Digital X-ray Processor User's Manual

$Rev: 12013 $

Model DXP Saturn USB2

Revision: C

With

ProSpect

version 0.1.x

XIA, LLC

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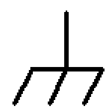
Safety

Please take a moment to review these safety precautions. They are provided both for your protection and to prevent damage to the Digital X-ray Processor (DXP) and connected equipment. This safety information applies to all operators and service personnel.

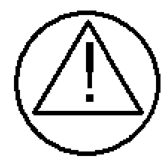
Symbols

These symbols appear on equipment, as required for safety:

DANGER
High Voltage



Protective
ground (earth)
Terminal



ATTENTION
Refer to the
manual

Specific Precautions

Observe all of these precautions to ensure your personal safety and to prevent damage to either the DXP Saturn or equipment connected to it.

Power Source

The DXP Saturn is intended to operate from a mains supply voltage of *either* 115V *or* 230V at 50-60Hz: THE REAR PANEL LINE VOLTAGE SELECTION SWITCH MUST BE SET before the system is powered on. Refer to the “Getting Started” section of the user manual for instructions on supply selection. Supply voltage fluctuations are not to exceed 10% of the nominal value. A protective ground connection, through the grounding conductor in the power cord, is essential for safe system operation.

Use the Proper Fuse

To avoid a fire hazard use only Time Lag 5mm x 20mm (IEC 127-2/III), 250mA fuses rated for 250V. A spare fuse is provided in the fuse drawer located at the power entry point.

User Adjustments/Disassembly

All user adjustments are accessible via the top panel. Do not attempt to remove any other panels or components. To avoid personal injury, and/or damage to the DXP Saturn, always disconnect power before removing the top panel.

Servicing and Cleaning

To avoid personal injury, and/or damage to the DXP Saturn, do not attempt to repair or clean the unit. The DXP hardware is warranted against all defects for 1 year. Please contact the factory or your distributor before returning items for service.To avoid personal injury, and/or damage to the DXP Saturn, do not attempt to repair or clean the unit. The DXP hardware is warranted against all defects for 1 year. Please contact the factory or your distributor before returning items for service.

End Users Agreement

XIA LLC warrants that this product will be free from defects in materials and workmanship for a period of one (1) year from the date of shipment. If any such product proves defective during this warranty period, XIA LLC, at its option, will either repair the defective products without charge for parts and labor, or will provide a replacement in exchange for the defective product.

In order to obtain service under this warranty, Customer must notify XIA LLC of the defect before the expiration of the warranty period and make suitable arrangements for the performance of the service.

This warranty shall not apply to any defect, failure or damage caused by improper uses or inadequate care. XIA LLC shall not be obligated to furnish service under this warranty a) to repair damage resulting from attempts by personnel other than XIA LLC representatives to repair or service the product; or b) to repair damage resulting from improper use or connection to incompatible equipment.

THIS WARRANTY IS GIVEN BY XIA LLC WITH RESPECT TO THIS PRODUCT IN LIEU OF ANY OTHER WARRANTIES, EXPRESSED OR IMPLIED. XIA LLC AND ITS VENDORS DISCLAIM ANY IMPLIED WARRANTIES OF MERCHANTABILITYOR FITNESS FOR A PARTICULAR PURPOSE. XIA'S RESPONSIBILITY TO REPAIR OR REPLACE DEFECTIVE PRODUCTS IS THE SOLE AND EXCLUSIVE REMEDY PROVIDED TO THE CUSTOMER FOR BREACH OF THIS WARRANTY. XIA LLC AND ITS VENDORS WILL NOT BE LIABLE FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES IRRESPECTIVE OF WHETHER XIA LLC OR THE VENDOR HAS ADVANCE NOTICE OF THE POSSIBILITY OF SUCH DAMAGES.

Contact Information:

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Telephone:	(510) 401-5760
Downloads:	http://xia.com/DXP_Saturn_Download.html
Hardware Support:	support@xia.com
Software Support:	software_support@xia.com

1 Introduction

The Saturn Digital X-ray Processor (DXP) is a high rate, digitally-based, multi-channel analysis spectrometer designed for energy dispersive x-ray or γ-ray measurements. The Saturn offers complete computer control over all amplifier and spectrometer controls including gain, filter peaking time, and pileup inspection criteria. The digital filter typically increases throughput by a factor of two or more over available analog systems at comparable energy resolution but at a lower cost. The Saturn is easily configured to operate with a wide range of common detector/preamplifier systems, including pulsed optical reset, transistor reset, and resistive feedback preamplifiers. The Saturn is controlled via the Universal Serial Bus (USB 2.0).

1.1 DXP Saturn Features:

- Single unit replaces spectroscopy amplifier, shaping amplifier, multi-channel analyzer and detector bias HV supply at significantly reduced cost.
- Operates with a wide variety of x-ray or γ-ray detectors using preamplifiers of pulsed optical reset, transistor reset or resistor feedback types.
- Instantaneous throughput up to 500,000 counts/second.
- Digital trapezoidal filtering, with programmable peaking times between 0.25 and 80 μsec.
- High precision internal gain control.
- Sophisticated pileup inspection criteria under computer control, including fast channel peaking time, threshold, and rejection criterion.
- Accurate ICR and live-time reporting for precise dead-time corrections.
- Multi-channel analysis with up to 8K bins, allowing for optimal use of data to separate fluorescence signal from backgrounds.
- Supplies preamplifier power on a NIM standard DB-9 connector.
- Supplies detector bias HV up to ± 1000V, with LN sensor HV inhibit input.
- External Gate and Sync signals synchronize data acquisition with external setup, for x-ray mapping and other specialized applications.
- Auxiliary bus with up to 24 digital I/O lines for custom applications.

1.2 Saturn Sub-Types

There are several hardware and firmware variants available for the Saturn, each with different combinations of the available options.

Name / Part#	*Timing*	*Extended Memory*	*ROI*	*ADC Clock*
SATURN	No	No	No	20 MHz
SATURN-TM0	Yes	No	No	20 MHz
SATURN-TM4	Yes	Yes	No	20 MHz
SATURN-ROI	No	No	Yes	20 MHz
SATURN-40	No	No	No	40 MHz
SATURN-ALL	Yes	Yes	Yes	40 MHz

Table 1.1: Saturn hardware/firmware variants.

1.2.1 SCA Timing Option (TM0)

This is a firmware option that allows for time-resolved single channel analyzer (SCA) data acquisition, or SCA Mapping. The GATE and/or SYNC inputs are used to increment the pixel and corresponding SCA table.

1.2.2 Extended Memory Timing Option (TM4)

The addition of 4 Mbytes of external memory allows for time-resolved full multi-channel analyzer (MCA) acquisition.

1.2.3 ROI Output Option (ROI)

The Auxiliary port is configured as a region-of-interest (ROI) output, with 16 digital output lines, each corresponding to a user selected ROI.

1.2.4 40MHz ADC Clock Option (40)

Doubling the ADC clock speed allows for shorter peaking times and thus higher maximum output count rates.

1.2.5 40MHz, ROI, Extended Memory Timing (ALL)

This deluxe variant includes all of the above hardware and firmware options.

1.3 System Requirements:

The digital spectroscopy system considered here includes a host computer, a DXP Saturn and an x-ray detector with a preamplifier. Please review this section to verify the compatibility of other system components with the DXP Saturn.

1.3.1 Host Computer

Windows 98/XP/NT/2000 computer with an available EPP port...

The DXP Saturn communicates with a host computer via USB 2.0. The USB 2.0 interface is described further in section 6.5. The host computer that runs XIA LLC’s ProSpect software must have the following minimum capabilities:

- ✓ 300 MHz or greater processor speed running most Microsoft Windows Operating systems (2000, XP).
- ✓ At least one available USB 2.0 port.

1.3.2 Detector:

Low current, high voltage devices can be powered by the DXP Saturn.

The DXP Saturn includes a high voltage supply for biasing solid-state and gas detectors, with the following specifications:

Parameter	*Value*
Bias voltage range*	+/-1000V
Output impedance	1.1MegΩ
Current Derating**	1.10V/µA
Maximum turn-on/off rate (fast mode - default)	100V/s
Maximum turn-on/off rate (slow mode)	20V/s

Table 1.2: Detector bias voltage supply specifications.

*Up to +/-5,000V with specially ordered assemblies.
** The supply's load regulation does not include the output filter. The actual output bias voltage must be derated from the front panel displayed voltage by 1.10V for each microampere drawn.

The detector bias voltage exits via a rear panel SHV connector. The adjacent 'Inhibit' BNC input accepts most liquid nitrogen (LN) sensor signals, and shuts down the bias supply when the detector is warm. Please refer to Appendix A section A.1 for further details.

1.3.3 Preamplifier:

Preamplifier signal and power specifications must be verified.

The DXP Saturn accommodates nearly all preamplifier signals, and provides power for NIM-standard preamplifiers. The two primary capacitor-discharge topologies, pulsed-reset and resistive-feedback, are both supported. The input voltage range of the DXP analog circuitry results in the following constraints:

Parameter	*Minimum*	*Maximum*	*Typical*
X-ray pulse-height (w/ input attenuator)	250 µV (1 mV)	375 mV (1.50 V)	25 mV (100 mV)
Input voltage range (w/ input attenuator)	-	+/-10 V (+/-40 V)	+/-5 V (+/-20 V)

Table 1.3: Analog input signal constraints for pulsed-reset preamplifiers.

Parameter	*Minimum*	*Maximum*	*Typical*
X-ray pulse-height (w/ input attenuator)	250 µV (1 mV)	625 mV (2.50 V)	100 mV (400 mV)
Input voltage range (w/ input attenuator)	-	+/-3 V (+/-12 V)	+/-3 V (+/-12 V)
Decay time τ	100 ns	infinity	50 µs

Table 1.4: Analog input signal constraints for resistive-feedback preamplifiers. Note that the maximum input range is less than for pulsed-reset preamplifiers.

The DXP Saturn provides preamplifier power on a NIM standard DB-9 connector:

Pin #	Name	Supply Current	Description
1	GND	-	Internal signal ground connection – NOT chassis ground
2	GND	-	Internal signal ground connection – NOT chassis ground
3	IN_ALT	-	Alternate signal input, selected with jumper JP10 (BNC default)
4	+12V_OUT	100mA	+12V (+5V solder option) DC for preamplifier
5	NC	-	No connection –- solder option +5V connection
6	-24V_OUT	100mA	-24V DC for preamplifier
7	+24V_OUT	100mA	+24V DC for preamplifier
8	REF_ALT	-	Alternate signal reference, selected with jumper JP9 (BNC default)
9	-12V_OUT	100mA	-12V (-5V solder option) DC for preamplifier

Table 1.5: NIM standard DSUB9 preamplifier pin-out detail.

1.3.4 AC Power:

User may select either US or European/Int'l line voltage at the rear panel of the unit. Use the provided IEC certified power cable to connect the line voltage source to the DXP Saturn.

AC Line Voltage/Frequency:	115 V/60 Hz	230 V/50 Hz
Maximum Current Draw:	200 mA	100 mA

Supply voltage fluctuations are not to exceed 10% of the nominal value. All DC voltages necessary for operation are generated internally.

1.3.5 Environment:

Temperature Range:	0° C - 50° C
Maximum Relative Humidity:	75%
Maximum Altitude:	3,000 meters

Pollution degree 2
Installation Category II

1.4 Software Overview

Three levels of 'software' are required to operate the DXP Saturn: a user interface for data acquisition and control, a driver layer that communicates between the host software and the USB 2.0 port, and firmware code that is downloaded to and runs on the DXP Saturn itself.

1.4.1 User Interface: ProSpect

The user interface communicates with and directs the DXP Saturn via the driver layer, and displays and analyzes data as it is received. As such XIA provides ProSpect as a general-purpose data acquisition application. ProSpect features full control over the DXP Saturn, intuitive data visualization, unlimited

ROI's (regions of interest) Gaussian fitting algorithms and the exporting of collected spectra for additional analysis. Please refer to Chapter 3 of this manual for instructions on using ProSpect with the DXP Saturn. Some users may decide instead to develop their own software to communicate via the driver layer with the DXP Saturn. XIA offers the Accelerated DevelOPmenT (ADOPT) support option at an additional fee to such users. ADOPT is described in section 1.5.5.

1.4.2 Device Drivers: Handel/Xerxes

XIA provides source code for both high-level (Handel) and low-level (Xerxes) driver layers to advanced users who wish to develop their own software interface. XIA recommends using Handel for almost all advanced applications. Handel is a high-level device driver that provides an interface to the DXP hardware in spectroscopic units (eV, microseconds, etc...) while still allowing for safe, direct-access to the DSP. The trade-off for this ease of use is an increase in size. Handel is built on top of the Xerxes driver libraries. Xerxes is a more compact low-level driver library made available to expert users who need more flexibility than the Handel driver can provide. ProSpect uses the Handel driver, and thus also serves as a development example. Installation files and user manuals for Handel and Xerxes are available online at http://xia.com/DXP_Saturn_Download.html.

1.4.3 Firmware and FDD Files

Firmware refers to the DSP (digital signal processor) and FiPPI (FPGA = Field Programmable Gate Array) configuration code that is downloaded to, and runs on, the DXP Saturn itself. Typically one DSP file and four FiPPI files are necessary to acquire spectra across the full range of peaking times with a given detector/preamplifier. For simplicity XIA provides complete firmware sets in files of the form "firmware_name.fdd". This file format is supported by Handel, XIA's digital spectrometer device driver, and is the standard firmware format used in ProSpect. The FiPPI and DSP are discussed in Chapters 5 and 7. Firmware file formats are further described in Appendix D.

1.5 Support

A unique benefit of dealing with a small company like XIA is that the technical support for our sophisticated instruments is often provided by the same people who designed them. Our customers are thus able to get in-depth technical advice on how to fully utilize our products within the context of their particular applications. Please read through this brief chapter before contacting us.

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Hardware Support:	support@xia.com
Software Support:	software_support@xia.com

1.5.1 Software and Firmware Updates

Check for firmware and software updates at: http://www.xia.com/DXP_Resources.html

It is important that your DXP unit is using the most recent software/firmware combination, since most problems are actually solved at the software level. Please check http://xia.com/DXP_Saturn_Download.html for the most up to date standard versions of the DXP software and firmware. Please contact XIA at DXP@xia.com if you are running semi-custom or proprietary firmware code. (*Note:* It a good practice to make backup copies of your existing software and firmware before you update).

1.5.2 Related Documentation

As a first step in diagnosing a problem, it is sometimes helpful to consult most recent data sheets and user manuals for a given DXP product, available in PDF format from the XIA web site. Since these documents may have been updated since the DXP unit has been purchased, they may contain information that may actually help solving your particular problem. All manuals, datasheets, and application notes, as well as software and firmware downloads can be found at http://xia.com/DXP_Saturn_Download.html. In order to request printed copies, please send an e-mail to support@xia.com, or call the company directly. In particular, we recommend that you download the following user manuals:

- ✓ ProSpect User Manual – All users
- ✓ Handel User Manual – Users who wish to develop their own user interface

1.5.3 E-mail and Phone Support

The DXP Saturn comes with one year of e-mail and phone support. Support can be renewed for a nominal fee. Please call XIA LLC if your support agreement has expired.

The XIA Digital Processors (DGF & DXP) are digitally controlled, high performance products for X-ray and gamma-ray spectroscopy. All settings can be changed under computer control, including gains, peaking times, pileup inspection criteria, and ADC conversion gain. The hardware itself is very reliable. Most problems are not related to hardware failures, but rather to setup procedures and to parameter settings. XIA's DXP software includes several consistency checks to help select the best parameter values. However, due to the large number of possible combinations, the user may occasionally request parameter values which conflict among themselves. This can cause the DXP unit to report data which apparently make no sense (such as bad peak resolution or even empty spectra). Each time a problem is reported to us, we diagnose it and include necessary modifications in the new versions of our DXP control programs, as well as adding the problem description to the FAQ list on our web site.

Submitting a problem report:

XIA encourages customers to report any problems encountered using any of our software. Unfortunately, due to limited resources XIA is unable to handle bug reports over the phone. In most cases, the XIA engineering team will need to review bug information and run tests on local hardware before being able to respond.

All software-related bug reports should be e-mailed to software_support@xia.com and should contain the following information, which will be used by our technical support personnel to diagnose and solve the problem:

- ✓ Your name and organization
- ✓ Brief description of the application (type of detector, relevant experimental conditions...etc.)
- ✓ XIA hardware name and serial number
- ✓ Version of the library (if applicable)
- ✓ OS
- ✓ Description of the problem; steps taken to re-create the bug
- ✓ Supporting data:
  The most important are digital settings of the spectrometer unit, i.e., the values of the DSP parameters such as the decimation, filter length, etc. The values of these parameters can be captured into an ASCII file in ProSpect. Please attach a copy of this file if possible. Also attach related spectrum files. Capturing an oscilloscope image of the preamp output will also be extremely helpful, which can be done with the diagnostic tool included in ProSpect.

For general questions and DXP hardware issues please e-mail: support@xia.com.

1.5.4 Feedback

XIA LLC strives to keep up with the needs of our users. Please send us your feedback regarding the functionality and usability of the DXP Saturn and ProSpect software. In particular, we are considering the following development issues:

1.5.4.1 Export File Formats

We would like to directly support as many spectrum file formats as possible. If we do not yet support it, please send your specification to software_support@xia.com.

1.5.4.2 Calibration

Currently the hardware gain of the DXP Saturn is modified during energy calibration. This approach produces a calibrated spectrum directly from the hardware. The drawback is that the calibration process often takes several iterations to settle. The other approach to calibration is re-binning of the spectrum data. This is not difficult to do, but may produce confusion for the novice user. We are considering supporting this feature in future ProSpect releases.

1.5.5 The Accelerated DevelOPmenT (ADOPT) Program

The ADOPT program is a support plan for users developing custom software using any of our driver libraries. It is intended for those who wish to get direct access to the XIA software team and obtain hands-on training in the use of XIA software tools as a method of reducing overall software development time.

The standard ADOPT package provides 12 months of support divided as follows:

- 1 month: on-site support and priority phone/e-mail support.
- 11 months: priority phone/e-mail support.

The specific number of hours for on-site support and priority phone/e-mail support depend on the driver library being used. Typically, the person who will be doing the majority of the development will visit XIA LLC for a hands-on tutorial with the XIA LLC software team. The visitor will be encouraged to work at XIA LLC for anywhere from a few days to two weeks, depending on the specific situation and complexity of the project. By working on-site, visitors will have access to live experimental setups on which they will be able to test their software. Furthermore, the XIA LLC software team will be available to provide assistance and help immediately without the limitations of either e-mail or phone.

For situations where more time is required, additional hours of support may be purchased at XIA LLC's standard consulting rate.

This program supports both our Handel and Xerxes driver libraries as well as custom driver development. Please contact XIA LLC to determine which driver library is right for your application (software_support@xia.com).

1.6 Manual Conventions

Through out this manual we will use the following conventions:

Convention	Description	Example
»	The » symbol leads you through nested menu items and dialog box options.	The sequence **File»Page Setup»Options** directs you to pull down the **File** menu, select the **Page Setup** item, and choose **Options** from the sub menu.
Bold	Bold text denotes items that you must select or click on in the software, such as menu items, and dialog box options.	...expand the **Run Control** section of the **DAQExplorer** to access the run presets.
[Bold]	Bold text within [ ] denotes a command button.	**[Start Run]** indicates the command button labeled Start Run.
`monospace`	Items in this font denote text or	`Setup.exe` refers to a file called “setup.exe” on the host

	characters that you enter from the keyboard, sections of code, file contents, html links and syntax examples.	computer.
“window”	Text in quotation refers to window titles, filenames and quotations from other sources	“Options” indicates the window accessed via **Tools»Options**.
Italics	Italic text denotes a new term being introduced , or simply emphasis	*peaking time* refers to the length of the slow filter. ...it is important first to set the energy filter Gap so that SLOWGAP to *at least one unit greater than* the preamplifier risetime...
<Key> <Shift-Alt-Delete> or <Ctrl+D>	Angle brackets denote a key on the keybord (not case sensitive). A hyphen or plus between two or more key names denotes that the keys should be pressed simultaneously (not case sensitive).	<W> indicates the W key <Ctrl+W> represents holding the control key while pressing the W key on the keyboard
Bold italic	Warnings and cautionary text.	***CAUTION:*** *Improper connections or settings can result in damage to system components.*
CAPITALS	CAPITALS denote DSP parameter names	SLOWLEN is the length of the slow energy filter

2 Installation

***CAUTION:** Improper connections or settings can result in damage to system components. Such damage is not covered under the Saturn warranty.*

Please carefully follow these instructions. *It is possible to damage your detector and/or preamplifier if the connections and settings described below are not made properly*. The term 'jumper' is used throughout this section. Jumpers short two adjacent pins of a PCB header, and are employed in the DXP Saturn to achieve certain digital and analog settings. For the most part jumpers are placed on 3-pin headers, connecting the center pin to one or the other peripheral pin, similar to a single-pole-double-throw (SPDT) switch. In several cases two adjacent headers are used to achieve a dual-pole-dual-throw (DPDT) switch. In such cases jumper placements that span the two 3-pin headers are not allowed:

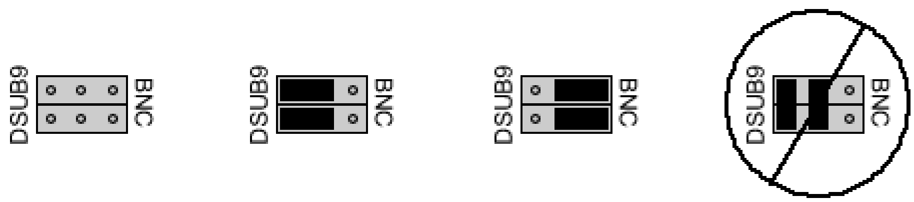


Figure 2.1: The header at left is empty. The second header includes jumpers selecting the 'DSUB9' connection, while the third is set to 'BNC'. The header at right has jumpers in a disallowed position.

Do not attempt to change jumper settings while the DXP Saturn is powered on. All jumper settings are accessed by first removing the top clamshell panel of the chassis. Refer to Figure 2.2 for jumper locations on the DXP Saturn. Appendix A describes the jumper settings, LED indicators and connector locations and part numbers in more detail.

2.1 Software Installation

Do not attempt to install the Saturn hardware until after the software and drivers have been installed. ProSpect operates on Windows XP and 2000 machines. Note that ProSpect also operates with the DXP Mercury. Firmware and libraries for both the Saturn and Mercury are installed. Updates to ProSpect are available online at:

`http://www.xia.com/DXP_Saturn_Download.html`

The update installation file is an executable, or .EXE file.

2.1.1 Running the Installer

1) Please close all applications that are currently running.
2) Insert the CD into the CD-ROM drive or, if your copy was delivered electronically, double-click the `setup.exe` program. If the CD installation does not start immediately, follow the instructions in steps (3) and (4).
3) Click the Start button and select the Run command.

4) Type `X:\Setup.exe` and click **[OK]**, where `X` is the letter of your CD-ROM drive.

5) After setup has completed, shut down your computer and complete the hardware configuration described in sections 2.2 through 2.5 before restarting.

- The ProSpect installation will create a new directory:

  `C:\Program Files\XIA\ProSpect 0.1`

- A new **Start Menu » Program** group will be created.
- A shortcut to the ProSpect executable is created on your desktop.
- The hardware driver file "xia_saturn_usb2.inf" is installed in:

  `C:\WINNT\inf`

  for Windows 2000, or

  `C:\Windows\inf`

  for Windows XP.

2.1.2 File Locations

After installation, ProSpect, by default, is located in:

`C:\Program Files\XIA\ProSpect 0.1`

This directory contains a sample INI file "saturn_usb2_reset.ini" that can serve as a starting point. After configuration and calibration the user should save to a unique INI file. Configuration code that is downloaded to the hardware, or firmware, is located in the "firmware" directory:

`~ \Firmware\Saturn`

This directory contains firmware, or FDD, files (see section 1.4.3):

File Name	*Preamplifier Type*	*ADC Clock Speed*
saturn_reset_revc.fdd	Pulsed Reset	20 MHz
saturn_reset_revc_40MHz.fdd	Pulsed Reset	40 MHz
saturn_rc_revc.fdd	RC Feedback	20 MHz
saturn_rc_revc_40MHz.fdd	RC Feedback	40 MHz

Table 2.1: Standard Firmware files.

Updates to the firmware are available online:

`http://www.xia.com/DXP_Saturn_Download.html`

2.1.3 Support

For the latest documentation, please refer to XIA's website at

`http://www.xia.com/DXP_Saturn_Download.html`

XIA LLC values feedback from customers. This feedback is an important component of the development cycle and XIA LLC looks to use this feedback to improve the software. All bug fixes and feature suggestions should be directed to software_support@xia.com. Please be sure to include as much information as possible when submitting a bug report. For further instructions please refer to section 1.5.

2.2 Line Voltage Selection and Fusing

***CAUTION:** Failure to properly set the Line Select switch before powering the unit can result in damage to the DXP Saturn and connected equipment*

The DXP Saturn can be set up to run on either 115 VAC or 230 VAC at 50/60 Hz. The recessed *Line Select* switch on the rear panel must be set to the appropriate position prior to powering the unit. The line voltage fuse can be replaced without opening the chassis. Use only 'Time Lag' 5mm x 20mm (IEC 127-2/III), 250mA fuses rated for 250V. A spare fuse is provided in the fuse drawer located at the power entry point. The power supply employs full-wave rectification and linear regulation to achieve the analog and digital DC voltage supplies. Each secondary AC voltage is also protected using a thermally resetting polymer fuse. *Nonetheless, failure to properly set the Line Select switch before powering the unit can result in damage to the DXP Saturn and connected equipment.*

2.3 Configuring the Analog Signal Conditioner

2.3.1 Input Signal Connection (BNC or DSUB9): JP9 and JP10

In a typical system power for the detector preamplifier will be supplied by the DXP Saturn via the NIM standard DSUB-9 'Preamplifier Power' connector. The output signal and its reference return via BNC coaxial cable to the DXP. Some manufacturers instead route the signal back through the preamplifier power cable in order to save space. The DXP Saturn accommodates either configuration. Jumpers JP9 and JP10 connect pins 8 and 3 of the DSUB9 connector to the BNC shield and BNC inner conductor, respectively. These jumpers are not stuffed by default, which is equivalent to stuffing the jumpers in the 'BNC' position.

*Refer to **Figure 2.2** for jumper locations.*

2.3.2 Input amplifier configuration: JP100 and JP101

JP100 and JP101 determine the topology of the input amplifier stage, either single-ended or differential. Single-ended mode should be used in almost all cases. Differential mode should be selected only if the preamplifier has a differential output and a balanced line is used, i.e. the signal and reference are carried on a twisted-pair in the DSUB9 cable.

RAMP for reset-type, OFFSET for RC feedback preamplifiers

2.3.3 Preamplifier Type—(RC-type vs Reset-type): JP104

The DXP employs different methods of analog signal conditioning, depending on the preamplifier type. Preamplifier types are described in detail in section 5.1. Briefly, RC-type refers to preamplifiers having resistive feedback, whose output signals thus exponentially decay after each x-ray pulse. Reset-type preamplifiers employ a feedback switch, resulting in a staircase waveform with periodic resets. The position of jumper JP104 determines which preamplifier type the Saturn will operate correctly with. The default position labeled "RAMP" should be used for reset-type preamplifiers. The position labeled "OFFSET" should be used for RC-type preamplifiers.

2.3.4 Input Attenuation: JP102

Attenuation may be necessary if the preamplifier gain is excessive and/or high-energy x-rays are to be processed. X-ray pulses under 300 mV in size can be accommodated without attenuation. The default position for JP102, labeled '0dB ATTEN', passes the signal directly. If larger signals must be processed, set JP102 to the '-12dB ATTEN.' position to reduce the signal by a factor of four.

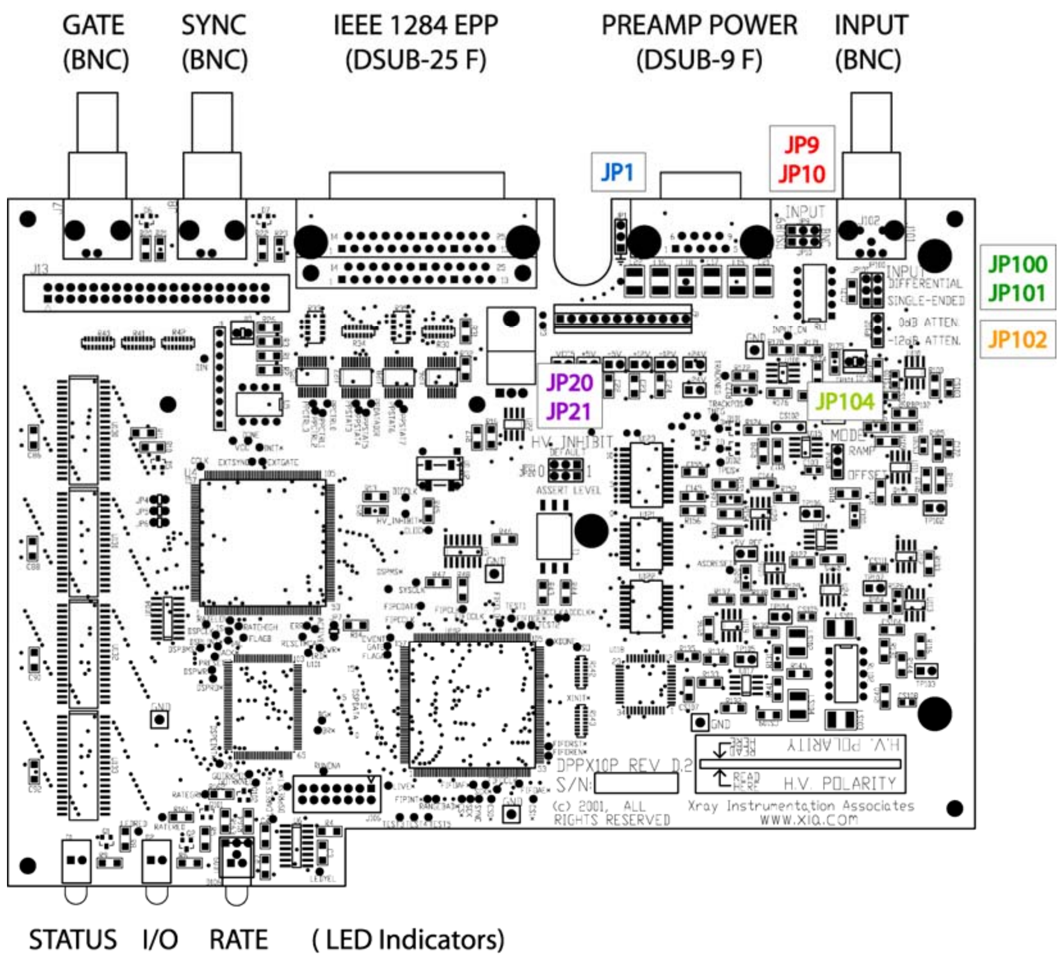


Figure 2.2: Diagram for the DPPX10P Revision D.2 printed circuit board.

2.4 Detector Bias Voltage Settings

> ***CAUTION:** Applying high-voltage of the wrong polarity or magnitude will almost certainly damage your detector.*

The DXP Saturn provides a detector bias voltage of up to ± 1,000 V. The output impedance is 1.1MegΩ due to low pass filtering. *The bias regulation circuitry and LCD display monitor the voltage before the series resistance, thus the actual output voltage must be derated by the output current flowing across 1.1MegΩ.*

2.4.1 Bias Voltage Polarity: PCB Key

Note: *Do not confuse detector bias polarity with the polarity of the preamplifier signal; which may be different. To change the high voltage polarity, the power must be turned off, and the top panel of the DXP Saturn removed.*

Check the polarity LEDs BEFORE attaching your detector.

The polarity of the high voltage is indicated by LEDs in the lower right of the front panel; the LED corresponding to the chosen polarity will glow when the unit is turned on: Yellow indicates that the high voltage is disabled; red indicates the supply is enabled and high voltage is appearing on the SHV output connector.

The polarity is set using the ‘HV Control Key’, the small printed circuit card with a finger hole that extends down through a slot in the top printed circuit board (PCB) to a card-edge connector in the bottom PCB. Align the proper polarity on the card with the arrow on the surface of the top board. As shipped, the units are set to –500V (negative). If you need to change the polarity, you should observe the front panel LEDs to confirm that you have completed the operation successfully before attaching the detector.

2.4.2 Bias Voltage Ramp Rate: JP1 (Power Supply Board)

Note: *Once enabled, the bias voltage ramps slowly to its set value at the user-defined rate. When disabled, the bias voltage ramps at the same rate back towards ground.*

The HV detector bias supply ramps up/down when enabled/disabled to prevent excessive power dissipation in the detector due to charging currents. Shorting jumper JP1 sets the ramping rate. *JP1 is located on the power-supply printed-circuit board mounted below the DPP board.* With some care it can be set using a pair of tweezers without removing the DPP board. Text adjacent to the jumper indicates either the “Slow” or “Fast” mode. The slow mode results in a 50-second ramp duration, with a maximum 20V/second at the 1,000V bias setting. The fast mode results in 10-second ramp duration, yielding a maximum 100V/second at 1,000V bias setting. The unit is shipped in fast mode, which is recommended for most x-ray applications.

2.4.3 Setting the L/N Sensor Inhibit Mode: JP20 and JP21

Note: *Many types of L/N sensors are commercially available, and XIA cannot guarantee proper performance with all types. It is strongly recommended that the functionality of the chosen configuration be tested prior to making the HV bias connection.*

The Inhibit function disables the detector bias voltage under a user-defined condition. The TTL/CMOS compatible input is typically connected to an external liquid nitrogen sensor that monitors the temperature of the detector and outputs a logic level, or presents a temperature-variable resistance, indicating whether the detector is ready for the bias voltage. The Inhibit input is *asserted* when the detector is warm, causing the Saturn to disable the HV supply.

The polarity of the asserted Inhibit signal is set with dual-pole jumper JP20. The two positions are labeled '0' and '1', corresponding to the logic level at which the bias supply is disabled, e.g. As in **Figure 2.3**(c) and (d), set JP20 to the '1' position if your L/N sensor asserts a high logic signal or presents a high resistance, i.e. open-circuit, when the detector is warm.

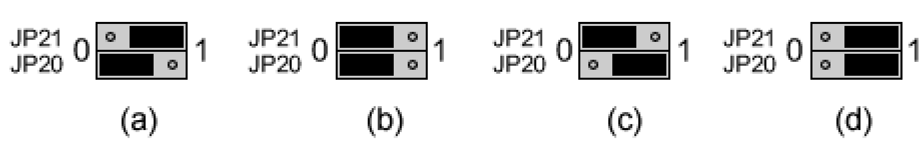


Figure 2.3: HV inhibit jumper connection examples:
(a) Inhibit asserts low (0) if detector is warm; HV is *not* disabled if Inhibit is open-circuit.

(b) Inhibit asserts low (0) if detector is warm; HV is disabled if Inhibit is open-circuit.
(c) Inhibit asserts high (1) if detector is warm; HV is *not* disabled if Inhibit is open-circuit.
(d) Inhibit asserts high (1) if detector is warm; HV is disabled if Inhibit is open-circuit.

Default operation for the open-circuit condition is selected w/ JP21. The open-circuit condition arises when a temperature-variable resistor sensor is in the warm state, and also applies to systems where the Inhibit input is simply not used. It is essentially a pull-up or pull-down resistor for the Inhibit logic input. Again, the two positions are labeled '0' and '1', corresponding to the default logic level applied, e.g. As shown in **Figure 2.3**(d) set JP21 to the '1' position if you want to disable the HV supply if the Inhibit input is open-circuit. ***The DXP Saturn is shipped as shown in Figure 2.3(a) and will thus supply high voltage without an attached L/N sensor.***

2.4.4 Setting the Bias Voltage

Note: *You will need a small flat-blade screwdriver to modify the bias voltage setting, accessible via the front panel.*

The DXP Saturn power must be turned on in order to set the bias voltage magnitude, which is set with a potentiometer accessible through the front panel using a small screwdriver. The front panel LCD display indicates the set value of the bias voltage, in Volts.

Once the displayed value is set properly, the supply may be turned on by pressing the recessed front panel “Enable” button. The front panel LED indicator should turn from yellow to red and the LCD should show the bias voltage as it ramps up to the prescribed voltage.

2.5 Making Connections

CAUTION: *Do not power the DXP Saturn until the line voltage has been properly selected, all internal settings have been made, and the top panel has be re-installed.*

CAUTION: *ALSO do not power the DXP Saturn until the high voltage polarity and value have been properly set has be re-installed.*

All electronic connections are made at the rear panel of the DXP Saturn. We recommend using cables under three meters in length for connections to the detector and preamplifier.

2.5.1 Connecting to the Detector/Preamplifier

The detector bias voltage connection uses standard SHV cable. If your detector uses either MHV or BNC for this connection, an adapter will be required. The bias voltage inhibit connection is made using standard a BNC cable. Preamplifier power is supplied via the NIM standard DSUB-9 ‘Preamplifier Power’ interface. The preamplifier output signal is connected either through a BNC cable or through the DSUB-9 cable used to supply preamplifier power. **CAUTION:** The DSUB-9 pinout, detailed in Table 2.2 below, is widely used in this industry. However, not all manufacturers adhere to it. *Verify the pinout for your detector/preamplifier before making the connection.*

P1 - Preamplifier Power: Connector: Output DC voltages to preamplifier: DSUB-9 Female (AMP P/N: 745781-4).		
Pin #	**Name**	**Description**
1	GND	Internal signal ground connection – NOT chassis ground
2	GND	Internal signal ground connection – NOT chassis ground
3	IN_ALT	Alternate signal input, selected with jumper

		JP10 (set to DSUB)
4	+12V_OUT	+12V (+5V solder option) DC for preamplifier
5	NC	No connection –- solder option +5V connection
6	-24V_OUT	-24V DC for preamplifier
7	+24V_OUT	+24V DC for preamplifier
8	REF_ALT	Alternate signal reference, selected with jumper JP9 (set to DSUB)
9	-12V_OUT	-12V (-5V solder option) DC for preamplifier

Table 2.2: Pin-out detail for the DSUB-9 preamplifier power connector.

2.5.2 Connecting to the Computer

The DXP Saturn communicates via the Universal Serial Bus (USB 2.0). Do not connect the USB cable until after the software has been installed. Windows should open the “Found New Hardware Wizard”, which guides you through the process of installing the USB driver.

Figure 2.4: Select “No, not this time” and press **[Next]**.

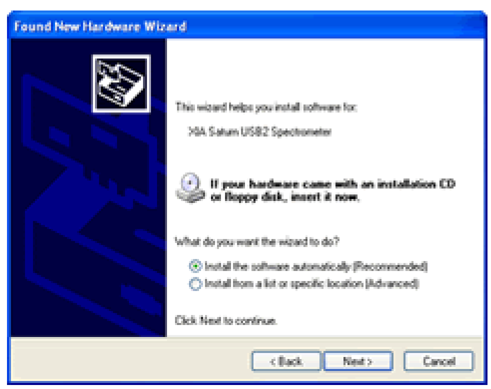


Figure 2.5: Select “Install the software automatically (Recommended)” and press **[Next]**.

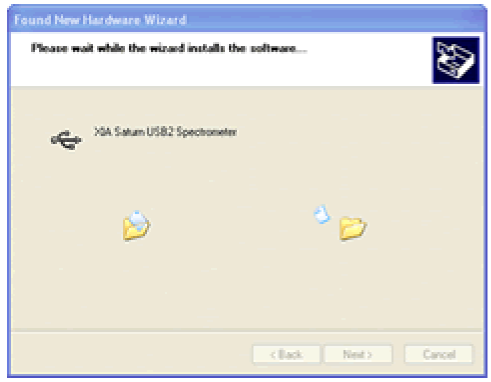


Figure 2.6: A warning about Windows Logo testing will pop up…

Figure 2.7: Press **[Continue Anyway]**.

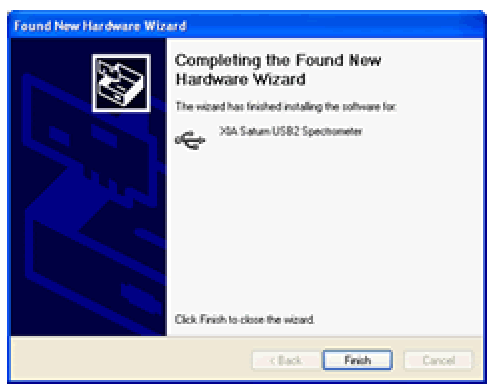


Figure 2.8: Press **[Finish]** to complete the driver installation.

3 System Configuration

At this point the ProSpect software and drivers should have been installed, and the Saturn hardware should be powered on and identified by Windows. This chapter will guide you in using the ProSpect Configuration Wizard utility.

3.1 Initialization Files

After power up the Saturn's DSP and programmable logic are in an unknown state. Program code, or firmware, for these devices must first be downloaded via the PCI bus before data can be acquired. After the devices are operational, user settings are downloaded.

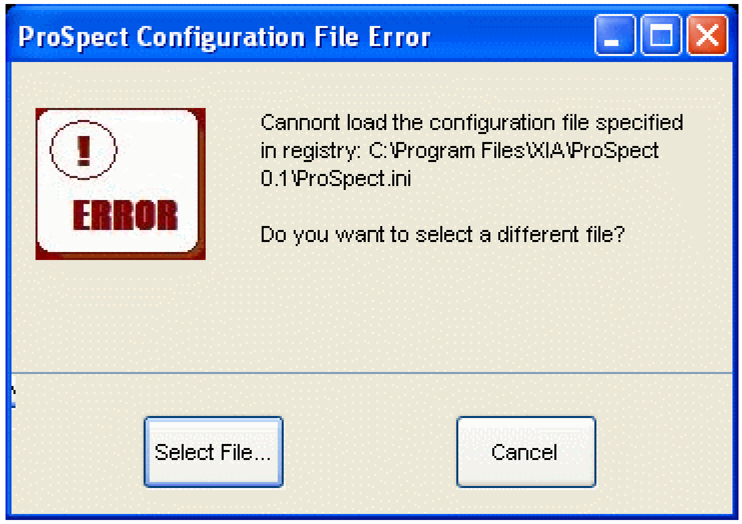
Handel (and thus ProSpect) uses an initialization (INI) file to store all necessary configuration information, including the path and filename of the firmware file on the host computer, number and slot location of Saturn modules in the system, detector characteristics and spectrometer settings, and timing and synchronization logic functions used. In order to start properly, ProSpect needs to have the following information:

- ✓ The location of the Saturn FDD firmware files (DSP and FPGA code that runs on the board, included in the installation package).
- ✓ Various properties of the detector preamplifier including type, polarity and gain.

INI files can be updated at any time, i.e. after the spectrometer settings have been optimized, and existing INI files can be loaded at any time. If you have previously run with ProSpect, your registry settings will point to the most recently used INI file, and ProSpect will automatically run with these settings upon startup.

3.1.1 Starting ProSpect without an INI File

Start ProSpect via the Start menu: Start > Programs > ProSpect 0.1 > ProSpect. The first time ProSpect starts up, the ProSpect Configuration File Error panel will appear, as shown in below.



***To open the Configuration Wizard:** Select "Configuration Wizard" from the "Tools" menu*

Figure 3.1: The Configuration File Error appears the first time you run ProSpect because a valid INI file has not been selected.

Press the **[Cancel]** button. The next section describes how to generate a customized INI file using the Configuration Wizard utility.

3.2 The Configuration Wizard

The Configuration Wizard utility can be launched at any time from the "Tools" menu in ProSpect.

3.2.1 General Settings

These basic settings are the bare minimum necessary to run the Saturn in normal single-spectrum mode.

1) **Welcome to the Prospect Configuration Wizard**
The first panel of the Configuration Wizard is simply a welcome screen with some information about the utility. Press **[Next]**.

2) **Module Interface**
Select the communications interface. For Saturn Revision C or later, select USB2 for USB 2.0. For Saturn Revision A or B, select USB1 for USB 1.0. For old DXP-X10P hardware, select EPP for extended parallel port interface.

3) **Detector Configuration**
Select the appropriate detector type**.** For **Reset** type, enter the **Reset Interval**. This is the time in microseconds that the preamplifier takes to reset and settle, and should be set conservatively to prevent associated voltage transients from entering the spectrum. If you don't know the reset time enter 10 (microseconds). For **RC Feedback** enter the RC **Decay Time** in microseconds. Click in the **Polarity** field to change the signal polarity (+ means a detector pulse has a rising-edge). Enter the **Gain** in milli-Volts per kilo-electron-Volt. Press **[Next]**.

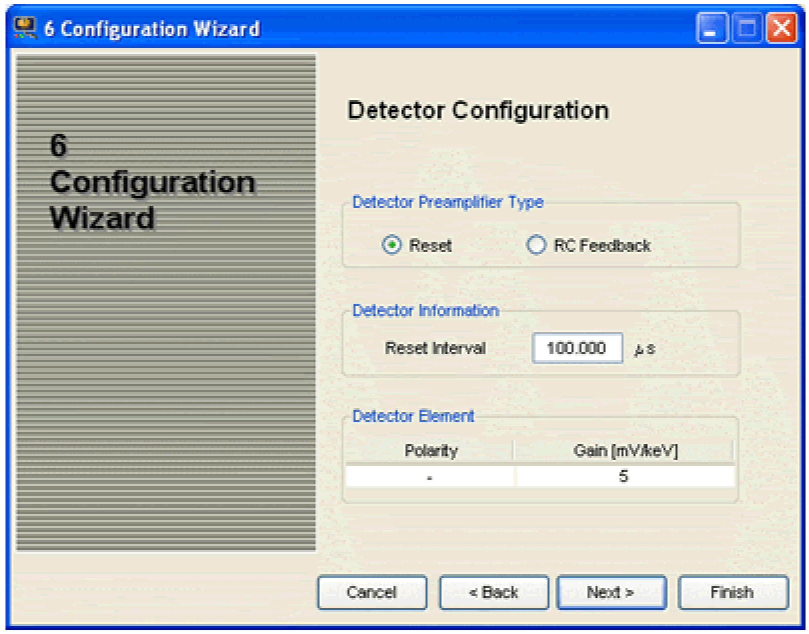


Figure 3.2: The Detector Configuration settings.

4) **Verify Preamp Type Jumper**
A reminder to set the hardware jumper according to the selected preamplifier type. See section 2.3.3.

5) **Firmware**
The firmware file contains all code for the programmable devices on the Saturn. Press the **[FDD File…]** button to browse to the appropriate FDD file and press **[Next]**. If you have updated your firmware since ProSpect was installed, be sure to select the new file. Note that different firmware files are required for pulsed-reset and RC-feedback type preamplifiers, and for 20MHz and 40MHz ADC clock rates (see section 2.1.2). Updates to the firmware are available online at:

`www.xia.com/DXP_Resources.html.`

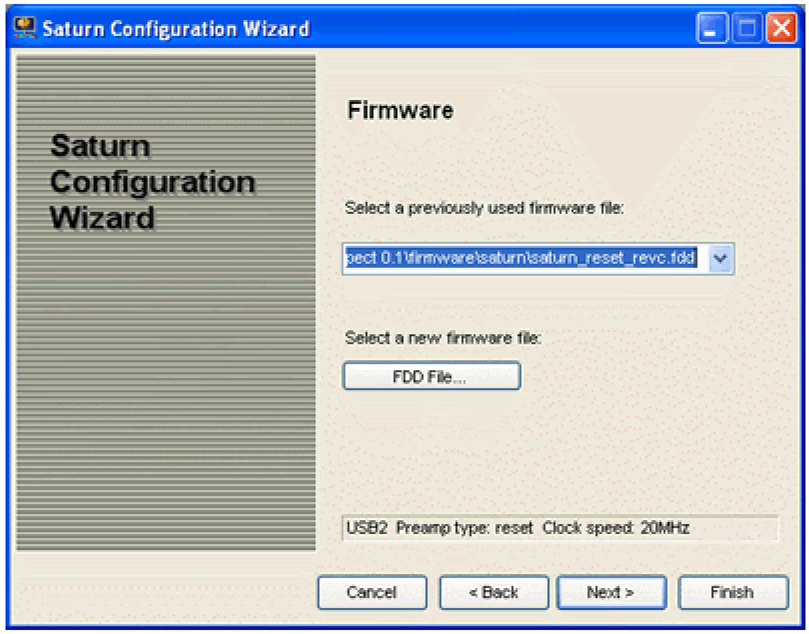


Figure 3.3: The firmware file contains program code for the Saturn's programmable devices.

6) **Save Completed Configuration**
The INI file you have created can now be saved. Select a unique name for the file, e.g. "saturn_vortex.ini". Press **[Finish]** to save the INI file and exit the **Configuration Wizard**. Note you must load the INI file to enact your changes.

3.3 Loading and Saving Initialization Files

INI files can be updated at any time, e.g. after spectrometer settings have been optimized, and existing INI files can be loaded at any time. If you have previously run with ProSpect, your registry settings will point to the most recently used INI file, and ProSpect will automatically run with these settings upon startup.

3.3.1 Loading an INI file

Select "Load Configuration…" from the File menu. Browse to and select an INI file that you just created and press "Open". ProSpect will download firmware and initialize the Saturn module.

3.3.2 Saving an INI file

INI files can be updated at any time by selecting "Save Configuration" or "Save Configuration As…" from the "File menu. You may find it useful to maintain several INI files, e.g. for operating with different detectors, or with different spectrometer settings.

4 Using ProSpect with the DXP Saturn

ProSpect is a PC-based application used with XIA's digital spectrometer products. ProSpect provides for the setup, optimization and failure diagnosis of the instrument, and allows for the reading out, displaying, analyzing and exporting of acquired energy spectra. A complete description of ProSpect can be found in the ProSpect User Manual. For the latest documentation, please refer to XIA's website at http://www.xia.com/DXP_Saturn_Download.html.

4.1 A Quick Tour of ProSpect

The installer should have created a shortcut for ProSpect on your Desktop in addition to a menu item for running and uninstalling ProSpect. When you start the program, the ProSpect main window should be displayed as in Figure 4.1. The **Settings** sidebar provides easy access to detector and acquisition settings. It is intended to be the primary interface for setup and optimization. Nearly all settings can also be accessed through the standard menus. The tabbed **Data Display** panel contains the MCA, Baseline, and ADC panels. The **Status Indicators** along the bottom display information about the state of the hardware and software. Zooming and panning can be customized using the **Display Controls** in conjunction with mouse operations both on the axes and in the data display area itself.

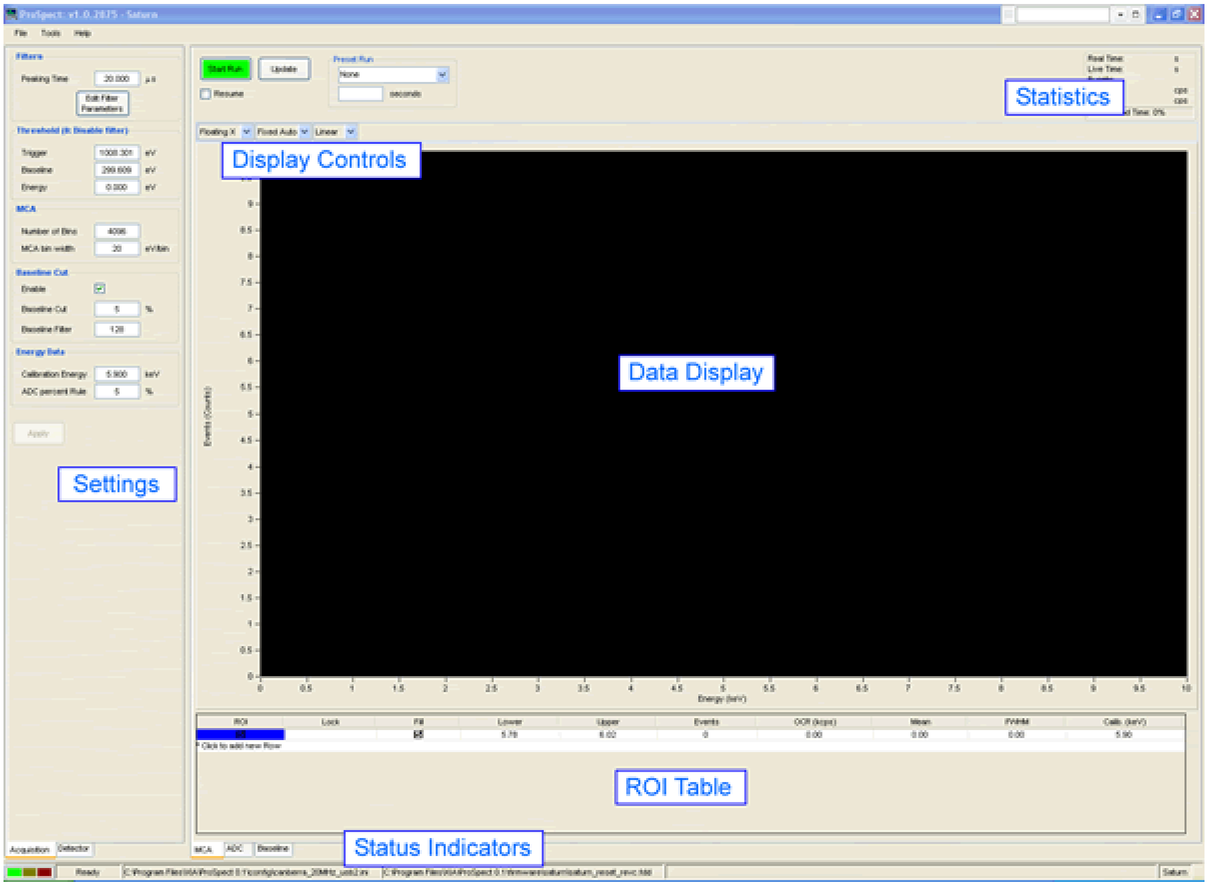


Figure 4.1: The ProSpect main window upon startup, after hardware initialization.

4.1.1 Settings Sidebar

The tabbed **Settings** sidebar provides easy access to hardware and firmware settings. It is intended to be the primary interface for setup and optimization. The **Acquisition** tab contains spectrometer settings such as peaking time and thresholds. The **Detector** tab contains detector and preamplifier settings such as polarity and gain.

4.1.2 Data Display Panel

The tabbed **Data Display** panel contains the **MCA**, **Baseline**, and **ADC** oscilloscope tool. The **MCA** tab is used for normal mode spectrum acquisition. Global MCA **Statistics** are displayed along the top. The **ROI Table** displays statistics for user specified spectral regions of interest. The **Baseline** tab displays the baseline histogram and history. The **ADC** tab contains the oscilloscope tool for displaying the digitized preamplifier signal. The **MCA** tab is used for normal mode spectrum acquisition.

4.2 Detector and Preamplifier Settings

If the Configuration Wizard was followed correctly as described in section 3.2, the system should be nearly ready for data acquisition. Before taking a spectrum, however, we recommend verifying the Detector and Preamplifier settings.

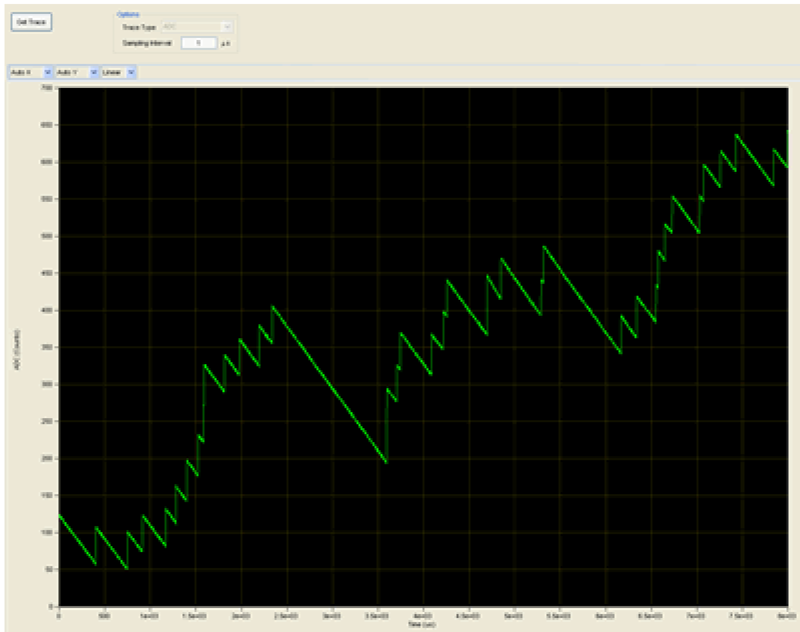


Figure 4.2: An ADC trace displayed in the **ADC** tab oscilloscope tool. Notice that the displayed x-ray events are voltage steps with *rising* edges, thus the polarity is set correctly.

Select the **ADC** tab in the data display panel to display the oscilloscope tool (see **Figure 4.2**). Set the **Sampling Interval** to "1.000" µs and press the **Get Trace** button to display an 8000-point raw ADC data set.

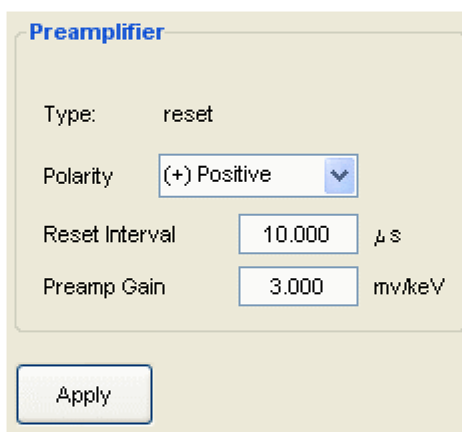


Figure 4.3: The **Detector** tab of the **Settings** panel.

Select the **Detector** tab of the **Settings** panel. The **Polarity** setting enables or disables a digital inverter depending on the signal polarity of the preamplifier. The **Reset Interval** is the settling time, in microseconds, of the preamplifier reset. The **Preamp Gain** is the gain, in milli-Volts per kilo-electron-Volt of the charge sensitive preamplifier. The **Apply** button downloads the adjusted setting(s) to the Saturn hardware. For a thorough discussion of oscilloscope diagnostic tool, please review section 4.6.1.

4.2.1 Preamplifier Type

The type of preamplifier is determined by code contained in the FDD (firmware) file. To change the preamplifier **Type,** create and/or select an INI file that points to the appropriate FDD file.

Note: Do not confuse detector bias polarity with the polarity of the preamplifier signal; they are not necessarily related.

4.2.2 Pre-Amplifier Polarity

Preamplifier polarity denotes the polarity of the raw preamplifier signal, NOT the detector bias voltage polarity. A positive polarity preamplifier produces a positive step, defined as a voltage step with a rising edge, response to an incident x-ray. The digital filters in the Saturn expect an input signal with positive steps. An optional input inverter is employed to correct the signal polarity for negative polarity preamplifiers. If the polarity has been set correctly, the ADC oscilloscope trace should display positive steps.

If the ADC trace displays positive steps (as in **Figure 4.2**), the polarity has been set correctly. If not, change the **Polarity** setting and press the **Apply** button. Acquire a new trace to verify that the polarity setting is correct.

Please read through section 4.6.1 for a thorough description and figures relating to the preamplifier signal polarity.

4.2.3 Reset Interval

The **Reset Interval** is the period of time after each preamplifier reset that the Saturn waits before re-enabling data acquisition. The delay is set based on the settling time of the preamplifier reset transient waveform, typically ranging from hundreds of nanoseconds to hundreds of microseconds. If you are unsure, enter "10" µs. Setting the delay shorter than the transient settling time may introduce ‘reset artifact’ events into the spectrum. Setting the delay longer than necessary introduces additional processor dead time, which will reduce the data throughput at high count rates.

4.2.4 Preamp Gain

The **Preamp Gain** setting, in combination with the **Calibration Energy** and **ADC Percent Rule**, controls the Saturn’s variable gain amplifier such that the input requirements of the ADC are satisfied, given the gain of the preamplifier. If you know the gain of your preamplifier, enter that value. Otherwise we recommend using the default value of 3mV/keV. This preliminary setting can then be adjusted automatically during energy calibration. In cases of extremely low or high preamplifier gain, it may be necessary to adjust the nominal gain before taking a spectrum. If the displayed x-ray steps are less than 20 ADC units in height, reduce the **Preamp Gain** setting. If the displayed x-ray steps are greater than 200 ADC units in height, increase the **Preamp Gain** setting.

4.2.5 Preamp Risetime

This is an advanced setting, accessible by pressing the **[Edit Filter Parameters]** in the **Acquisition** settings tab. The preamplifier risetime should be measured and the **Minimum Gap Time** set accordingly. This setting is described in detail in section 4.5.1.2. See section 4.6.1.2 for details on using ProSpect to measure the risetime for your system and section 5.3 for a theoretical discussion of the issues involved in trapezoidal filtering.

4.3 Spectrum Acquisition and Display

To begin data collection:

- *Press the* ***Start Run*** *button in the main spectrum window, or*
- **Saturn»Run Control»Start Run**

4.3.1 Starting a Run

Once the detector/preamplifier settings have been verified you are ready to collect a sample spectrum. Place a known X-ray source, for example an ^{55}Fe source that produces Mn K_{α} line at 5899 eV, such that x-rays impinge on the detector's active area at a moderate to low rate, i.e. less than 10,000 x-rays absorbed per second.

Select the **MCA** tab and press the **[Start Run]** button in the data display panel to begin data collection. An uncalibrated energy spectrum should appear. Figure 4.4 shows a sample uncalibrated ^{55}Fe spectrum. Proceed to section 0 if a spectrum is displayed.

No spectrum?
Check your hardware setup, e.g. x-rays present?

- ✓ *Check your initialization settings, e.g. preamplifier type and polarity correct?*
- ✓ *Troubleshoot the signal using the Oscilloscope tool, as described in §4.6.1.*

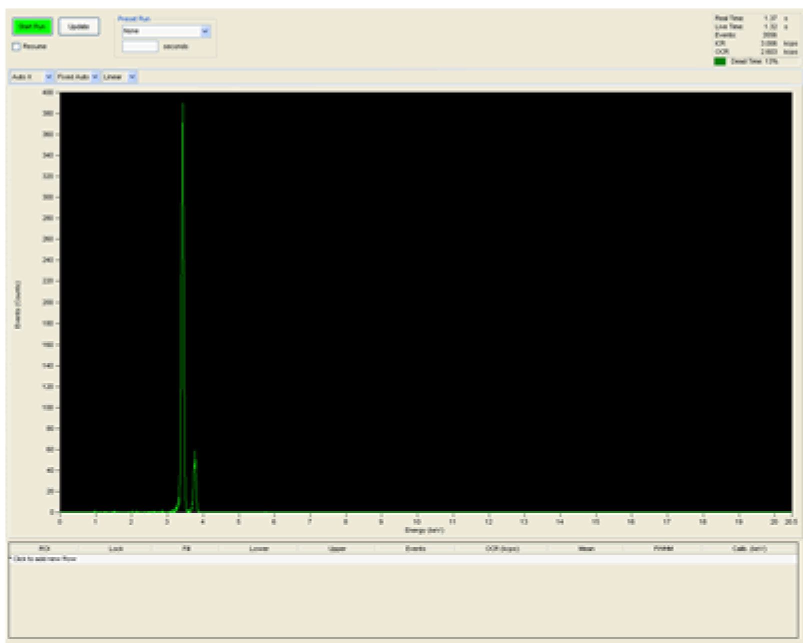


Figure 4.4: An uncalibrated ^{55}Fe spectrum.

Press the **[Refresh]** button to manually read out the MCA data, or check the **Continuous** checkbox to automatically refresh the spectrum. A horizontal line at zero on the y-axis indicates that no output events have been acquired, although the run is active. This can result from a hardware setup problem, e.g. x-rays not hitting detector; detector not powered, etc. Or it can result from incorrect configuration settings. The most common problem is incorrect detector/preamplifier settings. To troubleshoot these settings please refer to the Diagnostics section 4.6.

4.3.2 Peaking Time (Energy Filter)

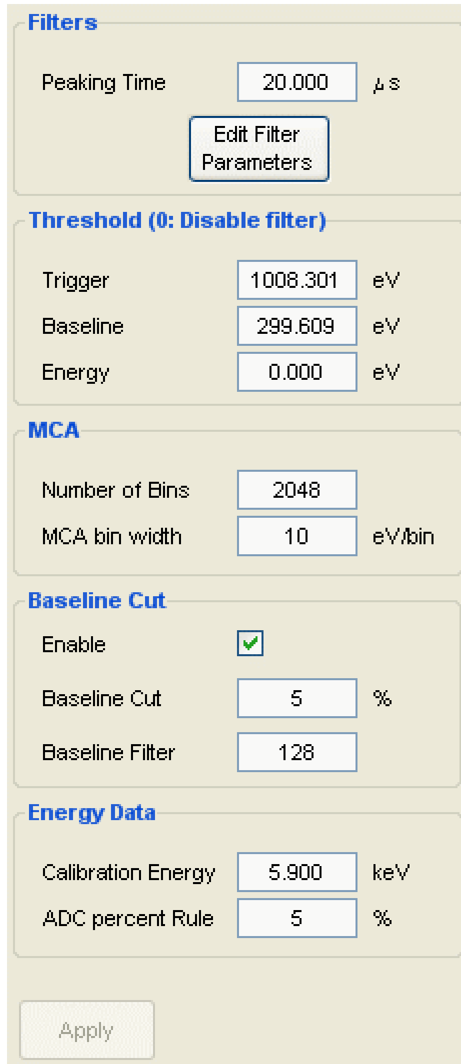


Figure 4.5: The **Acquisition** tab of the **Settings** panel.

Note: The energy filter peaking time is widely referred to as ***"peaking time"****, whereas the fast filter peaking time is referred to as* ***"fast peaking time"***

The energy filter peaking time is one of the primary user controls. Generally speaking, a longer peaking time produces better energy resolution at the cost of increased dead time, and thus lower output count rate. In practice, the user may set the peaking time to a shorter than optimal value in order to increase data throughput, making up for degraded energy resolution with improved statistics. Most detectors also have an upper limit above which the energy resolution gets worse. HPGe detectors typically have optimal peaking times between 16µs and 32µs. Silicon drift detectors often produce the best resolution at 10µs or less. On the other hand some SiLi detectors show resolution improvements out to 80µs or longer peaking times.

The default parameter settings relating to data acquisition, i.e. thresholds, baseline acquisition and pileup inspection criteria, reflect a compromise between robustness and performance. Energy resolution for a given peaking time can often be improved significantly if these settings are optimized. Optimization is described in section 4.5.

Making a plot of energy resolution versus peaking time provides a useful future reference.

You will generally find it useful, after making a first attempt to optimize settings, to capture a set of spectra over a wide range of peaking times, preferably over the full range that the Saturn supports and generate a plot of energy resolution versus peaking time. This will serve two purposes: first to serve as a standard of comparison, so that you can tell if further parameter adjustments are helping or not; and second, to provide you with some feedback about whether your spectroscopy system is behaving properly. Later, when everything is optimized and all the noise sources have been suppressed, you can go back and repeat these measurements to provide hard data for use in making the energy resolution versus count rate tradeoff described above.

Making a plot of energy resolution versus peaking time provides a useful future reference.

The **[Edit Filter Parameters]** button accesses additional filter parameters, including the energy gap time, the fast, or trigger, filter settings and pileup rejection parameters. The default filter settings reflect a compromise between robustness and performance and typically do not need to be changed. In some cases energy resolution for a given peaking time can be improved significantly if these settings are optimized as described in section 4.5.

4.3.3 Setting Thresholds

Proper settings for the filter output thresholds are critical to achieving the best performance.

4.3.3.1 Trigger Threshold

The trigger, or fast, filter threshold sets the low-energy limit for the fast filter, which is used primarily for pileup inspection. If the baseline threshold is employed, the *detection* of x-rays actually extends to energies significantly below the trigger threshold (see section 4.3.3.2). For this reason it is not necessary to set the trigger threshold aggressively, i.e. setting the threshold *as low as possible* will derive little benefit. If set too low, the trigger threshold will introduce a zero energy noise peak into the spectrum. In extreme cases it will halt data throughput entirely.

To optimize the fast filter threshold, set the **Baseline Threshold** to zero (so that output events are generated by fast filter triggers only), edit the **Trigger Threshold** value and press **[Apply]**. Typical values range from 600eV to 1500eV. A good procedure is to initially set the value too high, reduce it until the zero energy noise peak starts to become significant, and then raise it again until the noise peak is eliminated.

The fast filter length is independent of the energy filter length, or peaking time, thus the trigger threshold does NOT need to be optimized every time the peaking time is changed. All thresholds must be readjusted if the gain changes significantly.

4.3.3.2 Baseline Threshold

Note: The baseline threshold is not available for decimation 0, i.e. peaking times less than or equal to 500 ns.

The baseline threshold sets the low-energy limit for the intermediate, or baseline, filter, which is used for both baseline acquisition and low-energy x-ray detection. To optimize the baseline filter threshold, first optimize the trigger threshold as described above, then edit the **Baseline Threshold** value and press **[Apply]**. Typical values range from 150 eV to 1000 eV.

The baseline filter length is linked to the energy filter length, or peaking time, thus the baseline threshold should be optimized every time the peaking time is changed. All thresholds must be readjusted if the gain changes significantly.

Please review section **Error! Reference source not found.** for a detailed description of baseline acquisition and averaging. Section 4.6.2.1 describes the empirical optimization of the baseline threshold

4.3.3.3 Energy Threshold

CAUTION: In almost all cases the Energy Threshold should be set to zero. *An error term in the counting statistics is introduced when the Energy Threshold is enabled. For this reason it should only be enabled at low data rates.*

The energy threshold sets the low-energy limit for the slow, or energy, filter, which is used primarily for measuring the pulse-height, i.e. energy, of x-ray voltage steps. Triggering on the energy (slowest) filter can extend the detection range down to the lowest energies for a given detector, however, in most cases we recommend setting the **Energy Threshold** to zero. This is because the dead time associated with x-rays detected by the energy filter can not be directly measured. It remains available primarily for two special cases:

- A non-zero energy threshold is appropriate for ultra-soft x-ray detection at very low input count rates.
- A non-zero energy threshold may be used to extend the detection range for decimation 0, i.e. peaking times under 500 ns. Dead time and count rate statistics will however be distorted.

4.3.4 MCA Bins and Bin Width

The size and granularity of the spectrum can be easily adjusted. The number of spectrum bins sets the granularity of the acquired spectrum. The eV/Bin setting determines the size of each MCA bin in electron Volts. Together, these settings determine the dynamic range of the MCA: The resulting energy spectrum ranges from zero to a maximum equal to the number of spectrum bins multiplied by the set value of eV/Bin (e.g. a 40keV spectrum results from 2048 bins at 20eV per bin).

Note that these digital spectrum controls are independent of the analog signal gain control (more later), and it is possible to display an energy range far in excess of the detector, amplifier chain and/or ADC's capabilities (i.e. just because a 100keV spectrum is displayed doesn't mean that 80keV x-rays will show up).

4.3.5 Baseline Settings

Baseline selection and averaging is critical to optimum spectrum acquisition.

4.3.5.1 Baseline Cut

Often there are nonlinearities in the preamplifier signal, e.g. subsequent to the reset step, that result in spurious baseline samples. These samples will pollute the baseline average and thus degrade energy resolution. The DSP can inspect incoming baseline samples versus the statistical distribution, or histogram, of such samples and reject outliers prior to computing the running average. The **Baseline Cut** is the percentage of the peak of the histogram beyond which instantaneous baseline samples are rejected. We recommend enabling the cut, with a **Baseline Cut** value of 5.

4.3.5.2 Baseline Average

The baseline is the output of the energy filter in the absence of x-rays. A running average of baseline samples, acquired between x-ray events, is subtracted from the x-ray peak samples to arrive at the true energy of incident x-rays. A perfect detector and preamplifier would produce a constant baseline, however, in the real world the actual baseline varies. The number of **Baseline Average** samples can strongly affect performance. More samples improve noise reduction but slow the reaction time to actual changes in the baseline. In most cases a value between 64 and 512 will produce the best results.

Please review section 5.4 for a detailed description of baseline acquisition and averaging. Section 4.6.2.2 describes the empirical optimization of the number of samples in the baseline average.

4.3.6 Dynamic Range / Energy Data

The **Calibration Energy** and **ADC Percent Rule** combined with the **Preamp Gain** setting determine the Saturn hardware variable gain setting. Given the **Preamp Gain**, the DSP calculates the pulse amplitude of an x-ray with energy equal to the **Calibration Energy**. It then sets the variable gain such that this amplitude spans the percentage of the ADC input range defined by the **ADC Percent Rule**.

Output count rate is attenuated for pulse amplitudes greater than 20% of the ADC range. The recommendation is therefore to set **Calibration Energy** equal to the spectrum maximum energy, and set **ADC Percent Rule** to 20%.

4.3.7 Calibrating the Saturn Hardware Gain

If the spectrum looks reasonably good at this point, we can calibrate and proceed with data optimization. This process modifies the hardware gain of the DXP Saturn, and refines the **Preamplifier Gain** setting that was entered in **Detector** tab. Once calibration is completed we will save the modified settings to an INI file so that they will be retrieved the next time ProSpect is started. Due to the analog nature of the variable gain amplifier that is used, the precise analog gain following a hardware gain modification is unknown until it is measured. For this reason, calibration is an iterative process that must be executed any time acquisition values are changed that require a hardware gain modification, e.g. if the spectrum size is increased. What is more important is the stability of the gain at a fixed setting.

4.3.7.1 Adding ROIs

The **Region Of Interest** (ROI) table is located below the spectrum. A single ROI is displayed by default. If you cannot see the ROI table, slide the panel separator up. If the ROI table is empty, click in the first cell to create an ROI row. The first column indicates which ROI is active—only one ROI can be active at a time. Note that each ROI can be locked and the region is set by default to fill. The **Lower** and **Upper** bounds of the ROI can be set manually, but it is easier to use the **Auto ROI** function described below.

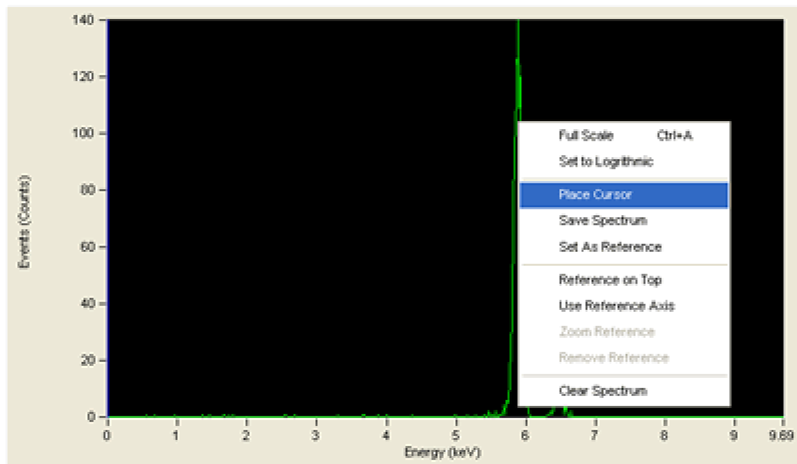


Figure 4.6: The full spectrum window 'right-click' menu is displayed. Context sensitive menus are available if the mouse pointer is located over the x-axis or y-axis, or over the cursor.

4.3.7.2 Auto ROI

Place the mouse pointer over the spectrum peak you wish to calibrate. Right-click and select "**Place Cursor**". Move the cursor to the center of the calibration peak, right click on the cursor and select "**Auto ROI**". A region of interest should automatically appear on the peak. In some cases, where few events have been collected, the Auto ROI feature will not properly enclose the peak. In these cases, the ROI can be adjusted directly in the Spectrum Window.

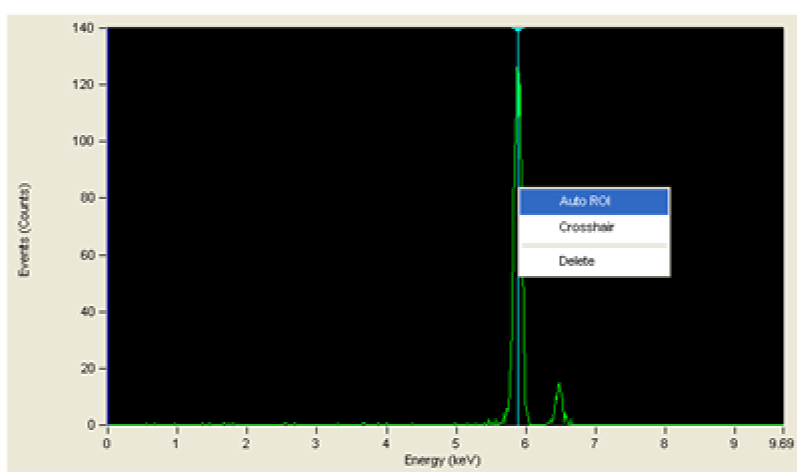


Figure 4.7: The **Auto ROI** function (cursor context menu) automatically defines a region of interest around the peak selected with the active cursor. The cursor context menu is displayed by right-clicking on a cursor.

4.3.7.3 Calibration Energy

Once and ROI has been defined, the table displays the number of events enclosed in the region, and the calculated mean energy and FWHM (full-width-half-maximum) in electron-Volts.

To calibrate: First make sure the ROI containing the selected peak is active, by clicking in the leftmost column. Enter the peak's known energy into the **Calib. (keV)** field then press the **[Calibrate ROI]** button. You should hear the Saturn hardware emit a few audible clicks as it carries out the calibration. The spectrum should now re-appear, with the peak properly calibrated. For the best calibration it is often necessary to run a few iterations. If the initial spectrum was badly out of calibration, the resulting change in gain may cause the peak to jump partially or fully out of its ROI. In this case, readjust the ROI so that it centers on the peak before repeating the calibration.

Note that the calibration routine can be executed during a data acquisition run. The run will automatically restart once the calibration is complete.

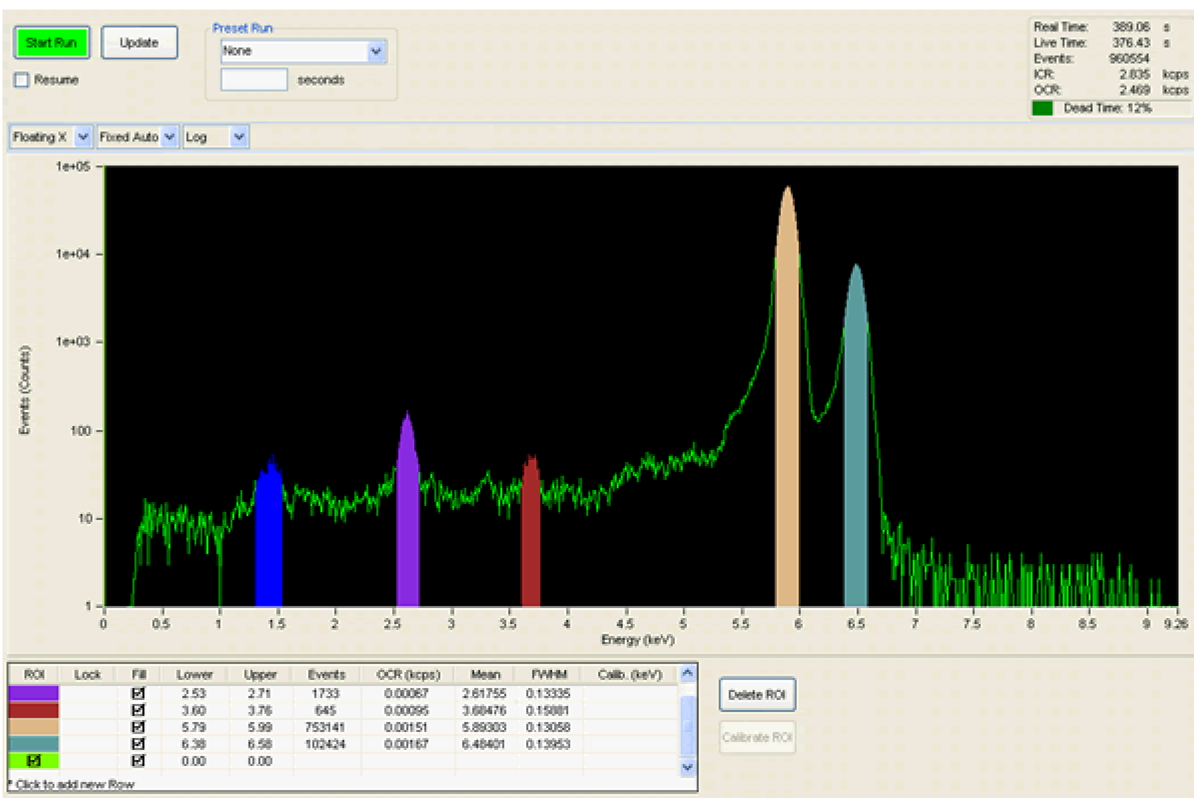


Figure 4.8: A calibrated ^{55}Fe spectrum with four regions of interest (ROIs).

4.3.8 Saving and Loading INI Files

Completion of the gain calibration is the final step in the verification of basic settings. *Note: Calibration is also typically executed any time acquisition values are changed, prior to data acquisition (see section 4.3.5 above).* The settings should now be saved to an INI file such that they will automatically reload whenever ProSpect is started. In general the goal is to store an *approximate* value for the **Preamplifier Gain**. The computed **Preamplifier Gain** will change slightly each time the calibration is executed, thus there is little benefit derived from saving the INI file every time, because the next time you change an acquisition value, e.g. **Peaking Time**, the gain will again be slightly off. However if you intend to run with all the same Acquisition Values in the future, then *do* save the INI file. In this limited case, the spectrum will be calibrated upon startup.

Select **File»Save Configuration** to save your current settings to the currently loaded INI file, or select **File»Save Configuration As…** to create a new INI file. Select **File»Load Configuration** to retrieve settings that were previously saved.

4.3.9 Output Statistics

Global statistics, such as ICR, OCR and Dead Time fraction are displayed along the top of the main window. Statistics for defined regions of interest are displayed in the ROI table.

4.3.9.1 Real Time

This is simply the time elapsed between the Start Run and Stop Run operations, measured in the DSP itself every 500µs with 800 ns accuracy. Intermediate values read out during the run will therefore have the lower accuracy, but the value reported at the end of the run will be fully accurate

Note: *The displayed* ***Live Time*** *does not express a relationship between the OCR and ICR. The* ***Dead Time Percentage*** *display does relate OCR to ICR.*

4.3.9.2 (Baseline/Trigger) Live Time

This is the time that the Baseline or Trigger filter remains under its threshold. This is not to be confused with the Energy Filter live time.

4.3.9.3 Events

This is the total number of events passed from the FiPPI to the DSP. This number includes overflows (events with energy greater than the spectrum maximum) and underflows (events below the spectrum minimum) as well as events displayed in the MCA.

4.3.9.4 Input Count Rate (ICR)

The measured input count rate (ICR) is displayed in units of thousands of counts per second [kcps]. The DSP applies internal correction procedures so that the measured ICR is very close to the true ICR, especially for longer peaking time settings. Please see section 0 for a discussion of this issue.

4.3.9.5 Output Count Rate (OCR)

The output count rate is also displayed in units of thousands of counts per second [kcps]. The OCR is simply the total number of detected events that did not pile up divided by the real time elapsed. Detected events that do not pile up, but whose measured energy falls outside the spectrum upper and lower limits, are called overflows and underflows, respectively. Both overflows and underflows are included in the OCR.

4.3.9.6 Dead Time Percentage

This high-level output is computed by ProSpect as the percentage of time that the energy filter is busy processing x-rays, calculated as:

$$\text{Dead Time} = (1 - \text{OCR}/\text{ICR})*100\%$$

4.3.9.7 ROI Statistics

The ROI table displays the number of events enclosed in each defined ROI, and the calculated mean energy and FWHM (full-width-half-maximum) in electron-Volts.

4.3.10 Display Controls

ProSpect features a wide array of display controls. Most of these controls can be accessed by right-clicking in the display area. X and Y axis scaling controls are accessible in the drop-down menus at the upper left of the data display panel.

4.3.11 Saving, Loading and Printing Data

4.3.11.1 Spectrum Files

MCA data can be saved for later display in ProSpect or for analysis in another program. Select **File»Save MCA Data…** to create an ASCII file. The default format includes bin scaling and other basic operating parameters and is date/time stamped. We would like to directly support as many formats as possible—please let us know if your format is not yet supported.

4.3.11.2 Diagnostic Files

The **ADC**, **Baseline** and **DSP Parameters** diagnostic tools allow for the export of displayed data to a file. Simply select **File» Save "X"**, where X refers to the desired data.

4.3.11.3 References

Data references are accessible via the mouse context menu in ProSpect. References are used for comparing different data sets in various acquisition and system modes. Right click in the data display panel and select **Set As Reference** to store the active data. When new data is acquired the reference data persists in the display.

4.4 Run Control

These settings determine the duration and display refresh rate of the data acquisition run and whether previous MCA data are cleared or retained at the start of a new run. The DXP Saturn can end the run when a specified preset real or live time has elapsed, or when a specified number of events have been detected or processed.

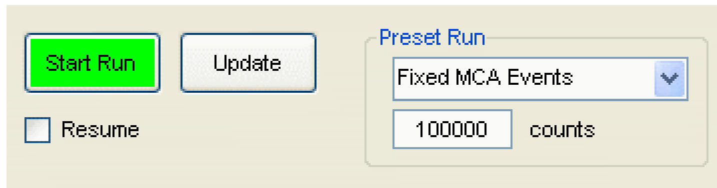


Figure 4.9: The run control area of the **MCA** panel.

4.4.1 Preset Runs

Select the **Preset Run** type:

- `None` - *run ends when user presses "Stop" button*
- `Fixed Real Time` – *run ends after specified real time elapses*
- `Fixed Energy Live Time` – *run ends after specified real time elapses*
- `Fixed MCA Counts` – *run ends after specified number of events have been processed.*
- `Fixed Input Triggers` – *run ends after specified number of events have been* detected.

4.4.2 The GATE Function

The external GATE (BNC) input can be configured to halt data acquisition in real time according to an external logic signal. The GATE function supports TTL/CMOS levels.

4.4.3 Auto Update Interval

The spectrum display can be set to automatically refresh with a user specified interval. Select **Tools»Options** then select the **Handel** tab of the **Prospect Options** panel. Enter the desired update interval in milliseconds.

4.4.4 Clear or Retain MCA Data

When a new run is started the data from the previous run can either be cleared or retained. This setting is accessed in the **MCA** panel via the **Resume** checkbox. When checked, data from the previous run will be retained.

4.5 Optimizations

4.5.1 Throughput (OCR)

The OCR depends only on the ICR and the dead time per event τ_d:

$$OCR = ICR_t * \exp -^{(ICRt\ \ \tau d)}, \text{where } \tau_d = 2*(t_p + t_g).$$

To increase the OCR at a given ICR, the dead time per event must be reduced. The obvious first step is to reduce the energy peaking time t_p. Further improvements can be made by reducing the gap time t_g.

4.5.1.1 Peaking Time (Energy Filter)

Making a plot of energy resolution versus peaking time provides a useful future reference.

The peaking time is the energy filter length, or integration time, i.e. the ramping interval of the trapezoid. It is the primary setting in determining the balance between count rate performance and energy resolution.

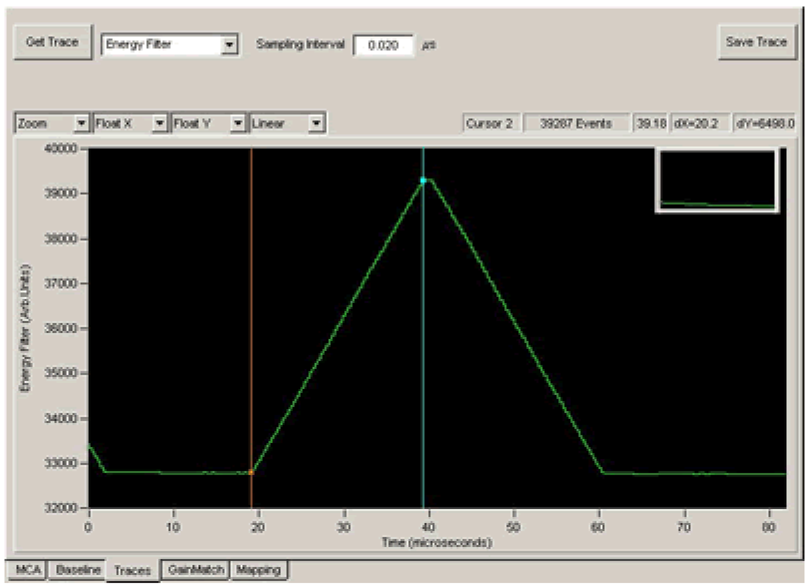


Figure 4.10: The output response of the Energy Filter with peaking time (ramping time) = 20.16µs and gap time (flattop time) = 0.96µs. The trapezoid is the response to an x-ray.

You will generally find it useful, after making a first attempt to optimize settings, to capture a set of spectra over a wide range of peaking times, preferably over the full range that the Saturn supports and generate a plot of energy resolution versus peaking time. This will serve two purposes: first to serve as a standard of comparison, so that you can tell if further parameter adjustments are helping or not; and second, to provide you with some feedback about whether your spectroscopy system is behaving properly. Later, when everything is optimized and all the noise sources have been suppressed, you can go back and repeat these measurements to provide hard data for use in selecting the best peaking time for a given input count rate.

4.5.1.2 Gap Time (Energy Filter)

*Reducing the **gap time** can significantly increase the data throughput at a given peaking time.*

The gap time of the energy filter sets the flattop length of the output trapezoid. Because the gap time directly affects the dead time, it is advantageous to set the gap time as short as possible. The gap time is subject to several constraints.

Generally the gap time should be set to a value that exceeds the 0 – 100 % preamplifier risetime in response to a detected x-ray. As long as this constraint is met, the trapezoid peak is tolerant of variations of the x-ray arrival time relative to the ADC clock. The digital filter architecture further constrains the gap time to an integer between 3 and 64 decimated clock intervals. In ProSpect, the user sets the **Minimum Gap Time** slightly larger than the the measured preamplifier risetime, and ProSpect automatically maintains the gap time based on the decimation-dependent filter constraints. Pleaser refer to section 4.6.1.2 for details on using ProSpect to measure the risetime for your system, and section 6.3.2 for a discussion of decimation and decimated clock periods.

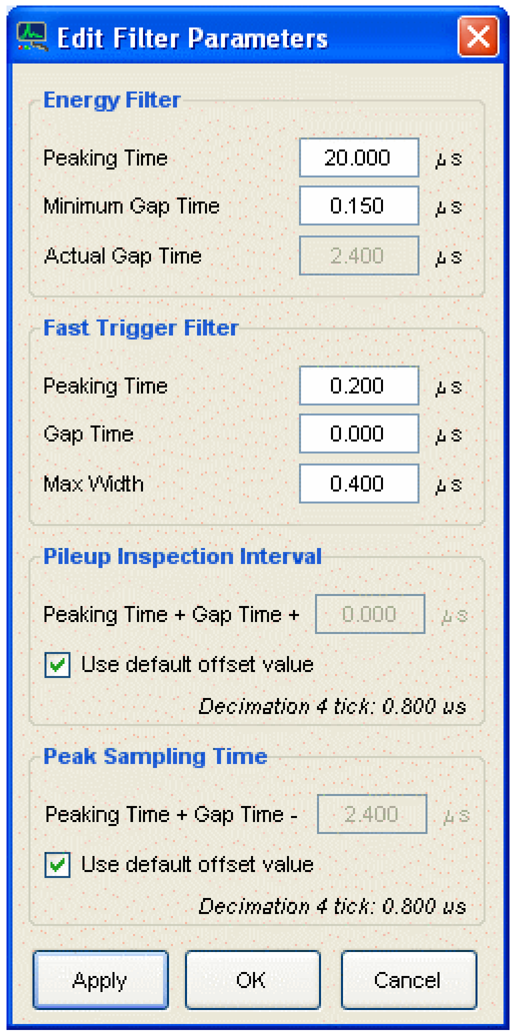


Figure 4.11: The **Edit Filter Parameters** panel.

To edit the **Minimum Gap Time** press the **Edit Filter Parameters** button in the **Acquisition** settings panel to open a dialog. Enter the desired value for **Minimum Gap Time** and press **[OK]**.

Normally the **Minimum Gap Time** should be set to a value that exceeds the preamplifier risetime in response to a detected x-ray, however, there is one exception. At very high count rates, where resolution is less of a concern, it can be advantageous to set the **Minimum Gap Time** to a smaller value, even to zero. This setting will only have an effect for decimation 0, i.e. for peaking times less than 0.50µs. For other decimations the gap time will be set to the minimum value of 3 decimated clock cycles. Note that you may have to adjust other settings as a result:

1. **Peak Sampling Time** – Because you are reducing or even eliminating the flattop section of the trapezoid, performance becomes more sensitive to the energy sampling time. Refer to section 4.5.3.6.
2. **Gain Calibration** – A consequence of setting the gap time less than the preamplifier risetime is ballistic deficit: The peak value of the trapezoid is reduced. As a result you will almost certainly have to increase the gain after the gap time has been changed. See section 4.3.6.

4.5.2 Pileup Rejection

Pileup inspection is described in detail in section 5.8. These settings should only be modified by users with a good understanding of the principles of pileup inspection.

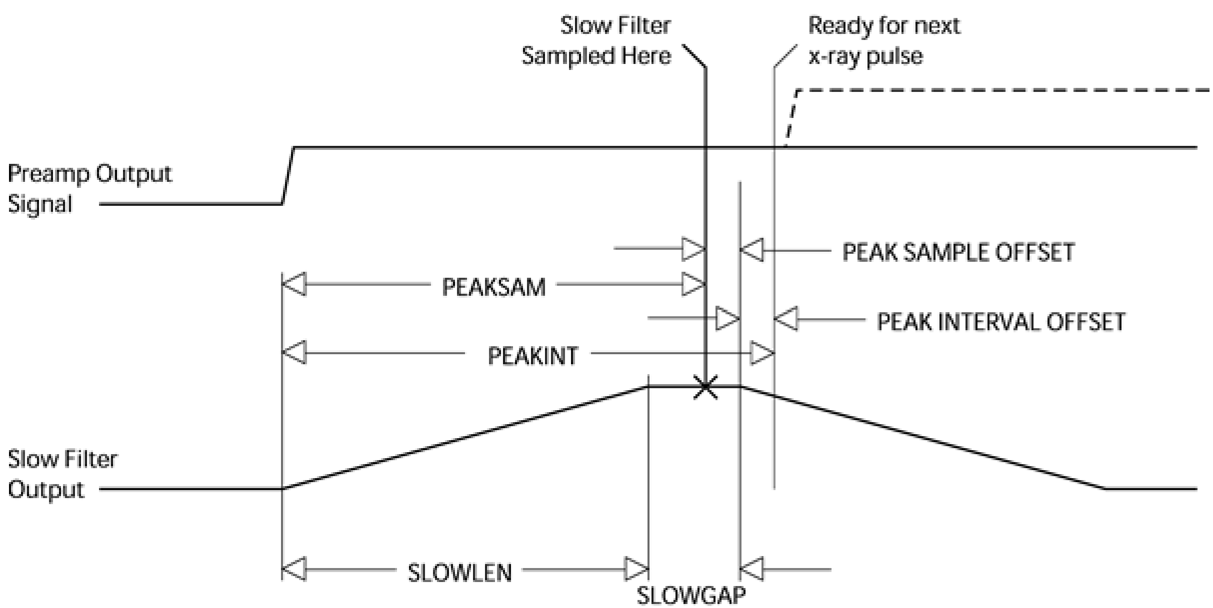


Figure 4.12: Slow, or Energy, filter output waveform diagram.

***CAUTION:** When set too low, the MAXWIDTH criterion can reject non-piled-up x-rays, resulting in attenuation at higher energies.*

4.5.2.1 Maximum Width Constraint

The DSP parameter MAXWIDTH sets the maximum acceptable time that the fast trigger output can stay above threshold for a single event. Properly set, this constraint detects fast pileup (event separation on the order of 100ns). See section 5.8 for more information. The **Max Width** setting is accessible in the **Edit Filter Parameters** panel. By default it is set to 400ns, allowing for a preamplifier risetime up to 200ns. MAXWIDTH should be *at least* twice the fast peaking time plus the preamplifier's 1% settling time:

Max Width > 2*Fast Peaking Time + Preamp Risetime

4.5.2.2 Peak Interval

The DSP parameter PEAKINT sets the minimum acceptable time that the slow energy filter needs to process a single event, i.e. the interval between peaks that can be properly sampled. This constraint detects slow pileup (event separation on the order of the energy peaking time). See section **Error! Reference source not found.** for more information.

The optimum peak interval is usually fixed relative to the sum of the peaking time and gap time. The **Peak Interval Offset** is measured forwards in time from this sum, i.e. measured forwards from the end of the flattop period (see **Figure 4.12**):

Peak Interval = Peaking Time + Gap Time + Peak Interval Offset

The **Peak Interval** setting is accessible in the **Edit Filter Parameters** panel. In most cases it should be left at zero. Larger values will result in a more conservative pileup inspection at the cost of increased dead-time-per-event.

4.5.2.3 Reducing the Fast Peaking Time

At very high rates the ***fast filter peaking time*** *may be reduced, to maintain good pileup inspection.*

The default fast peaking time of 100 ns should be used in most cases. Generally speaking, a longer fast filter peaking time produces a lower pileup inspection threshold at the cost of a longer pileup inspection time interval. Little if any real benefit is derived from *increasing* the fast peaking time unless the preamplifier signal is extremely noisy. For good pileup rejection, the fast filter peaking time should be much shorter than the energy filter, which becomes a problem when the shortest energy filter peaking times are used. In these cases, some improvements in pileup rejection may be possible if the fast filter peaking time is *reduced*, e.g. to 60ns. We don't recommend using a fast gap time other than zero.

Open the **Edit Filter Parameters** panel and enter a new value for the **Fast Trigger Filter Peaking Time** and press **[Apply]**. Note that you may have to adjust other settings as a result:

1. **Trigger Threshold** – Because of the zero gap time, the **Fast Trigger Filter** normally produces some ballistic deficit. Reducing the trigger peaking time can heighten this effect. For best results the threshold be checked, as described in section 4.3.3.
2. **Max Width** – The time over threshold is directly related to the filter length. If you previously optimized **Max Width**, i.e. the maximum time over threshold, you may need to re-optimize. See section 4.5.2.1.

4.5.3 Energy Resolution

There are many possible reasons for poor energy resolution. This section points to the most common issues.

4.5.3.1 Proper Peaking Time Selection

The first step in improving energy resolution is, of course, to optimize the **Peaking Time**. Use your plot of energy resolution versus peaking time to select a peaking time where you get good energy resolution before making these adjustments.

4.5.3.2 Baseline Acquisition

Capturing good baseline values and proper averaging are vital to achieving good energy resolution. The **Baseline Threshold** and **Baseline Average Samples** settings must be set properly for a given peaking time. See section 4.6.2 for making adjustments in ProSpect, and section 5.4 for more detailed explanations of baseline issues.

4.5.3.3 Eliminate Noise Pickup

Noise pickup can destroy performance. It is very important to identify and eliminate excess noise in the hardware. Typically this involves eliminating ground loops, removing switching power supplies in close proximity and improving shielding. Please refer to section 4.6.1 below for a brief introduction to using the **Trace** panel to identify noise issues.

4.5.3.4 Sufficient Gain to Sample Noise

If the signal gain is such that noise is not properly digitized at the ADC, energy resolution will not be optimal. This would result from a **Preamp Gain** setting that is too high (resulting in a Saturn variable gain setting that is tool low). Set the gain so that the noise is sufficiently digitized – see section 4.6.1.1.

4.5.3.5 Sufficient Gap Time

If the gap time is too short, the trapezoid peak sample (the energy sample) becomes dependent on the arrival time of the x-ray relative to the ADC clock. Make sure that the **Minimum Gap Time** is longer than the preamplifier risetime as described above in section 4.5.1.2.

4.5.3.6 Peak Sampling Time

The optimum sampling time of the energy filter is usually fixed relative to the sum of the peaking time and gap time. The **Peak Sample Offset** is measured backwards in time from this sum, i.e. measured backwards from the end of the flattop period (see **Figure 4.12**):

Sampling Time = Peaking Time + Gap Time – Peak Sample Offset

The **Peak Sample Offset** setting is accessible in the **Edit Filter Parameters** panel. In most cases it should not be edited. An exception is when running with a very short gap time at decimation 0 (see section 4.5.1.2 above). In this case the **Peak Sample Offset** should be reduced empirically. Please see section 5.6.2 for a full discussion before attempting this procedure.

4.6 Diagnostics

The Saturn and ProSpect provide several diagnostic tools for identifying and resolving functional and performance issues.

*To open the **Traces** panel, click on the Traces tab in the main window.*

4.6.1 The ADC Panel (Oscilloscope)

The **ADC** panel displays waveforms captured at the input of the digital filter, i.e. the preamplifier signal as seen at the Saturn's analog-to-digital-converter (ADC). The most significant 10 bits of the 12-bit ADC signal is plotted over 8000 sample points, with a user settable sampling interval. It can be a useful diagnostic tool for checking preamplifier polarity and gain, measuring the risetime, and for tracking down noise pickup.

To acquire and view a waveform select the **ADC** tab in the data display panel. Enter the **Sampling Interval** per sample point in microseconds and press the **[Get Trace]** button.

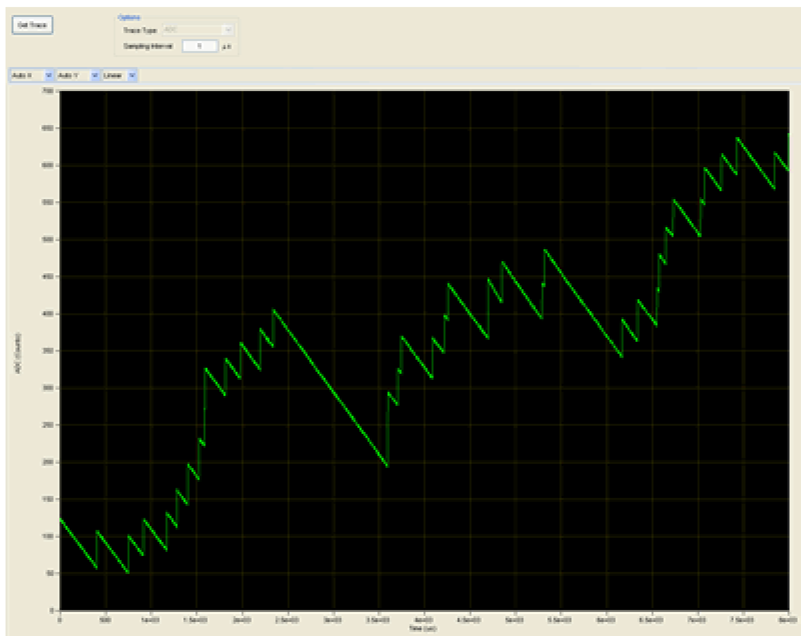


Figure 4.13: The **ADC** panel is a useful diagnostic tool.

*The preamplifier **Gain** and **Polarity** settings are accessed in the **Detector** tab of the **Settings** panel:*

4.6.1.1 Determining the Preamplifier Polarity and Gain

A common configuration error involves setting either the preamplifier signal polarity or gain incorrectly. Note: The preamplifier type, i.e. pulsed-reset or RC-feedback, is determined by the firmware file that is downloaded to the hardware (see section 3.2.1)

The Preamplifier Polarity configuration setting determines whether the ADC code is inverted prior to the digital filter pipeline, which expects x-ray pulses with a rising edge. The Trace panel displays the digital signal after this optional inversion. If the x-ray pulses are displayed with a falling edge, as shown in **Figure 4.14**, then the polarity setting is incorrect; if pulses are displayed with a rising edge, as in **Figure 4.15**, then the polarity setting is correct.

The **Preamp Gain** setting in the **Detector** panel, in combination with the **Dynamic Range** setting in the **Configuration** panel, determines the Saturn analog variable gain setting. The variable gain is set such that an x-ray with energy equal to the dynamic range value produces a voltage step of the maximum allowable amplitude at the ADC input. X-rays with energies exceeding the dynamic range value cannot be processed correctly. The **Dynamic Range** setting should thus be set above the largest x-ray energy present in the system.

In order to get the best energy resolution the gain must be set such that electronic noise is digitized sufficiently that it can be properly filtered. In practice this means that the noise should span 20 or more vertical units in the display. In **Figure 4.14** the noise is contained in less than 10 displayed vertical units, indicating that the hardware gain setting is too low. This could be due either to a **Preamp Gain** configuration setting that is too high or to the **Dynamic Range** being set too large. The noise displayed in **Figure 4.15** spans approximately 40 vertical display units, indicating that the Preamplifier Gain is set correctly and the spectrum is properly sized.

For best results ***the noise should span 20 or more vertical units*** *in the Oscilloscope Panel display.*

To adjust your own system, first select the **Trace** tab in the main window and acquire a few traces, until you have recognizable x-ray events displayed. Compare the polarity and noise amplitude to the figures. If necessary, change the **Polarity** and **Preamp Gain**. You may also need to modify the **ADC Rule** (see section 4.3.6).

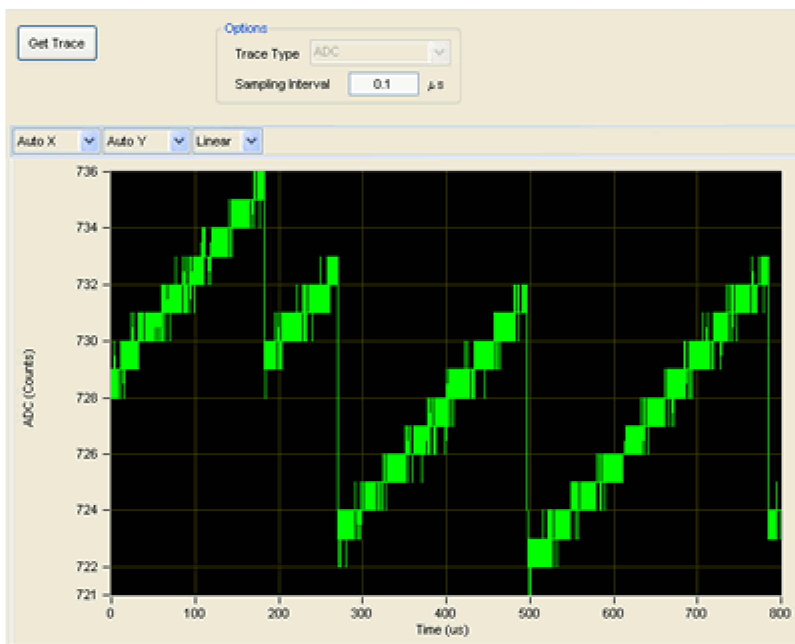


Figure 4.14: An ADC trace of a reset-type detector with the Saturn configured with the wrong polarity and a gain setting that is too low. X-ray steps displayed in this panel should have a rising edge, and noise should span 20 or more vertical units.

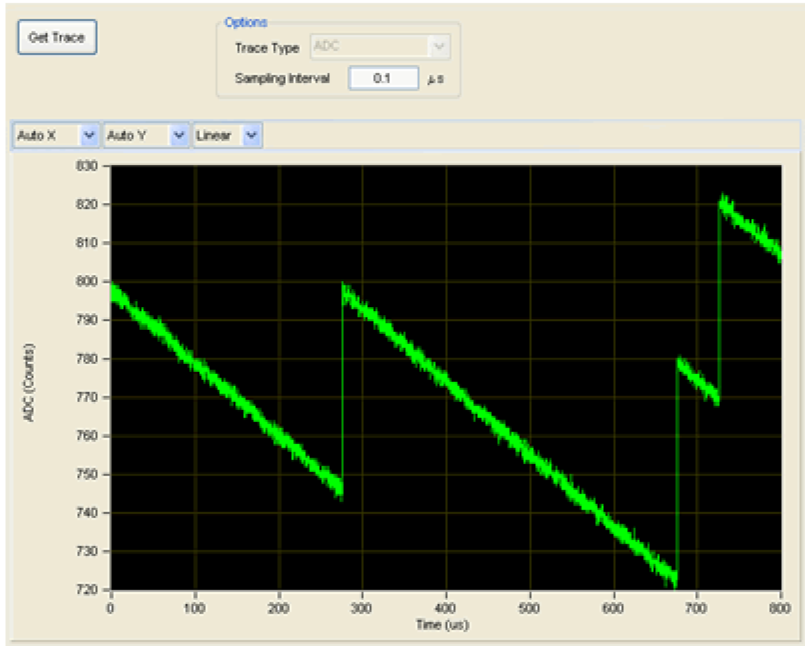


Figure 4.15: An ADC trace with correct polarity and a typical gain. Note that the noise is well digitized at roughly 40 vertical units.

4.6.1.2 Measuring the Preamplifier Risetime

The **ADC** panel is also useful for measuring the preamplifier signal risetime, which should be done before modifying the **Minimum Gap Time** as described in section 4.5.1.2.

As mentioned earlier, the minimum sampling interval in the display is 20ns—the actual ADC sampling period. Acquire an ADC trace at the minimum sampling interval of 0.10µs that includes at least one well separated x-ray event. Use the zoom tool (accessed via the right click menu or through the display controls at the graph's upper left) to expand the horizontal axis about the selected event. Place a cursor by right-clicking in the display area and selecting **Place Cursor**, immediately before the x-ray pulse. Place a second cursor immediately after the signal has settled following the pulse. The **dX** field of the cursor data area in the upper right hand corner should now display the 0 – 100% preamplifier risetime in µs.

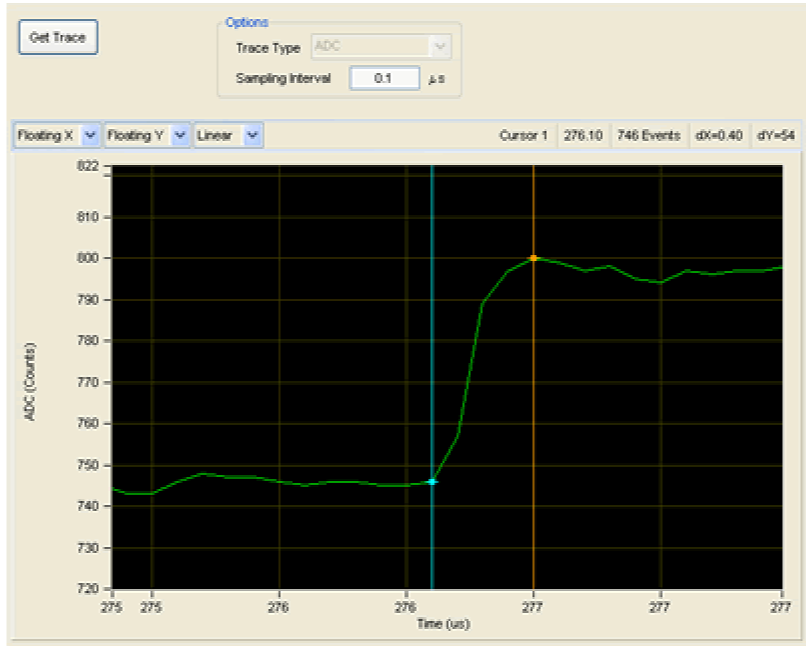


Figure 4.16: Use the zoom function and cursors to measure the preamplifier risetime. The risetime is approximately 400ns.

4.6.1.3 Measuring the RC Decay Time τ (RC-Feedback Preamplifiers only)

The **Trace** panel is also useful for measuring the decay time for RC-feedback preamplifiers.

Acquire an ADC trace that includes at least one well separated x-ray event. Use the zoom tool (accessed via the right click menu or through the display controls at the graph's upper left) if necessary to expand the horizontal axis about the selected event *such that the entire decay time is displayed*. Place a cursor by right-clicking in the display area and selecting **Place Cursor** at the peak value of the x-ray pulse. Place a second cursor mmediately before the x-ray pulse such that a baseline value is selected. Record the **dY** value from the cursor data display—this is the pulse height. Now move the second cursor to the point on the decay curve that produces a new dY value that is 1/e times the measured pulse height:

$$dY' = (1/e) \cdot dY \sim 0.37 \cdot dY$$

The cursors should now be separated by the time constant τ, displayed in µs in the **dX** field.

*To open the **Baseline** panel, click on the **Baseline** tab in the main window.*

4.6.2 The Baseline Panel

Baseline measurements are continually updated samplings of the output of the energy filter when no event is being processed. A running average of these baseline samples is then made to reduce the noise in this measurement and the result is subtracted from instantaneous raw pulse-height measurements to determine their true amplitudes. Please first review section 5.4 for a thorough discussion of baseline acquisition.

The **Baseline** panel displays a statistical distribution or **Histogram** of the instantaneous baseline samples and a **History** of the running average of those samples. The baseline histogram and history are powerful tools for diagnosing electronic noise and common nonlinearities in the detector and preamplifier.

Select the **Baseline** tab, select **Histogram** and press **[Get Baseline]** to acquire a baseline histogram. You should see a Gaussian peak with few, if any, outliers, as in **Figure 4.17**. If there are many outliers to the right of the peak, as in **Figure 4.18**, the threshold is set too high. If the right side of the peak is attenuated, non-Gaussian as in **Figure 4.19**, the threshold is set too low.

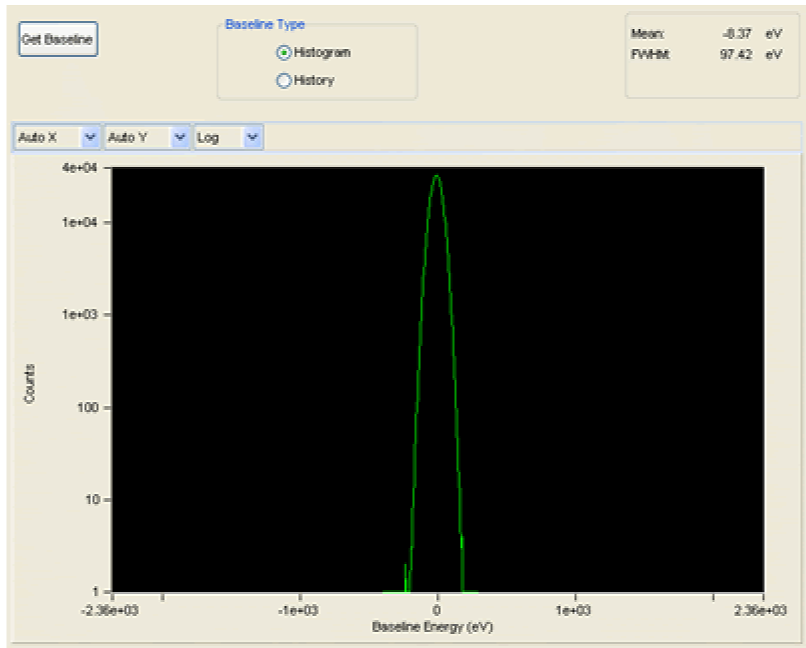


Figure 4.17: A good baseline histogram: the shape of the noise peak is Gaussian with no outlying data points.

4.6.2.1 The Baseline Threshold

Section 4.3.3 includes a discussion about setting thresholds based on visual feedback in the **MCA** panel. Threshold settings also affect baseline acquisition: Baseline acquisition is enabled only when the fast **Trigger** filter output is below **Trigger** threshold and the intermediate **Baseline** filter output is below the **Baseline** threshold. It is assumed that the **Trigger** threshold is set conservatively, so that baseline acquisition is dominated by the **Baseline** threshold. Note: The baseline threshold is not available for decimation 0, i.e. peaking times less than or equal to 500 ns.

Edit the **Baseline** threshold value in the **Acquisition** tab and press **[Apply]**. Typical values range from 150 eV to 1000 eV. The baseline filter length is linked to the energy filter length, or peaking time, thus the baseline threshold should be optimized every time the peaking time is changed. All thresholds must be readjusted if the gain changes significantly. For this reason it is useful to save INI files for commonly used peaking times after optimizations are complete.

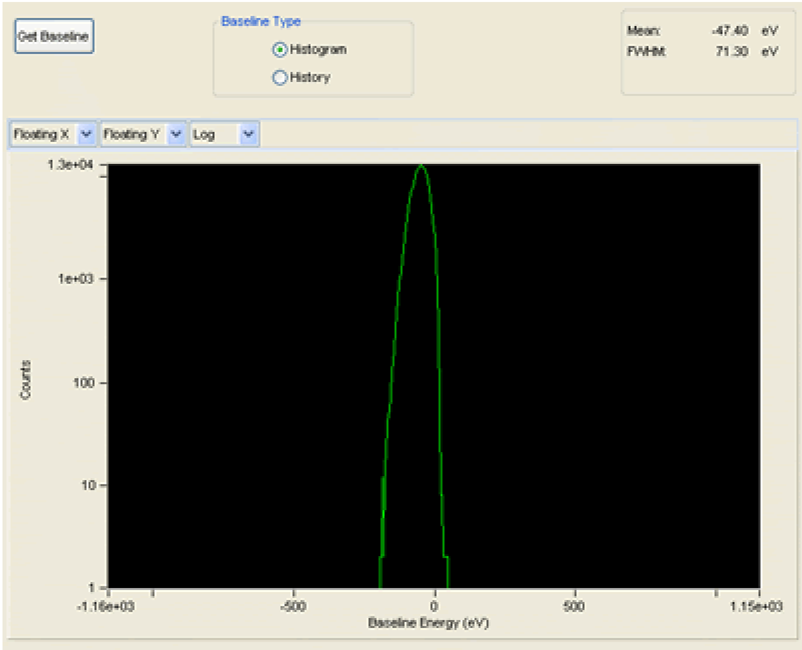


Figure 4.18: A baseline histogram with the threshold too low. Notice that the right side of the noise peak is attenuated. The rest of the noise peak will show up in the energy spectrum.

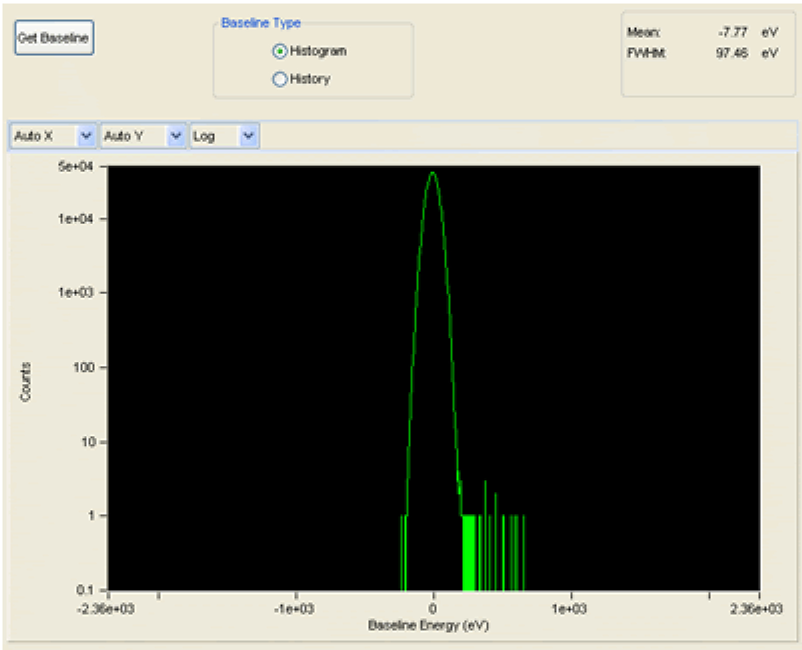


Figure 4.19: A baseline histogram with the threshold too high. The baseline samples to the right of the noise peak are partial energy events that should be in the energy spectrum.

4.6.2.2 Optimizing the Baseline Average Length

The **Baseline** panel is also useful for optimizing the number of samples in the baseline average. Please first review section 5.4 for a thorough discussion of baseline acquisition.

The baseline average length refers to the number of samples of the **Baseline Filter** raw output in the running average of baseline samples, which should be:

- Large enough to average out electronic noise at the higher frequencies.
- Small enough to track low frequency fluctuations in the front end, i.e. detector dark current.

The precise noise distribution and the low-frequency signal characteristics of the detector and preamplifier together yield an optimum number of samples in the average. Too small a value will not allow for proper filtering of electronic noise. Too large a value will not allow proper tracking of low frequency signals, e.g. due to EMI, that can be cancelled out with double correlation.

Select **History** and press **[Get Baseline]** to view the baseline running average. You want to achieve a waveform similar to that shown in **Figure 4.21**, where noise is filtered out but the average still tracks real variations. If you see something more like **Figure 4.20** or **Error! Reference source not found.**, adjust the **Baseline Average Samples** setting in the **Configuration** panel and press **[Apply]**. Acquire another trace and adjust as necessary. In most cases the values 128 and 256 yield the best results. At high rates it may be advantageous to reduce the number of samples as low as 16. For near perfect preamplifiers the average can be increased to 1024 or more. In any case the optimization is not complete until you acquire a spectrum and verify the energy resolution has improved.

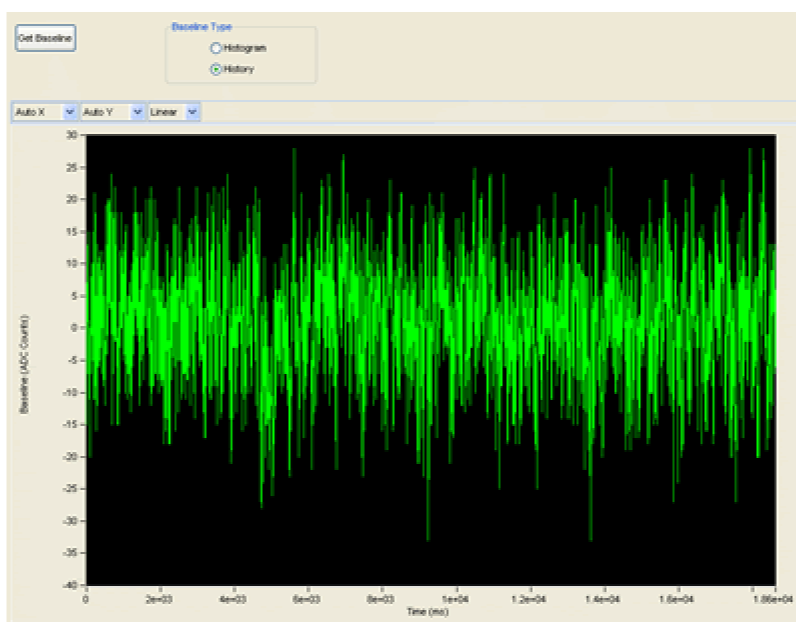


Figure 4.20: The baseline average with the number of samples set too low (16 samples in the average). Notice that there is still a lot of noise, as well as some real variations in the baseline.

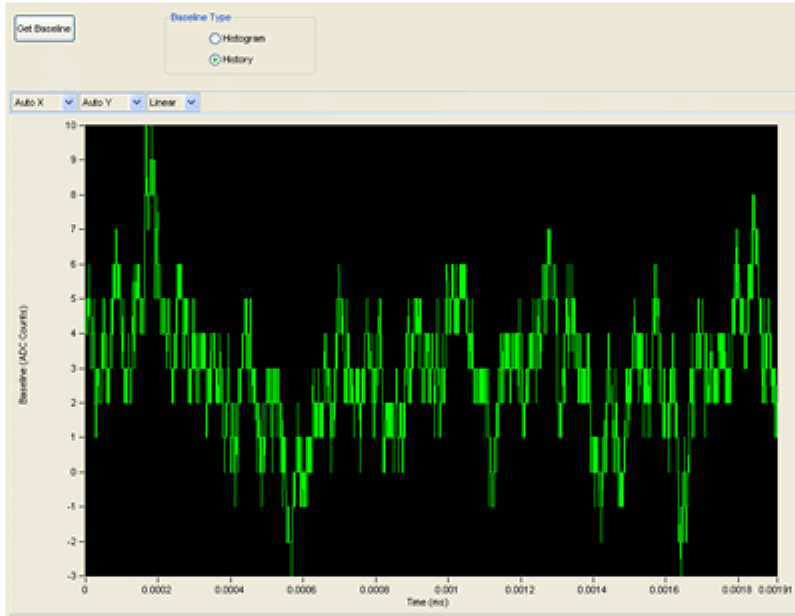


Figure 4.21: The baseline average with the number of samples set properly (128 samples in the average). Notice that there is very little noise, but that real baseline variations are tracked. In this case the downward variation is due to some curvature in the preamplifier output following a reset.

> ***Warning:*** *Changing DSP parameters without understanding them is discouraged..*

4.6.3 DSP Parameters

The **DSP Parameters** panel, accessible via the **Tools** menu, provides a diagnostic display of all DSP's internal parameters. The **Hex** and **Decimal** radio buttons determine whether parameters are displayed in hexadecimal or decimal format. Press the **[Update]** button to refresh the display. Note that various active parameters will change every time the **[Update]** button is pressed.

4.6.3.1 Generating a Diagnostic DSP Parameters File

The **[Export to File…]** button generates a ASCII text file containing all of the parameters for the currently selected processing channel. You may be asked to generate this file by technical support.

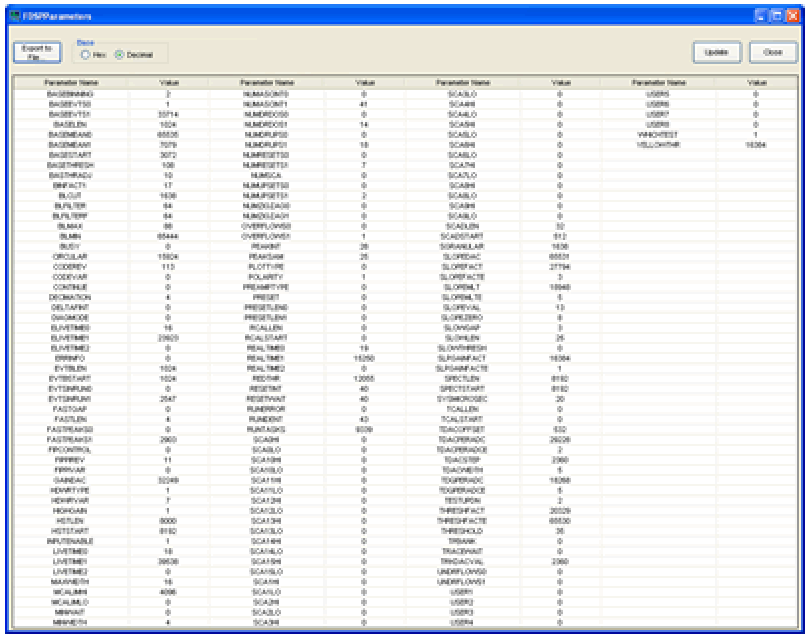


Figure 4.22: The DSP Parameters panel. Do not modify these values unless as instructed by XIA support staff.

4.6.3.2 Modifying DSP Parameters

In some cases, as directed by the XIA support staff, it may be necessary to modify the DSP's operating parameters directly. To edit a parameter select the field using the mouse, enter the new value and press [Return]. If you do not press [Return] the parameter will return to its unmodified value when another item is selected. Changing parameters in this panel without a deep understanding of XIA's DSP processors may produce exotic and unpredictable results. We recommend doing so only under the guidance of XIA support staff.

4.6.4 Submitting a problem report:

XIA encourages customers to report any problems encountered using any of our software via email. In most cases, the XIA engineering team will need to review bug information and run tests on local hardware before being able to respond.

All software-related bug reports should be e-mailed to software_support@xia.com and should contain the following information, which will be used by our technical support personnel to diagnose and solve the problem:

- ✓ Your name and organization
- ✓ Brief description of the application (type of detector, relevant experimental conditions...etc.)
- ✓ XIA hardware name and serial number
- ✓ Version of the library (if applicable)
- ✓ OS
- ✓ Description of the problem; steps taken to re-create the bug

- ✓ Additional data:
  - Saved MCA data, if relevant (see section 4.6.4.1)
  - Saved Baseline data, if relevant (see section 4.6.4.2)
  - Saved Trace data, if relevant (see section 4.6.4.3)

Please compress the Error Report into a ZIP archive and attach the support request email.

4.6.4.1 Saving MCA Data

If you are having difficulty acquiring a spectrum, or the spectrum looks strange, please save and submit a sample MCA file with the **Error Report**. In the **MCA** tab, acquire a spectrum, and then pres select **File>>Save MCA Data…**. Save the file in the "ProSpect_xxxxxx_Rpt" sub-directory in the ProSpect installation directory.

4.6.4.2 Saving Baseline Data

If you are having difficulty acquiring a good baseline histogram, or the spectrum looks strange, please save and submit a sample baseline histogram file with the **Error Report**. In the **Baseline** tab, acquire a histogram, and then pres select **File>>Save Baseline…**. Save the file in the "ProSpect_xxxxxx_Rpt" sub-directory in the ProSpect installation directory.

4.6.4.3 Saving Trace Data

If your ADC or filter output traces look strange, please save and submit a sample trace file with the **Error Report**. In the **Trace** tab, acquire a trace, and then pres select **File>>Save Trace…**. Save the file in the "ProSpect_xxxxxx_Rpt" sub-directory in the ProSpect installation directory.

5 Digital Filtering: Theory of Operation and Implementation Methods

This chapter provides an in-depth discussion of x-ray pulse-processing theory both generally and as implemented in the DXP Saturn. The topics include x-ray detection how, digital trapezoidal filter basics, thresholds, baselines, peak sampling, pileup inspection, and input and output count rates. Topics are covered to illustrate the theoretical issues, practical implementation, and how to adjust parameters to obtain best performance.

The acronym DXP stands for "Digital X-ray Processor" and refers to a digital processing technology, for which XIA has received several US and International patents.

5.1 X-ray Detection and Preamplifier Operation:

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. When an x-ray is absorbed in the detector material it releases an electric charge $Q_x = E_x/\varepsilon$, where the material constant ε is the amount of energy needed to form an electron-hole pair. Q_x is integrated onto the preamplifier's feedback capacitor C_f, to produce the voltage $V_x = Q_x/C_f = E_x/(\varepsilon C_f)$. Measuring the energy E_x of the x-ray therefore requires a measurement of the voltage step V_x in the presence of the amplifier's noise σ. Figure 5.1 and Figure 5.3 depict reset-type and RC-type charge sensitive amplifiers, respectively. In both figures the detector D is biased by voltage source HV (either positive or negative) and connected to the input of amplifier A. Note that the *signal polarity* must be distinguished from the *bias voltage polarity*. The signal polarity is positive if the voltage step V_x is a rising edge, as displayed in Figure 5.1. Whether signal polarity is positive or negative depends upon the preamplifier's design and does not depend upon bias voltage polarity, which is specified on the detector and is determined by its design.

5.1.1 Reset-Type Preamplifiers

Figure 5.1a is a simplified schematic of a reset-type preamplifier, wherein C_f is discharged through the switch S from time to time when the amplifier's output voltage gets so large that it behaves nonlinearly. Switch S may be an actual transistor switch, or may operate equivalently by another mechanism. In pulsed optical reset preamps light is directed at amplifier A's input FET causing it to discharge C_f. In transistor reset preamps, the input FET may have an additional electrode which can be pulsed to discharge C_f. The output of a reset-type preamplifier following the absorption of an x-ray of energy E_x in detector D is a voltage step of amplitude V_x. Two x-ray steps are shown in Figure 5.3b as a step.

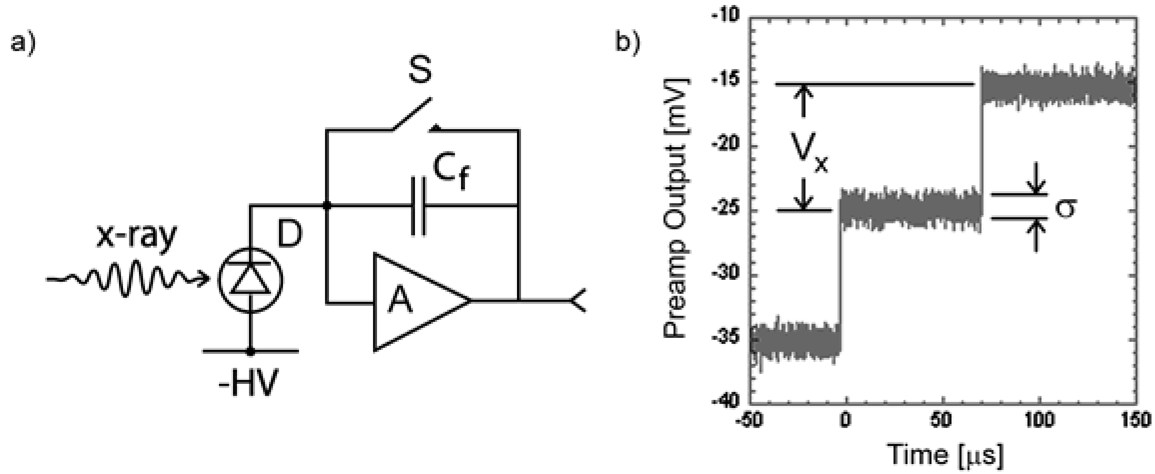


Figure 5.1: **a)** Reset-type charge sensitive preamplifier with a negatively biased detector; **b)** Output on absorption of x-ray rays. Note that the steps have a rising edge, so that the signal polarity is positive.

Figure 5.2 depicts the large-signal sawtooth waveform that results from successive x-ray steps followed by the reset. Note that the units here are Volts and milliseconds vs. millivolts and microseconds in the previous figure.

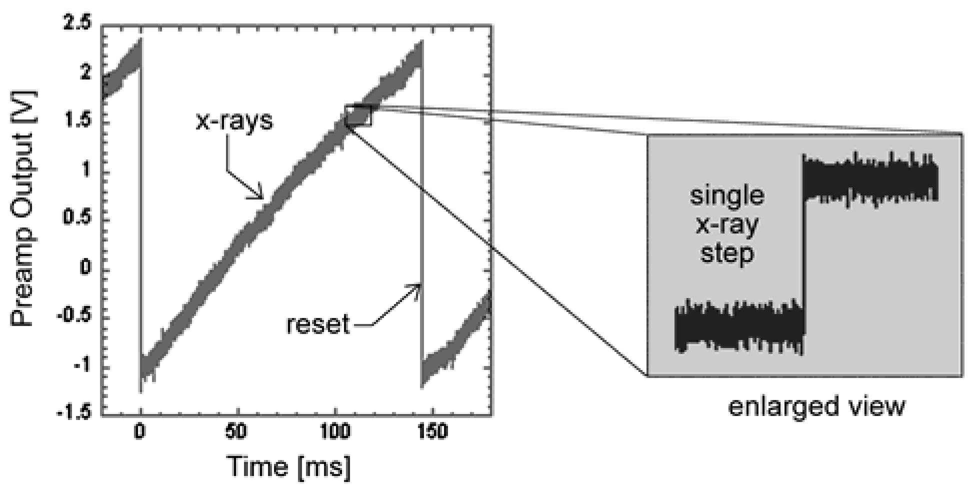


Figure 5.2: The large-signal reset waveform for a reset-type preamplifier with positive signal polarity, as displayed on a real oscilloscope. Note that the large signal character of the DXP Saturn diagnostic ADC readout, used in ProSpect's **ADC** panel, looks quite different because of the dynamic range reduction carried out in the ASC, as described in section 6.2.

5.1.2 RC-Type Preamplifiers

Figure 5.3a is a simplified schematic of an RC-type preamplifier, wherein C_f is discharged continuously through feedback resistor R_f. The output of an RC-type preamplifier following the absorption of an x-ray of energy E_x in detector D is, again, a voltage step of amplitude V_x. The continuous discharge of C_f through R_f results in an exponential voltage decay after the x-ray step, with decay constant τ, where:

$$\tau = R_f C_f$$

Equation 5-1

In practice the decay time may depend on subsequent circuitry, i.e. if a pole-zero cancellation circuit is used, thus τ may not be directly related to the feedback elements of the front-end. The point of this simplified model is that the resulting waveform is a single-pole RC decay. The discussion in section 5.2 through section 5.6.2 assumes a reset-type preamplifier, but is mostly applicable to RC-type preamplifiers. section 5.7 describes the few key differences in the processing of RC-type preamplifier signals.

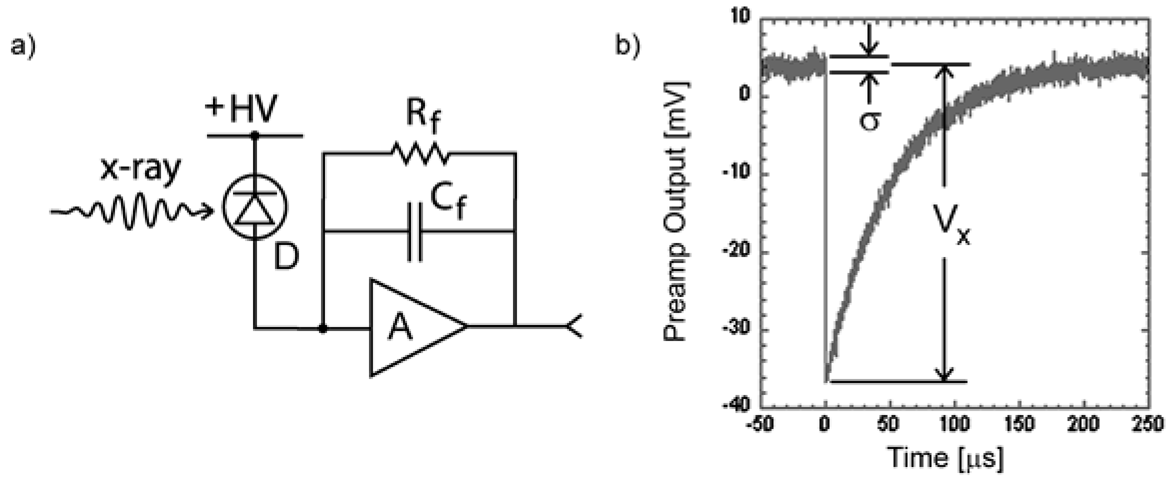


Figure 5.3: **a)** RC-type charge sensitive preamplifier with a positively biased detector; **b)** Output on absorption of an x-ray. Note that the step has a falling edge, thus the signal polarity is negative.

5.2 X-ray Energy Measurement & Noise Filtering:

Reducing noise in an electrical measurement is accomplished by filtering in the frequency, or conversely, the time domain. When discussing digital pulse-processor filters it's more straightforward to use the time domain. Traditional analog pulse-processing filters use combinations of a differentiation stage and multiple integration stages to convert the preamp output steps, such as shown in Figure 5.1b, into either triangular or semi-Gaussian pulses whose amplitudes (with respect to their baselines) are then proportional to V_X and thus to the x-ray's energy.

5.2.1 Digital Filtering Theory

Digital filtering proceeds from a slightly different perspective. Here the signal has been digitized and is no longer continuous, but is instead a string of discrete values, such as shown in Figure 5.4. The data displayed are actually just a subset of Figure 5.3b, which was digitized by a Tektronix 544 TDS digital oscilloscope at 10 MHz (10 million 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

5.4, 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:

$$V_{x,k} = -\sum_{i\,(before)} w_i v_i + \sum_{i\,(after)} w_i v_i$$

Equation 5-2

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.

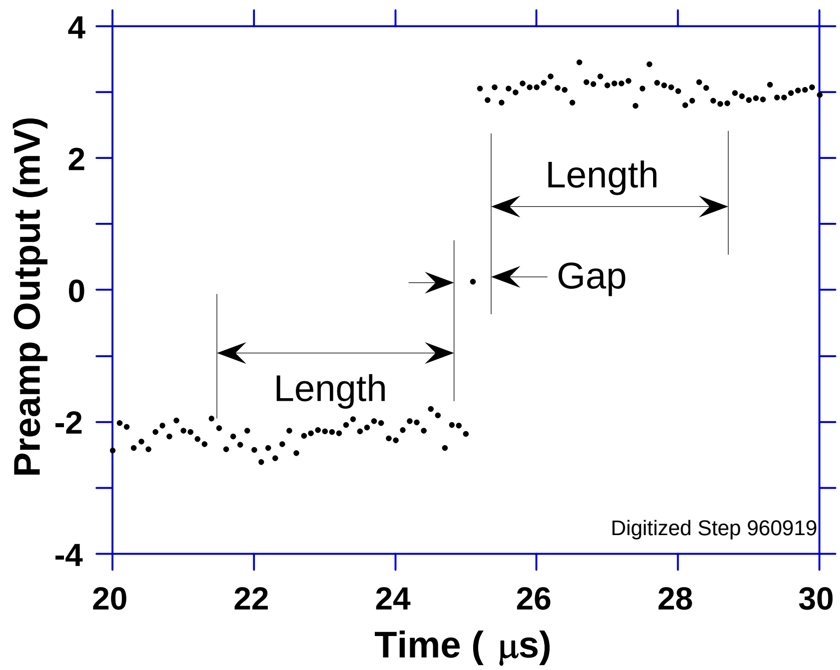


Figure 5.4: Digitized version of one of the x-ray steps of Figure 5.3b.

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 $V_{x,k} = -\sum_{i\,(before)} w_i v_i + \sum_{i\,(after)} w_i v_i$

Equation 5-2. Thus, for example, when the weighting values decrease with separation from the step, then the equation 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 more information about its height, they should be more 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 x-rays arrive randomly and the lengths between them vary accordingly, one can make maximum use of the available information by adjusting Length on a pulse by pulse basis.

In principal, 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. A few such systems have been produced but typically cost about $13K per channel and are count rate limited to about 30 Kcps. Even time invariant systems with cusp-like filters are still expensive due to the computational power required to rapidly execute strings of multiply and adds. One commercial system exists which can process over 100 Kcps, but it too costs over $12K per channel.

5.2.2 Trapezoidal Filtering

The DXP processing system developed by XIA takes a different approach because it was optimized for very high speed operation and low cost per channel. 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:

$$L\,V_{x,k} = -\sum_{i=k-2L-G+1}^{k-L-G} v_i + \sum_{i=k-L+1}^{k} v_i$$

Equation 5-3

where the filter length is L and the gap is G. The factor L multiplying Vx,k arises because the sum of the weights here is not normalized. Accommodating this factor is trivial for the DXP's host software. The operations are carried out using hardwired logic in a field programmable gate array (FPGA) that is called the FiPPI because is implements Filtering, Peak capture, and *P*ileup Inspection.

In the FiPPI, Equation 5-3 is actually implemented by noting the recursion relationship between Vx,k and Vx,k-1, which is:

$$L\,V_{x,k} = L\,V_{x,k-1} + v_k - v_{k-L} - v_{k-L-G} + v_{k-2L-G}$$

Equation 5-4

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 = 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 Equation 5-4 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.

5.3 Trapezoidal Filtering in the DXP:

From this point onward, we will only consider trapezoidal filtering as it is implemented in the DXP according to Equation 5-3 and Equation 5-4. The result of applying such a filter with Length L = 20 and Gap G = 4 to the same data set of Figure 5.4 is shown in Figure 5.5. The filter output V_X is clearly trapezoidal in shape and has a risetime equal to L, a flattop equal to G, and a symmetrical falltime equal to L. The basewidth, which is a first-order measure of the filter's noise reduction properties, is thus 2L+G.

5.3.1 Comparing DXP Performance

This raises several important points in comparing the noise performance of the DXP to analog filtering amplifiers. First, semi-Gaussian filters are usually specified by a *shaping time*, which is roughly half of the peaking. Their pulses typically are not symmetric so that the basewidth is about 5.6 times the shaping time or 2.8 times their peaking time. Thus a semi-Gaussian filter typically has a slightly better energy resolution than a triangular filter of the same peaking 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 peaking time a bit, so that the *true* triangular peaking time is typically 1.2 times the selected semi-Gaussian peaking 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 peaking time. A valid energy resolution comparison *must start with filters that have equal basewidths, and thus equal throughput,* e.g. The energy resolution of an analog system with shaping time of 1 µs should be compared to that of a DXP with a peaking time of 2.8 µs.

5.3.2 Decimation and Peaking Time Ranges

***Decimation** by N means to pre-average sequential sums of length D = 2^N.*

A practical limitation on the implementation of Equation 5-4 is that two FIFO memories are required, one of length L and one of Length L+G. Since memory space is limited in FPGAs, we have restricted our designs to values of L+G less than 32; reserving 7 samples for the gap time leaves 25 samples for the filter length. The DXP Saturn samples at 20 MHz (the fast-variant Saturn samples at 40MHz) so this corresponds to a maximum peaking time of 1.25 µs. XIA overcomes this limitation by first pre-averaging the data stream from the ADC by performing sequential sums of D data points, where D = 2^N. We refer to this pre-averaging procedure as "Decimating by N". By feeding the decimated data in an Equation 5-4 filter, we now obtain peaking times that are extended to L*D. It is important to understand that no data are lost in this procedure, we have merely rearranged the order of the summations represented in Equation 5-3. By extension, a "Decimation N FiPPI" is one that decimates the data by N before applying the energy filter. The common decimation values in the DXP Saturn are 0, 2, 4, and 6, corresponding to averaging times of 50 ns (no averaging), 200 ns, 800 ns, and 3.2µs, respectively.

Decimation N	*ADC Clock Period Δt*	*#ADC Samples in Average 2^N*	*Decimation Period Δt *2^N*	*Peaking Time Range**
Standard 20MHz Saturn				
0	50 ns	1	50 ns	200 ns – 1.25μs
2	20 ns	4	200 ns	800 ns – 5.00 μs
4	50 ns	16	800 ns	3.20 μs – 20.0 μs
6	50 ns	64	3.20 μs	12.8 μs – 80.0 μs
Fast 40MHz Saturn				
0	25 ns	1	25 ns	100 ns – 625 ns
2	25 ns	4	100 ns	400 ns – 2.50 μs
4	25 ns	16	400 ns	1.6 μs – 10.0 μs
6	25 ns	64	1.60 μs	6.4 μs – 40.0 μs

*Experience has shown that an absolute minimum slow filter length of 4 should be used.

Table 5.1: FiPPI decimation details.

In practice it is important to realize that implementing an energy filter in a Decimation N FiPPI sets certain limitations on the flat-top lengths that can be obtained in trapezoidal filters. Because the decimation process is uncorrelated with the arrival of x-rays, the gap G must be 3 or greater to assure that the filter's peak truly represents the x-ray's energy. Therefore, the minimum Decimation N gap time is $G*2^N*\Delta t$, where Δt is the ADC's sampling interval. With the DXP Saturn's Δt = 50 ns sampling interval, for instance, the smallest useful flat-top in Decimation 6 is 3*3.2 μs = 9.6 μs.

Given the significant overlap in peaking time ranges, it is generally better to choose a lower decimation value, such that a shorter gap time can be used. Decimation 0 has other limitations, i.e. no intermediate baseline filter, and is thus an exception to this rule. The FDD firmware file defines the actual, i.e. non-overlapping, peaking time ranges used.

5.3.3 Time Domain Benefits of Trapezoids

One extremely 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 which have tails which may persist up to 40% of the peaking 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.

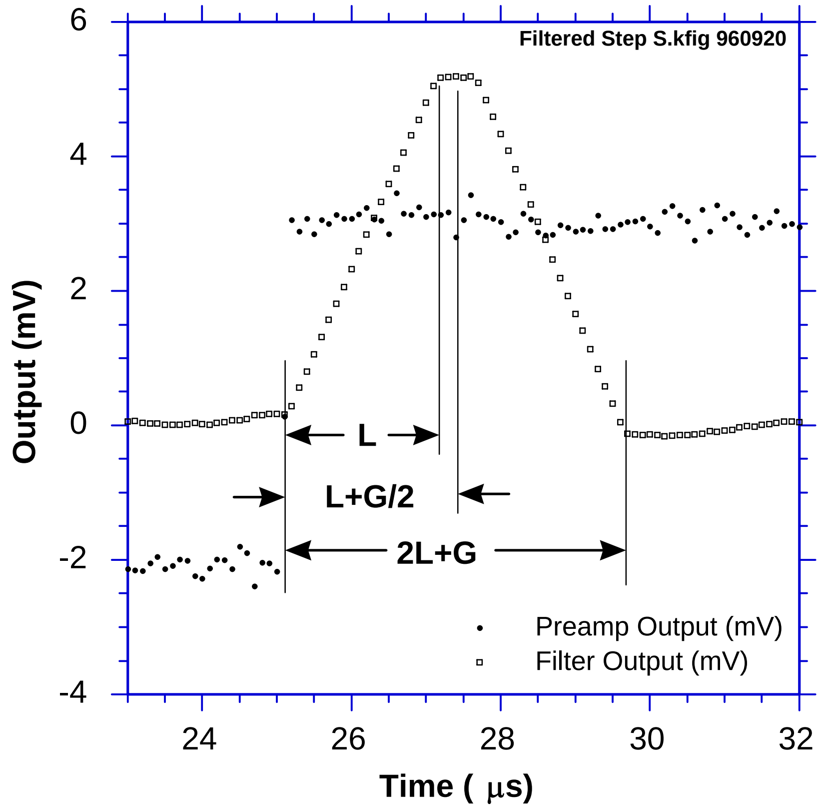


Figure 5.5: Trapezoidal filtering the Preamp Output data of Figure 5.4 with L = 20 and G = 4.

5.4 Baseline Issues:

5.4.1 The Need for Baseline Averaging

Figure 5.6 shows the same event as is Figure 5.5 but over a longer time interval to show how the filter treats the preamplifier noise in regions when no x-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 signal is termed the *baseline* because it establishes the reference level or offset from which the x-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 peaking time of the filter used. Riding on top of this noise, the x-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 x-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

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

Equation 5-5

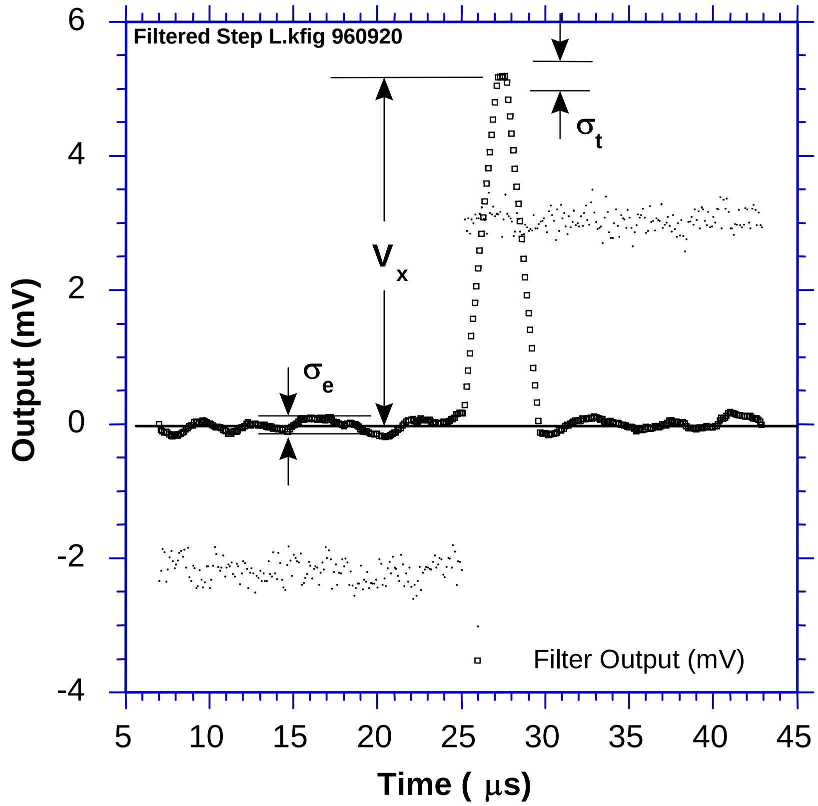


Figure 5.6: The event of Figure 5.5 displayed over a longer time period to show baseline noise.

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.

In the general case, the mean baseline value is not zero. This situation arises whenever the slope of the preamplifier signal is not zero between x-ray pulses. This can be seen from Equation 5-3. When the slope is not zero, the mean values of the two sums will differ because they are taken over regions separated in time by L+G, on average. Such non-zero slopes can arise from various causes, of which the most common is detector leakage current.

When the mean baseline value is not zero, it must be determined and subtracted from measured peak values in order to determine V_x values accurately. If the error introduced by this subtraction is not to significantly increase σ_t, then the error in the baseline estimate σ_b must be small compared to σ_e. Because the error in a single baseline measurement is σ_e, by definition, this means that multiple baseline measurements will have to be averaged. This number, N_B is the Baseline Average. For example, if N_B = 128 measurements are averaged then the total noise will be as shown in Equation 5-6.

$$\sigma_t = \mathrm{sqrt}(\ \sigma_f^2 + (1+1/128)\sigma_e^2)$$

Equation 5-6

This results in less than 0.5 eV degradation in resolution, even for very long peaking times, when resolutions of order 130 eV are obtained.

5.4.2 Raw Baseline Measurement

The output of the energy filter (or a derivative of the energy filter, the *intermediate filter*) is sampled periodically in the explicit absence of an x-ray step, defined by a baseline threshold. In practice, the DXP initially makes a series of N_B baseline measurements to compute a starting baseline mean. It then makes additional baseline measurements at quasi-periodic intervals to keep the estimate up to date. These values are stored internally and can be read out to construct a spectrum of baseline noise, referred to as the Baseline Histogram. This is recommended because of its excellent diagnostic properties. When all components in the spectrometer system are working properly, the baseline spectrum should be Gaussian in shape with a standard deviation reflecting σ_n. Deviations from this shape indicate various pathological conditions which may also cause the x-ray spectrum to be distorted and therefore have to be fixed.

*Applying a **Baseline Cut** can improve performance when the Baseline Histogram is non-Gaussian. Outlying data points are'cut' from the running **Baseline Average** (though still included in the histogram)*

The situation is remedied by removing ("cutting") outlying samples from the baseline average described below. If the maximum in the baseline distribution lies at E_0, then captured baseline values that deviate from E_0 by more than ΔE^+ and ΔE^-, respectively, are not included in the running baseline average. Note that *all captured baseline values are included in the Baseline Histogram*, however, so that it is always a valid representation of the system's behavior.

5.4.3 Baseline Average Settings and Recommendations

A FIR running average of baseline measurements is computed, which is then subtracted from sampled peak values to compute the energy of corresponding incident x-rays. The number of baseline samples averaged is set in ProSpect as "Baselines Average Samples". In the DSP this is converted into the parameter BLAVGDIV according to the equation:

$$\#\ \text{baseline samples averaged} = 2^{(\mathrm{BLAVGDIV}+1)}$$

Decimation	**# Baseline Samples to Average**	**BLAVGDIV** (DSP Parameter)
0	64	5
2	128	6
4	256	7
6	256	7

Table 5.2: Typical values used for baseline averaging. The best value for each decimation should be determined empirically, though the general trend illustrated in the table, i.e. larger number to average for higher decimations, should be followed.

5.4.4 Why Use a Finite Averaging Length?

Physically, the baseline is a measure of the instantaneous slope (volts/sec) for a pulsed-reset detector, and a measure of the DC offset for an RC-feedback preamplifier. The variation in leakage current of the detector and offset drift and 1/f noise of the preamplifier often contribute to a baseline with significant low-frequency (i.e. relative to the energy filter cutoff) noise. These variations pass through the energy filter, and thus should also pass through the baseline averaging stage to achieve good cancellation when the baseline average is subtracted from the energy filter sample. The goal is to produce a baseline average that has a sufficient number of samples to average out the high frequency noise, but which still reflects the 'local' instantaneous baseline upon which the x-ray step 'rides'. Generally speaking, the number of baseline samples in the average is set to achieve the best energy resolution performance over the desired range of input count rate. There are two considerations worth emphasizing:

1. *Excess detector/preamplifier noise and pickup (all decimations):* The values in the table above implicitly assume a flat noise spectrum from the preamplifier. A high-frequency noise peak can result in poor relative performance at the corresponding 'resonant' peaking time. Often this problem can be mediated, though not eliminated, by *increasing* the number of baseline samples in the average for the affected peaking times. On the other hand, excess low-frequency noise, i.e. wandering, can be remedied by *reducing* the number baseline samples in the average.
2. *High rate performance (decimation 0):* At higher rates, i.e. > 50% deadtime, the slow filter returns less and less often to baseline, thus the time between baseline samples grows longer. This is the primary cause of degraded energy resolution at high rates. Decimation 2,4 and 6 firmware now employs a proprietary circuit that virtually eliminates this problem, resulting in industry-leading count rate stability. This improvement cannot however be implemented in the decimation 0 firmware. The resolution can nonetheless be improved in most cases by *reducing* the number of baseline samples in the average.

5.5 X-ray Detection & Threshold Setting:

Before capturing a value of V_X we must first detect the x-ray. X-ray steps (in the preamp output) are detected by digitally comparing the output of a trapezoidal filter to a threshold.

In the DXP up to three trapezoidal filters are implemented: *fast*, *intermediate* and *slow;* each with a threshold that can be individually enabled or disabled. A fast filter very quickly detects larger x-ray steps. A slow (energy) filter averages out the most noise and can thus detect smaller x-ray steps, but has a response that is much slower. An intermediate filter (used in decimations 2, 4 and 6 only) is a derivative of the slow filter that provides a balance between the speed of the fast filter and the noise reduction of the slow filter.

The fast filter is used solely for x-ray detection, i.e. a threshold crossing initiates event processing. Its short basewidth (2L+G) means that successive pulses that would 'pile-up' in the slow filter can be resolved in the fast filter and rejected from the spectrum (see Figure 5.11 below). Conversely, little noise reduction is achieved in the fast filter, thus the fast threshold cannot be set to detect particularly low x-ray energies.

The intermediate filter is used for reset-type preamplifiers, in decimations 2, 4 and 6 only. Its threshold is automatically set by the DSP and applied as part of the baseline acquisition circuitry, i.e. baseline measurements are taken when the signal is *below* this threshold. Intermediate threshold crossings by default also trigger event processing, extending the detectable energy range significantly below the fast filter threshold.

After an x-ray has been detected, the step height is measured at the slow filter output. The slow filter's excellent noise reduction also allows for *detection* of the very lowest energy x-rays however its slow response precludes accuracy both in the determination of pulse pileup and the measurement of deadtime. The intermediate filter, which does not suffer this loss of accuracy, typically provides sufficient low energy detection. When present the intermediate threshold is enabled by default, and should be used in most cases. The slow threshold should be used cautiously, and only at low rates.

5.6 Peak Capture Methods

As noted above, we wish to capture a value of V_X for each x-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 capture the peak value – it is immediately ready to be added to the spectrum. If the addition process can be done in less than one peaking time, which is usually trivial digitally, then no system deadtime is produced by the capture and store operation. This is a significant source of the enhanced throughput found in digital systems.

Once an active threshold is exceeded, the DXP Saturn employs one of two methods to capture the slow energy filter output such that the best measure of V_x results. For decimations 2,4 and 6 the slow filter output is monitored over a finite interval of time in the region of its maximum, and the *maximum value within that interval* is captured. This method is referred to as "peak finding" or "max capture". For decimation 0, the slow filter is *sampled at a fixed time interval* after the pulse is detected by the fast filter. This method is referred to as "peak sampling".

After describing in section 5.6.1 below how to set the Gap parameter so that there will be a quality value of the energy filter to capture, we describe the two methods in detail in section 5.6.2.

5.6.1 Setting the Gap Length

When starting with a new detector, it is important first to set SLOWGAP to a minimum of 3, and *at least one unit greater than* the smallest value, in decimated clock cycles (see Table 5.3), that encloses the entire preamplifier risetime, per section 4.6.1.2.

Decimation	**# ADC Samples averaged**	**Decimated Clock frequency**	**Decimated Clock cycle interval**	**Peaking Time Range (in μs)**
0	1	20 MHz	50 ns	0.25– 1.25
2	4	5 MHz	200 ns	1.0 – 5.0
4	16	1.25 MHz	800 ns	4 – 20
6	64	312.5 kHz	3.2 μs	16 – 80

Table 5.3: For decimation 0 the slow filter output is sampled a fixed time after the x-ray is detected. PEAKSAM must be set properly to achieve optimum performance.

For example, consider a preamplifier with a pulse risetime of 260ns. For decimations 2, 4 and 6 SLOWGAP would be set to 3 or greater. For decimation 0 SLOWGAP would be set to 5 or greater. ProSpect will select these values automatically if you enter a Gap Time of 260 ns. SLOWGAP is independent of SLOWLEN, thus all peaking times having a common decimation can share the same SLOWGAP value.

5.6.2 Peak Sampling vs. Peak Finding

The figures below illustrate the two peak capture methods. Under the 'peak finding method' the slow filter output is monitored over a finite interval of time, and the *maximum value within that interval* is selected. The interval is set automatically, solely based on the values of the DXP parameters SLOWLEN and PEAKINT. SLOWLEN and PEAKINT are both automatically derived from the peaking time value selected in ProSpect and should normally not be adjusted by the user. PEAKINT is also a pileup inspection parameter, as will be discussed in further detail in section 5.8.

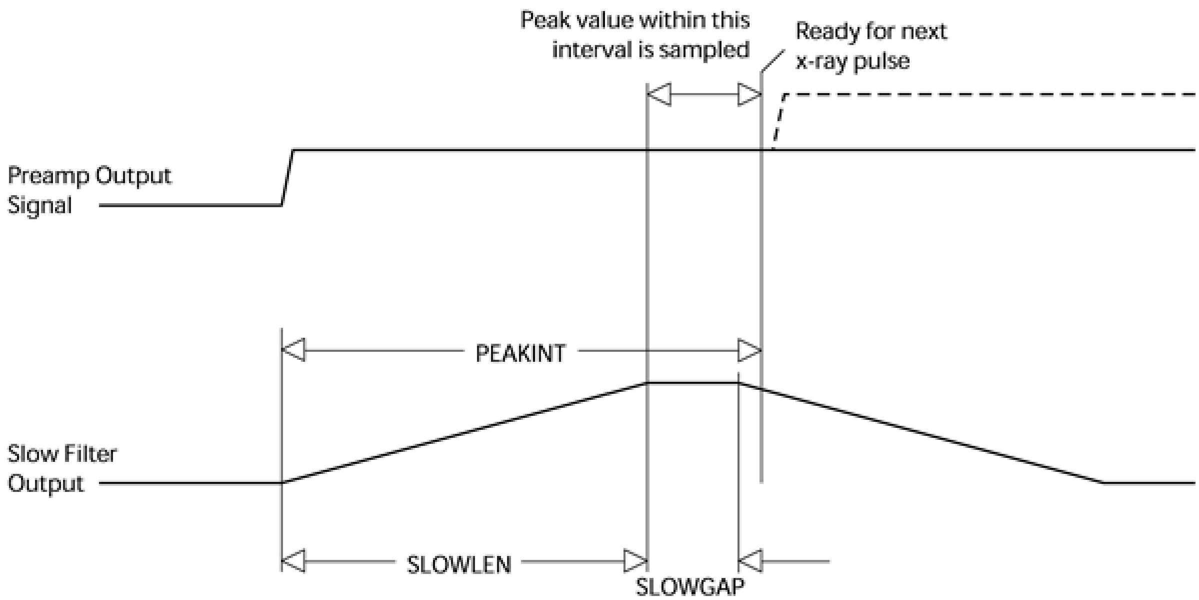


Figure 5.7: Peak finding method: The slow filter output is monitored and the peak value is selected.

In the 'peak sampling' method, the slow filter output is instead sampled a *fixed time* after the x-ray is detected. An additional ‘Peak Sampling’ timer is started when an x-ray step is detected which expires after PEAKSAM decimated clock cycles. PEAKSAM must be less than PEAKINT, and should typically be set such that the sample point lies in the ‘flat-top’ region of the slow filter output:

$$\text{SLOWLEN} \leq \text{PEAKSAM} \leq \text{SLOWLEN} + \text{SLOWGAP}$$

Equation 5-7

The precise PEAKSAM setting has a strong effect on energy resolution and should be determined empirically for each new detector. More on this below...

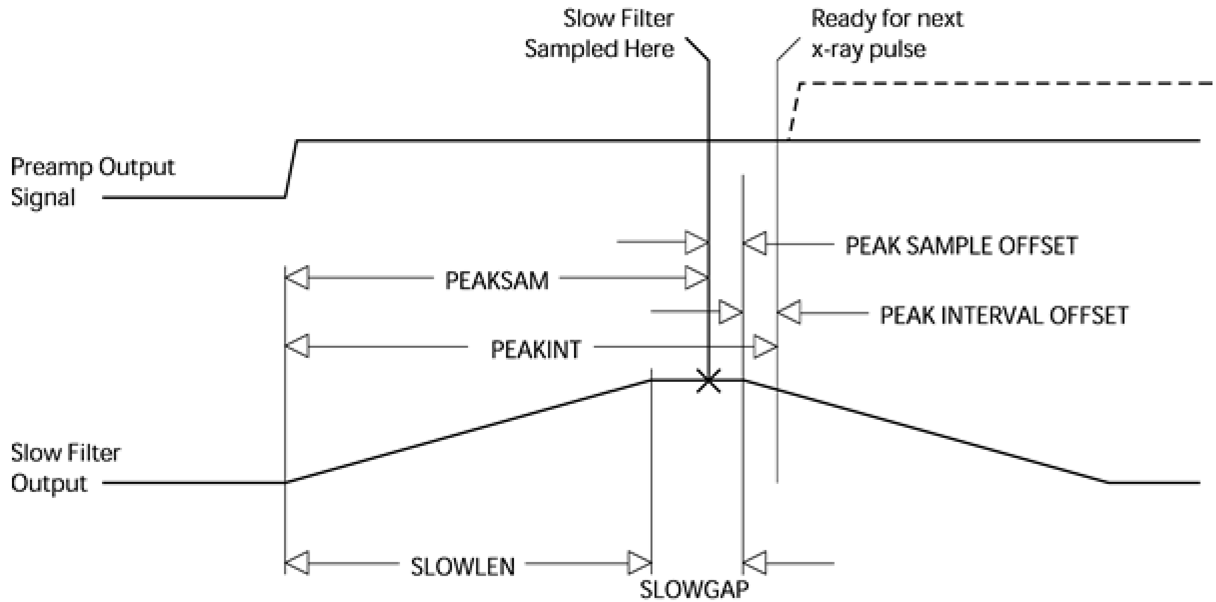


Figure 5.8: Peak sampling method: The slow filter output is sampled a fixed time after the x-ray is detected. PEAKSAM must be set properly to achieve optimum performance.

In our experience values at the low end (i.e. PEAKSAM ~ SLOWLEN) tend to work better. We recommend that you record the initial value of PEAKSAM and then change it in steps of 1, working out from the initial value. Certain PEAKSAM values may cause the DXP Saturn to crash. Do not be alarmed, just restart and be sure to enter a valid PEAKSAM value before proceeding. Making a plot of energy resolution versus PEAKSAM will indicate the best value to select.

This determination need only be done for one peaking time per decimation. The result can then be applied to any value of SLOWLEN and SLOWGAP using the following recipe:

$$\text{PEAKSAM} = (\text{SLOWLEN} + \text{SLOWGAP}) - X$$

Equation 5-8

5.7 Energy Measurement with Resistive Feedback Preamplifiers

In previous sections, the pulse height measurement was shown for the case of reset-type preamplifiers. The reset-type scheme is most often used for optimum energy resolution x-ray detectors. Other detectors use an RC-type preamplifier, as described in section 5.1.2. Resistive feedback is most often used for gamma-ray detectors which cover a larger dynamic range and where the electronic noise is not as significant a contribution to energy resolution.

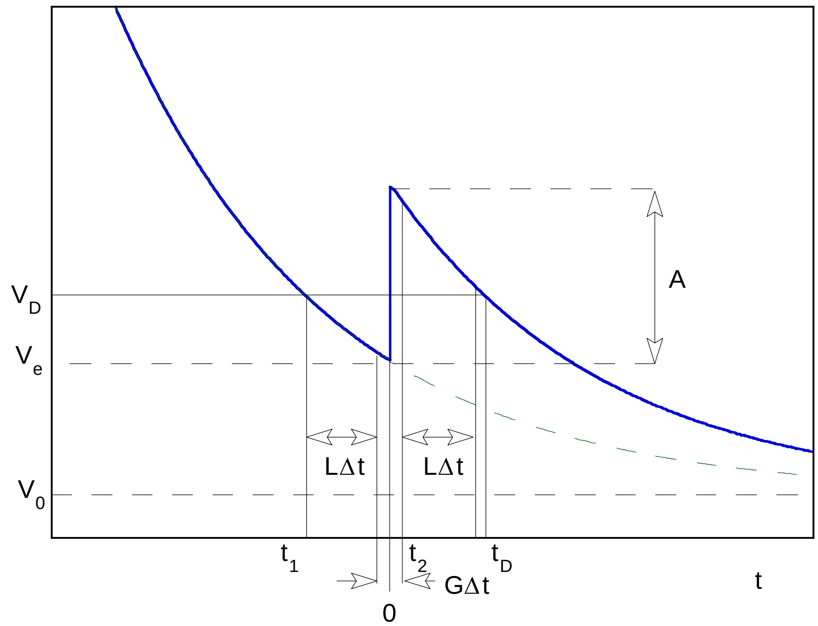


Figure 5.9: RC preamplifier output voltage. An x-ray step of amplitude A occurs at time t=0.

Where analog shaping amplifiers typically have a “pole-zero” adjustment to cancel out the exponential decay, the DXP uses a patented digital correction to achieve good energy resolution without a pole-zero stage. Figure 5.9 and Figure 5.10 illustrate the method used. The first shows the output voltage of a RC feedback preamplifier with a x-ray or γ-ray step of amplitude A appearing at t=0. V_e is the voltage just before the step pulse arrives and V_0 is the asymptotic value that the signal would decay to in the absence of steps. t_1 is the earliest time used in the slow filter, L and G are the length and gap of the trapezoidal filter in clock units, and Δt is the clock period, In addition to the normal slow filter measurement of the step height, the ADC amplitude, V_D is made at time t_D. In the following discussion, it is assumed that the signal rise-time is negligible.

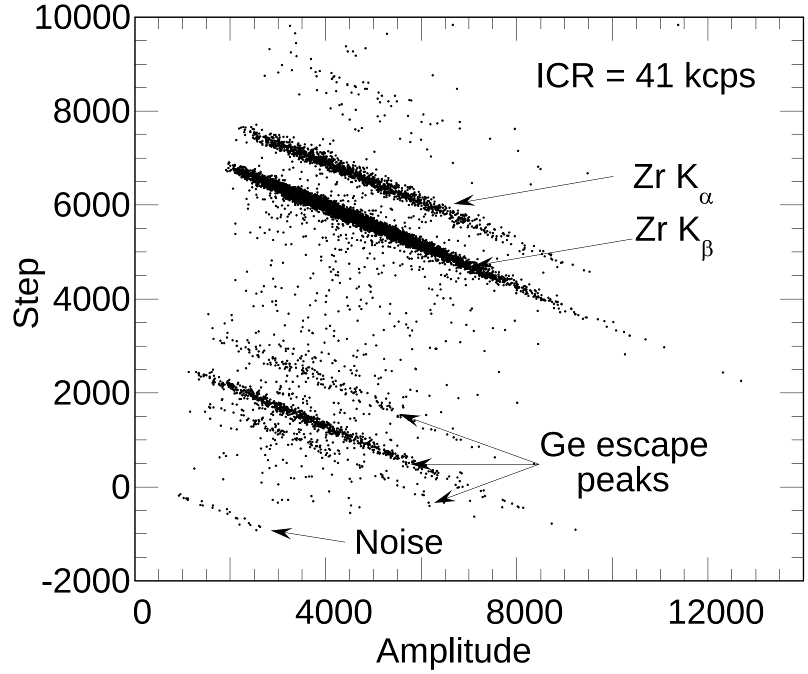


Figure 5.10: Correlation between step size and amplitude for Zr Kα x-ray events measured with the DXP-4C.

As Figure 5.10 makes clear, there is a linear correlation between the step height from the trapezoidal filter and the ADC amplitude, for pulses of a given energy. This is due to the fact that the exponential decay causes a deficit in the measured step height, which grows linearly with the distance from the asymptotic ADC offset at zero count rate.

The DSP reads these two values for each event that passes the FiPPI's trigger criteria, and makes a correction of the form:

$$E = k_1 (S_X + k_2 V_X - < S_B + k_2 V_B >)$$

Equation 5-9

Here the quantities S_X and V_X are the step height and ADC amplitude measured for the step, and the corresponding values with the B subscript are "baseline" values, which are measured frequently at times when there is no trigger. The brackets <> indicate that the baseline values are averaged over a large enough number of events to not introduce additional noise in the measurement. The constant k_2 (the DSP parameter called RCFCOR) is inversely proportional to the exponential decay time; this correction factor is a constant for a detector channel at a fixed gain and shaping time. The constant k_1 is effectively a gain factor, and is taken into account with a detector gain calibration.

The parameter RCFCOR is a function of the digital filter parameters (SLOWLEN, SLOWGAP and DECIMATION) and the preamplifier decay time (the DSP parameter RCTAU). The decay time defined by RCTAU (and fractional word RCTAUFRAC) has 50 ns granularity, and is measured and entered by the user. At the start of an acquisition run, the DSP calculates RCFCOR using the following approximate expression:

$$RCFCOR = 2^{DEC} * (LEN + GAP) / (RCTAU – (LEN + GAP/2 + 3)*2^{DEC})$$

Equation 5-10

The above expression is valid for peaking times less than about RCTAU/2. Alternatively, RCFCOR can be determined empirically in a special test run from a linear fit of data, as in Figure 5.10.

5.8 Pile-up Inspection:

The captured value V_X (see Figure 5.6) will only be a valid measure of its associated x-ray's energy provided that its filtered pulse is sufficiently well separated in time from its preceding and succeeding neighbor pulses so that its peak amplitude is not distorted by the action of the trapezoidal filter on those neighbor pulses. That is, if the pulse is not *piled up*. The relevant issues may be understood by reference to Figure 5.11, which shows 5 x-rays arriving separated by various intervals.

Because the triangular 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. In Figure 5.11 the pulses are separated by intervals of 3.2, 1.8, 5.7, and 0.7 µs, respectively. The fast filter has a peaking time of 0.4 µs with no gap. The slow filter has a peaking time of 2.0 µs with a gap of 0.4 µs.

The first kind of pileup is *slow pileup*, which refers to pileup in the slow channel. This occurs when the rising (or falling) edge of one pulse lies under the peak (specifically the sampling point) of its neighbor. Thus peaks 1 and 2 are sufficiently well separated so that the leading edge (point 2a) 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 (point 1c) 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/2. Peaks 2 and 3, which are separated by only 1.8 µs, are thus seen to pileup in the present example with a 2.0 µs peaking time.

This leads to an important first point: whether pulses suffer slow pileup depends critically on the peaking time of the filter being used. The amount of pileup which occurs at a given average signal rate will increase with longer peaking times. We will quantify this in section 0, where we discuss throughput.

Because the fast filter peaking time is only 0.4 µs, these x-ray pulses do not pileup in the fast filter channel. The DXP can therefore test for slow channel pileup by measuring for the interval PEAKINT after a pulse arrival time. If no second pulse occurs in this interval, then there is no trailing edge pileup. PEAKINT is usually set to a value close to L + G/2 + 1. Pulse 1 passes this test, as shown in the figure. Pulse 2, however, fails the PEAKINT test because pulse 3 follows in 1.8 µs, which is less than PEAKINT = 2.3 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.

Pulses 4 and 5 are so close together that the output of the fast filter does not fall below the threshold between them and so they are detected by the pulse detector as only being a single x-ray pulse. Indeed, only a single (though somewhat distorted) pulse emerges from the slow filter, but its peak amplitude corresponds to the energy of neither x-ray 4 nor x-ray 5. In order to reject as many of these fast channel pileup cases as possible, the DXP implements a fast channel pileup inspection test as well.

The fast channel pileup test is based on the observation that, to the extent that the risetime of the preamplifier pulses is independent of the x-rays' energies (which is generally the case in x-ray work except for some room temperature, compound semiconductor detectors) the basewidth of the fast digital filter (i.e. $2L_f + G_f$) will also be energy independent and will never exceed some maximum width MAXWIDTH. Thus, if the width of the fast filter output pulses is measured at threshold and found to exceed MAXWIDTH, then fast channel pileup must have occurred. This is shown graphically in the figure where pulse 3 passes the MAXWIDTH test, while the piled up pair of pulses 4 and 5 fail the MAXWIDTH test.

Thus, in Figure 5.11, only pulse 1 passes both pileup inspection tests and, indeed, it is the only pulse to have a well defined flattop region at time PEAKSAMP in the slow filter output.

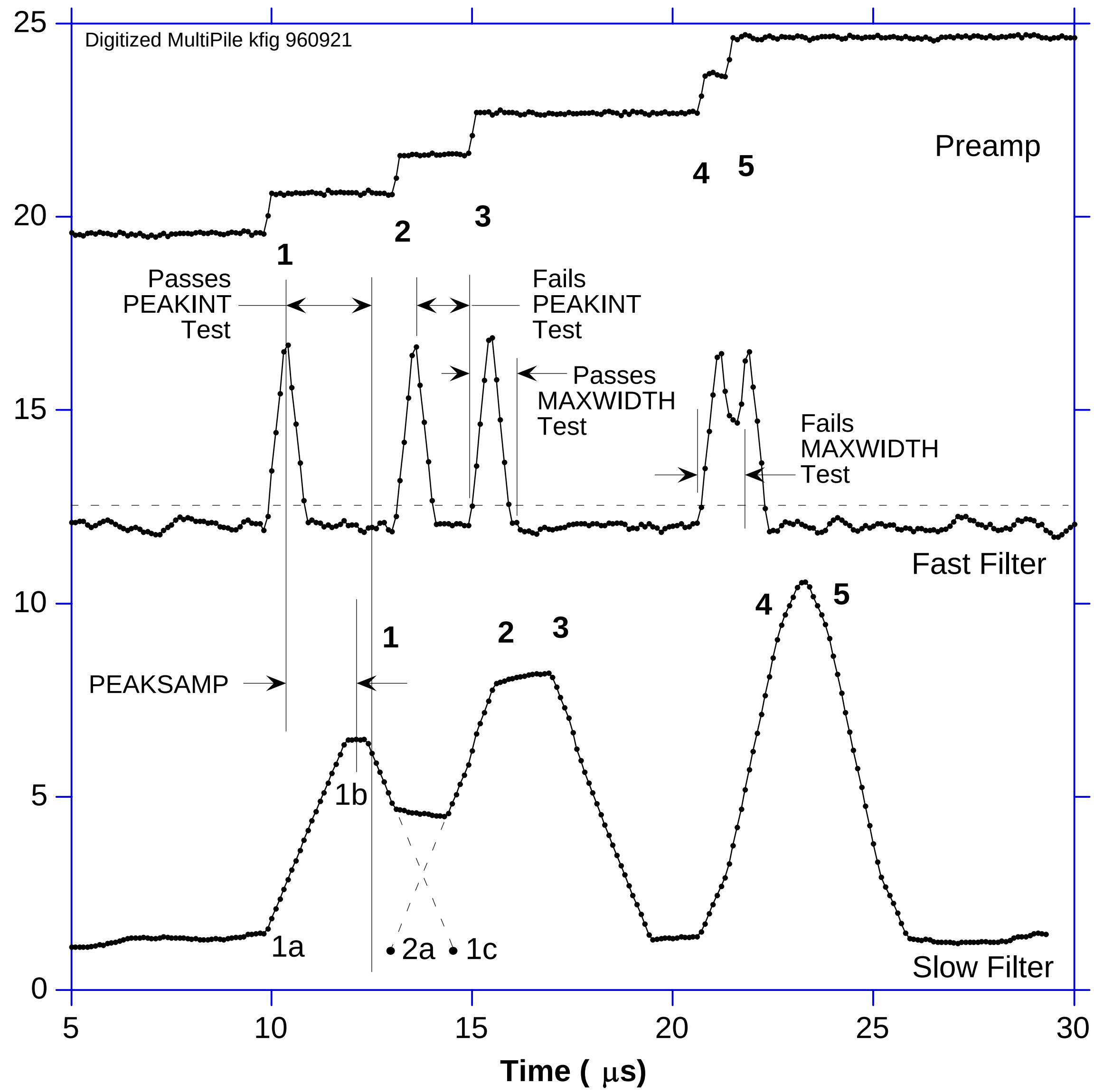


Figure 5.11: A sequence of 5 x-ray pulses separated by various intervals to show the origin of both slow channel and fast channel pileup and demonstrate how the two cases are detected by the DXP.

Note that PEAKINT and MAXWIDTH are both DSP parameters and are normally set automatically. In particular, there is almost never any benefit to a longer value of PEAKINT than the standard value as it does not improve energy resolution and only decreases throughput for a given input rate. Please see section **Error! Reference source not found.** for details on how to adjust MAXWIDTH.

5.9 Input Count Rate (ICR) and Output Count Rate (OCR):

During data acquisition, x-rays will be absorbed in the detector at some rate. This is the *true input count rate* , which we will refer to as ICR_t. Because of fast channel pileup, not all of these will be detected by the DXP's x-ray pulse detection circuitry, which will thus report a *measured input count rate* ICR_m, which will be less than ICR_t. This phenomenon, it should be noted, is a characteristic of all x-ray detection circuits, whether analog or digital, and is not specific to the DXP.

Of the detected x-rays, some fraction will also satisfy both fast and slow channel pileup tests and have their values of V_x captured and placed into the spectrum. This number is the *output count rate*, which we refer to as the OCR. The DXP normally returns, in addition to the collected spectrum, the REALTIME for which data was collected, the fast channel LIVETIME for which the fast channel was below threshold (and thus ready to detect a subsequent x-ray) together with the number FASTPEAKS of fast peaks detected and the number of V_x captured events EVTSINRUN. From these values, both the OCR and ICR_m can be computed according to Equation 5-11. These values can then be used to make deadtime corrections as discussed in section 5.11.

$$ICR_m = FASTPEAKS/LIVETIME; \quad OCR = EVTSINRUN/REALTIME$$

Equation 5-11

Note: The fast channel LIVETIME should only be used to determine the input count rate according to Equation 5-11. Specifically, it is NOT related to the energy filter livetime and should not be interpreted as the inverse of the processor deadtime. The DSP *does* calculate the energy filter livetime ELIVETIME, however, it is only an approximation. The most accurate deadtime measurement is obtained from ICR_m and OCR in Equation 5-11, as discussed in section 5.11.

5.10 Throughput:

Figure 5.12 shows how the values of ICR_m and OCR vary with true input count rate for the DXP and compare these results to those from a common analog shaping amplifier plus SCA system. The data were taken at a synchrotron source using a detector looking at a CuO target illuminated by x-rays slightly above the Cu K absorption edge. Intensity was varied by adjusting two pairs of crossed slits in front of the input x-ray beam so that the harmonic content of the x-ray beam striking the detector remained constant with varying intensity.

NOTE: *The DXP's peaking time is twice as long as the analog system peaking time in this comparison, and yet the throughput is nearly the same.*

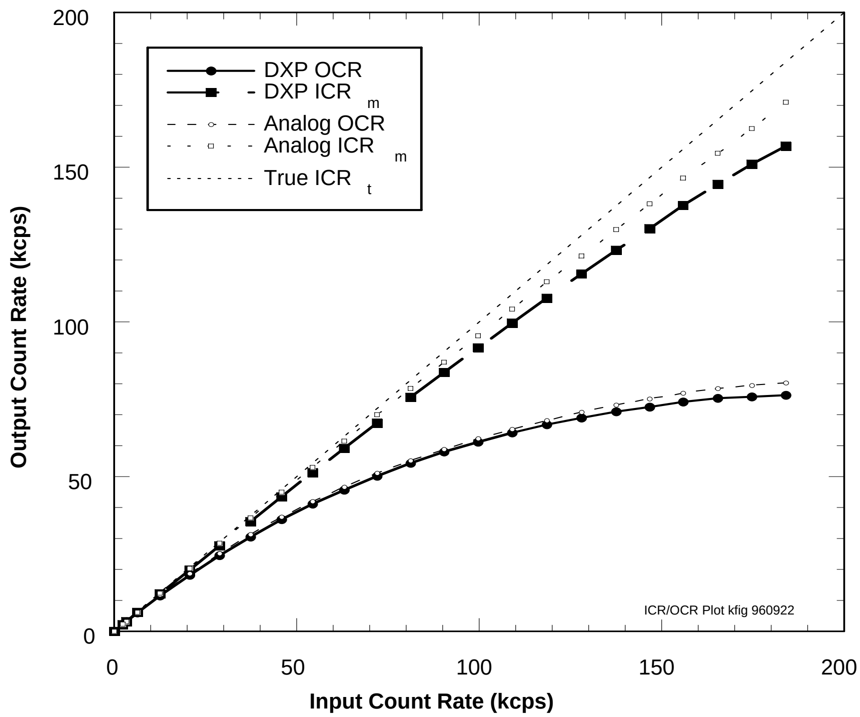


Figure 5.12: Curves of ICR_m and OCR for the DXP using 2 µs peaking time, compared to a common analog SCA system using 1 µs peaking time.

System	OCR Deadtime (µs)	ICR Deadtime (µs)
DXP (**2 µs** τ_p, 0.6 µs τ_g)	4.73	0.83
Analog Triangular Filter Amp (τ_p = **1 µs**)	4.47	0.40

Table 5.4: Comparing the deadtime per event for the DXP and an analog shaping amplifier. Notice that that the DXP produces a comparable output count rate even though its peaking time is nearly twice as long.

Functionally, the OCR in both cases is seen to initially rise with increasing ICR and then saturate at higher ICR levels. The theoretical form, from Poisson statistics, for a channel which suffers from paralyzable (extending) dead time is given by:

$$OCR = ICR_t * \exp(- ICR_t * \tau_d),$$

Equation 5-12

where τ_d is the *dead time*. Both the DXP and analog systems' OCRs are so describable, with the *slow channel dead times* - τ_d - shown in Table 5.4. The measured ICR_m values for both the DXP and analog systems are similarly describable, with the *fast channel dead times* - τ_{df} - as shown. The maximum value of OCR can be found by differentiating Equation 5-12 and setting the result to zero. This occurs when the value of the exponent is -1, i.e. when ICR_t equals $1/\tau_d$. At this point, the maximum OCR_{max} is 1/e multiplied by the ICR, or:

$$OCR_{max} = 1/(e\ \tau_d) = 0.37/\tau_d$$

Equation 5-13

These are general results and are very useful for estimating experimental data rates.

Table 5.4 illustrates a very important result for using the DXP: the slow channel deadtime is nearly the minimum value that is theoretically possible, namely the pulse basewidth. For the shown example, the basewidth is 4.6 µs ($2L_s + G_s$) while the deadtime is 4.73 µs. The slight increase is because, as noted above, PEAKINT is always set slightly longer than L_s - $G_s/2$ to assure that pileup does not distort collected values of V_x.

The deadtime for the analog system, on the other hand is much larger. In fact, as shown, the throughput for the digital system is almost twice as high, since it attains the same throughput for a 2 µs peaking time as the analog system achieves for a 1 µs peaking time. The slower analog rate arises, as noted earlier both from the longer tails on the pulses from the analog triangular filter and on additional deadtime introduced by the operation of the SCA. In spectroscopy applications where the system can be profitably run at close to maximum throughput, then, a single DXP channel will then effectively count as rapidly as two analog channels.

5.11 Dead Time Corrections:

The fact that both OCR and ICR_m are describable by Equation 5-12 makes it possible to correct DXP spectra quite accurately for deadtime effects. Because deadtime losses are energy independent, the measured counts N_{mi} in any spectral channel i are related to the true number N_{ti} which would have been collected in the same channel i in the absence of deadtime effects by:

$$N_{ti} = N_{mi}\ ICR_t/OCR$$

Equation 5-14

Looking at Figure 5.12, it is clear that a first order correction can be made by using ICR_m of Equation 5-11 instead of ICR_t, particularly for OCR values less than about 50% of the maximum OCR value. For a more accurate correction, the fast channel deadtime τ_{df} should be measured from a fit to the equation:

$$ICR_m = ICT_t * \exp(-ICR_t\ \tau_{df})$$

Equation 5-15

Then, for each recorded spectrum, the associated value of ICR_m is noted and Equation 5-15 inverted (there are simple numerical routines to do this for transcendental equations) to obtain ICR_t. Then the spectrum can be corrected on a channel by channel basis using Equation 5-12. In experiments with a DXP prototype, we found that, for a 4 µs peaking time (for which the maximum ICR is 125 kcps), we could correct the area of a reference peak to better than 0.5% between 1 and 120 kcps.

6 DXP Saturn Hardware Description

6.1 Organizational Overview:

The DXP channel architecture is shown in Figure 6.1, showing the three major operating blocks in the DXP: the Analog Signal Conditioner (ASC), Digital Filter, Peak Detector, and Pileup Inspector (FiPPI), and Digital Signal Processor (DSP). Signal digitization occurs in the Analog-to-Digital converter (ADC), which lies between the ASC and the FiPPI. In the DXP Saturn, the ADC is a 12 bit, 40 MSA device, which is currently being used as a very linear 10-bit, 20 MHz ADC. The functions of the major blocks are summarized below.

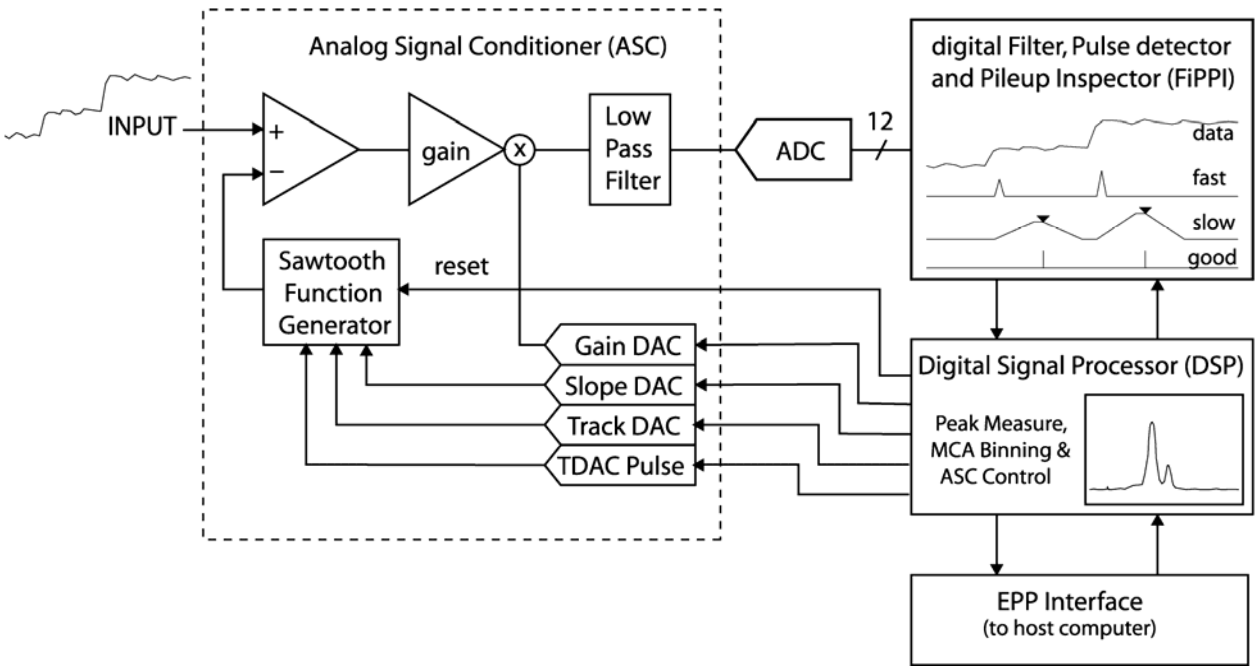


Figure 6.1: Block diagram of the DXP channel architecture, showing the major functional sections.

6.2 The Analog Signal Conditioner (ASC):

The ASC has two major functions: to reduce the dynamic range of the input signal so that it can be adequately digitized by a 12 bit converter and to reduce the bandwidth of the resultant signal to meet the Nyquist criterion for the following ADC. This criterion is that there should be no frequency component in the signal which exceeds half of the sampling frequency. Frequencies above this value are aliased into the digitized signal at lower frequencies where they are indistinguishable from original components at those frequencies. In particular, high frequency noise would appear as excess low frequency noise, spoiling the spectrometer’s energy resolution. The DXP Saturn therefore has a 4 pole Butterworth filter with a cutoff frequency of about 8 MHz.

The dynamic range of the preamplifier output signal is reduced to allow the use of a 12 bit ADC, which greatly lowers the cost of the DXP. This need arises from two competing ADC requirements: speed and resolution. Speed is required to allow good pulse pileup detection, as described in section 5.8. For high count rates, pulse pair resolution less than 200 ns is desirable, which implies a sampling rate of 10 MSA or more. The DXP uses a 20 MSA ADC. On the other hand, in order to reduce the noise σ in measuring V_X (see Figure 5.1 and Figure 5.3), experience shows that σ must be at least 4 times the ADC's single bit resolution ΔV_1. This effectively sets the gain of the amplifier stages preceding the ADC. Then, if the preamplifier's full scale voltage range is V_{max}, it must digitize to N bits, where N is given by:

$$N = \log_{10} (V_{max}/\Delta V_1)/\log_{10} (2)$$

Equation 6-1

For a typical high resolution spectrometer, N must equal at least 14. However, ADCs with 14 bits *effective* resolution (14-bit ADCs typically have between 12 and 13 effective bits, due to integral and differential non-linearities) operating in excess of 10 MSA are very expensive. At the time of this writing a 12 bit 20 MSA ADC costs less than $10, while a real 14-bit 20 MSA ADC costs several hundred dollars, which would more than triple the parts cost per channel.

The ASC circumvents this problem using a novel dynamic range technology, for which XIA has received a patent, which is indicated in Figure 6.2. Here a resetting preamplifier output is shown which cycles between about -3.0 and -0.5 volts. We observe that it is not the overall function which is of interest, but rather the individual steps, such as shown in Fig. 3.1b, that carry the x-ray amplitude information. Thus, if we know the average slope of the preamp output, we can generate a sawtooth function which has this average slope and restarts each time the preamplifier is reset, as shown in Figure 6.2. If we then subtract this sawtooth from the preamplifier signal, we can amplify the difference signal to match the ADC's input range, also as indicated in the Figure. Gains of 8 to 16 are possible, thus reducing the required number of bits necessary to achieve the same resolution from 14 to 10. The generator required to produce this sawtooth function is quite simple, comprising a current integrator with an adjustable offset. The current, which sets the slope, is controlled by a DAC (SLOPEDAC), while the offset is controlled by adding a current pulse of either polarity using a second DAC (TRACKDAC). The DAC input values are set by the DSP, which thereby gains the power to adjust the sawtooth generator in order to maintain the ASC output (i.e. the "Amplified Sawtooth Subtracted Data" of Figure 6.2) within the ASC input range.

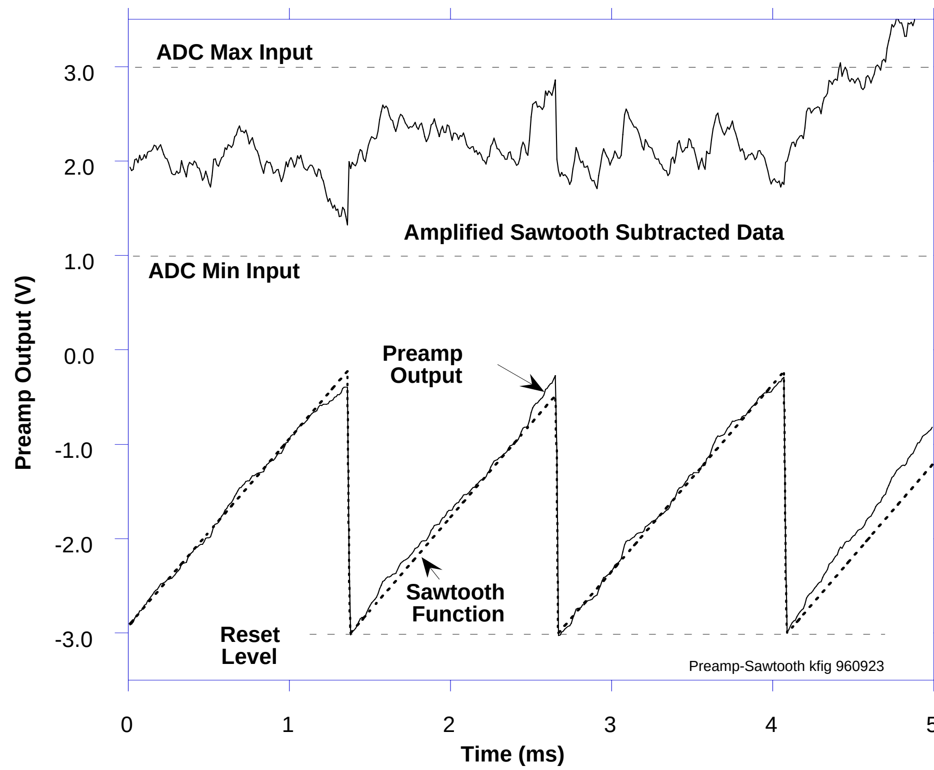


Figure 6.2: A sawtooth function having the same average slope as the preamp output is subtracted from it and the difference amplified and offset to match the input range of the ADC.

Occasionally, as also shown in Figure 6.2, fluctuations in data arrival rate will cause the conditioned signal to pass outside the ADC input range. This condition is detected by the FiPPI, which has digital discrimination levels set to ADC zero and full scale, which then interrupts the DSP, demanding ASC attention. The DSP remedies the situation by adjusting the TRACKDAC until the conditioned signal returns into the ADC's input range. During this time, data passed to the FiPPI are invalid. Preamplifier resets are detected similarly. When detected the DSP responded by resetting the current integrator with a switch.

6.3 The Filter, Pulse Detector, & Pile-up Inspector (FiPPI):

The FiPPI is implemented in a field programmable gate array (FPGA) to accomplish the various filtering, pulse detection and pileup inspection tasks discussed in chapter 4.6. As described there, it has a fast channel for pulse detection and pileup inspection and a slow channel for filtering, both with fully adjustable peaking times and gaps. The "fast" filter's τ_p (τ_{pf}) can be adjusted from 100 ns to 1.25 µs, while the "slow" filter's τ_p (τ_{ps}) can be adjusted from 0.25 µs to 80 µs. Adjusting τ_{pf} allows tradeoffs to be made between pulse pair resolution and the minimum x-ray energy that can be reliably detected. When τ_{pf} is 200 ns, for example, the pulse pair resolution is typically less than 200 ns. When τ_{pf} is 1 µs, x-rays with energies below 200 eV can be detected and inspected for pileup. To maximize throughput, τ_{PS} should be chosen to be as short as possible to meet energy resolution requirements, since the maximum throughput scales as $1/\tau_{PS}$, as per Eqn. 3.9. If the input signal displays a range of risetimes (as in the "ballistic deficit" phenomenon) the slow filter gap time can be extended to accommodate that range. The shortest value of τ_{PS} 0.25 µs, is set by the response time of the DSP to the FiPPI when a value of V_X is captured. At this setting, however, with a gap time of 100 ns, the dead time would be about 0.65 µs and the maximum throughput according to Equation 5-13 would be 560 kcps. This throughput cannot be reached in practice by the 20 MHz version of the Saturn, which is restricted by its DSP processing speed to maximum OCR values of about 450 kcps. There is also a 40 MHz version of the Saturn that can handle peaking times down to 0.125 µs and OCR values in excess of 700 kcps.

The FiPPI also includes a livetime counter which counts the 20 MHz system clock, divided by 16, so that one "tick" is 800 ns. This counter is activated any time the DSP is enabled to collect x-ray pulse values from the FiPPI and therefore provides an extremely accurate measure of the system livetime. In particular, as described in section 6.2, the DSP is not live either during preamplifier resets or during ASC out-of-ranges, both because it is adjusting the ASC and because the ADC inputs to the FiPPI are invalid. Thus the DXP measures livetime more accurately than an external clock, which is insensitive to resets and includes them as part of the total livetime. While the average number of resets/sec scales linearly with the countrate, in any given measurement period there will be fluctuations in the number of resets which may affect counting statistics in the most precise measurements.

All FiPPI parameters, including the filter peaking and gap times, threshold, and pileup inspection parameters are externally supplied and may be adjusted by the user to optimize performance. Because the FiPPI is implemented in a Xilinx field programmable gate array (FPGA), it may also be reprogrammed for special purposes, although this process is non-trivial and would definitely require XIA contract support.

6.3.1 FiPPI Variants

The FiPPI pipeline topology for RC-type preamplifiers is different than for reset-type preamplifiers, thus two standard code variants are offered for each decimation. See section 6.4.1 below for the variant file names included in the distributed FDD firmware files.

6.3.2 FiPPI Decimation

FiPPI's are distinguished also by 'decimation'. Decimation refers to pre-averaging of the ADC signal prior to the FPGA processing pipeline. Each decimation accommodates a specific range of peaking times, i.e. shaping or integration times. Typically four (4) FiPPI configuration files are required by the DXP Saturn. When the peaking time is changed such that a range boundary is crossed, the host software downloads the appropriate FiPPI configuration to the DXP Saturn.

Decimation	*#ADC Samples in Average*	*Peaking Time Range*	*'Shaping Time' Range*
0	1	250ns – 1.25μs	500ns – 2.5μs
2	4	1 μs – 5 μs	2 μs – 10 μs
4	16	4 μs – 20 μs	8 μs – 40 μs
6	64	16 μs – 80 μs	32 μs – 160 μs

Table 6.1: FiPPI decimation details.

6.4 The Digital Signal Processor (DSP):

The Digital Signal Processor acquires and processes event data from the FiPPI, controls the ASC through DACs, and communicates with the host. The processor is an Analog Devices ADSP-2183 16 bit Fixed-Point DSP optimized for fixed point arithmetic and high I/O rates. Different DSP program variants are used for different types of data acquisition and different preamplifier types. section 7 describes in detail the DSP operation, its tasks, and parameters which control them.

The ADSP-2183 has 16K words of 16-bit wide data memory and 16K words of 24-bit wide program memory, part of which is used as data memory to hold the MCA spectrum. (If more memory is required for special purposes, up to 4 Mbytes of extended memory can be added by specifying option M). Transferring data to/from these memory spaces is done through the DSP's built-in IDMA port, which does not interfere with the DSP program operation.

6.4.1 Code Variants

6.4.1.1 MCA acquisition with RC-type preamplifiers

Variant 0 is the standard firmware variant supplied with the DXP Saturn, as described in this manual. It is intended for use with reset-type preamplifiers (described in section 5.1.1).

FDD file:	**X10P_RESET.FDD**
DSP file name:	X10P_0106.HEX
Fippi file names:	FXPD00J_PSAM.FIP
	FXPD200J_ST.FIP
	FXPD420J_ST.FIP
	FXPD640J_ST.FIP

Note: To use this variant, the "Ramp/Offset" jumper should be in the "Ramp" position.

6.4.1.2 MCA acquisition with RC-type preamplifiers

This firmware variant is intended for use with resistive feedback preamplifiers (described in section 5.1.2).

FDD file:	**X10P_RC.FDD**
DSP file name:	X10PRC_0103.HEX
Fippi file names:	FXRC00J.FIP
	FXRC200J.FIP
	FXRC420J.FIP
	FXRC640J.FIP

Additional parameters (described in Section 5.10):

RCTAU: Exponential decay time in 1 μs units.

RCTAUFRAC: Fractional decay time in 1.15 format.

RCFCOR: Correction factor (calculated automatically at start of run if RCTAU not 0)

Note: To use this variant, the "Ramp/Offset" jumper should be in the "Offset" position.

6.5 Interface to the Host Computer:

ADVICE!! *XIA strongly recommends using the Handel libraries to develop your own code to drive the Saturn, instead of trying to understand the rest of this manual.*

Communications between the DXP and host computer occur through the Enhanced Parallel Port (EPP), and complies with IEEE specification 1284. Such a port is included in most Pentium class PCs, and if not a very inexpensive card can be added. The DXP Saturn interface is implemented in an FPGA which can be thus be relatively easily modified by a PROM upgrade. Access to the DXP Saturn is supported t on Windows 95/98/NT platforms both by the application ProSpect and by a function library named Handel, that can be called using spectrometrically relevant parameters. In this way a programmer who wants to develop his own Saturn interface application needs to know very little about interface specifics. Handel is available for download on XIA's website.

The following paragraphs, as well as section 7 are provided for the benefit of programmers who have special needs that require an intimate knowledge of how the DXP's interface and DSP code work at the lowest level. XIA strongly recommends using Handel as a preferred approach to developing applications.

The host application is responsible for downloading firmware to the FiPPI, software to the DSP program memory segment and parameters to the DSP data memory segment. The Control Status Register (CSR) is used to control the downloading of firmware and the starting and stopping data acquisition. Reading and writing to the DSP (program download, parameter download, spectrum download...) takes place directly through an IDMA transfer. These transfers involve first writing an address to the EPP address port followed by one or more reads/writes from/to the EPP data port.

The following is the address space of the DXP. Addresses 0x0000-0x7FDF map directly into the on board DSP, while those addresses greater the 07FFF are decoded by the DXP interface circuit.

Address	*Name*	*Description*
0x0000 - 0x3FFF	Program memory	Contains the DSP instructions and 24-bit data
0x4000 - 0x7FDF	Data memory	16-bit data, including the parameters memory
0x7FE0 - 0x7FFF	Reserved	
0x8000	Control Status Register (CSR)	A bitwise flag register for controlling the DSP. See below for further details.
0x8001-0x8002		Diagnostic or special purpose registers
0x8003		FiPPI configuration register

Table 6.2: Map of the DXP memory.

Bit	*Access*	*Name*	*Meaning*
0	R/W	RunEnable	Disable(0) or Enable(1) data
1	r/w	NewRun	Update(0) or Reset(1) spectra, statistics at run start
8	r	FPGAErr	Set if FiPPI configuration download error
9	r	DSPErr	Set of DSP error condition exists
11	r	Active	Set if data acquisition is in progress

Table 6.3: The Control Status Register flag bits.

7 DXP Saturn DSP Code Description

NOTICE: if you are curious about how the DSP operates in controlling the DXP and processing data from the FiPPI, then please read on. You will also find this information useful if you wish to develop your own control code for the Saturn. However, in the latter case, we strongly advise you to use XIA's support libraries (Handel) to interface between your program and the Saturn module.

7.1 Introduction and Program Overview

The following sections are intended to provide the DXP user with a good understanding of the various tasks performed by the DSP in the DXP Saturn. The DSP performs several functions:

1) Respond to input and output calls from the host computer to start and stop data collection runs, download control parameters, and download collected data.
2) Perform system calibration measurements by varying the various DAC settings under its control and noting the output change at the ADC.
3) Make initial measurements of the slow filter baseline and preamplifier slope value at the start of data taking runs to assure optimum starting parameter values.
4) Collect data:
   a) Read energy values E_X from the FiPPI, under interrupt control, and store them in DSP buffer memory in less than 0.25 µs.
   b) Adjust the ASC control parameters, under interrupt control, to maintain its output within the ADC's input range.
   c) Process captured E_X values to build the x-ray spectrum in DSP memory.
   d) Sample the FiPPI slow filter baseline and build a spectrum of its values in order to compute the baseline offset for E_X values.

Several DSP program variants are available to cover a range of applications. The standard program provided with the DXP Saturn is for typical x-ray fluorescence spectroscopy using a reset-type preamplifier. Additional program variants are available for other applications, including hardware diagnostics and other specialized measurements, e.g.:

- *X-ray mapping*
- *Quick XAFS scanning*
- *Switching between multiple spectra synchronously with an experimentally derived signal (e.g. "Phased locked EXAFS")*
- *Time resolved spectroscopy (e.g. "multi-channel scaling")*

Standard variants available to all users via our website are described in section 7.11. Several other variants have been developed for particular customers and may be made available upon request.

By convention, the DSP programs are named “NAMEmmnn.HEX”, where NAME is the variant name listed in the table, mm and nn are major and minor version numbers, respectively. The hex file format is in ASCII, with the parameter table at the top followed by the code generated by the Analog Devices 218x development system.

The internal data memory area is subdivided into three sections. The first section, starting at location 0x4000, contains DSP parameters and constants, both those used for controlling the DSP's actions and those produced by the DSP during normal running. These parameters and their addresses are listed and described in the following sections. When these parameters are referred to they will be denoted by all capital letters (e.g. RUNTASKS). The locations of parameters can (and, for forward compatibility should) be determined from the symbol table.

The second section of data memory contains acquired monitoring data such as the baseline event histogram. The third section of internal data memory is used as a circular buffer for storing events from the FiPPI. Note that future hardware revisions may eliminate the need for this buffer area, in which case it could be switched to more histogramming area.

7.2 Program Flow

The flow of the DSP program is illustrated in Figure 7.1. It is essentially identical for all program variants. The structure is very simple; after initialization, the DSP enters an idle phase, waiting for a signal from the host to start a run. During this idle phase, the DSP is continuously collecting baseline events from the FiPPI as well as monitoring the Analog Signal Conditioner (ASC) to keep the ADC input signal in the proper range and to adjust the slope generator to match the current input rate. When the Begin Run signal is received (from the host through the CSR register), the DSP first determines whether the run is a normal data-taking run or a special run.

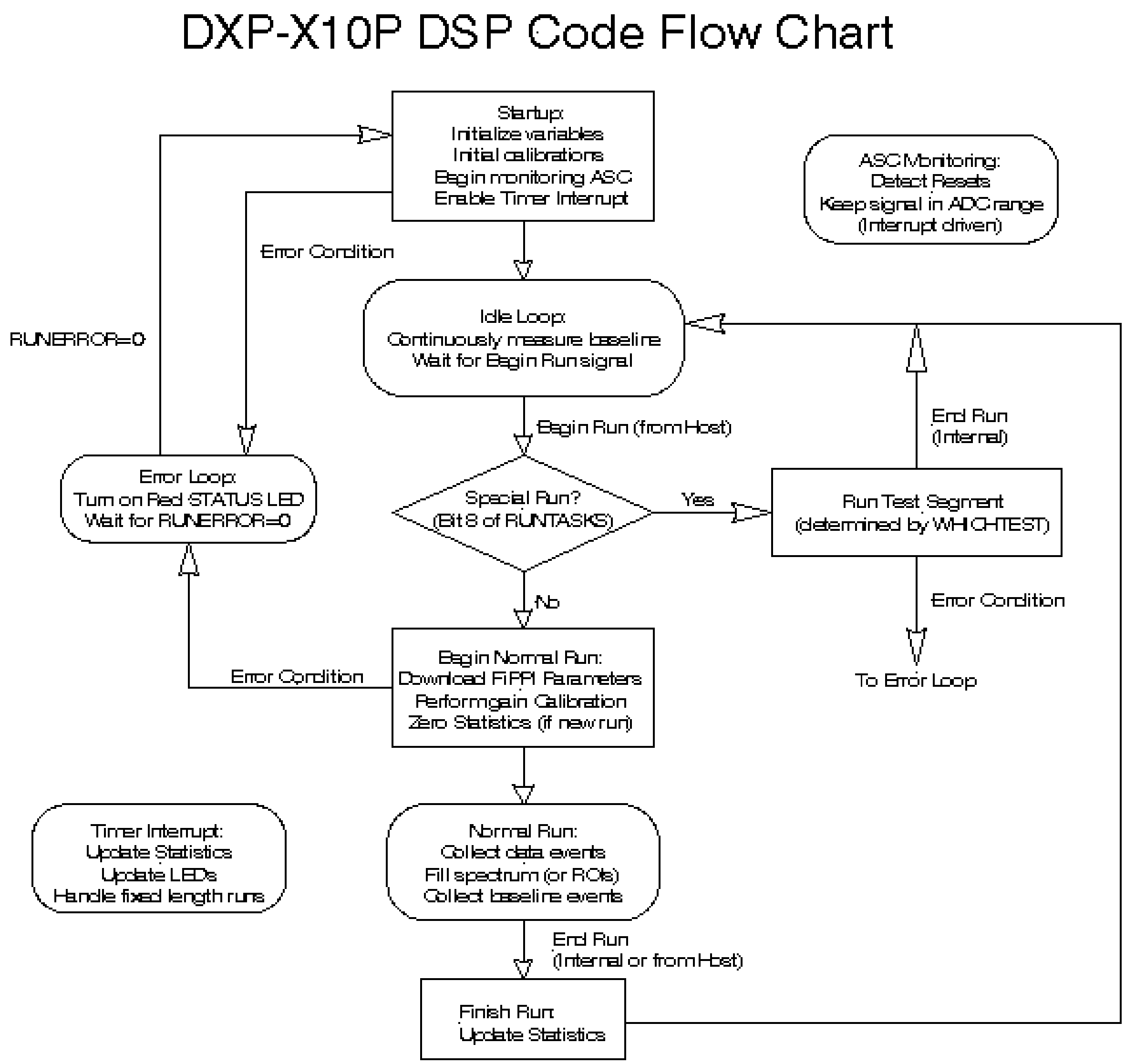


Figure 7.1 DSP code flow diagram.

In a normal run, ASC monitoring and baseline collection continue as in the idle phase. Event interrupts are enabled; when the FiPPI detects an event, it interrupts the DSP, which quickly responds and reads the energy value from the FiPPI into an internal buffer in data memory. The events in the buffer are then used to build the x-ray spectrum (or fill regions of interest).

In a special run, the action is determined by the value of the parameter WHICHTEST. The special runs include calibration tasks such as collecting an ADC trace, as well as ways of putting the DSP code into a special state (such as putting it into a dormant state to allow reprogramming the FiPPI on the fly). Special runs normally end on their own and the DSP returns to the idle state.

After the initialization phase, the Timer interrupt is enabled. This interrupt is used to handle the housekeeping type chores, such as updating the statistics during a run, controlling the rate LED, and handling fixed length runs. The Timer interrupt occurs with a period of 500 µsec.

If the DSP encounters an error condition, the DSP turns on the red status LED and waits for the host to set the parameter RUNERROR to 0 (after finding and fixing the problem that resulted in the error condition).

Each phase of the DSP program is discussed in more detail below.

7.3 Initialization

The DSP code starts running immediately after the DSP download is complete. During the initialization phase, several tasks are performed:

5) Setup internal DSP control registers
6) Zero spectrum and data memory, then initialize parameters to default values.
7) Set ASC DACs to initial default values
8) Initialize FiPPI and download default filter parameters
9) Perform initial calibrations for controlling the ASC:
   a) Find the SlopeDAC setting corresponding to zero slope
   b) TrackDAC Calibration (determine TrackDAC step needed to move the ADC input signal from the edge of the range to the center of the range)
   c) Measure conversion factor used to calculate the contribution of the slope generator to the FiPPI baseline.
10) Enable the input relay and enable the ASC and timer interrupts.

After the interrupts are enabled, the DSP is alive and ready to take data. After completing the initialization phase, the DSP enters the idle phase. In the idle phase, the DSP continuously samples the FiPPI baseline and updates the baseline subtraction register in the FiPPI so that the FiPPI is always ready to take data as soon as a run is started. There are two primary tasks performed during a normal data-taking run: event processing and baseline measurement. These tasks are described in detail below.

7.4 Event Processing

7.4.1 Run Start

Prior to the start of a normal run, the DSP performs several tasks:

1) Sets the desired gain (by setting the GAINDAC). If the gain has changed, the TrackDAC calibration is redone (for reset detectors only).
2) Sets the desired polarity (the internal DSP polarity and the FiPPI polarity must be changed simultaneously to avoid ASC instability). Only applicable if the desired polarity differs from the default negative polarity (and then only for the first run).
3) Downloads the specified FiPPI parameters (SLOWLEN, SLOWGAP, etc) to obtain the desired peaking time.
4) Updates the internal calibrations with the new gain and FiPPI values.
5) If desired, the run statistics and the MCA are cleared (determined by the NewRun bit in the CSR). Otherwise, the run is treated as a

continuation of the previous run. Note that for a run continuation, no gain or FiPPI changes are performed. In either case, the run number (parameter RUNIDENT) is incremented.

7.4.2 Event Interrupt

When the FiPPI detects a good event, it triggers a high priority interrupt in the DSP. Upon receiving the interrupt, the DSP immediately reads the event energy from the FiPPI into an internal circular buffer and increments the write pointer into that buffer. The normal event loop compares the write pointer to the read pointer to determine that there is a new event to process.

7.4.3 Event Loop

The processing that takes place during a normal collection run is very simple, in order to allow high event rates. The structure of the event loop is illustrated below in pseudocode:

```
while (RunInProgress)
      {
      if (EventToProcess)
            ProcessEvent
      else
            CollectBaseline
      endif
      }
RunFinish
goto IdleLoop
```

The run can be stopped by the host by clearing the RunEnable bit in the CSR, or can be stopped internally for fixed length runs; see Section 0 below.

The event processing involves either binning the energy into an MCA or determining whether the event falls into a defined SCA window, depending upon the DSP code variant. If there is no event to process, the DSP reads a baseline value from the FiPPI; see below for a detailed description of the baseline processing. Once the run is over, the statistics are finalized and the DSP returns to the idle state where it continuously samples baseline and waits for a command to start a new run.

7.4.4 Spectrum Binning

The primary event processing task is to use the energies measured in the FiPPI to build up a full energy spectrum (MCA). The MCA bin width is determined by the analog gain, the FiPPI filter length, and the binning parameter BINFACT1. The DSP determines the spectrum bin by multiplying the FiPPI energy output by (1/BINFACT1). If the bin is outside the range determined by the parameters MCALIMLO and MCALIMHI, the event is classified as an underflow or overflow. Otherwise, the appropriate bin is incremented. A 24-bit word is used to store the contents of each bin, allowing nearly 16.8 million events per MCA channel.

7.4.5 SCA Mapping

An alternate variant of the DSP code allows the user to define up to 24 SCA regions and count the number of events that fall into each region. The regions are defined in terms of MCA bin number, and can overlap. A useful method for defining the SCA windows is to take a run with the full MCA spectrum, and use the spectrum as an aid in choosing the limits for each SCA. The reduced amount of data storage in SCA mapping mode is very useful in time resolved spectroscopy or scanning applications, where separate spectral data are desired for many different time or spatial points.

7.5 Baseline Measurement

The DSP collects baseline data from the FiPPI whenever there are no events to process, both during a run and between runs (when there are never events to process). The DSP keeps a running average of the most recent baseline samples; this average is written back into the FiPPI where it is subtracted from the raw energy filter value to get the true energy. The baseline data read from the FiPPI is just the raw output of the energy filter. One bit of the baseline register is used to indicate whether the sample occurred while an event was in progress, in which case it is not used.

Two methods are available to determine the average baseline value. By default, an *infinite impulse response (IIR)* filter is used, where the baseline average is calculated by combining a new baseline sample with the old average, using weights x and (1-x) respectively, where x is typically 1/128. By setting the appropriate bit in the parameter RUNTASKS (see below), a *finite impulse response (FIR)* filter is used, where the baseline mean is just the straight average of the N most recent baseline samples. Both averaging methods are described in more detail in the following sections. The baseline mean is stored with 32 bit precision in the parameters BASEMEAN0 (high order word) and BASEMEAN1.

7.5.1 IIR (Infinite Impulse Response) Filter

By default, the baseline mean is calculated using an infinite impulse response filter, characterized in the following way:

$$< B_i >= \frac{N-1}{N} < B_{i-1} > + \frac{1}{N} B_i$$

Equation 7-1

where $<B_i>$ is the baseline mean after the *i*th baseline sample, B_i is the *i*th baseline sample, and $<B_{i-1}>$ is the baseline mean before the *i*th sample. With this filter, the most recent baseline samples are weighted the most, but (up to the precision of the stored mean value) all baseline values have a small effect on the mean (hence the infinite in the name).

The length of the filter is controlled by the parameter BLFILTER, which holds the value 1/N in 16 bit fixed point notation, which has 1 sign bit and 15 binary bits to the right of the decimal point. Expressed as a positive integer, BLFILTER = $(1/N)*2^{15}$. The default value for BLFILTER corresponds to N=64. Interpreting BLFILTER as an integer gives $(1/128)*2^{15} = 2^9 = 256$.

7.5.2 FIR (Finite Impulse Response) Filter

By setting the appropriate RUNTASKS bit, it is possible to choose a finite impulse filter to calculate the baseline mean. With this filter, a straight average of the N most recent valid baseline samples is used to calculate the mean. To implement this filter, a buffer large enough to hold all N samples is necessary. For this reason, the length of the finite response filter is limited to 1024. The filter length is stored in the parameter BLFILTERF.

7.5.3 Baseline Histogram

As part of the baseline processing, all valid baseline samples are entered into the baseline histogram, which occupies 1024 words of data memory. The baseline histogram can be very useful in monitoring or evaluating the performance of the DXP Saturn, as discussed in section 4.6.2. The parameter BASESTART contains the pointer to the location of the histogram in data memory, and the length (nominally 1K) is contained in the parameter BASELEN.

The baseline histogram is centered about a zero baseline. The parameter BASEBINNING determines the granularity of the histogram; 2**BASEBINNING baseline values are combined into one bin of the baseline histogram. The default value of BASEBINNING is 2 (i.e., the baseline value is divided by 4 to determine the bin). All valid baseline values are included in the histogram, even if there is a baseline cut (see section 7.5.5 below) in use.

The baseline histogram is only filled during a normal data taking run; when the DSP is idle, the baseline average is calculated but the histogram is not filled. Since the baseline histogram is stored in data memory, 16-bit words are used to record the bin contents. As a result, the histogram overflows quite often; the time to overflow depends on the baseline sample rate (typically several 100 kHz) and the width of the baseline distribution. When the DSP detects an overflow, all bins are scaled down by a factor of 2 and histogramming continues.

The baseline distribution should be very Gaussian; the width of the distribution reflects the electronic noise in the system (including the effects of the energy filter). A tail on the positive side of the distribution indicates the presence of energy in the baseline, resulting from undetected pileup or energy depositions that did not satisfy the trigger threshold. The tail should be very small compared to the peak of the histogram; it will grow with rate. If this tail is too large, it can have a noticeable effect on the baseline mean, leading to negative peak shifts. Under these circumstances, enabling the baseline cut is useful in eliminating the bias.

A tail on the low energy side of the baseline distribution is usually caused by baseline samples just after a preamplifier reset; the effects of the reset can last quite a while (tens of microseconds), especially for optical reset preamplifiers. It is usually best not to take data while the reset is in effect; the dead time associated with a reset can be adjusted using the parameter RESETWAIT, which sets the dead time in units of 250 ns or, more easily, by using the ProSpect path **Saturn » Detector Preamplifier Settings » Reset Interval** to enter a dead time value (See section 4.2.3)

7.5.4 Residual Baseline

When operating with a reset type preamplifier, the raw baseline measured in the FiPPI (which is just the output of the energy filter) comes from two sources: the detector preamplifier and the slope generator in the DXP Saturn itself. At high rates, the slope gets rather large in order to balance the high energy deposition rate in the detector; under these conditions, the baseline due to the slope is by far the dominant factor in the baseline.

By default, the DSP continually adjusts the slope to match the current rate; these slope adjustments result in an instantaneous change in the baseline. If the baseline due to the slope generator is included in the baseline mean, the change in the calculated mean would be delayed relative to the change in the slope, due to the effect of all the baseline samples prior to the slope change. For this reason, the baseline due to the slope is subtracted out of the overall baseline prior to calculating the mean value (and added back in prior to loading the FiPPI baseline subtraction register). The *residual* baseline included in the mean reflects the detector leakage current, and should be fairly constant with rate (to the extent that the leakage current does not depend on rate). The calibration procedure used to determine the baseline due to the slope generator is performed during the initial startup procedure.

By default, the baseline due to the slope generator is taken out of the baseline average. You can choose to include the slope baseline in the mean (e.g. for diagnostic purposes) you can do so by clearing the residual baseline bit (6) in RUNTASKS.

7.5.5 Baseline Cut

As specified above, a baseline cut is available to exclude baseline samples that include real event energy, which can lead to peak shifting at high event rates. The cut is expressed as a fraction of the peak value of the baseline distribution; by default, the baseline cut is set to 5%. The cut values are based on the baseline histogram, and are recalculated every time the histogram overflows (every few seconds). The DSP searches on either side of the peak of the baseline distribution for the first bin whose contents are less than the cut (.05 by default) times the peak value; these bin numbers are used to calculate the actual baseline cut.

The cut fraction is stored in the parameter BLCUT, expressed in 16-bit fixed-point notation. Interpreted as an integer, BLCUT = (cut fraction)* 2^{15}; the default 5% cut corresponds to BLCUT=1638 decimal (or 666 hex). The actual cut values determined by the DSP code are stored in BLMIN and BLMAX. The baseline cut is enabled or disabled by setting or clearing a bit (10) in the RUNTASKS parameter.

7.6 Interrupt Routines

There are several tasks performed under interrupt control within the DSP on the DXP Saturn. The event interrupt routine (which just transfers event data from the FiPPI to an internal buffer) is described above in Section 7.4

above. There are two other interrupt routines: the ASC interrupt is used to keep the analog signal within the input range of the ADC, and the timer interrupt is used to handle such housekeeping chores as updating statistics. These routines are described in more detail below.

7.6.1 ASC Monitoring

There are four main tasks performed by the ASC interrupt routine:

1) Detects Resets (reset-type detectors only)
2) Adjusts the slope generator to match the event rate (reset-type detectors only)
3) Adjusts the offset value to keep the signal in range (RC feedback detectors only)
4) Moves the signal back to the center of the ADC range whenever it drifts out of range (high or low)

The ASC interrupt routine is triggered whenever the FiPPI detects the ADC going out of range. If the out of range is due to the signal drifting out of range (instead of a reset), the DSP triggers a TrackDAC step to bring the signal back to the center of the ADC range, and data taking resumes. If the DSP determines that the out of range is due to a reset, then the DSP holds the signal at the center of the ADC range for a time determined by the parameter RESETINT, which specifies the dead time after a reset in 0.25 μsec units. After the reset interval, the signal is released and data taking resumes.

The DSP keeps track of how many times the signal drifts out of range in both directions, and adjusts the slope such that the number of drifts high (DriftUps) roughly matches the number of drifts low (DriftDowns). If the DSP determines that the slope must be changed to match the rate, the SlopeDAC value is modified by a constant fraction of the parameter SLOPEVAL determined by the value of the parameter SGRANULAR. By default, the slope adjustment granularity is 5%, which is a good compromise between adjusting the slope quickly to match quickly changing input rates and being able to set the SlopeDAC just right.

For an RC feedback detector, the offset added to the input signal is adjusted such that the signal stays in range as much as possible.

7.6.2 Timer Interrupt

Every 500 μsec, the DSP is interrupted to take care of the regular 'maintenance' type tasks. These tasks include:

1) Update the run statistics EVTSINRUN, LIVETIME, REALTIME and FASTPEAKS (only during a run).
2) Control the Rate LED. This LED flashes whenever a reset is detected (reset detector only), and during a run the color indicates the current output/input ratio. By default, the LED flashes green for OCR/ICR>0.5, flashes yellow (green plus red) for 0.5>OCR/ICR>1/e, and flashes red for OCR/ICR<1/e. The thresholds are determined by the parameters YELTHR and REDTHR.

3) Handle fixed length runs. During a fixed length run, the current value of EVTSINRUN (output events), FASTPEAKS (input events), LIVETIME or REALTIME is compared to the desired run length. Once the value exceeds the desired value, the run is ended.

7.7 Error Handling

When the DSP detects an error in the operation of the DXP Saturn, the red Status LED is turned on, and the source of the error is stored in the parameter RUNERROR. The possible values for RUNERROR are listed below:

RUNERROR Value	Meaning
0	No Error
1	FiPPI communication error
2	ASC setup failure
3-5	Reserved
6	TrackDAC calibration error

Table 7.1: Identification of DXP errors according to the DSP parameter RUNERROR.

A FiPPI communication error could mean that the FiPPI configuration was not successful. An ASC calibration error can indicate a hardware problem, or possibly that a jumper is not set properly (for example, the DSP code for reset preamplifiers will generate an error if the jumper is set to run in OFFSET mode).

Once the source of the error has been located and cleared, the host can set RUNERROR to 0 to force the DSP to exit the error loop and reinitialize the system. Note that all system settings are saved when initialization is performed coming out of the error loop. Of course, another valid method for clearing the error is to redownload the DSP code after fixing the problem.

7.8 Specifying Data Acquisition Tasks (RUNTASKS):

Many aspects of the operation of the DXP Saturn are controlled by individual flag bits of the parameter RUNTASKS. The meaning of each RUNTASKS bit is described in Table 7.2 below:

Bit	Meaning if set (1)	Meaning if cleared (0)
0	Reserved (set to 0)	Reserved (set to 0)
1	Update SlopeDAC or OffsetDAC value to match current rate (DEFAULT)	SlopeDAC or OffsetDAC adjustments disabled
2	Use Finite Impulse Response (FIR) filter to calculate baseline average	Use Infinite Impulse Response (IIR) filter to calculate baseline average (DEFAULT)
3	Acquire baseline values for histogramming and averaging (DEFAULT)	Disable baseline acquisition
4	Adjust fast filter threshold to compensate for rate shifts	Disable fast filter threshold adjustment
5	Correct for baseline shift, either in FiPPI (pulse reset) or DSP (RC feedback) (DEFAULT)	Disable baseline correction
6	Apply residual baseline correction (DEFAULT)	No residual baseline correction
7	Disable writing baseline values to baseline history circular buffer	Continuously write baseline values to baseline history circular buffer (DEFAULT)
8	Indicates special task or calibration run specified by WHICHTEST	Indicates normal acquisition run
9	Histogram DeltaBaseline (baseline - <baseline>)	Histogram raw baseline (DEFAULT)
10	Enable baseline cut	Disable baseline cut (DEFAULT)
11-15	Reserved (set to 0)	Reserved (set to 0)

Table 7.2: Data acquisition tasks controlled by the DSP parameter RUNTASKS.

7.9 Special Tasks (WHICHTEST)

Special tasks are selected by starting a run with bit 8 of the RUNTASKS parameter set. The following tasks are currently supported:

Number	Test Segment
0	Set ASC DAC values to current value of GAINDAC, SLOPEDAC and/or OFFSETDAC
1	Acquire ADC trace in history buffer
2	Gain calib (measure TDACPERADC)
3	Slope calibration (measure SLOPEMULT)
4	Measure ADC non-linearity
5	Not currently used
6	Put DSP to sleep while FPGA logic is downloaded
7	Not currently used
8	OffsetDAC calibration (measure OFFDACVAL)
9-10	Not currently used
11	Program Fippi
12	Set internal polarity to current value of POLARITY parameter
13	Close input relay
14	Open input relay
15	RC feedback calibration trace of baseline filter and decimator values
16	RC feedback calibration trace of event filter and decimator values

Table 7.3: Special tasks and test segments that can be selected with the DSP parameter WHICHTEST.

7.10 DSP Parameter Descriptions

As noted above, DSP operation is based on a number of parameters. Some are control parameters required to operate the DXP, some are calibration values determined by the DSP, and others are run statistics.

NOTE: in general you will not want to modify these parameters directly, but only through a host control program like ProSpect or, if you are a programmer, through a software library like XIA's Handel library.

Variable	***Type***	***Description***	***Reference***
PROGNUM	Constant	Program variant number.	
CODEREV	Constant	Current DSP program revision.	
HDWRVAR	Constant	Hardware variant. DSP reads this from interface FPGA.	
FIPPIREV	Constant	FiPPI design revision. DSP reads this from FiPPI FPGA.	
FIPPIVAR	Constant	FiPPI design variant. DSP reads this from FiPPI FPGA.	
DECIMATION	Constant	Slow filter decimation factor. DSP reads this from FiPPI FPGA.	
RUNIDENT	Returned	Run identifier	
RUNERROR	Returned	Error code if run is aborted, 0 for success	
BUSY	Returned	DSPs current acquisition status. Values listed below.	
Acquisition Statistics:			
LIVETIME0,1,2	Statistic	Intermediate filter live time in 800 nsec units	
ELIVETIME0,1,2	Statistic	Energy filter live time in 800 nsec units	
REALTIME0,1,2	Statistic	Elapsed acquisition time in 800 nsec units	
EVTSINRUN0,1	Statistic	Number of events in MCA spectrum	
UNDRFLOWS0,1	Statistic	Number of MCA underflow events	
OVERFLOWS0,1	Statistic	Number of MCA overflow events	
FASTPEAKS0,1	Statistic	Number of input events detected by FiPPI	
NUMASCINT0,1	Statistic	Number of ASC interrupts	
NUMRESETS0,1	Statistic	Number of "reset" events seen	
NUMUPSETS0,1	Statistic	Number of "upset" events seen	
NUMDRUPS0,1	Statistic	Number of "drift up" events seen	
NUMDRDOS0,1	Statistic	Number of "drift down" events seen.	
NUMZIGZAG0,1	Statistic	Number of "zigzag" events seen	
BASEEVTS0,1	Statistic	Number of baseline events acquired	
BASEMEAN0,1	Statistic	Updating mean baseline value	
Control parameters:			
WHICHTEST	Parameter	Which test segment to execute.	
RUNTASKS	Parameter	Which tasks will be executed in run sequence	
BINFACT1	Parameter	MCA binning factor	
MCALIMLO	Parameter	Lower limit of MCA spectrum	
MCALIMHI	Parameter	Upper limit of MCA spectrum	
TRACEWAIT	Parameter	ADC trace time factor	
ASCTIMOUT	Parameter	Timeout for ASCSetup in tenths of seconds	
YELLOWTHR	Parameter	Medium rate throughput threshold for front panel LED	
REDTHR	Parameter	High rate throughput threshold for front panel LED	
PRESET	Parameter	Preset type (0:none; 1:real time; 2:live time; 3: output cts; 4: input cts)	
PRESETLEN0,1	Parameter	Preset run length	
FiPPI Digital Filter/Event selection parameters:			
SLOWLEN	Parameter	Slow filter length	
SLOWGAP	Parameter	Slow filter gap	
PEAKINT	Parameter	Peak interval	
FASTLEN	Parameter	Fast filter length	
FASTGAP	Parameter	Fast filter gap	
THRESHOLD	Parameter	Threshold value for fast filter trigger (range: 1-255, 0 disables)	

MINWIDTH	Parameter	Minimum peak width
MAXWIDTH	Parameter	Maximum peak width
BASETHRESH	Parameter	Automatically set threshold for intermediate filter trigger (range 1-255, 0 disables both baseline and event discrimination—use FIPCONTROL to disable event discrimination only)
BASETHRADJ	Parameter	Coefficient for BASETHRESH auto-set algorithm (range 1-255, smaller values result in tighter thresholds)
FIPCONTROL	Parameter	FiPPI advanced control, bitwise flag register: bit 0 – fast threshold (0: enabled) bit 1 – intermediate threshold (0: enabled) bit 2 – slow threshold (0: enabled)
SLOWTHRESH	Parameter	Threshold for slow filter trigger (range 1-255, 0 disables)
PEAKSAM	Parameter	Peak sampling time
Baseline Related Parameters:		
BLFILTER	Parameter	Filtering parameter for baseline (IIR filtering)
BLFILTERF	Parameter	Filtering parameter for baseline (FIR filtering)
BASEBINNING	Parameter	Baseline binning for histogram (0:finest to 6:coarsest)
BLCUT	Parameter	DSP baseline cut (cut at BLCUT*FWHM, units defined below)
BLMIN	Calibration	Min baseline value accepted in average (calculated from BLCUT)
BLMAX	Calibration	Max baseline value accepted in average (calculated from BLCUT)
ASC Control Parameters and Calibrations (all variants)		
POLARITY	Parameter	Preamplifier signal polarity (0:negative step; 1:positive step)
GAINDAC	Parameter	Current Gain DAC value (16 bit serial DAC, range 0-65535).
INPUTENABLE	Parameter	Input Enable relay setting
ASC Control Parameters and Calibrations (reset-type variants)		
RESETWAIT	Parameter	Quick Reset time, 25ns units
RESETINT	Parameter	Reset time, 0.25 usec units
SLOPEDAC	Calibration	Current Slope DAC value (16 bit serial DAC, range 0-65535)
SLOPEZERO	Calibration	Slope DAC zero value (approximately center of range)
SLOPEVAL	Calibration	Abs(SLOPEDAC-SLOPEZERO)
SGRANULAR	Parameter	Slope DAC step size
TRKDACVAL	Parameter	Tracking DAC value: 12-bit parallel
TDACWIDTH	Parameter	Track DAC pulse width 50 ns units
TDQPERADC	Calibration	
TDQPERADCE	Calibration	
ASC Control Parameters and Calibrations (RC feedback variants)		
OFFSETDAC	Parameter	Current offset DAC value (16 bit serial DAC, range 0-65535).
OFFSETSTEP	Parameter	Offset DAC step size
RCTAU	Parameter	Preamplifer decay constant, in 1 μs units (RCF variant only)
RCTAUFRAC	Parameter	Fractional (1.15) decay constant (RCF variant only)
RCFCOR	Calibration	Preamplifer decay correction (RCF variant only)
Miscellaneous Constants:		
SPECTSTART	Constant	Address of MCA spectrum in program memory
SPECTLEN	Constant	Length of MCA spectrum buffer
BASESTART	Constant	Address of baseline histogram in data memory (offset by 0x4000)
BASELEN	Constant	Length of baseline histogram
EVTBSTART	Constant	Address of event buffer in data memory (offset by 0x4000)
EVTBLEN	Constant	Length of baseline histogram
HSTSTART	Constant	Address of history buffer in data memory (offset by 0x4000)
HSTLEN	Constant	Length of history buffer
NUMSCA	Parameter	Number of SCA regions defined (mapping variants only)
SCAxLO, x=0-23	Parameter	Lower MCA channel for SCA region x (mapping variants only)
SCAxHI, x=0-23	Parameter	Upper MCA channel for SCA region x (mapping variants only)
USER1-USER8	User	User variables. Host software can use these for any purposes

Table 7.4: Summary of DSP parameter definitions

7.10.1 Specifying fixed run lengths (PRESET, PRESETLEN0,1):

By default, the DXP Saturn acquires data until a stop command is received from the host.

A fixed run length can be specified using the parameters PRESET and PRESETLEN0,1, as follows:

PRESET specifies the type of run: 0 = indefinite (default)
1 = fixed realtime
2 = fixed (energy filter) livetime
3 = fixed output events
4 = fixed input counts

PRESETLEN0,PRESETLEN1 specifies the length of preset fixed length run, as a 32 bit quantity. For fixed realtime or livetime, the units are 800 nanosecond intervals.

7.10.2 Setting the slow filter parameters (SLOWLEN, SLOWGAP)

The DXP uses a trapezoidal filter, characterized by the peaking time, T_p, and gap time, T_g. The peaking time is determined by the SLOWLEN and DECIMATION values. SLOWLEN is the interval of time, in units of decimated clock cycles, during which the decimated ADC signal is integrated, referred to as the peaking time. DECIMATION is automatically sensed by the DSP and should not be modified. For T_p and T_g. in µsec, and the pipeline clock running at 20MHz, the following gives the value of SLOWLEN and SLOWGAP:

$$SLOWLEN = 20 * T_p * 2^{-DECIMATION}$$

e.g. At DECIMATION = 4, T_p = 16 µsec yields SLOWLEN=20. The user will want to be able to choose the peaking time based on resolution and throughput requirements as described earlier in this document.

SLOWGAP is the gap time, visible as the ‘flat-top’ region of the trapezoid.

$$SLOWGAP = 20*T_g*2^{-DECIMATION}$$

Subject to the restriction that it must exceed 3, SLOWGAP is set such that the flat-top interval is longer than the 0%-100% risetime of the preamplifier output pulses by at least 1 decimation period:

$$\text{Gap Time} = (2^D * SLOWGAP * 50ns) > \text{pulse risetime} + 2^D * 50\ ns$$

$$\text{or: } (2^D * (SLOWGAP-1) * 50ns) > \text{pulse risetime}$$

7.10.3 Setting the fast filter parameters(FASTLEN, FASTGAP)

The fast filter is also trapezoidal but has a decimation of 0 for all FiPPI designs. The values of FASTLEN and FASTGAP are given, for T_p’ fast peaking time and T_g’ = fast gap time in µsec:

$$FASTLEN = 20*T_p'$$

$$FASTGAP = 20*T_g'$$

Typical values of these parameters are FASTLEN=4 and FASTGAP=0.

7.10.4 Setting the pulse detection parameters (THRESHOLD, MINWIDTH, BASETHRESH, BASETHRADJ, SLOWTHRESH, FIPCONTROL)

X-rays are identified when a filter output goes above an active threshold. Thresholds can be applied to the fast (THRESHOLD), intermediate (BASETHRESH, BASETHRADJ) and energy filters (SLOWTHRESH), though in practice the energy threshold is rarely used. The user will typically only adjust the fast filter threshold, THRESHOLD.

All thresholds are scaled by their respective filter lengths. Further, they cannot be expressed in energy units until the DXP conversion gain (see section 7.10.6 below), G_{DXP} = number of ADC counts per eV at the DXP input, is known. For an energy threshold E_{th} in eV,

$$THRESHOLD=G_{DXP}*E_{th}*FASTLEN$$

$$BASETHRESH=G_{DXP}*E_{th}*SLOWLEN$$

$$SLOWTHRES=G_{DXP}*E_{th}*SLOWLEN$$

THRESHOLD is typically set by the user. A good procedure is to initially set the value too high. Once a spectrum is observed, reduce THRESHOLD until the zero energy noise peak starts to become significant, and then raise it again until only a trace of the noise peak remains. The MINWIDTH parameter is used for noise rejection: It is the minimum number of time bins the fast filter is above threshold. A typical value that works with FASTLEN=4 is MINWIDTH=4.

BASETHRESH is automatically set by the DSP and applied to the intermediate filter as part of the baseline acquisition circuitry, i.e. baseline measurements are taken when the signal is below this threshold. BASETHRESH threshold crossings by default also trigger event processing, effectively extending the detectable energy range significantly below the fast filter THRESHOLD. The parameter BASETHRADJ controls the algorithm that calculates BASETHRESH, with larger BASETHRADJ values resulting in more conservative BASETHRESH values. In the rare case the the baseline threshold is set incorrectly by the DSP algorighm, we recommend adjusting BASETHRADJ rather than BASETHRESH itself.

The use of a slow threshold introduces significant errors in the counting statistics. Specifically, the dead-time-per-event is markedly different for x-rays above and below the threshold. SLOWTHRESH should only be used if:

- ✓ Your detector has a very thin window and operates in a vacuum.
- ✓ You understand that it is not possible to compute input count rates for x-ray peaks below the threshold relative to x-ray peaks above the threshold.

Setting a threshold to zero disables that threshold. Individual thresholds can also be enabled and disabled via the lowest 3 bits of the parameter FIPCONTROL:

FIPCONTROL BIT	Meaning, if = 0	Meaning, if = 1
0	THRESHOLD event discrimination *enabled*	THRESHOLD event discrimination *disabled*
1	BASETHRESH event discrimination *enabled*; baseline discrimination *enabled*	BASETHRESH event discrimination *disabled*; baseline discrimination ***enabled***
2	SLOWTHRESH event discrimination *enabled*	SLOWTHRESH event discrimination *disabled*

Table 7.5: Threshold control via FIPCONTROL.

The two methods of disabling thresholds are equivalent, except in the case of the intermediate filter threshold BASETHRESH, which is used for both baseline and energy discrimination,

e.g. setting FIPCONTROL = XXXX XXXX XXXX X110 enables event discrimination based on the fast filter THRESHOLD, disables event discrimination based on the intermediate filter BASETHRESH and slow filter SLOWTHRESH, however, BASETHRESH still discriminates baseline measurements in the intermediate filter; alternatively, setting BASETHRESH to zero would disable both event and baseline discrimination, regardless of the value of FIPCONTROL.

7.10.5 Setting the Pile-up inspection parameters (MAXWIDTH, PEAKINT)

MAXWIDTH is used to reject pulse pile-up on a time scale that is comparable to FASTLEN as discussed in section 5.8. A typical value is

MAXWIDTH = 2*FASTLEN + FASTGAP +N

where N is in the range 4-8. If the signal rise-time depends on the x-ray energy (e.g. bandwidth limited preamplifier or low field regions of the detector that are preferentially sampled at some energy) this cut can bias the spectrum if it is too small.

PEAKINT is used to reject energy channel pulse pile-up when the pulses are well resolved by the fast channel. This value should be set as:

PEAKINT = SLOWLEN + SLOWGAP + N

where N = 0 typically. Setting N to higher values will increase the deadtime per event.

7.10.6 Setting the Analog Gain (GAINDAC)

The DXP internal gain is chosen to set the ADC dynamic range appropriately for the signals of interest. If it is set too low, the energy resolution may be compromised, while if is set too high there may be excessive deadtime and thus attenuation of higher energy x-rays. The ADC range is one volt full scale. Two guidelines are suggested for the internal gain setting:

1) This is appropriate when there is a single peak of interest: Set the gain such that the typical pulse height is between 5 and 10% of the ADC range (for 10 bit ADC; or between 2 and 10% of the ADC range for 12 bit ADC).

2) This is appropriate when looking at a fixed energy range, with no particular peak of interest: Set the gain such that the maximum energy pulses are around 300-400 displayed vertical units in the ADC Trace readout.

The parameter GAINDAC sets the internal amplifier gain. For particularly high gain detectors, the coarse gain jumper setting via JP102 offers a factor of 4 input signal attenuation. See Appendix A for the location of JP102. The overall gain can be expressed as follows:

$$G_{tot} = G_{in}' * G_{var} * G_{base}$$

where

G_{in}': the nominal input stage gain G_{in} ~ 1 (JP102 set to “0dB Attenuation”) or ~ ¼ (JP102 set to “12dB Attenuation”), is modified by the resistive divider created by the output impedance of the preamplifier and the input impedance of the Saturn to the value G_{in}'.

G_{var}: variable gain setting = 0.5 to 35.5 depending on GAINDAC setting

G_{base}: reference gain ~ 0.8

The total internal gain ranges from 0.2 V_{ADC}/V_{INPUT} to 57.7 V_{ADC}/V_{INPUT}.

The digital gain control is a 16 bit DAC which sets the gain of a “linear in dB” variable gain amplifier. The gain setting accuracy is approximately one bit (or 0.00061 dB = 0.007%). The relationship between G_{var} and GAINDAC is:

$$\text{Gain (in dB)} = (\text{GAINDAC}/65536) * 40 \text{ dB}$$

$$G_{var} = 10^{**}(\text{Gain(in dB)}/20)$$

The output impedance R_{OUT} of the preamplifier creates a resistive divider with the Saturn input impedance R_{IN}, and thus affects the input gain term G_{in}. If JP102 is set to “0dB Attenuation”, the input impedance R_{IN} = 10.0kW. If JP102 is set to “-12dB Attenuation”, the input impedance R_{IN} = 1.00kΩ. This factor can be expressed as follows:

$$G_{in} (R_{OUT})' = 2k /((1k \text{ or } 500) + \text{Output Impedance}))$$

7.11 Standard Program Variants

7.11.1 MCA acquisition with reset-type preamplifiers

Variant 0 is the standard firmware variant supplied with the DXP Saturn, as described in this manual. It is intended for use with reset-type preamplifiers (described in Section 3).

FDD file:	**X10P_RESET.FDD**
DSP file name:	X10P_0106.HEX
Fippi file names:	FXPD00J_PSAM.FIP
	FXPD200J_ST.FIP
	FXPD420J_ST.FIP
	FXPD640J_ST.FIP

Note: To use this variant, the “Ramp/Offset” jumper should be in the “Ramp” position.

7.11.2 MCA acquisition with RC-type preamplifiers

This firmware variant is intended for use with resistive feedback preamplifiers (described in Section 3.6).

FDD file:	**X10P_RC.FDD**
DSP file name:	X10PRC_0103.HEX
Fippi file names:	FXRC00J.FIP
	FXRC200J.FIP
	FXRC420J.FIP
	FXRC640J.FIP

Additional parameters (described in Section 5.10):

RCTAU: Exponential decay time in 1 μs units.

RCTAUFRAC: Fractional decay time in 1.15 format.

RCFCOR: Correction factor (calculated automatically at start of run if RCTAU not 0)

Note: To use this variant, the “Ramp/Offset” jumper should be in the “Offset” position.

Appendices

Appendix A. DPP-X10P Revision D.2 Circuit Board Description

This Appendix to the DXP Saturn User's Manual is provided for DXP-OEM customers. It summarizes jumper settings, connector locations, part numbers and pinouts, and power consumption calculations for the DPP-X10P Revision D.2 digital x-ray processor circuit board.

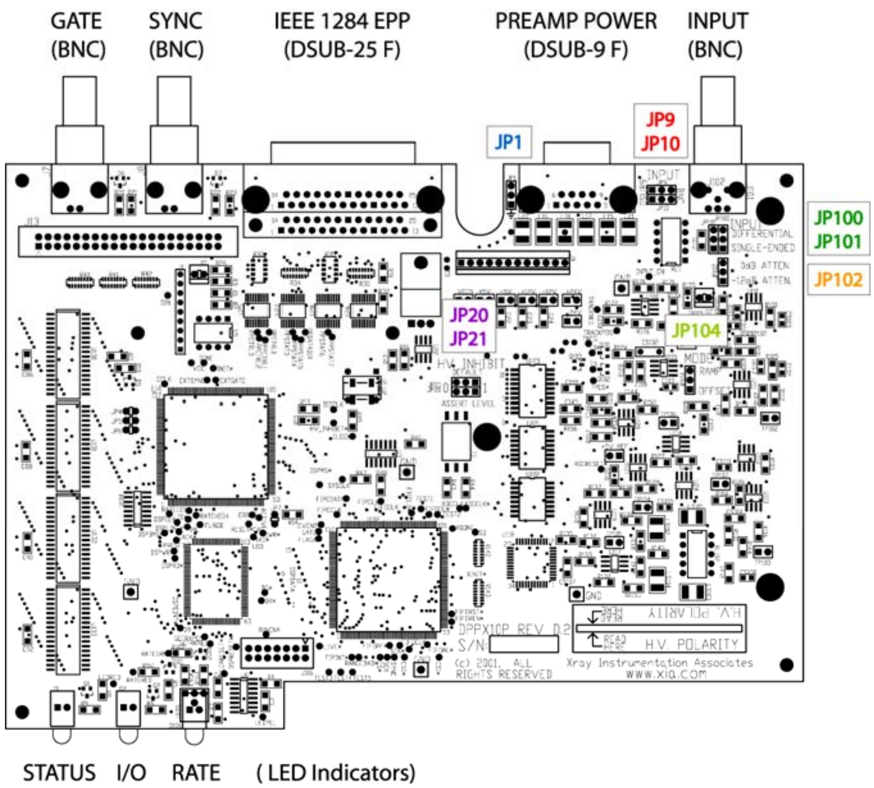


Figure A.1: Jumper and connector locations for the DPPX10P Rev. D.2 printed circuit card.

A.1. Jumper Settings

Reference	Jumper Label	Position Labels	Description
JP1	-	- GND (symbol)	- Chassis and internal ground not connected - Chassis connected to internal ground *Improves signal integrity in some cases, but can introduce a ground loop.*
JP9 & JP10	INPUT	DSUB-9 BNC	- Signal entry via DSUB-9 connector - Signal entry via BNC connector
JP20	HV INHIBIT -ASSERT LEVEL	0 1	- HV inhibited when BNC input is LO - HV inhibited when BNC input is HI
JP21	HV INHIBIT -DEFAULT	0 1	- If BNC disconnected, asserted level is LO - If BNC disconnected, asserted level is HI
JP100 & JP101	INPUT	SINGLE-ENDED DIFFERENTIAL	- Single-ended input configuration (standard) - Differential input configuration (rare)
JP102	INPUT	-12dB ATTEN. 0dB ATTEN.	- input signal divided by four (-12dB attenuation) - input signal not divided (0db attenuation) *The –12dB setting should be selected if the preamplifier output voltage exceeds +/- 10V.*
JP104	MODE	RAMP OFFSET	- Setting for pulsed-reset preamplifiers - Setting for resistive-feedback preamplifiers

A.2. LED Indicators

D1 – Status LED: Red, illuminated when an error condition is present
QT Optoelectronics P/N: MV67539.MP7

D2 – I/O LED: Yellow, illuminated during USB transfers
QT Optoelectronics P/N: MV63539.MP7

D2 – Rate LED: Red/Green bi-color LED, flashes at a frequency proportional to x-ray event rate. Flashes green, yellow or red, depending on the processor dead time.
Gilway P/N: E250

A.3. Connectors

J101 - Signal Input: BNC, connects preamplifier output to the DPP. **Bomar P/N: 364A595BL**

J7 - Gate Input: BNC, halts data acquisition when asserted (polarity selectable) **Bomar P/N: 364A595BL**

J8 - Sync Input: BNC, timing signal for time-resolved spectroscopy and other special modes **Bomar P/N: 364A595BL**

J9 - DC Power Entry: 0.100" Header with lock/ramp, input from the DC power supply
Molex P/N: 22-23-2121

Pin #	Name	Description
1	GND	Internal ground connection – NOT chassis ground
2	VCC_RAW	+5V DC supply (regulated on-board to 3.3V DC) for digital components
3	GND	Internal ground connection – NOT chassis ground
4	+5V_RAW	+5V DC supply for on-board analog components Optional preamplifier supply (individually, or substituted for +12V, both options require soldering)
5	-5V_RAW	+5V DC supply for on-board analog components Optional preamplifier supply (substituted for -12V, requires soldering)
6	+12V_RAW	+12V DC supply for on-board analog components Standard supply for preamplifier
7	-12V_RAW	-12V DC supply for on-board analog components Standard supply for preamplifier
8	+24V_RAW	+24V DC analog supply for preamplifier – not used by DPP
9	-24V_RAW	-24V DC analog supply for preamplifier– not used by DPP
10	HV_INHIBIT*	*HV Inhibit output – only used in conjunction with PWR-X10P supply*
11	EXT_INHIBIT	*HV Inhibit input – only used in conjunction with PWR-X10P supply*
12	GND	Internal ground connection – NOT chassis ground

P1 - Preamplifier Power Exit: DSUB-9 Female, output DC voltages to preamplifier.
AMP P/N: 745781-4

Pin #	Name	Description
1	GND	Internal ground connection – NOT chassis ground
2	GND	Internal ground connection – NOT chassis ground
3	IN_ALT	Alternate signal input, selected with jumper JP10 (BNC standard)
4	+12V_OUT	+12V (+5V solder option) DC for preamplifier
5	NC	No connection –- solder option +5V connection
6	-24V_OUT	-24V DC for preamplifier
7	+24V_OUT	+24V DC for preamplifier
8	REF_ALT	Alternate signal reference, selected with jumper JP9 (BNC standard)
9	-12V_OUT	-12V (-5V solder option) DC for preamplifier

P2 – IEEE 1284 Standard EPP Port: DSUB-25 Female, parallel communications port; standard pinout.

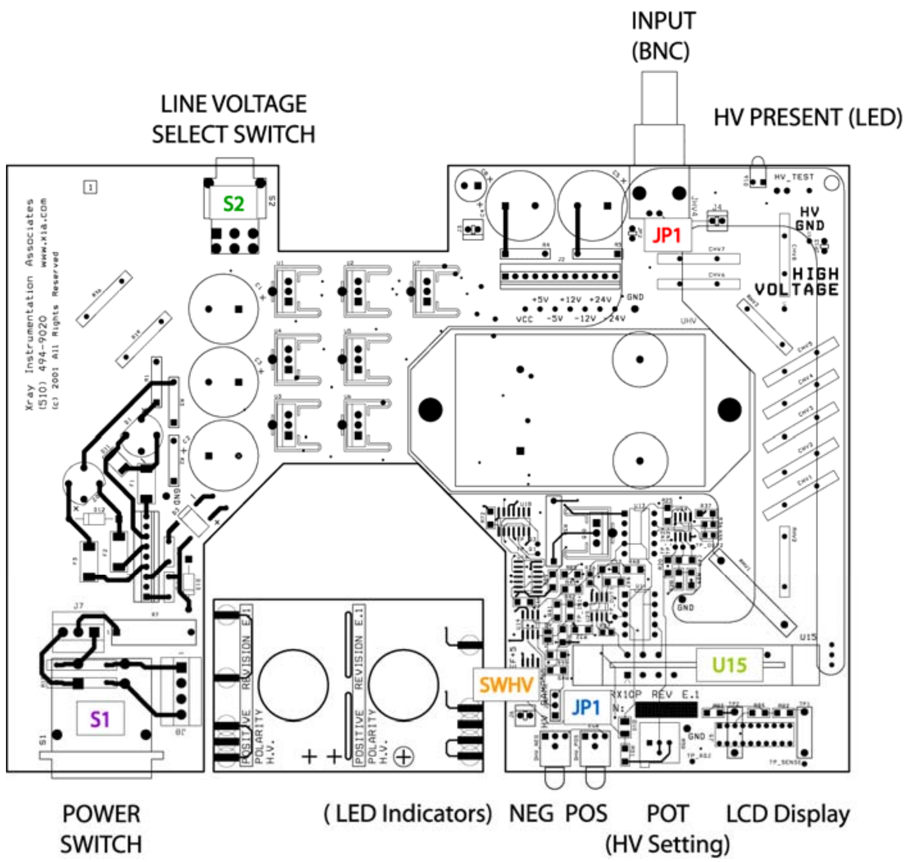
AMP P/N: 745783-4

A.4. Power Consumption:

DPP-X10P Only (preamplifier power consumption NOT INCLUDED)					
		Standby		**Active**	
Name	*Voltage [V]*	*Current [mA]*	*Power [mW]*	*Current [mA]*	*Power [mW]*
VCC	5	**120**	600	**240**	1200
V+5	5	**220**	1100	**230**	1150
V-5	-5	**100**	500	**100**	500
V+12	12	**40**	480	**40**	480
V-12	-12	**30**	360	**40**	480
Total			**3040**		**3810**

Appendix B. PWR-OEM (PWR-X10P) Revision E.1 - Preliminary

This addendum to the DXP Saturn User's Manual is provided for PWR-OEM customers. It summarizes switches/controls, jumper settings, connector locations, part numbers and pinouts, displays (LEDs and LCD), power consumption and power supplied.



B.1. Switches and Controls

Reference	Function	Part #	Description
S1	Power (rocker)	C&K DF62J12S2AHQF	Connects the AC line voltage input to the toroidal transformer such that unit is powered on. *Jumper wires in footprints R17 and R18 bypass the power switch, routing the AC line votage directly to the transformer.*

S2	Line Voltage Select (slide)	C&K 1201M2S3AQE2	- Left-hand position selects 115V/60Hz - Right-hand position selects 230V/60Hz *Jumper wires in footprints R16 and R19 select 115V (standard).*
SWHV	HV Enable (momentary pushbutton)	Molex 22-23-2021 (Mountain Switch 10PA032)	Momentary short (debounce circuit on PCB) enables/disables the high voltage supply.
U15	HV Polarity (cardedge 'switch')	Sullivan EZM10DRXH + Custom PCB Key	**Only two (out of four) positions are valid!** Desired polarity indicator **enclosed in a circle** should be located at lower left. Note also that the more widely spaced contacts should be on the right-hand side.
R50	HV Setting Potentiometer	Phillips CT9P102	Clockwise (CW) increases the HV bias. Pin 1 = CCW; Pin 2 = Wiper; Pin 3,4 (center pins) = CW

B.2. Jumper Settings

Reference	Jumper Label	Position Labels	Description
JP1	HV RAMP	FAST SLOW	- HV ramp-up (and down) interval is ~10 seconds - HV ramp-up (and down) interval is ~50 seconds *FAST mode is typically used (maximum rate 100V/s).*
JP2	-	-	- When present, bypasses the Inhibit loop to/from DPP card (HV is inhibited when the logic level is LOW) *The DPP card has additional jumpers to set the polarity and default level (when Inhibit cable disconnected).*

B.3. LED Indicators and LCD Display

DHV_NEG – HV Control Status LED: Only illuminated when polarity is set to NEGATIVE. Yellow when disabled (though possibly ramping down); Red when enabled. Current drive is approximately 15mA per color. Gilway P/N: E247 (T-5mm, bi-color, 3-pin: pin 1= red anode; center pins = cathode (GND); pin = yellow anode)

DHV_POS – HV Control Status LED: Only illuminated when polarity is set to POSITIVE. Yellow when disabled (though possibly ramping down); Red when enabled. Current drive is approximately 15mA per color. Gilway P/N: E247 (T-5mm, bi-color, 3-pin: pin 1= red anode; center pins = cathode (GND); pin = yellow anode)

D16 – HV Present LED: Illuminated (red) when HV is present, i.e. ramping or not. Current approximately 15mA. Gilway P/N: E247 (T-3mm,bi-color, 3-pin: pin 1= red anode; center pins = cathode (GND); pin = yellow anode)

J5 – HV LCD Display: connection for +/- 200mV LCD voltmeter; supplies +/-5V
e.g. Lascar P/N: DPM 2AS-BL (3 ½ digits)

Pin #	Name	Description
1	-5V	locally decoupled negative 5V supply
3	Input (low)	connected to ground (
5	Input (high)	HV divided by 10,000 (e.g. 1kV HV --> 100mV); **1 MΩ impedance**

7	COM	simply connected to pin 9
9	REF	simply connected to pin 7
11	NC	not connected
13	CAP-	negative terminal of a 1uF, 25V tantalum capacitor
15	CAP+	positive terminal of a 1uF, 25V tantalum capacitor
17	GND	ground connection
19	+5V	locally decoupled positive 5V supply
even #'d	**NC**	**not connected (this is the entire row adjacent to the board edge)**

B.4. Connectors

J7 – Line Voltage Entry: 0.156", 3-pin, lock-ramp, polarity-keyed Header **Molex P/N: 26-60-4030**		
Pin #	**Name**	**Description**
1	Neutral	Neutral (isolated within the unit)
2	Earth	Earth is typically connected to the chassis. Local GND is connected to Earth by a 1kΩ 1W on-board resistor (R7)
3	Line	Hot (isolated within the unit)

J2 – DC Output Voltages (to DPPX10P, preamplifier): 0.100" 12-pin Header; **Molex P/N: 22-23-2121**		
Pin #	**Name**	**Description**
1	GND	Local GND
2	VCC	Pos. 5V digital supply voltage (DPPX10P board regulates down to pos. 3.3V)
3	GND	Local GND
4	V+5	Pos. 5V analog supply voltage
5	V-5	Neg. 5V analog supply voltage
6	V+12	Pos. 12V analog supply voltage
7	V-12	Neg. 12V analog supply voltage
8	V+24	Pos. 24V analog supply voltage
9	V-24	Neg. 24V analog supply voltage
10	HV Inhibit Return	TTL/CMOS logic level signal returned from DPP card, which optionally changes the polarity of the signal. Use jumper **JP2** to bypass the DPP send/return loop, resulting in an active low Inhibit function (HV inhibited for a low logic level).
11	HV Inhibit Send	TTL/CMOS logic level. Connects directly to the Inhibit BNC inner conductor. Use jumper **JP2** to bypass the DPP send/return loop, resulting in an active low Inhibit function (HV inhibited for a low logic level).
12	GND	Local GND

JHV4 - Inhibit Input: BNC, inhibits the HV bias supply. Inhibit signal is usually routed through the DPP card for optional polarity inversion and default (disconnected) mode. Use jumper **JP2** to bypass the DPP loop, resulting in an active low Inhibit function (HV inhibited for a low logic level). **Bomar P/N: 364A595BL**

J3 –Fan Supply: Unregulated 6-12 Volt supply for fan (e.g. EBM/Pabst P/N: 412)—right-hand pin is positive. Electrolytic capacitor C8 (e.g. Panasonic P/N:EEU-FA1E471) MUST be present.
Molex P/N: 22-23-2021

J8 – Transformer Primaries (CAUTION: AC Line, Neutral): 0.156”, 4-pin, lock-ramp, polarity-keyed Header
USE ONLY WITH XIA-SUPPLIED TOROIDAL TRANSFORMER!!!
Molex P/N: 26-60-4040

J1 – Transformer Secondaries: 0.100”, 9-pin, lock-ramp, polarity-keyed Header
USE ONLY WITH XIA-SUPPLIED TOROIDAL TRANSFORMER!!!
Molex P/N: 22-23-2091

B.5. Power Consumption:

PWRX10P Total Capacity and Estimated Reserves					
Voltage	**Total Capacity**	**DPP Load (active)**	**HV Load (enabled)**	**Combined Load***	**Estimated Reserves**
Secondary	*Current [mA]*	*Current [mA]*	*Current [mA]*	*Current [mA]*	*Current [mA]*
VCC and V+5**	**1000**	370	90	**460**	**540**
V+12	**500**	40	80	**120**	**380**
V-12 and V-5**	**500**	140	90	**230**	**270**
V+24	**100**	-	-		**100**
V-24	**100**	-	-		**100**

*Doesn't include preamplifier or accessory (eg. OPLC) load currents.
**Regulators share the same secondary winding and voltage rectifier, thus total current limit is shared; either voltage capable of providing full current rating.

Appendix C. Sample INI File(s)

Below is a sample INI file that is appropriate for a detector with:

- Reset-type preamplifier
- 6.6mV/keV detector gain
- positive signal polarity

```
[detector definitions]

* Kevex Detector
START #1
alias = detector1
number_of_channels = 1
type = reset
type_value = 10.0
channel0_gain = 6.6
channel0_polarity = +
END #1

[firmware definitions]

START #1
alias = firmware1
filename = c:\program files\xia\ProSpect\firmware\saturn_reset.fdd
END #1

[module definitions]

START #1
alias = module1
module_type = dxpx10p
number_of_channels = 1
interface = epp
epp_address = 0x378
channel0_alias = 1
channel0_detector = detector1:0
channel0_gain = 1.0
firmware_set_all = firmware1
END #1
```

Below is a sample INI file that is appropriate for a detector with:

- RC-type preamplifier
- 3.0mV/keV detector gain
- negative signal polarity

```
[detector definitions]

* Ketek Detector
START #1
alias = detector1
number_of_channels = 1
type = rc_feedback
type_value = 10.0
channel0_gain = 3.0
channel0_polarity = -
END #1

[firmware definitions]

START #1
alias = firmware1
filename = c:\program files\xia\ProSpect\firmware\saturn_rc.fdd
END #1

[module definitions]

START #1
alias = module1
module_type = dxpx10p
number_of_channels = 1
interface = epp
epp_address = 0x378
channel0_alias = 1
channel0_detector = detector1:0
channel0_gain = 1.0
firmware_set_all = firmware1
END #1
```

Appendix D. Firmware File Formats

D.1. Firmware and FDD Files

Firmware refers to the DSP and FiPPI (FPGA) configuration code that is downloaded to, and runs on, the DXP Saturn itself. Typically one DSP file and four FiPPI files comprise a complete firmware set. For simplicity XIA combines a complete firmware set into a single file of the form "firmware_name.fdd". This file format is supported by Handel, XIA's digital spectrometer device driver, and is the standard firmware format used in ProSpect. The FiPPI and DSP are discussed in chapters 5 and 7.

D.1.1. Code Variants

MCA acquisition with RC-type preamplifiers

Variant 0 is the standard firmware variant supplied with the DXP Saturn, as described in this manual. It is intended for use with reset-type preamplifiers (described in section 5.1.1).

FDD file:	**SATURN_RESET_REVC.FDD**
DSP file name:	SAT_0113.HEX
Fippi file names:	FXPD00L.FIP (decimation 0)
	FXPD200L.FIP (decimation 2)
	FXPD420L.FIP (decimation 4)
	FXPD640L.FIP (decimation 6)

Notes:
- This is the 20MHz version. The 40MHz version is SATURN_RESET_REVC_40MHZ.FDD.
- To use this variant, the "Ramp/Offset" jumper should be in the "Ramp" position.

MCA acquisition with RC-type preamplifiers

This firmware variant is intended for use with resistive feedback preamplifiers (described in section 5.1.2).

FDD file:	**SATURN_RC_REVC.FDD**
DSP file name:	SAT_RC_0111.HEX
Fippi file names:	F00XRC00L.FIP (decimation 0)
	F00XRC20L.FIP (decimation 2)
	F00XRC40L.FIP (decimation 4)
	F00XRC60L.FIP (decimation 6)

Additional parameters (described in Section 5.10):

RCTAU: Exponential decay time in 1 μs units.

RCTAUFRAC: Fractional decay time in 1.15 format.

RCFCOR: Correction factor (calculated automatically at start of run if RCTAU not 0)

Notes:

- This is the 20MHz version. The 40MHz version is SATURN_RC_REVC_40MHZ.FDD.
- To use this variant, the “Ramp/Offset” jumper should be in the “Offset” position.

D.2. DSP Code

The Digital Signal Processor acquires and processes event data from the FiPPI, controls the analog front-end through DACs, and communicates with the host. Different DSP program variants are used for different types of data acquisition and different preamplifier types. Section 7 describes in detail the DSP operation, its tasks, and parameters which control them. The DSP file takes the form “dsp_name.hex”. Two standard DSP programs are available: One for reset-type detectors and one for RC-type detectors. Program variants for specialized applications are developed on an NRE basis. Please contact XIA for more information.

D.3. FiPPI Code

The Filter-Pulse-Pileup-Inspector (FiPPI) performs real-time digital waveform processing and pileup inspection, and extracts user-defined metrics. FiPPI configurations take the form “fippi_name.fip”. FiPPI’s are distinguished by preamplifier type, but also by ‘decimation’. Decimation refers to pre-averaging of the ADC signal prior to the FPGA processing pipeline. Each decimation accomodates a specific range of peaking times, i.e. shaping or integration times. Typically four (4) FiPPI configuration files are required by the DXP Saturn. When the peaking time is changed such that a range boundary is crossed, the host software downloads the appropriate FiPPI configuration to the DXP Saturn.

Decimation	*#ADC Samples in Pre-Average*	*Peaking Time Range*	*Equivalent Shaping Time Range*
0	1	250ns – 1.25µs	500ns – 2.5µs
2	4	1 µs – 5 µs	2 µs – 10 µs
4	16	4 µs – 20 µs	8 µs – 40 µs
6	64	16 µs – 80 µs	32 µs – 160 µs

Table 0.1: FiPPI decimation details (assumes 20MHz ADC clock).