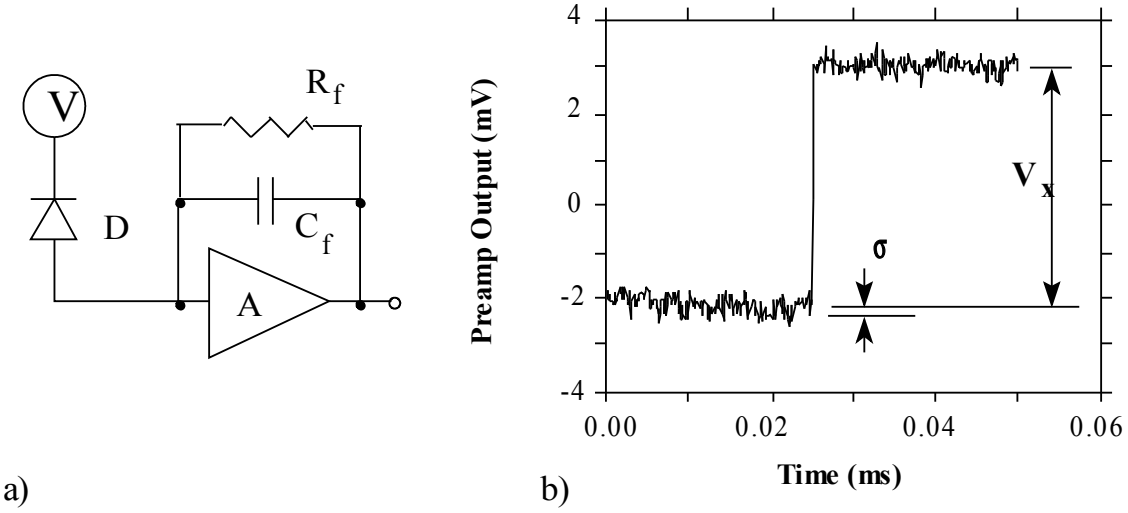


Figure 6.1: (a) Charge sensitive preamplifier with RC feedback; (b) Output on absorption of an γ-ray.

Reducing noise in an electrical measurement is accomplished by filtering. Traditional analog filters use combinations of a differentiation stage and multiple integration stages to convert the preamp output steps, such as shown in Figure 6.1 (b), into either triangular or semi-Gaussian pulses whose amplitudes (with respect to their baselines) are then proportional to V_x and thus to the γ-ray's energy.

Digital filtering proceeds from a slightly different perspective. Here the signal has been digitized and is no longer continuous. Instead it is a string of discrete values as shown in Figure 6.2. Figure 6.2 is actually just a subset of Figure 6.1 (b), in which the signal was digitized by a Tektronix 544 TDS digital oscilloscope at 10 MSPS (mega samples per second). Given this data set, and some

kind of arithmetic processor, the obvious approach to determining V_x is to take some sort of average over the points before the step and subtract it from the value of the average over the points after the step. That is, as shown in Figure 6.2, averages are computed over the two regions marked "Length" (the "Gap" region is omitted because the signal is changing rapidly here), and their difference taken as a measure of V_x. Thus the value V_x may be found from the equation:

$$V_{x,k} = -\sum_{i(before)} W_i V_i + \sum_{i(after)} W_i V_i \tag{6.1}$$

where the values of the weighting constants W_i determine the type of average being computed. The sums of the values of the two sets of weights must be individually normalized.

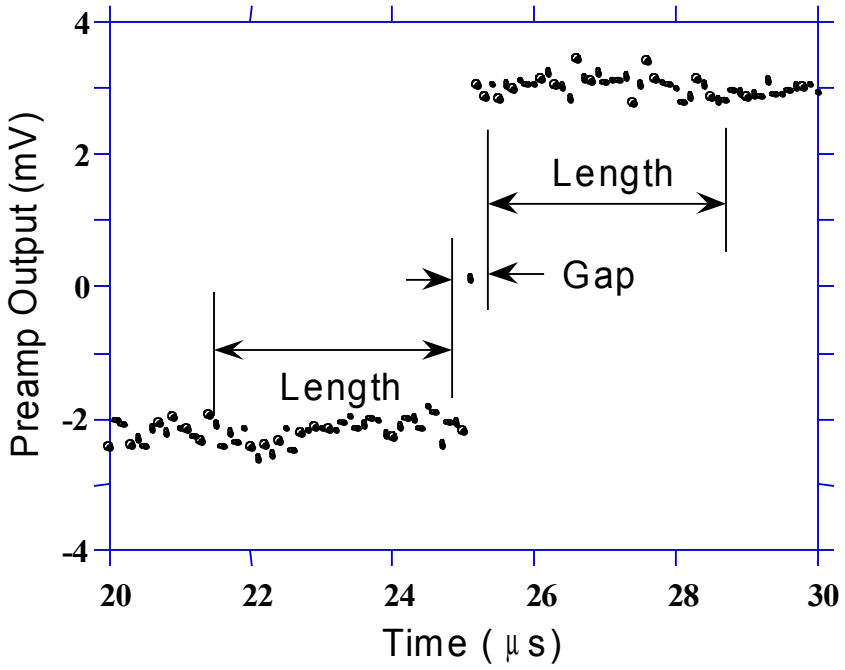


Figure 6.2: Digitized version of the data of Figure 6.1 (b) in the step region.

The primary differences between different digital signal processors lie in two areas: what set of weights $\{W_i\}$ is used and how the regions are selected for the computation of Eqn. 6.1. Thus, for example, when larger weighting values are used for the region close to the step while smaller values are used for the data away from the step, Eqn. 6.1 produces "cusp-like" filters. When the weighting values are constant, one obtains triangular (if the gap is zero) or trapezoidal filters. The concept behind cusp-like filters is that, since the points nearest the step carry the most information about its height, they should be most strongly weighted in the averaging process. How one chooses the filter lengths results in time variant (the lengths vary from pulse to pulse) or time invariant (the lengths are the same for all pulses) filters. Traditional analog filters are time invariant. The concept behind time variant filters is that, since the γ-rays arrive randomly

and the lengths between them vary accordingly, one can make maximum use of the available information by setting the length to the interpulse spacing.

In principle, the very best filtering is accomplished by using cusp-like weights and time variant filter length selection. There are serious costs associated with this approach however, both in terms of computational power required to evaluate the sums in real time and in the complexity of the electronics required to generate (usually from stored coefficients) normalized $\{W_i\}$ sets on a pulse by pulse basis.

The Pixie-500 Express takes a different approach because it was optimized for high speed operation. It implements a fixed length filter with all W_i values equal to unity and in fact computes this sum afresh for each new signal value k. Thus the equation implemented is:

$$LV_{x,k} = -\sum_{i=k-2L-G+1}^{k-L-G} V_i + \sum_{i=k-L+1}^{k} V_i \qquad (6.2)$$

where the filter length is L and the gap is G. The factor L multiplying $V_{x,k}$ arises because the sum of the weights here is not normalized. Accommodating this factor is trivial.

While this relationship is very simple, it is still very effective. In the first place, this is the digital equivalent of triangular (or trapezoidal if $G \neq 0$) filtering which is the analog industry's standard for high rate processing. In the second place, one can show theoretically that if the noise in the signal is white (i.e. Gaussian distributed) above and below the step, which is typically the case for the short shaping times used for high signal rate processing, then the average in Eqn. 6.2 actually gives the best estimate of V_x in the least squares sense. This, of course, is why triangular filtering has been preferred at high rates. Triangular filtering with time variant filter lengths can, in principle, achieve both somewhat superior resolution and higher throughputs but comes at the cost of a significantly more complex circuit and a rate dependent resolution, which is unacceptable for many types of precise analysis. In practice, XIA's design has been found to duplicate the energy resolution of the best analog shapers while approximately doubling their throughput, providing experimental confirmation of the validity of the approach.

6.2 Trapezoidal Filtering in a Pixie Module

From this point onward, we will only consider trapezoidal filtering as it is implemented in a Pixie module according to Eqn. 6.2. The result of applying such a filter with Length L=1μs and Gap G=0.4μs to a γ-ray event is shown in Figure 6.3. The filter output is clearly trapezoidal in shape and has a rise time equal to L, a flattop equal to G, and a symmetrical fall time equal to L. The basewidth, which is a first-order measure of the filter's noise reduction properties, is thus 2L+G.

This raises several important points in comparing the noise performance of the Pixie module to analog filtering amplifiers. First, semi-Gaussian filters are usually specified by a *shaping time*. Their rise time is typically twice this and their pulses are not symmetric so that the basewidth is about 5.6 times the shaping time or 2.8 times their rise time. Thus a semi-Gaussian filter typically has a slightly better energy resolution than a triangular filter of the same rise time because it has a longer filtering time. This is typically accommodated in amplifiers offering both

triangular and semi-Gaussian filtering by stretching the triangular rise time a bit, so that the *true* triangular rise time is typically 1.2 times the selected semi-Gaussian rise time. This also leads to an apparent advantage for the analog system when its energy resolution is compared to a digital system with the same nominal rise time.

One important characteristic of a digitally shaped trapezoidal pulse is its extremely sharp termination on completion of the basewidth 2L+G. This may be compared to analog filtered pulses whose tails may persist up to 40% of the rise time, a phenomenon due to the finite bandwidth of the analog filter. As we shall see below, this sharp termination gives the digital filter a definite rate advantage in pileup free throughput.

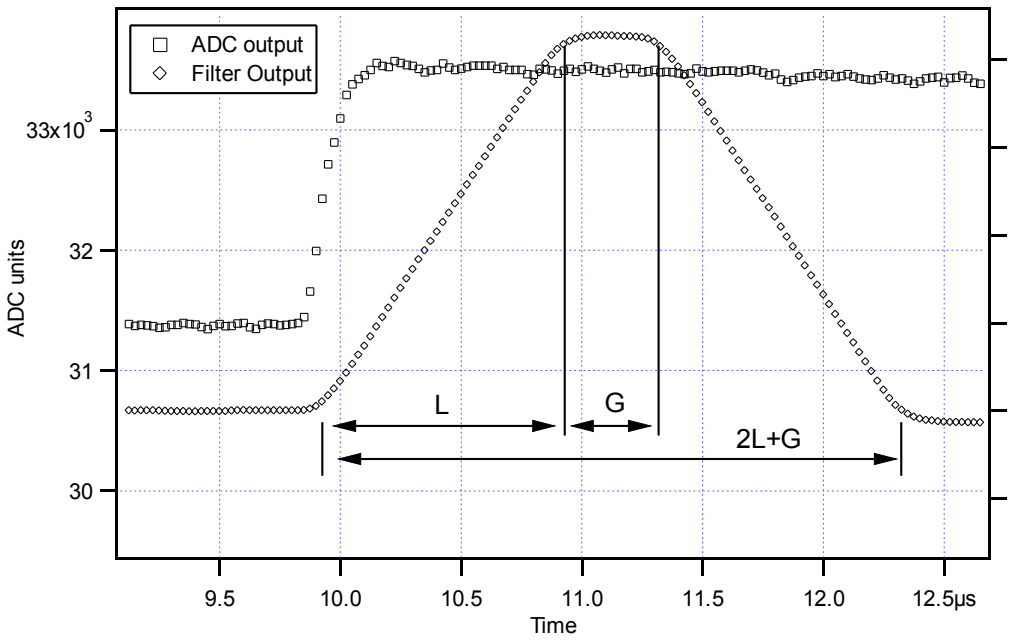


Figure 6.3: Trapezoidal filtering of a preamplifier step with L=1µs and G=0.4µs.

6.3 Baselines and Preamplifier Decay Times

Figure 6.4 shows an event over a longer time interval and how the filter treats the preamplifier noise in regions when no γ-ray pulses are present. As may be seen the effect of the filter is both to reduce the amplitude of the fluctuations and reduce their high frequency content. This region is called the *baseline* because it establishes the reference level from which the γ-ray peak amplitude V_x is to be measured. The fluctuations in the baseline have a standard deviation σ_e which is referred to as the *electronic noise* of the system, a number which depends on the rise time of the filter used. Riding on top of this noise, the γ-ray peaks contribute an additional noise term, the *Fano noise*, which arises from statistical fluctuations in the amount of charge Q_x produced when the γ-ray is absorbed in the detector. This Fano noise σ_f adds in quadrature with the electronic noise, so that the total noise σ_t in measuring V_x is found from

$$\sigma_t = \mathrm{sqrt}(\sigma_f^2 + \sigma_e^2) \qquad (3)$$

The Fano noise is only a property of the detector material. The electronic noise, on the other hand, may have contributions from both the preamplifier and the amplifier. When the preamplifier and amplifier are both well designed and well matched, however, the amplifier's noise contribution should be essentially negligible. Achieving this in the mixed analog-digital environment of a digital pulse processor is a non-trivial task, however.

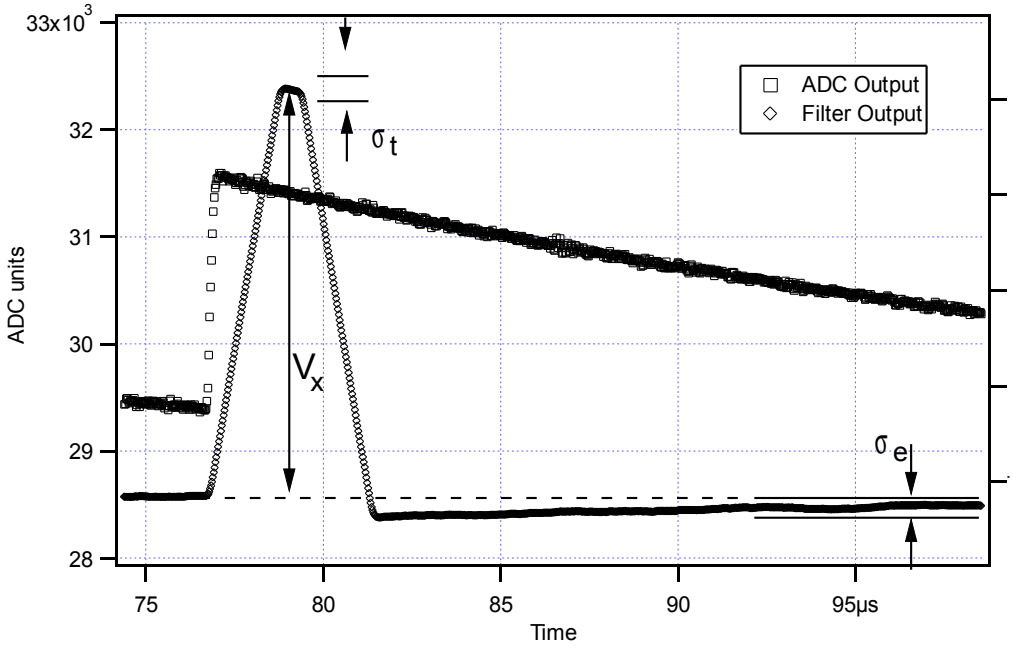


Figure 6.4: A γ-ray event displayed over a longer time period to show baseline noise and the effect of preamplifier decay time.

With a RC-type preamplifier, the slope of the preamplifier is rarely zero. Every step decays exponentially back to the DC level of the preamplifier. During such a decay, the baselines are obviously not zero. This can be seen in Figure 6.4, where the filter output during the exponential decay after the pulse is below the initial level. Note also that the flat top region is sloped downwards.

Using the decay constant τ, the baselines can be mapped back to the DC level. This allows precise determination of γ-ray energies, even if the pulse sits on the falling slope of a previous pulse. The value of τ, being a characteristic of the preamplifier, has to be determined by the user and host software and downloaded to the module.

6.4 Thresholds and Pile-up Inspection

As noted above, we wish to capture a value of V_x for each γ-ray detected and use these values to construct a spectrum. This process is also significantly different between digital and analog systems. In the analog system the peak value must be "captured" into an analog storage device, usually a capacitor, and "held" until it is digitized. Then the digital value is used to update a memory location to build the desired spectrum. During this analog to digital conversion process the system is dead to other events, which can severely reduce system throughput. Even single channel analyzer systems introduce significant deadtime at this stage since they must wait some

period (typically a few microseconds) to determine whether or not the window condition is satisfied.

Digital systems are much more efficient in this regard, since the values output by the filter are already digital values. All that is required is to take the filter sums, reconstruct the energy V_x, and add it to the spectrum. In the Pixie-500 Express, the filter sums are continuously updated in the FPGA (see section 5.2), and only have to be read out by the DSP when an event occurs. Reconstructing the energy and incrementing the spectrum is done by the DSP, so that the FPGA is ready to take new data immediately after the readout. This usually takes much less than one filter rise time, so that no system deadtime is produced by a "capture and store" operation. This is a significant source of the enhanced throughput found in digital systems.

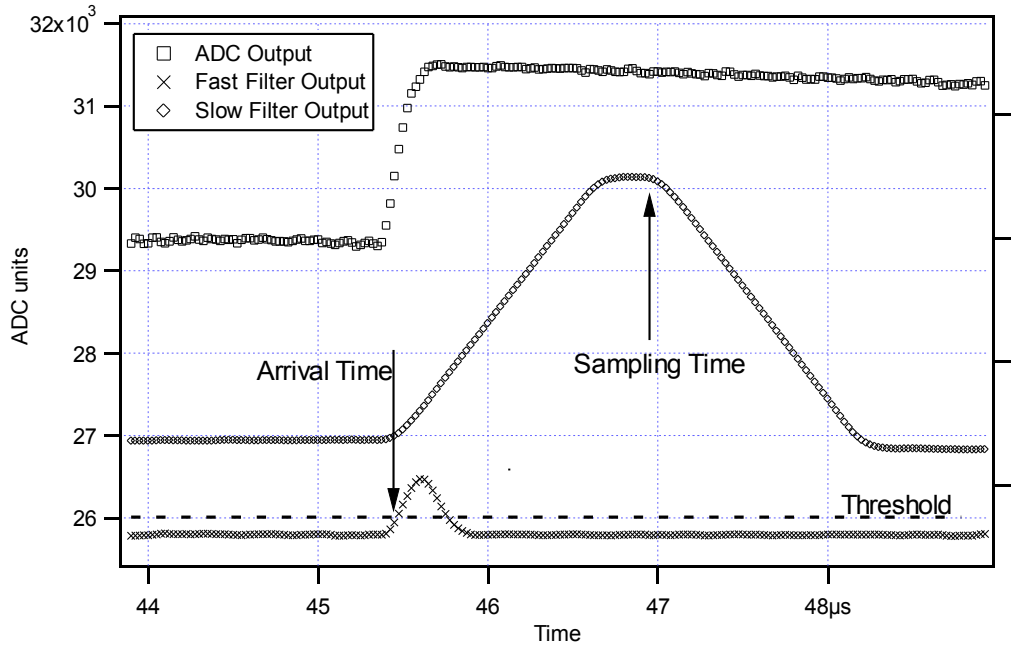


Figure 6.5: Peak detection and sampling in a Pixie module.

The peak detection and sampling in a Pixie module is handled as indicated in Figure 6.5. Two trapezoidal filters are implemented, a *fast filter* and a *slow filter*. The fast filter is used to detect the arrival of γ-rays, the slow filter is used for the measurement of V_x, with reduced noise at longer filter rise times. The fast filter has a filter length $L_f = 0.1\mu s$ and a gap $G_f = 0.1\mu s$. The slow filter has $L_s = 1.2\mu s$ and $G_s = 0.35\mu s$.

The arrival of the γ-ray step (in the preamplifier output) is detected by digitally comparing the fast filter output to THRESHOLD, a digital constant set by the user. Crossing the threshold starts a counter to count PEAKSAMP clock cycles to arrive at the appropriate time to sample the value of the slow filter. Because the digital filtering processes are deterministic, PEAKSAMP depends only on the values of the fast and slow filter constants and the rise time of the preamplifier pulses. The slow filter value captured following PEAKSAMP is then the slow digital filter's estimate of V_x.

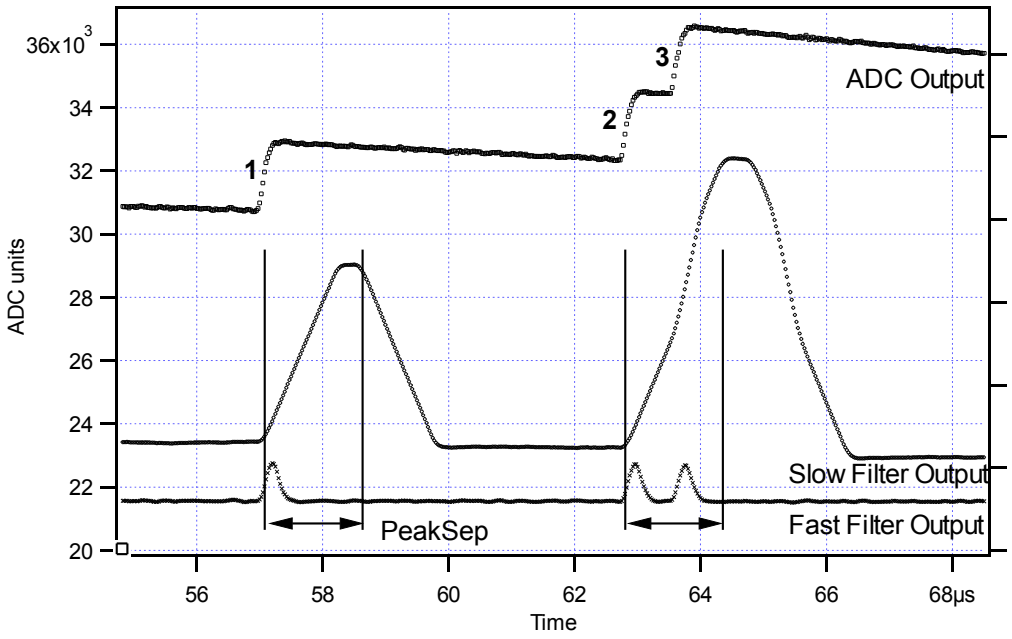


Figure 6.6: A sequence of 3 γ-ray pulses separated by various intervals to show the origin of pileup and demonstrate how it is detected by the Pixie module.

The value V_x captured will only be a valid measure of the associated γ-ray's energy provided that the filtered pulse is sufficiently well separated in time from its preceding and succeeding neighbor pulses so that their peak amplitudes are not distorted by the action of the trapezoidal filter. That is, if the pulse is not *piled up*. The relevant issues may be understood by reference to Figure 6.6, which shows 3 γ-rays arriving separated by various intervals. The fast filter has a filter length $L_f = 0.1\mu s$ and a gap $G_f = 0.1\mu s$. The slow filter has $L_s = 1.2\mu s$ and $G_s = 0.35\mu s$.

Because the trapezoidal filter is a linear filter, its output for a series of pulses is the linear sum of its outputs for the individual members in the series. Pileup occurs when the rising edge of one pulse lies under the peak (specifically the sampling point) of its neighbor. Thus, in Figure 6.6, peaks 1 and 2 are sufficiently well separated so that the leading edge of peak 2 falls after the peak of pulse 1. Because the trapezoidal filter function is symmetrical, this also means that pulse 1's trailing edge also does not fall under the peak of pulse 2. For this to be true, the two pulses must be separated by at least an interval of L + G. Peaks 2 and 3, which are separated by less than 1.0 µs, are thus seen to pileup in the present example with a 1.2 µs rise time.

This leads to an important point: whether pulses suffer slow pileup depends critically on the rise time of the filter being used. The amount of pileup which occurs at a given average signal rate will increase with longer rise times.

Because the fast filter rise time is only 0.1 µs, these γ-ray pulses do not pileup in the fast filter channel. The Pixie module can therefore test for slow channel pileup by measuring the fast filter for the interval PEAKSEP after a pulse arrival time. If no second pulse occurs in this interval, then there is no trailing edge pileup and the pulse is validated for acquisition. PEAKSEP is usually set to a value close to L + G + 1. Pulse 1 passes this test, as shown in Figure 6.6. Pulse 2, however, fails the PEAKSEP test because pulse 3 follows less than 1.0 µs. Notice, by the

symmetry of the trapezoidal filter, if pulse 2 is rejected because of pulse 3, then pulse 3 is similarly rejected because of pulse 2.

6.5 Filter Range

To accommodate the wide range of filter rise times from 0.053 µs to 106 µs, the filters are implemented in the FPGA with different clock decimations (filter ranges). The ADC sampling rate is always 2ns, but in higher clock decimations, several ADC samples are averaged before entering the filtering logic. In filter range 1, 2^1 samples are averaged, 2^2 samples in filter range 2, and so on. Since the sum of rise time and flat top is limited to 127 decimated clock cycles, filter time granularity and filter time are limited to the values listed in Table 6.1.

Table 6.1: Filter clock decimations and filter time granularity

Filter range	Filter granularity	max. $T_{rise}+T_{flat}$	min. T_{rise}	min. T_{flat}
1	0.016µs	2.032µs	0.032µs	0.048µs
2	0.032µs	4.064µs	0.064µs	0.096µs
3	0.064µs	8.128µs	0.128µs	0.192µs
4	0.128µs	16.256µs	0.256µs	0.384µs
5	0.256µs	32.512µs	0.512µs	0.768µs
6	0.512µs	65.024µs	1.024µs	1.536µs

6.6 Dead Time and Run Statistics

6.6.1 Definition of dead times

Dead time in the Pixie-500 Express data acquisition can occur at several processing stages. For the purpose of this document, we distinguish three types of dead time, each with a number of contributions from different processes.

6.6.1.1 Dead time associated with each pulse

1. Filter dead time

At the most fundamental level, the energy filter implemented in the FPGA requires a certain amount of pulse waveform (the "filter time") to measure the energy. Once a rising edge of a pulse is detected at time T0, the FPGA computes three filter sums using the waveform data from T- (a energy filter rise time before T0) to T1 (a flat top time plus filter rise time after T0), see section 6.4 and figure 6.7. If a second pulse occurs during this time, the energy measurement will be incorrect. Therefore, processing in the FPGA includes pileup rejection which enforces a minimum distance between pulses and validates a pulse for recording only if no more than one pulse occurred from T0 to T1 (in the previous firmware, T- to T1). Consequently, each pulse creates a dead time Td = (T1 – T0) equal to the filter time. This dead time, simply given by the time to measure the pulse height, is unavoidable unless pulse height measurements are allowed to overlap (which would produce false results).

Assuming randomly occurring pulses, the effect of dead time on the output count rate is governed by Poisson statistics for paralyzable systems with pileup rejection[7]. This means the output count rate OCR (valid pulses) is a function of filter dead time Td and input count rate ICR given by

$$OCR = ICR * \exp(-ICR* 2 * Td), \quad (4)$$

which reaches a maximum $OCR_{max} = ICR_{max}/e$ at $ICR_{max} = 1/(2*Td)$. Simply speaking, the factor 2 for Td comes from the fact that not only is an event E2 invalid when it falls into the dead time of a previous event E1, but E1 is rejected as piled up as well. This filter dead time is recorded in the SFDT counter in each processing channel.

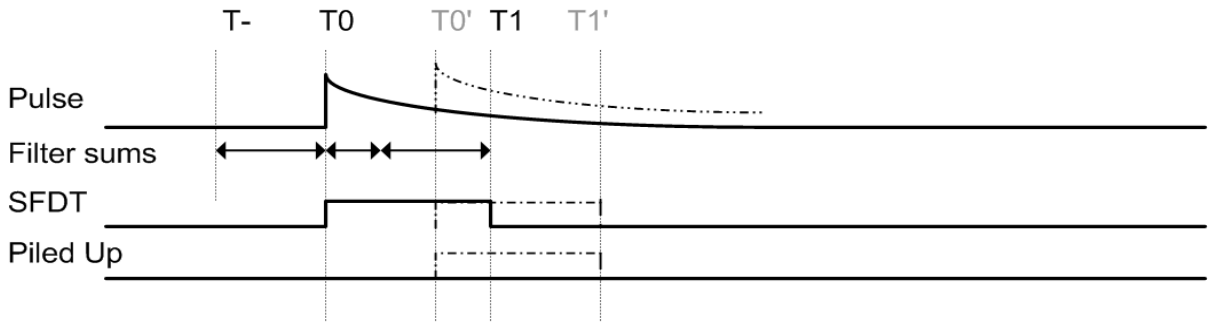


Fig. 6.7. Pulse dead time. A pulse arriving at T0 will incur slow filter dead time (for energy measurement) until T1. At T1, the pileup status is latched – for a single pulse, it is logic low and the event is accepted. A second pulse arriving at T0' will extend the dead time and cause the pileup status to be logic high. Unless pileup rejection is disabled, both events are rejected.

2. Fast trigger dead time (FTDT)

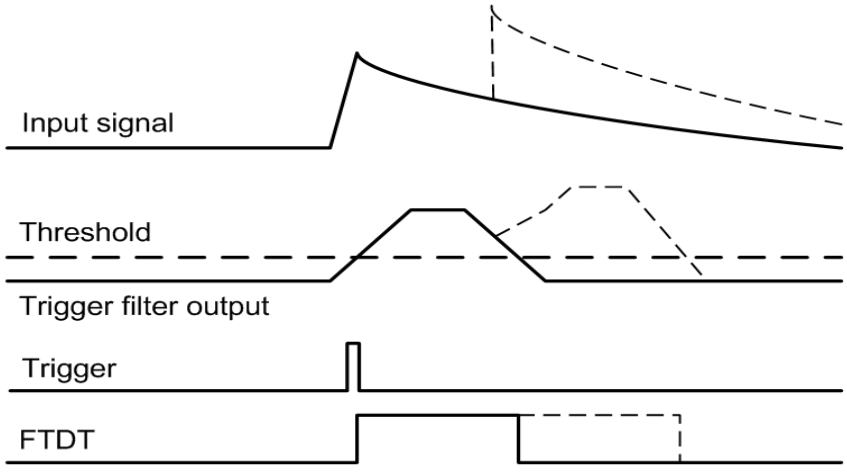


Fig. 6.9. Fast Trigger Dead Time (FTDT). A second pulse is not detected if the trigger filter output is still above threshold.

An second type of dead time only affects the trigger filter. Triggers are issued when the trigger filter output goes above the trigger threshold set by the user. However, depending on the length

[7] G. Knoll, Radiation and Measurement, J Wiley & Sons, Inc, 2000, chapters 4 and 17.

of the trigger filter and the rise time of the input signal, the trigger filter output will remain above threshold for a finite amount of time. During this time, no second trigger can be issued[8]. Therefore triggers are not counted during this time, and when computing the input count rate, the time lost has to be taken into account. FTDT is thus purely a correction for the computation of the input count rate.

3. Other

In the Pixie-4 and Pixie-500, as well as in earlier versions of the Pixie-500 Express firmware, there were additional dead times associated with reading out the data, since only one event at a time was stored in the FPGA. In the current firmware, up to 16 events (and/or total 8K waveform samples) are buffered in the FPGA. Thus new events are accepted while captured ones are read out and processed further, and these types of dead time are eliminated. If the buffers fill up, the channel pauses acquisition and stops the live time counter.

6.6.1.2 Dead time associated with external conditions

There are three dead time effects that originate from outside the trigger/filter FPGA. The first two have the effect of stopping the Pixie-500 Express live time counter, the last is counted separately.

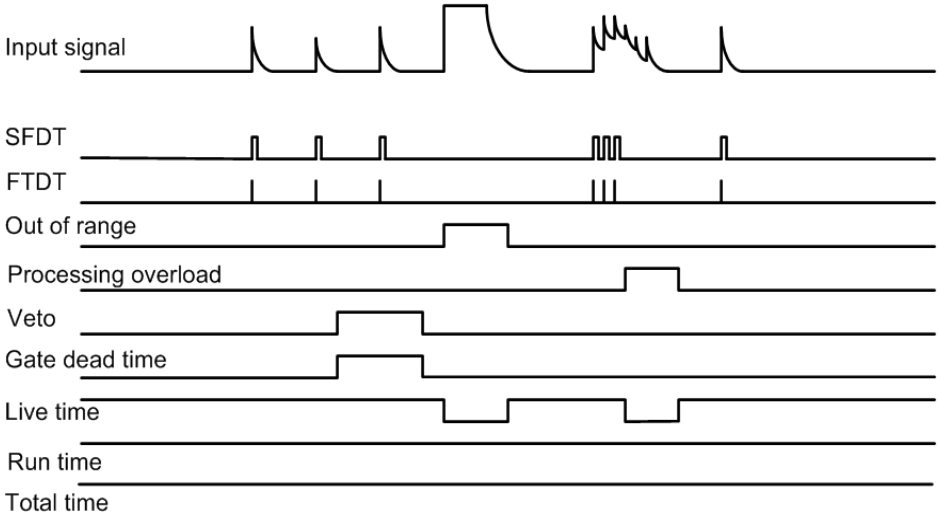


Fig. 6.10. The live time counter is stopped when the signal is out of range and when events are rejected because of a processing backlog (e.g. local buffer memory full or SDRAM not read out by host). SFDT and FTDT are only counted when the live time is on. The gate dead time is counted in a separate counter, but also only when the live time is on. Run time and total time are always on unless the run is stopped (see below).

1. Signal out of range

[8] The MAXWIDTH parameter can be used to define a maximum acceptable time over threshold and thus to reject events piled up "on the rising edge".

When detector gains or offsets drift, or an unusual large pulse is generated in the detector, the analog input of the ADC may go out of range. In this condition, the FPGA can not accumulate meaningful filter sums and thus is considered dead. This dead time is enforced during the actual out-of-range condition and several filter times afterwards until the bad ADC samples are purged from filter memory. The live time counter is stopped during the out-of-range condition because no triggers can be issued and no pulses are counted.

2. On-board pulse processing limit

The on-board pulse processing by the DSP computes the pulse height (energy) from raw energy filter sums, which is then stored in list mode memory and/or binned into spectrum memory. In the Pixie-500 Express, the computation itself takes only a few DSP cycles, but the readout and other overhead amounts to approximately 1 microsecond per pulse to read raw sums, compute the energy, and send it to the memory SDRAM. Waveforms are transferred within the FPGA at ~1 GB/s. Every microsecond of captured waveform thus takes one microsecond for SDRAM data transfer. The measured processing limit is roughly 700,000 pulses/s if a single channel is processed per event, and about 1,700,000 pulses/s for events with 4 active channels in MCA mode. (Processing events containing pulses from several channels has less overhead and is thus faster per pulse.) This rate is much higher than the maximum throughput set by Poisson statistics for most typical filter times. In List mode with nonzero waveforms, the limit is strongly dependent on the length of the captured waveform.

3. Gating or Veto (GFLT)

If an external signal prohibits acquisition using the GATE or VETO signals, the channel is also dead (disabled on purpose). As further described in section 7.4, the use of these signals may depend on the application:

a) On one hand they may be used to reject an individual pulse (e.g. externally summing multiplicities from several channels and issuing a short validation pulse at the right time in the validation process). In this case the actual length of the pulse does not correspond to a dead time. The VETO input is set up for this purpose and we call this mode of operation GFLT (global first level trigger for validation).

b) On the other hand GATE or VETO may block validation of events for certain amounts of time (e.g. changing sources or activating beams). In this case they should be counted clock cycle by clock cycle as dead time. Both the VETO and the GATE inputs are available for this purpose, VETO as a global signal for the whole system, GATE as a dedicated signal for each channel. VETO acts at the time of pulse validation, GATE acts at the time of the rising edge of the pulse. However, the VETO input can be routed to replace the GATE input with a user option.

c) In a third class of application, the acquisition may only be of interest when GATE or VETO are off. The pulse rejection logic would be similar to b), but livetimes and count rates should only be counted when GATE/Veto are off as count rates would be different in on and off times. (In b) one would be more interested in an overall livetime and average count rate and additionally the time inhibited by GATE or VETO to make corrections.)

The appropriate way to count GATE or VETO dead time may thus depend on the experiment. See below (GDT) for the current methods implemented in the firmware.

6.6.1.3 Dead time associated with host readout

The final type of dead time comes from the readout of data from Pixie-500 Express memory to the host PC. In MCA mode, this is limited to the access arbitration for the spectrum memory. The memory has only a single port for both the increments according to the pulse height computed by the DSP and for readout to the host PC, arbitrated by the FPGA. While the host is reading the memory, spectrum increments are queued in a buffer (2K long). At maximum count rate, it will take the DSP at least (2K * processing time) to fill the buffer and correspondingly longer at lower count rates, while the host readout typically takes ~30 ms. Thus host readout dead time is usually not an issue in MCA runs unless spectra are read very frequently.

In list mode runs, the data is buffered in a large SDRAM memory organized as a FIFO. In a major improvement compared to the Pixie-4 or Pixie-500, the Pixie-500 Express therefore never stops the acquisition for data readout. The host PC can read the memory from one end at the rate set by the PCIe interface (max. 800 MB/s) while new data is added on the other end. Given the data bandwidth of the PXIe interface, it is rather unlikely for the SDRAM to fill up, except for very high rates at very long waveforms. (If the SDRAM actually does fill up, data acquisition is *paused* but as soon as the host frees up SDRAM memory by reading and storing data to disk, the acquisition continues. Any such pause is counted as dead time by turning off the livetime counter.)

At the current firmware and SDRAM operation rate, the SDRAM reads and writes data at about 0.9 GB/s, for a combined average throughput of ~0.45 GB/s, and the PXI Express readout matches that rate, transferring data from Pixie memory to host PC memory at up to ~0.48 GB/s.[9] With the buffering of up to 16 event in each channel's first processing stage, and of up to 256 MB in the SDRAM, temporary bursts of pulses creating higher data rates can still be captured without loss of data. We note that streaming ADC data in real time, amounting to 4 x 2 bytes x 500 MHz = 4 GB/s, is still beyond the capacity of the PCIe x4 interface used by the Pixie-500 Express. Few, if any, PXIe crates, controllers, and/or hard drives can accommodate such rates. Streaming ADC data is therefore only possible if some kind of data compression is applied, please contact XIA for details.

6.6.2 Live and dead time counters

The Pixie-500 Express firmware has been optimized to reduce the dead time as much as possible, and a number of counters measure the remaining dead times as well as the number of counts to provide information for dead time correction. The result of these counters is stored in the following DSP output variables:

TOTAL TIME

The TOTAL TIME is an attempt to measure the real laboratory time during which the Pixie module was requested to take data. It essentially counts the time from the command to start a data acquisition to the command to end it. The TOTAL TIME includes the time spent for run start initialization and host readout. However, since it is based on the PXI chassis' internal clock (a part with 50 ppm accuracy from module to module) and only updated periodically (~1 ms), it may not be as precise as a “laboratory wall clock” over long time spans (e.g. the host PC’s

[9]However, writing data to hard disk is usually much slower, in the order of 0.1 GB/s depending on the particular system. Advances system architectures may improve this data rate, for example multiple hard drive arrays.

internal clock). Also, it does not take into account the time required to send commands from the PC to the module.

RUN TIME

The RUN TIME variable tracks the time during which the DSP on the Pixie module was "switched on" for data acquisition. The usefulness of this variable is limited. It may be less than the TOTAL TIME because it omits the time the SDRAM is full and waiting for readout (during which the data acquisition is paused in all channels). It is larger than the time an individual channel is ready to take data because it does not account for the dead time from the pileup inspection, out-of-range condition and energy filter in each individual channel. Thus its main uses are to compute an average event rate (total output counts of all channels / RUN TIME), and to compute the fraction of time the SDRAM was not full and acquisition not paused, which is the "DAQ Fraction" displayed in the Pixie Viewer: RUN TIME / TOTAL TIME.

LIVE TIME

The LIVE TIME is counted in the FPGA independently for each channel and measures the time the channel is ready for acquisition. The LIVE TIME counter starts when the DSP finished all setup routines at the beginning of a run, omits the times the ADC signal is out of range, each channels local 16-event buffer is full, or the SDRAM memory is full and ends when the DSP encounters an end run condition (e.g. host stop). It is thus the time during which triggers are counted and can cause recording (or pile up) of data, the best available measurement of the time the channel was active. The difference between LiveTime and RunTime can be used to determine how long the local 16-event buffers were full and waiting for readout or other events prevented the channel from data taking (e.g. out of range).

FTDT (fast trigger dead time)

The fast trigger dead time counts the time the trigger filter is unable to issue triggers because the trigger filter output is already above threshold (and can not recognize a second pulse). It does not include the time triggers have been "paused" for a short time after a first trigger (an advanced user option to suppress double triggering), because the concept is that all triggers occurring during the pause are counted as only one trigger. When computing the input count rate, one should divide the number of triggers counted (FASTPEAKS) by the difference (LIVE TIME – FTDT) since triggers are not counted during FTDT.

SFDT (slow filter dead time)

The slow filter dead time counts the time new triggers will not lead to the recording of new data. This includes effect 1 listed in section 6.6.1.1 as dead time associated with a pulse. In detail,

- it includes the time the pileup inspection is taking place and the summation of energy filter sums is in progress,
- in case pileup inspection is inverted or disabled, it is not contributing to SFDT

For the "DAQ Fraction" displayed in the Pixie Viewer, the PC's time is used.

GDT (GATE dead time)

The dead time from VETO/GFLT is counted separately from SFDT for each channel. As mentioned above and further described in section 7.4, the use of these signals may depend on the application.

In the current firmware, the (optionally inverted) signal on the VETO input is fed into VETO_ON. While VETO_ON is high, GDT is incremented every clock cycle and thus counts the time pulses can be rejected from acquisition. (The rejection has to be enabled independently). The GDT counter is additionally subject to the channel being live, i.e. GDT is only counted if a run is in progress, signal in range, etc.

For the case that the Veto input is used for a GFLT-type validation pulse, it may be more useful to work with the number of pulses issued. They can be counted by using the VETO input as the source for GATE PULSEs, which are counted in the variable GCOUNT.

6.6.3 Count Rates

Besides the live and dead times, the Pixie-500 Express counts the numbers of triggers in each channel, FASTPEAKS, the number of valid single channel events, NUMEVENTS, and the number of valid pulses stored for each channel, NOUT. In addition, it counts the number of gate pulses for each channel, GCOUNT. FASTPEAKS and GCOUNT are inhibited when the live time is not counted. NUMEVENTS and NOUT by nature only count events captured when the live time is counted.

Count rates are then computed in the C library as follows:

Input count rate	ICR	=	FASTPEAKS / (LIVE TIME – FTDT)
Event rate	ER	=	NUMEVENTS / RUN TIME
Channel output count rate	OCR	=	NOUT / LIVE TIME
Gate count rate	GCR	=	GCOUNT / LIVE TIME

The Pixie Viewer also computes a “DAQ fraction” in Igor, defined as LIVETIME / Igor run time, which is an indication of the overall dead time lost to those processes not included in SFDT, as well as to run start/stop overhead. Users are free to use the reported values to compute rates and time better matching their preferred definitions.

Notes:

1) Output pulse counters are updated whenever an event has been processed; input, gate and all time counters are updated every ~7ms. Therefore reading rates at random times, e.g. clicking *Update* in the Pixie Viewer, might return slight inconsistencies between input rates and output rates. At the end of the run, all rates are updated and these effects should disappear.
2) NOUT is counted for each event a channel is processed no matter if the channel had a valid hit or not. Thus a channel that is processed in “group trigger” mode may have an output count rate even though its input count rate is zero.
3) Since LIVE TIME counters are paused when SDRAM or local 16-event buffers are full, the input and output count rates should be considered as “rates while active” as opposed

to actual rates per elapsed lab time. For input count rates, this is the more intuitive case, since the detector will not stop generating pulses when the channel becomes inactive due to a full SDRAM and the input count rate should closely correspond to the detector's rate. For output count rates, it is a matter of perspective – should it mean the total number of counts per acquisition lab time or the number of counts processed while the module is active. The former would produce unreasonably low count rates when e.g. the signal goes out of range periodically, since it will not account for the duty cycle of the signal source. The latter would produce unreasonably high rates if the system is near its processing limit and be often paused for SDRAM readout, though it may better reflect the pileup rejection statistics. The choices made in the current firmware select the latter case, but by qualifying the output count rate with the LIVE TIME / TOTAL TIME, the former can be recovered.

7 Operating Multiple Pixie-500 Express Modules Synchronously

When multiple Pixie modules are operating as a system, it is usually required to synchronize clocks and timers between them and to distribute triggers across modules. It will also be necessary to ensure that runs are started and stopped synchronously in all modules. All these signals are distributed through the PXIe backplane.

7.1 Clock Distribution

Unlike the Pixie-4 or Pixie-500, the Pixie-500 Express uses the 10 MHz and 100 MHz clocks provided by the PXI Express chassis. These clocks are routed on the backplane to tight tolerances and ensure that all modules receive the same clock with very little phase skew. Every module in the chassis is therefore a clock slave to the backplane, and no jumpers or switches are required to change the clock mode.

7.2 Trigger Distribution

7.2.1 Trigger Distribution Within a Module

Within a module, each channel can be enabled to issue triggers. Such a *Fast Trigger* indicates that the trigger filter just crossed the threshold at the rising edge of a pulse, and is used to start pileup inspection and to latch time stamps, among other things.

Each trigger-enabled channel issues triggers to the central "system logic", which builds an OR of all triggers and sends it back to all channels. If a channels is set to "group trigger" mode, it uses the distributed fast trigger instead of its own local triggers to capture data. In this way, one channel can cause data to be acquired at the same time in all channels of the trigger group. However, the DSP then reads data from all participating channels individually and stores it as one event record per channel.

Notes:

1) Each channel, trigger enabled or not, always also generates a "hit" flag for a coincidence test when it detects a rising edge. To disable this, mark the channel as not "good" or set the trigger threshold to zero.
2) In group trigger mode, all data is captured based on the distributed trigger. This may cause slight shifts in waveforms and timestamps due to the extra delay of routing signals through the central logic.

7.2.2 Trigger Distribution Between Modules

Fast triggers can also be distributed over the PXIe backplane. The fast trigger signal uses a common backplane line for all modules, which is set up to work as a wired-OR. Normally pulled high, the signal is driven low by the module that issues a trigger. All other modules detect the lines being low and send the triggers to all of their channels. In other words, the backplane line

carries a system-wide trigger that essentially acts as a 5th input to the trigger OR in the central "system logic" of each module.

Each module can be enabled to share triggers over the backplane lines or not. In this way, a trigger group can be extended over several modules or each module can form its local sub-group.

7.2.3 Trigger Distribution across PXI segment boundaries

Not yet implemented

In PXIe chassis with more than 8 slots, the PXIe bussed backplane lines are divided into segments with not more than 8 slots. The PXI bussed backplane lines are usually only buffered from one segment to the next; i.e. the line in one segment drives the line in the neighboring segment. Since this buffer is essentially a one-way communication (though the direction may be selectable), no wire-OR can be build across the segment boundary. (Note: Sometimes there is no connection at all.)

For applications with more than 7 modules, the Pixie-500 Express have to be operated in a chained OR mode, where trigger signals are passed from module to module using the PXIe nearest neighbor lines which are not interrupted by the segment boundaries. In this mode, each module ORs the trigger signal from its right neighbor with its own contributions and passes it to the left. The leftmost module issues the combined OR to a bussed PXIe line. The chassis has to be configured such that the leftmost segment drives all other segments to the right. The Pixie-500 Express modules can be set up to operate in this mode using the chassis control panel of the Pixie Viewer. The PXIe backplane buffering has to be set up with the tools provided by the chassis manufacturer: the lines named PXI_TRIG0 (fast trigger), PXI_TRIG1 (event trigger) and PXI_TRIG2 (synchronization) have to be set up to be driven from the leftmost segment.

7.2.4 Trigger Distribution between PXI chassis

In principle it is possible to distribute triggers between several chassis with Pixie-500 Express modules with a suitable PXIe module to bring out signals from the backplane. Please contact XIA for details.

7.2.5 External Triggers

Not yet implemented

External triggers usually do not have the correct format and fast trigger vs event trigger timing required by the Pixie-500 Express trigger logic. The Pixie-500 Express therefore includes specific logic to turn an external signal into distributed triggers.

External signals (3.3V TTL standard) can be connected to a Pixie-500 Express front panel input. The DSP variable XETDELAY (Control field *Validation delay* ... in the CHASSIS SETUP panel controls generation of fast and event triggers. If the value is zero, no triggers are generated. If the value is nonzero, a fast trigger is issued to the backplane immediately after detection of a rising edge on the front panel, and an event trigger is issued the specified delay thereafter. As the triggers are sent to the backplane, the external triggers appear as if an additional module with a pileup inspection time (energy filter rise time plus flat top) equal to XETDELAY had seen a pulse. Sharing triggers over the backplane must be enabled even for the module connecting to the external signal.

7.3 Run Synchronization

It is possible to make all Pixie-500 Express modules in a system start and stop runs at the same time by using a wired-OR SYNC line on the PXIe backplane. The feature is enabled by checking the corresponding checkbox in the *Run Control* tab of the Pixie Viewer.

The run synchronization works as follows: When the host computer requests a run start, the Pixie-500 Express's DSP will first execute a run initialization sequence (clearing memory etc). At the beginning of the run initialization the DSP causes the SYNC line to be driven low. At the end of the initialization, the DSP enters a waiting loop, and allows the SYNC line to be pulled high by pullup resistors. As long as at least one of all modules is still in the initialization, the SYNC line will be low. When all modules are done with the initialization and waiting loop, the SYNC line will go high. The low->high transition will signal the DSP to break out of the loop and begin taking data.

If the timers in all modules are to be synchronized at this point, check the corresponding checkbox in the *Run* tab of the Pixie Viewer. This instructs the DSP to reset all timers to zero when coming out of the waiting loop. This is implemented as a pulse on an additional backplane line distributed to all modules. From then on they will remain in synch until the next power cycle or reboot.

Whenever a module encounters an end-of-run condition and stops the run it will also drive the SYNC line low. This will be detected in all other modules, and in turn stop the data acquisition.

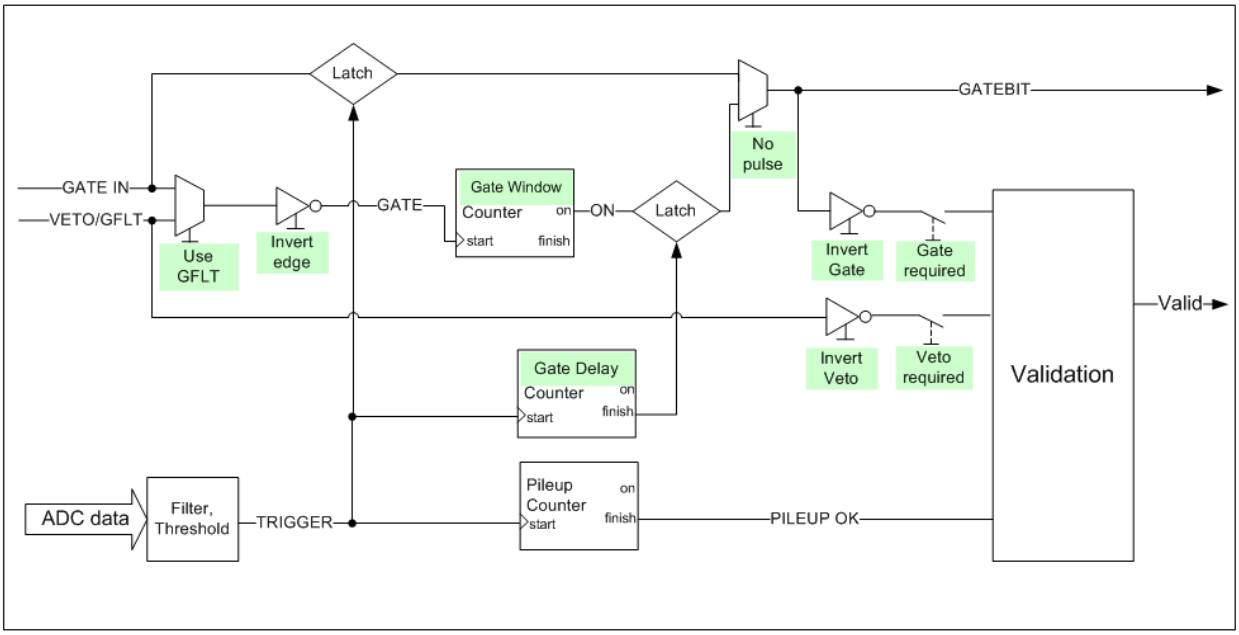
7.4 External Gate and Veto (GFLT)

Not yet implemented

It is common in larger applications to have dedicated external electronics to create event triggers or vetoes. Besides the external trigger described in section 7.2.5, the Pixie-500 Express also accepts a global first level trigger (GFLT). This signal acts as a validation for an event already recognized by the Pixie-500 Express. Using multiplicities and/or other information, the external logic needs to make the decision whether to accept or reject a given event. If that decision can be made within the filter time (energy filter rise time plus flat top) of all Pixie-500 Express channels involved, then the GFLT function can be used. By definition, GLFT is a global signal that applies to all channels.

In a second scenario, the acquisition may have to be inhibited for certain intervals. An example is the on/off cycle of a neutron generator, and events may only be of interest if the generator is off. This condition can also be accommodated by the GFLT function, but is often described as vetoing the acquisition while the signal is on. We thus use the names GFTL and VETO interchangeably.

In a third scenario, it may be desirable to reject pulses that occur while a GATE signal is on (or off). Usually this is a dedicated signal for each channel, for example derived from a BGO shield around the detector. When the BGO shield sees a pulse, not all of the energy was deposited in the detector, and therefore this event should be rejected. The GATE signal is thus coincident with the rising edge of the detector pulse (give or take a cable delay), in contrast to the GFLT function that contributes to the event validation a filter time after the rising edge.



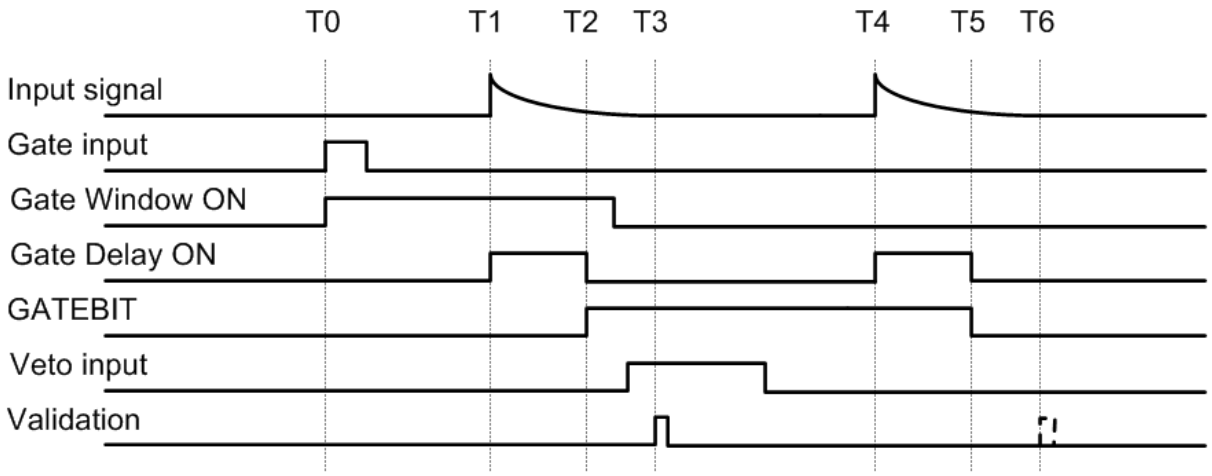


Figure 7.3. Block and timing diagrams of the GATE and VETO circuitry in the trigger/filter FPGA. If required by the user, pulses are validated only if VETO and/or GATEBIT are present during validation. GATEBIT reflects the status of the GATE input at the time of the trigger either directly or after a coincidence window is applied. Names highlighted in green are controlled by the parameters in the *Gate* tab of the PARAMETER SETUP Panel.

The Pixie-500 Express accommodates these scenarios in the following way (figure 7.3): In each channel, the VETO signal contributes to the validation of a pulse at time T3 if it is set by the user to be *required* to do so. The polarity of the input can be optionally *inverted*. The rising edge of the GATE signal (optionally the VETO signal, optionally *edge inverted*) starts a counter of length Gate *Window* at time T0. The time the Gate Window counter is ON is called GATE PULSE. A trigger generated at the rising edge of a pulse from the detector starts a counter of length Gate *Delay* at time T1. When the Gate *Delay* counter is finished at T2, the status of the

Gate *Window* counter is latched as GATEBIT. Alternatively, the pulsing logic can be bypassed and the status of the GATE input is latched directly as GATEBIT by the trigger. If gating is *required*, the GATEBIT (optionally inverted) also contributes to the pulse validation at T3, else it is only recorded in the output data stream (in list mode data). In all cases, the trigger also starts the standard pileup counter that validates a pulse a filter time after the rising edge of the pulse. The validation thus always takes place a filter time after the rising edge of the pulse, but is optionally subject to the current status of the VETO input and/or the status of the GATE input stretched by Gate *Window* and latched a time Gate *Delay* after the rising edge of the pulse.

The action of Gate *Window* and Gate *Delay* is thus to set a coincidence window for the GATE signal, and adjust for the delay between detector signal (from the ADC) and the GATE signal. Mainly due to the pipelined processing inside the ADC, it takes about 200 ns from a rising edge at the front panel analog input of the Pixie-500 Express until a trigger is issued by the Pixie-500 Express trigger circuit. The GATE signal starting the Gate *Window* counter is therefore delayed by ~200 ns inside the FPGA to compensate for this intrinsic delay. Any delay due to cables or the physics of the experiment will be additional. Both Gate *Delay* and Gate *Window* can range from 13.3ns to 3.4 µs.

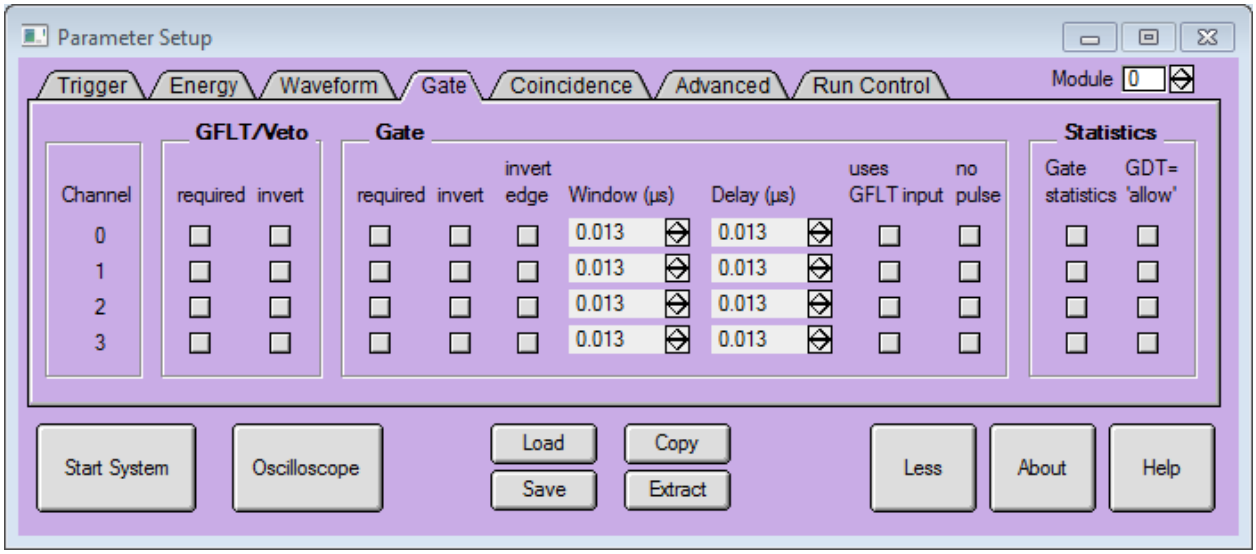


Figure 7.4. *Gate* tab of the PARAMETER SETUP Panel.

The VETO signal is distributed through the PXI backplane. Using XIA's PDM module or a custom board, external signals can be connected to the backplane. In addition, the Pixie-500 Express front panel input labeled "DSP-OUT" [sic] can be used to send the signal to the backplane. The input signal must be LVTTL, i.e. logic 0 = 0V, logic 1 = 3.3V. Only one module within a chassis may use this option to avoid conflicts in driving the backplane. The option is enabled in software by setting the corresponding checkbox in the Pixie Viewer's CHASSIS SETUP panel. Setting it for one module will automatically disable it for all other modules.

The GATE signal is also distributed over the backplane, using 4 PXI nearest neighbor lines. Therefore a module to the left of a Pixie-500 Express can be used to input 4 GATE signals to the Pixie-500 Express. XIA's PDM can provide this function (inputs 8-5 for channel 0-3). The alternative is to use the VETO signal distributed to all modules and channels as the common GATE input for each channel.

7.5 External Status

Not yet implemented

Besides Veto, a second function for the Pixie-500 Express's front panel input is to contribute to a wired-OR backplane line called "Status". Several modules can be enabled to contribute to the Status line. The backplane status line will be logic 1 whenever the "DSP-OUT" input of any enabled module is high (3.3V). The status of this line is read as part of the event acquisition and is stored in the list mode data. It is also possible to send the hit status bit of channel 3 to the STATUS line so that all modules will include this channel's information in their event record (see 7.6.2)

The fourth function for the Pixie-500 Express's front panel input is to contribute one "Front" bit in the event hit pattern. If the front panel is not used as Veto or Status input, this allows recording of an externally created logic level in each module individually. For example, each module may be assigned to a detector or radiation source that is enabled/disabled individually, and so the status of that detector is recorded in the event data stream.

Notes: The front panel input can be used for Veto, Status, and Front at the same time, if necessary. The wired-OR backplane lines are of type active low, i.e. logic 1 is 0V.

7.6 Coincident Events

7.6.1 Coincidences Within a Module

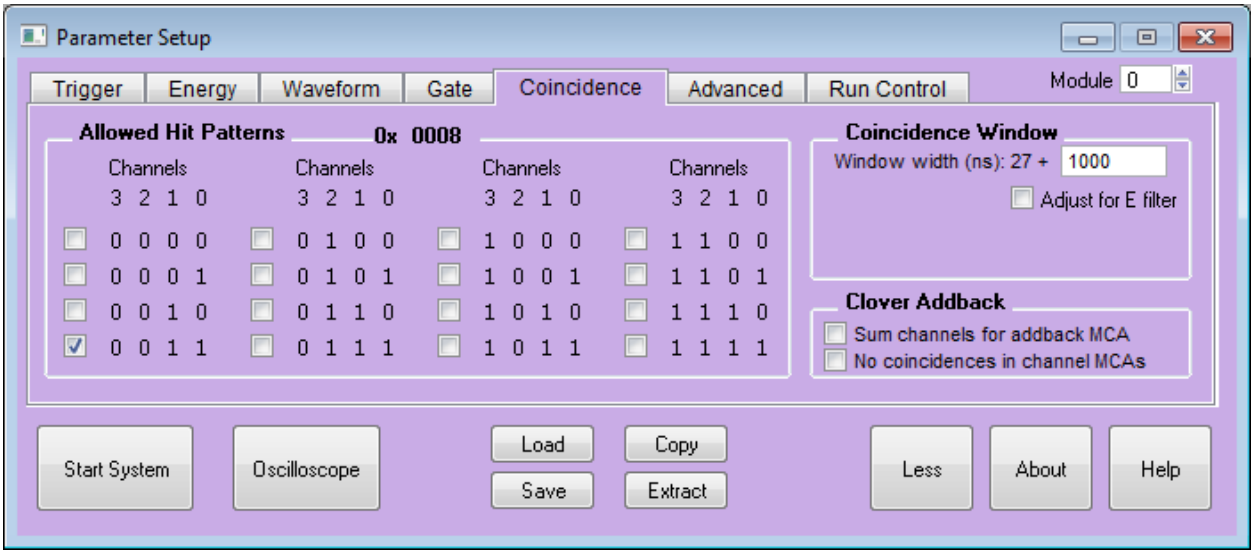


Figure 7.5. Coincidence Pattern and Coincidence Window Settings in the Pixie Viewer

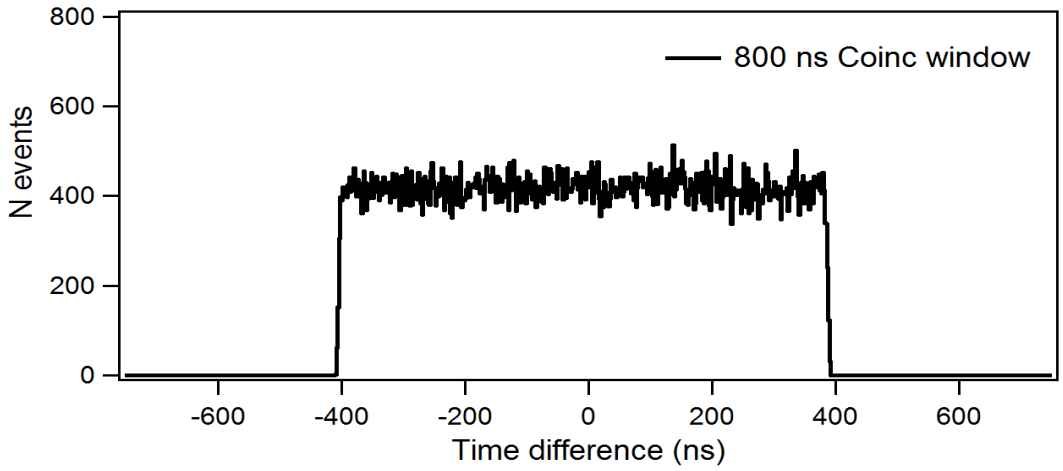
In any given event, a single Pixie module will have up to four channels with a "hit", i.e. a rising edge of a pulse detected in the signal of a channel's ADC. The four channels thus form one of 16 possible Hit Patterns, described in a 4-bit word. In this representation, the Hit Pattern ranges from "no channel hit" [0000] over "only channel 1 hit" [0010] to "all four channels hit" [1111].

The user can define a combination of allowed hit patterns, the Coincidence Pattern, to accept one or more hit patterns. Usually this is done to reduce the recorded event rate, omitting non-

coincident events that are of no interest. In the *Coincidence* Tab of the PARAMETER SETUP Panel, there are 16 checkboxes for the 16 possible hit patterns, and selecting one sets the corresponding bit in the Coincidence Pattern. For example, allowing all except for Hit Pattern [0000] makes the Coincidence Pattern 0xFFFE. Allowing only [0011] as in shown in Figure 7.5 makes the Coincidence Pattern 0x0008. Several of the check boxes can be set at the same time, for instance to accept any pattern with two or more channels. If all checkboxes are set, any possible Hit Pattern is acceptable and the Coincidence Pattern is 0xFFFF.

Each channel with a pulse above threshold, whether trigger enabled of not, contributes to the hit pattern. A channel hit flag is set to logic high for a user specified time, the Coincidence Window, after the fast trigger. The hit flags from all four channels of a module are continuously tested against the coincidence pattern (local coincidence test). Each channel latches the 4 Hit flags from all 4 channels and the result of the coincidence test in the middle of its coincidence window. This data become part of the event status flags, and the DSP can decide to accept or reject events based on this information.

The plot below shows the time of arrival difference histogram for an acquisition using one periodic and one quasi-random pulser with a Coincidence Window of 800 ns. The resulting distribution is basically flat with a sharp cutoff at +/- 400 ns. The recorded event rate dropped by a factor ~60 compared to the acquisition without coincidence requirement.



Notes:

- To prevent a channel from contributing to the hit pattern, set the threshold to zero (disables triggers) or uncheck the "good channel" check box.
- The coincidence is based on triggers at the rising edge, but a pulse can subsequently be rejected as piled up. That may lead to coincidence records with missing channels. For example, if channels 0-2 were in coincidence and channel 0 saw a second pulse to be rejected as piled up, then only channels 1 and 2 will be recorded but will show the actual 3-channel hit pattern (bits 8-10 set for channels 0-2). To avoid such missing records, disable pileup rejection.

- The LIST MODE TRACE display applies an independent coincidence window for viewing events. Under the option "show 4 pulses within", events within that range are extracted from the specified file, whereas the Coincidence Window described above limits the acquisition of events into the file. To view coincidence events properly, the range in the LIST MODE TRACE display should be set at least as large as the acquisition coincidence window.
- Coincidence acquisitions can be conducted with independent triggers (EACH channel is recorded when IT is hit AND all channels match the coincidence pattern) or with distributed triggers (ALL channels with the "group trigger" option set are recorded when ANY trigger enabled channel is hit AND all channels match the coincidence pattern).

  In the former case, waveforms will not appear significantly shifted relative to each other even though they may be a few hundred ns delayed – waveforms are shown vs time from first sample. The time stamps carry the delay information.

  The latter case will lead to multiple records per coincidence if the delays between channels are greater than a few dozen nanoseconds so triggers are recognized separately. Event info bit 4 identifies such "group trigger without local hit" records, also their energy is set to zero unless the "estimate energy" option is set.
- If waveforms are of interest, it is advised to make *Trace Lengths* long enough to cover at least half of the coincidence window. That way, waveforms in event N (triggered by the first channel and recorded for the first channel) and in event N+1 (triggered by the first channel and recorded for the second channel) will start at the same time and will contain the rising edge of trigger and delayed pulse, respectively. Otherwise, matching events becomes somewhat more difficult.

7.6.2 Coincidences Between Modules

Not yet implemented

If more than one module is operated in the same PXI chassis, acceptance of events can also be subject to the results of a system-wide ("global") coincidence test. The result of the global test is distributed over the TOKEN backplane line. This module coincidence test takes place in the following steps:

After receiving a valid event trigger and waiting for the user defined coincidence window, each module sends its channel hit pattern to slot 2 of the chassis using the PXI STAR trigger line

Each module determines the result of the local coincidence test based on its own 4 channels. If enabled to do so, it signals the test result on the TOKEN line. If the local test passed, the TOKEN line is left pulled up (3.3V, logic 1); else the TOKEN line is driven low (logic 0).

The module in slot 2, typically XIA's PXI-PDM module, uses the up to 48 bit hit pattern from up to 12 modules (slots 3-14) to make an accept/reject decision. If the hit pattern is acceptable, the TOKEN line is left pulled up. If not acceptable, the TOKEN line is driven low (logic 0). The decision criteria is based on a user defined control word, downloaded to the PXI-PDM by its neighboring Pixie-500 Express module.
The acceptance decisions implemented in the current PDM firmware are described in detail in

the Pixie Viewer online help. For example, if the control word is 0x13 (0x14, 0x15, etc) events are only acceptable if at least 3, (4, 5, etc) channels are hit. If the control word is 0x0200, channel 0, but not 1, 2, and 3 must be hit in each module 0 and 1. The current firmware does not claim to cover all cases. Please contact XIA to request additional cases or to obtain verilog source code to write custom PDM firmware.

Each module, after waiting ~100ns for the global accept/reject decision to be made, captures the status of the TOKEN line and puts it in the event hit pattern. The hit pattern also contains the status of the backplane STATUS line, the result of the local coincidence test, and the status of the front panel input at this moment. Depending on user settings, the event will be recorded or discarded if the TOKEN and/or LOCAL bits are set in the hit pattern.

A full implementation of this feature thus requires an additional module in slot 2 of the chassis, receiving hit patterns over the PXI STAR Trigger lines, making a coincidence decision, and signaling the result on the TOKEN line. This can be XIA's PXI-PDM module or any other compatible PXI module. A limited coincidence decision can be made with Pixie-4 modules only, e.g. one or more "master modules" can inhibit acquisition in all other modules based on their local hit pattern.

In the Pixie Viewer, the module coincidence is configured in the CHASSIS SETUP panel (Fig. 7.4). With the checkboxes in the "Module Coincidence Setup" block, each module can be set to accept events if

a) only the local coincidence test is passed (check "*local*")

b) only the global coincidence test is passed (check "*global*")

c) either the local OR the global coincidence test is passed (check "*global*" and "*local*")

d) the global test AND local tests from all "master modules: pass (check "*global*" for all module and "*local adds to global*" for the "master modules)

Other checkboxes and controls define if a module sends its hit pattern to slot 2, if a module is writing the global coincidence control word to a neighboring PDM, and the control word to write. There is also a checkbox for each module to send the hit bit of its channel 3 to the status line. As the status line information is included in the event hit pattern in all modules, this allows one specific channel to contribute information to the event records of all modules.

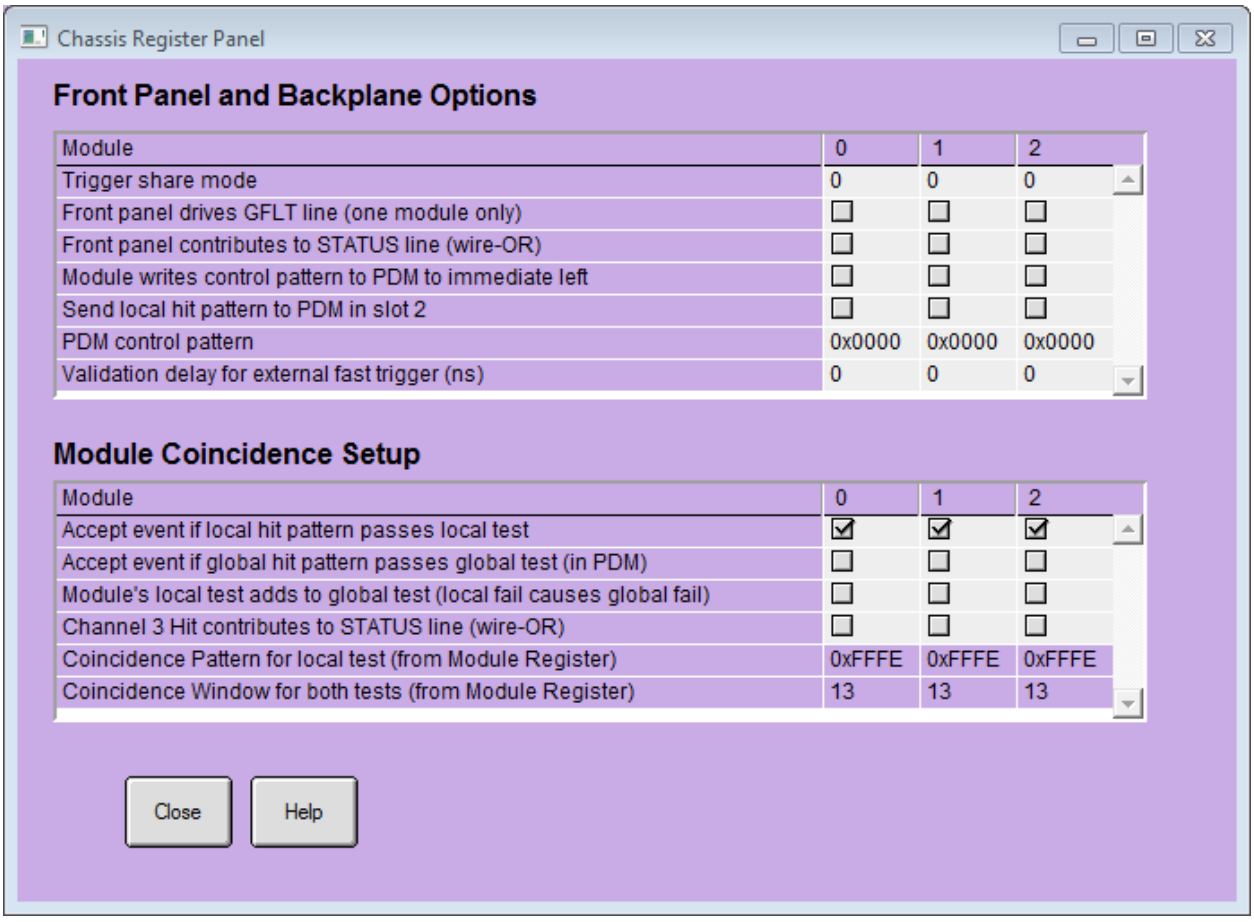


Figure 7.6 Module coincidence setup in the Pixie Viewer

Examples:

1. To require a local coincidence of channels 0-1, 2-3, or both (as above), set the coincidence pattern to 0x9008 in the ModuleRegisterPanel and check only the "local test" box in the Chassis RegisterPanel
2. To require coincidence of channels 0 and 1 in Module 0, and no other channel/module matters, in the ModuleRegisterPanel set the coincidence pattern in Module 0 to 0x8888 and in all other modules to 0xFFFF. In the Chassis Register Panel, check the "global test" box for all modules and the "local adds to global" box for module 0. No PXI PDM is required.
3. To require at least 3 channels to be active in all modules, use a PDM module in slot 2 and set the [PDM control pattern] to 0x0013 for the module in slot 3. Make sure the [Module writes control pattern ...] box is checked for this module and the [Send local hit pattern to PDM] box is checked for all modules. Then check the "global test" box for all modules

8 Using Pixie-500 Express Modules with Clover detectors

Not yet implemented

When working with clover detectors, the Pixie-500 Express can be operated in a specific “clover mode”. In this mode, the DSP will calculate the pulse height for each channel as in normal operation, and in addition – for events with hits in more than one channel – calculate the sum of

individual channel energies. The result, the full energy of gamma rays scattered within the clover detector, is binned in an additional “addback” spectrum.

In the current implementation of the clover mode, the spectrum length is fixed to 16K. The clover binning mode applies all runs, but in list mode runs, no sum energy is reported in the list mode data. The clover mode is enabled by setting the corresponding checkbox in the Pixie Viewer’s Module Control Register panel. There is also the option of binning only those events in the individual channel spectra that do not have multiple hits.

Additional clover functions are under development.

9 Troubleshooting

9.1 Startup Problems

1. **When starting the Pixie Viewer, IGOR reports compile error or missing module**
   For IGOR to start up properly, a number of driver files have to be in the correct locations. In particular, the file "pixie.xop" has to be located in the "Igor Extensions" folder – usually C:\Program Files\Wavemetrics\Igor Pro\Igor Extensions in a default installation – and the file "PlxApi650.dll" has to be in C:\Windows\System32 (or the 64 bit equivalent)

2. **When starting up modules in the Pixie Viewer, downloads are not "successful"**
   This can have a number of reasons. Verify that
   - The files and paths point to valid locations (run the "UseHomePaths" macro)
   - The serial numbers entered in the Startup panel match the location of the modules.

3. **OSCILLOSCOPE *Refresh* results in no or bad data, history window reports error of DMA timeout:**
   - The SDRAM may have to be reinitialized. Please reboot the module.

9.2 Acquisition Problems

1. **Signal from PMT shows unusual pulse shape**
   Verify the input jumpers are set to the correct termination. When taking the signal directly from the PMT without a preamplifier, the correct termination is usually 50Ω

2. **Missing peaks in spectra**
3. **Unusually low count rate**
4. **Unusually low Live Time**
   Open the OSCILLOSCOPE and verify that the signal is in range, i.e. that large pulses are not cut off at the upper end of the range (16K) and that the baseline is above zero

5. **Low efficiency for high energy peaks in MCA spectrum**
   At high rates, pulses overlap with the decaying tail of a previous pulse. When two or more pulses overlap in this way, higher energy pulses are more likely to go out of range

=> reduce gain and/or adjust the offset

If the detector output shows significant ringing or overshoots, it can happen that the Pixie-500 Express triggers twice on the same pulse (first on the rising edge, then on the overshoot). This would be more likely for higher energy pulses, because the ringing or overshoot has a larger amplitude.
=> increase the trigger threshold and/or the trigger filter rise time or use the advanced options to "pause" or (for low count rates) disable the pileup inspection.

6. **Data collection in list mode has low DAQ fraction**
7. **SFDT is a large fraction of the live time**
8. **Rate at which list mode data is written to file is low**
   The number of events collected in a given time depends on a) the data per event, b) time required to record an event, and c) the data transfer rate.
   To reduce a),
   - shorten the tracelength as much as possible (even in compressed list mode!)
   To reduce b)
   - in compressed list mode runs, set the tracelength to zero, if no pulse shape analysis is required,
   To increase c)
   - avoid frequent updates of run statistics and spectra
   - set the polling time to a small value (0.1-0.01)

9. **Bad energy resolution in MCA spectrum**
   - verify the decay time is set correctly
   - increase energy filter rise time
   - make the energy filter flat top approximately equal to the rise time of the pulse
   - ensure the "integrator" is set to zero
   - if "integrator" is set to 1 on purpose (e.g. fast scintillator pulses), make sure the energy filter flat top covers the entire pulse
   - if "integrator" is set to 2 on purpose (e.g. square pulses), make sure the energy filter flat top covers the portion of the pulse that should be disregarded for the energy measurement (e.g. the rising edge)

10. **Signals are unusually noisy and show a consistent offset between even and odd samples**
    - *Calibrate* the ADC gain and offset matching of the cores. Calibrations are reset at every power cycle or reboot of the module. The process started with the button in the OSCILLOSCOPE panel will measure the mismatch, then modify the gain and offset match in an iterative process.

10 Appendix A

This section contains hardware-related information.

10.1 Front end switches for termination and attenuation

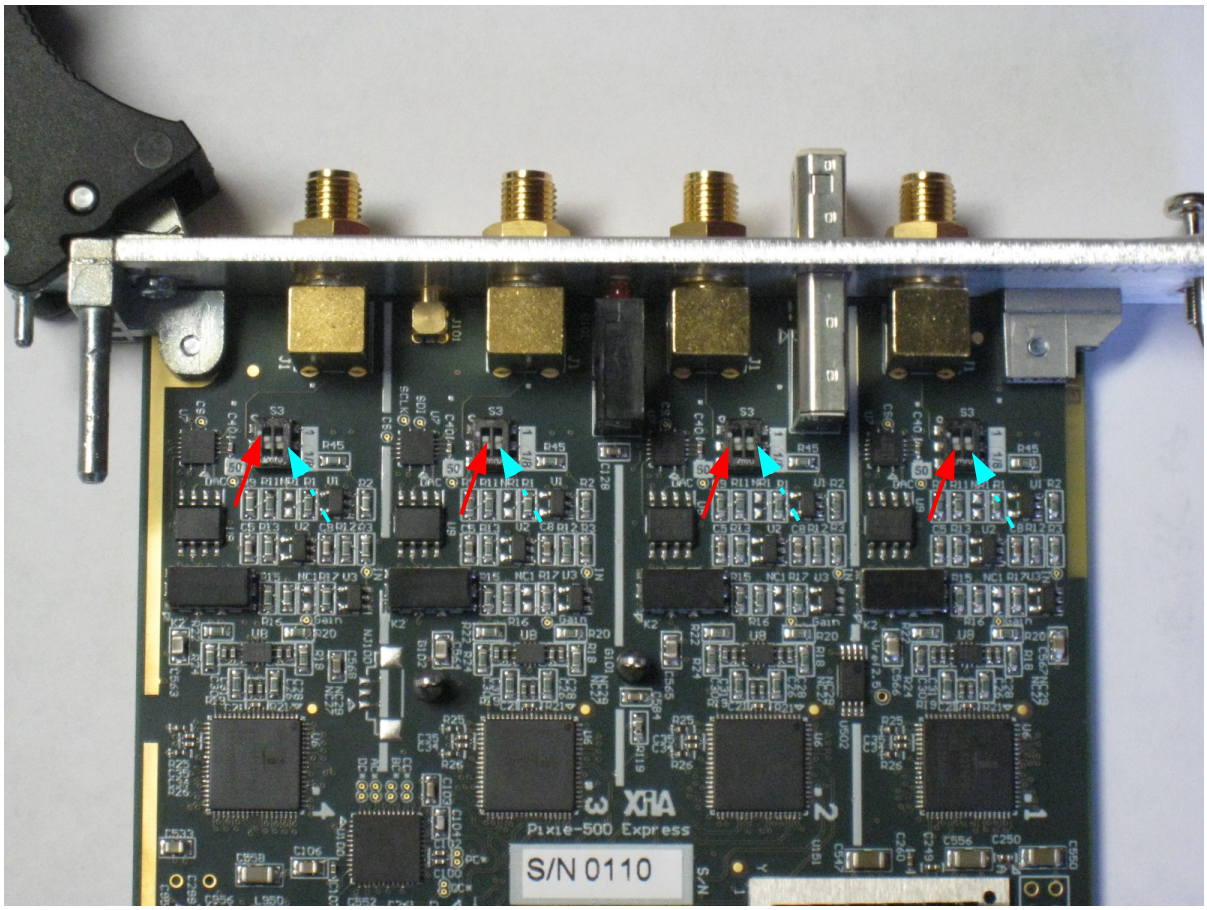


Table 10.1: Analog conditioning selection switches on Pixie-500 Express modules. Switches are marked with solid red (50Ω) and dashed blue (attenuation) arrows. On the PCB, inverse labels describe the switch positions.

Switch reference	PCB Label	Function
S3.x(a)	"1" "1/8"	Attenuation will be 1:1 or 1:8
S3.x(b)	"50"	Input impedance will be 50Ω. or 2KΩ.

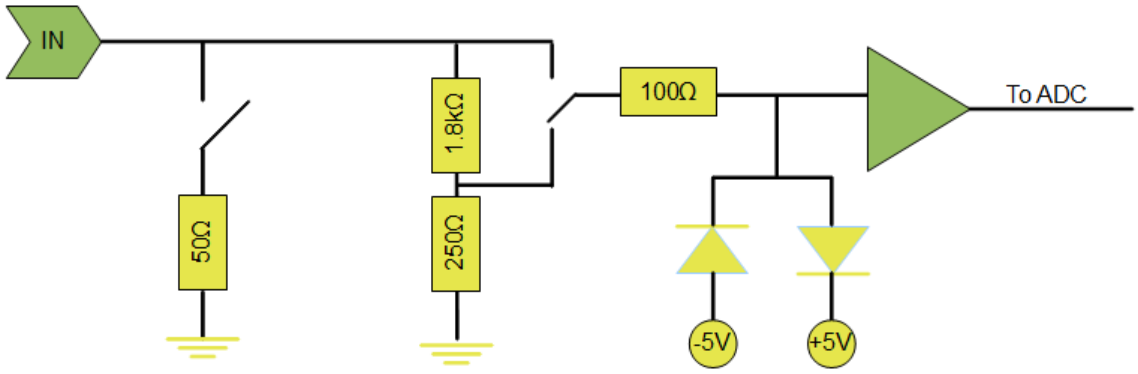


Figure 10.1. Simplified input stage of Pixie-500 Express showing switches, input termination and attenuation, and the overvoltage protection circuit.

10.2 LEDs

The Pixie-500 Express has 3 LEDs on the front panel.

A green LED indicates the firmware has been booted correctly and clocks have been programmed.

A yellow LED indicates that a run is in progress. This can be a very short flash, e.g. for parameter I/O, or continuous, for data acquisition runs.

A red LED indicates an error occurred. Currently that will be one of two cases:
a) the module has been powered up, but not booted yet
b) in a list mode run, the SDRAM has been filled with data so that the acquisition has been paused. Acquisition will resume (and the LED goes off) if the host catches up with data readout.

10.3 PXI backplane pin functions

Table 10.3: Pins of the J2 or XJ4 backplane connector defined in the PXI(e) standard used by the Pixie-500 Express.

PXI J2 pin	PXIe XJ4 pin	pin name	Connection Type	Pixie pin function
1A		LBL9*	Left neighbor	Event Trigger output (chained OR)
3A		LBR7*	Right neighbor	reserved
16A	7A	TRIG1	Bussed	Clock synchonization
17A	6A	TRIG2	Bussed	Veto
18A	5A	TRIG3	Bussed	Sync
19A		LBL2*	Left neighbor	Sync output (chained OR)
20A		LBR4*	Right neighbor	reserved
21A		LBR0*	Right neighbor	Clock output
16B	7B	TRIG0	Bussed	Fast Trigger
18B	5B	TRIG4	Bussed	Status
20B		LBR5*	Right neighbor	reserved
1C		LBL10*	Left neighbor	Fast Trigger output (chained OR)
3C		LBR8*	Right neighbor	reserved
18C	5C	TRIG5	Bussed	Token
19C		LBL3*	Left neighbor	Control data to PDM (left)
20C		LBL0*	Left neighbor	Clock input
2D		LBL7*	Left neighbor	GATE input channel 3
3D		LBR9*	Right neighbor	Event Trigger input (chained OR)
15D	8D	LBL6	Left neighbor	GATE input channel 2
17D	6D	STAR	Star trigger to slot 2	Hit pattern to slot 2
19D		LBL4*	Left neighbor	GATE input channel 0
21D		LBR2*	Right neighbor	Sync input (chained OR)
2E		LBL8*	Left neighbor	reserved
3E		LBR10*	Right neighbor	Fast Trigger input (chained OR)
15E	8E	LBR6	Right neighbor	reserved
16E	7E	TRIG7	Bussed	Bussed Clock
17E	6E	CLK10	Clock	PXI Clock
19E		LBL5*	Left neighbor	GATE input channel 1
21E		LBR3*	Right neighbor	reserved

* not available in PXIe standard