User's Manual
Digital X-ray Processor

Saturn Revision A

Release 3.0

X-ray Instrumentation Associates

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Release Notes for the DXP Saturn Version 3.0

Contents:

This note accompanies release 3.0 of the host software and firmware for the DXP Saturn. Please check the DXP Software page of XIA's website (www.xia.com/DXP_Software.html) for the upcoming release of . This release includes the following components:

Firmware files:

DSP programs, version 1.0:

X10P.HEX Standard pulsed reset (variant3)

Fippi FPGA firmware, revision J:

FXPDxG.FIP (x=0,2,4,6) Standard pulsed reset variant

Host software:

XiaSystems.DLL XiaSystems interface library

XiaDemo.exe version 3.0 Demo program for setting up and acquiring data

Documentation:

DXP Saturn Documentation version 1.5

Guide for installation:

The host software runs on Windows 95,98, Me and NT. If you are updating from a previous version, you should not need to uninstall the previous version before installing this new version. Please direct your questions or comments to software_support@xia.com.

Installation from CD-rom:

To install from CD-rom, run the program "setup.exe" in the Installation directory. You will be prompted for the location for the program files. If not already installed, the DriverLinx Port IO driver (DLPORTIO) needs to be installed also. The DLPORTIO driver is included in the release with the file name PORT95NT.EXE. To install the driver, just run the program PORT95NT.EXE. If installing under WindowsNT, you should be logged on as Administrator.

Notes:

The DSP program .HEX file format has been changed in the parameter table section. Where the previous version had a comment header (* in the first column) followed by the number of parameters and the list of parameters, one per row, in the new format the list of parameters includes access codes ("-" for read only, "*" for read/write) and allowable bounds for the read/write parameters. For example:

PROGNUM	-			(the program number PROGNUM is read only)
WHICHTEST	*	0	15	(the test segment WHICHTEST is read write, with valid range 0-15

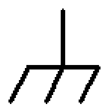
Safety

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.

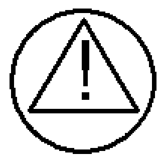
Symbols

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, however 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.

WARRANTY

Xray Instrumentation Associates (XIA) 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, at its option, 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 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 shall not be obligated to furnish service under this warranty a) to repair damage resulting from attempts by personnel other that XIA 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 XRAY INSTRUMENTATION ASSOCIATES (XIA) WITH RESPECT TO THIS PRODUCTI IN LIEU OF ANY OTHER WARRANTIES, EXPRESSED OR IMPLIED. XIA 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 AND ITS VENDORS WILL NOT BE LIABLE FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES IRRESPECTIVE OF WHETHER XIA OR THE VENDOR HAS ADVANCE NOTICE OF THE POSSIBILITY OF SUCH DAMAGES.

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1. Overview

The 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 using semiconductor detectors. The DXP offers complete computer control over all amplifier and spectrometer controls including gain, filter peaking time, and pileup inspection criteria. The DXP's 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 DXP 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 DXP Saturn is a single channel unit which is controlled with the Enhanced Parallel Port (EPP), an upgraded version of the IBM-compatible PC standard parallel printer port.

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.
- Pileup inspection criteria computer settable, including fast channel peaking time, threshold, and rejection criterion.
- Accurate ICR and live-time reporting for precise dead-time corrections.
- Multi-channel analysis, 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.

1.2. Unit Specifications:

1.2.1. Performance:

The following quantities are specified for a particular detector (i.e. the Ortec Iglet-x) and may vary somewhat for other detectors:

- Count rate precision ≤ 0.1%, or limited by statistics
- Peak stability with count rate ≤ 0.1% up to highest counting rates
- Energy Scale Integral Nonlinearity ≤ 0.1% of full scale
- Gain stability with temperature ≤ 0.05%/degree C

At high event rates, for a particular detector, the resolution and non-linearity may degrade somewhat. For POR preamplifiers, this is primarily due to time dependent leakage currents within a preamplifier reset interval. These produce baseline shifts which occur too rapidly for the DXP to track perfectly.

1.2.2. Host Interface:

The DXP Saturn communicates w/ the host computer via the Enhanced Parallel Port, defined by IEEE specification 1284. The interface is described further in Section 4.

1.2.3. Preamplifier Interface:

The following specifications describe the preamplifier power supply port and signal input connection:

- +/- 24V supply rating: 100mA/each
- +/- 12V supply rating: 100mA/each
- Input signal range: +/-10V
- Input impedance 10KΩ

1.2.4. Detector Interface:

- Bias voltage range: +/-1000V
- Bias voltage output impedance: 10MegΩ
- Bias voltage turn-on/off time: 3-30s

1.2.5. Power Requirements:

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

Supply voltage fluctuations are not to exceed 10% of the nominal value. All DC voltages necessary for operation are generated internally. In addition, the DXP Saturn produces +/- 12V and +/- 24V (up to 100mA per voltage) to power an external preamplifier.

1.2.6. Environment:

- Temperature Range: 0° C - 50° C
- Maximum Relative Humidity: 75%
- Maximum Altitude: 3,000 meters
- Pollution degree 2
- Installation Category II

2. Getting Started with the DXP Saturn

2.1. Setting up the DXP Saturn

2.1.1. Line Voltage Selection and Fusing

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

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

2.1.2. Detector Bias Voltage Settings

The DXP Saturn provides a detector bias voltage of up to +/- 1000V. The output impedance is 10MegΩ due to low pass filtering thus the current is limited to a few microamperes. Do not connect the supply to your detector until the following settings have been confirmed.

2.1.3. Bias Voltage Polarity

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. To change the high voltage polarity, the power must be turned off, and the top panel of the DXP Saturn removed. 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).

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

- **Enable/Disable Ramp Rate**

Shorting jumpers JP10 and JP11 on the HV Control Key determine the rate at which the detector bias voltage ramps up and down upon enabling and disabling the supply. Text on the key itself indicates the selected ramp duration. The default is ten seconds, selected by a solder short across JP11. A three second ramp duration is selected by shorting the terminals of JP10 together (and removing the solder from JP11, if present). A thirty-second duration is achieved by removing solder shorts from both JP10 and JP11.

- **Setting the LN Inhibit Mode and Default Level**

The Inhibit function shuts down 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 alternatively closes a switch (ie. 'contact-closure'), reflecting whether the detector is safe to operate. The polarity of the asserted Inhibit signal is set with dual-pole jumper JP21. The two positions are labeled 0 and 1, corresponding to the logic level at which the bias voltage is inhibited. Default operation for the open-circuit condition (eg. contact-closure systems, or Inhibit simply not used) is selected w/ JP20. It is essentially a pull-up/pull-down switch for the Inhibit logic input. Again, the two positions are labeled 0 and 1, corresponding to the default logic level applied. The DXP Saturn is shipped w/ the Inhibit assert-level set to 0, and the default level set to 1.

NOTE: as many types of sensors are commercially available, it is difficult to guarantee proper performance with all types. It is strongly recommended that the functionality of the chosen configuration be tested prior to making connections to the detector.

While the DXP Saturn top panel is removed, proceed to the "Internal Jumper Settings" section below.

- **Setting the Bias Voltage**

The DXP Saturn power must be turned on in order to set the bias voltage magnitude. **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.**

The magnitude of the high voltage is set with a potentiometer accessible through the front panel using a small screwdriver. The front panel LDC display indicates the set value of the bias voltage. Note: once enabled, the high voltage ramps slowly to its set value at the user-defined rate (see above).

2.1.4. Internal Jumper Settings

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

In the typical configuration, power for the detector preamplifier is supplied by the DXP via the NIM standard DB-9 ‘Preamplifier Power’ interface. 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 DB9 connector to the BNC shield and inner conductor, respectively. These jumpers are not stuffed by default.

- **JP101: Signal Reference (DXP ground vs Detector ground)**

JP101 connects the signal reference to the DXP ground. It is stuffed by default. If JP101 is removed, the preamplifier signal and reference are amplified differentially. This configuration may improve performance if a ground loop is present, but will increase susceptibility to electromagnetic radiation. See section 4.2.1 “Signal Grounding” for further information.

- **JP102 and JP103: Input Voltage Range**

The default input range of the DXP is +/-10V, sufficient for nearly all preamplifiers thus far encountered. Larger voltage ranges (up to +/- 15V) can be accommodated by reducing the gain of the first amplifier stage. Align jumpers JP102 and JP103 with R100 and R103, respectively, to use the extended input range. Note: the extended input range is not currently supported by the host software.

- **JP104: Preamplifier Type—(RC Feedback vs Pulsed Reset)**

The DXP employs different methods of analog signal conditioning, depending on the preamplifier type. The position of jumper JP104 determines the digitally controlled signal to be subtracted from the preamplifier signal. In the default position labeled “RAMP”, a saw-tooth signal is employed, accommodating pulsed-reset preamplifier types. In the position labeled “OFFSET”, a low-frequency offset, suitable for resistive feedback preamplifier types, is used.

At this point the top panel of the DXP Saturn can be reassembled. Proceed to “Setting the Bias Voltage” above.

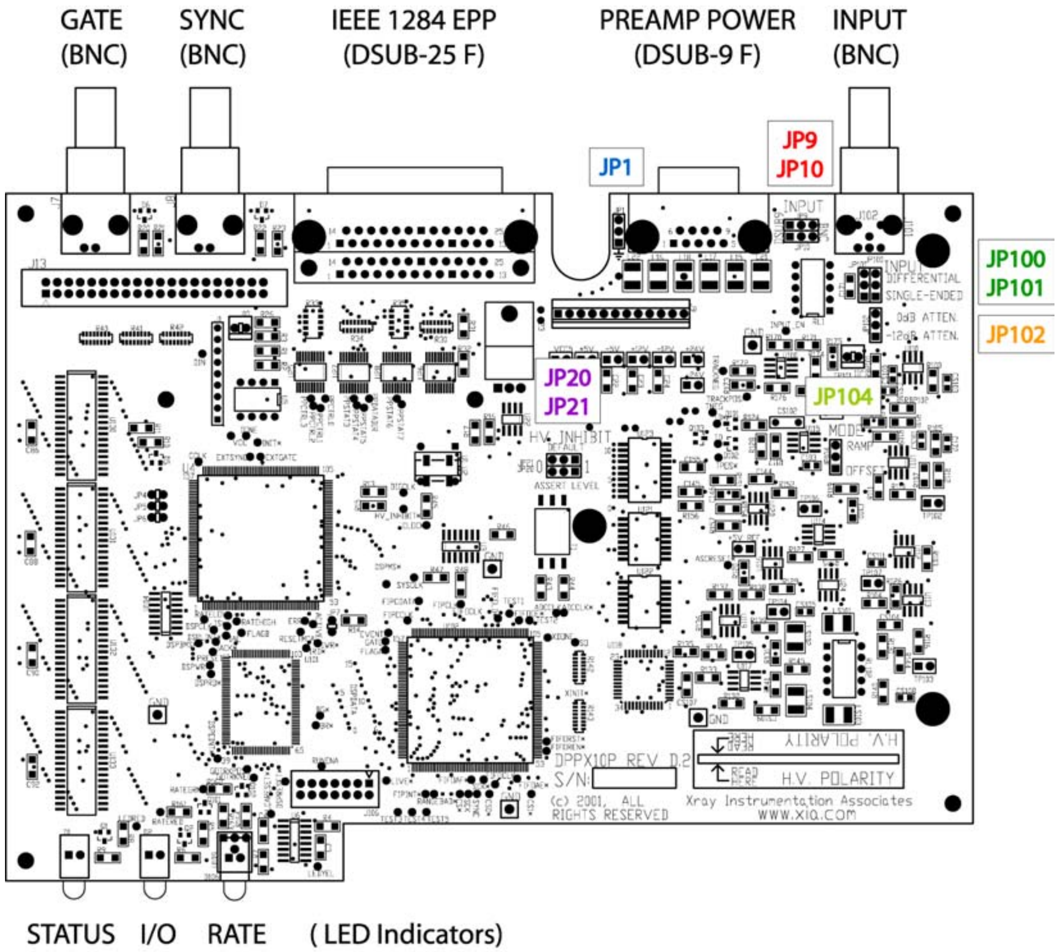


Figure 2.1: PCB Diagram

2.2. Making Connections

2.2.1. Connecting to the Detector/Preamplifier

The detector bias voltage connection is made using a standard SHV cable. If your detector uses either MHV or BNC for this connection, an adapter will be required. The bias voltage inhibit, and preamplifier signal connections are made using standard BNC cables. Preamplifier power is supplied via the NIM standard DB-9 'Preamplifier Power' interface. The DXP Saturn is specified for operation with cables under three meters in length.

2.2.2. Connecting to the Computer

The DXP Saturn connects to the parallel port of a standard PC. The parallel port must be set to run in EPP mode; you may need to adjust the port setup in your BIOS (CMOS setup). If this option is not available in the BIOS setup, and there are problems communicating with the DXP Saturn, the BIOS may need to be upgraded.

2.3. DXP Saturn Firmware

The DXP Saturn requires several firmware files to run; these include the code for the onboard digital signal processor (DSP) as well as configuration files for the programmable logic chip used for the energy filtering (the FiPPI, for Filter Peak and Pileup Inspector). The most recent versions of these files can be obtained from the XIA ftp site ftp.xia.com, in the pub/DXP-X10/ directory. The DSP code has file names of the form X10Pnnnn.hex where nnnn is a version number. FiPPI configurations are in files of the form fx10pnx.fip where n is the decimation value (0, 2, 4 and 6 – different decimation values are needed to cover the full range of peaking times) and x is the version letter.

2.4. Installing and using the DxpDemo Program

The DxpDemo program is provided for getting started quickly with the DXP Saturn. It is intended for demonstration purposes and making some basic spectrum measurements with the unit. XIA does not intend to support this program in the long term, and is working on replacing DxpDemo with a more comprehensive software program.

The DxpDemo program works on Windows 95/98 and NT machines. If not provided with the unit, the latest version of DxpDemo can be copied from the XIA FTP site: ftp.xia.com (User=Anonymous), in the area ftp/pub/DXP-X10/HostSoftware. The installation file is a ZIP archive, which can be "un-zipped" with WinZip or a similar program. Then, the program Setup.exe can be used to install the program, using the familiar InstallShield. For Windows NT machines, you may need to be logged into the Administrator account to install the software.

DxpDemo and the other XIA software uses a share-ware parallel port driver called DLPORTIO from Driver Linx. The installation file for this is called PORT95NT.exe, which can also be copied from the XIA ftp site. The quickest way to get started is if you have the following information:

- ✓ The detector/preamplifier gain in mV/keV. If you don't know it, you can measure it with a source of known energy x-rays and a scope. See the Appendix below for details.
- ✓ The detector polarity: positive polarity means that an x-ray produces a positive step in voltage at the preamplifier output.
- ✓ A known source of X-rays, for example an Fe-55 source produces 5900 eV X-rays.

When you start up the program the first time, the following screen should appear:

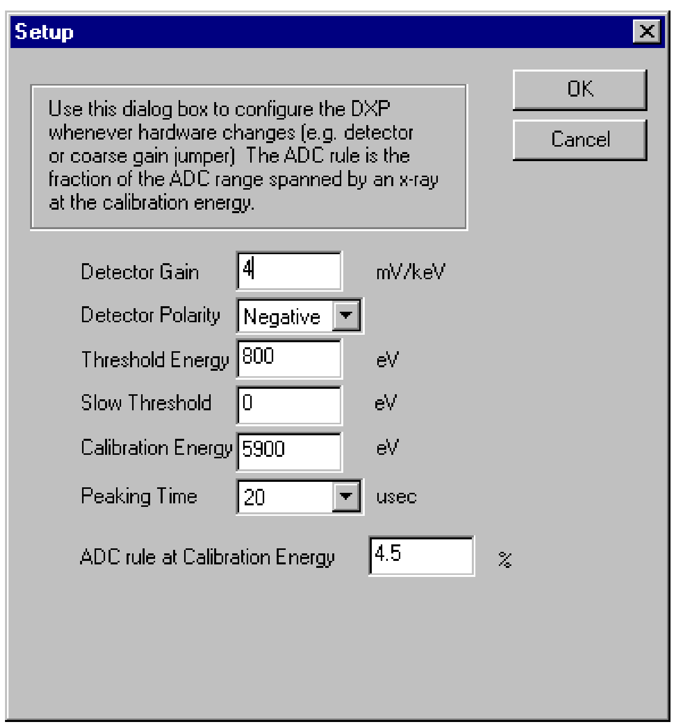


Figure 2.2: Setup Dialog

- ✓ Enter the detector gain and polarity in the fields provided.
- ✓ Enter the detector polarity
- ✓ Enter the Threshold energy. This depends upon several factors. Eventually, you will want to set this as low as possible, but to start, use a conservative value -- say 2000 eV, or 1500 eV below the calibration energy peak, which ever is lower. This is only a starting point -- it can be changed later
- ✓ Leave the Slow Threshold field at 0
- ✓ Enter the known x-ray energy of your source as the calibration energy.
- ✓ Choose a peaking time -- the default is 20 µsec which will work fine for count rates up to 20-30 kcps. If you are initially starting higher rates, choose a shorter peaking time.
- ✓ The ADC rule is used to set the DXP conversion gain: a typical value is 5% -- this means that one X-ray of the calibration energy spans 5% of the ADC range (10 bits) or 51.2 ADC counts. A value larger than 5% may improve the resolution by decreasing digitization errors, but at long peaking times where many ADC samples are used in the energy measurement, this effect is usually quite small. The disadvantage of using a large value of the ADC rule (say 20%) is that small fluctuations in the arrival times of X-rays can push the signal out of the ADC range -- this will degrade system livetime.

Once all of the fields have been selected, click OK. You may be prompted to change the ADC rule or the gain jumper on the DXP (or both) if you request an ADC rule and detector gain that is outside the DXP's gain ranges. At this point the DXP should be set up to take data. Click on the Update button and a spectrum should appear:

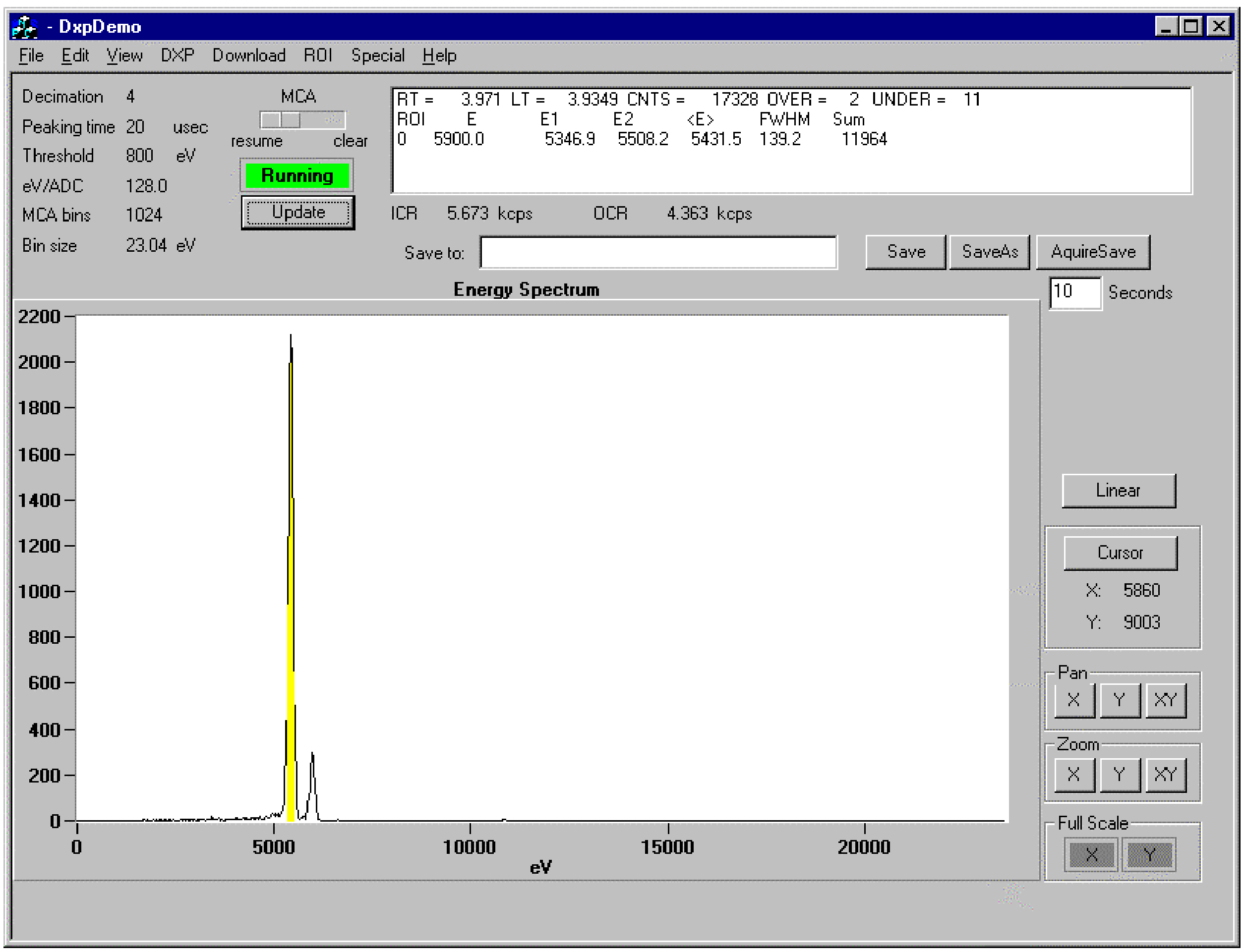


Figure 2.3: Main window after DXP-->Setup

If the setup procedure worked properly, you should see a 1024 bin spectrum with the calibration peak centered near ¼ of full scale. If you see a peak near 0, this indicates that the threshold energy is too low. To adjust the threshold energy, select the DXP-->Setup menu item and the Setup Dialog will reapear. Note: if the threshold is really low, no events will be in the spectrum, but the ICR (Input Count Rate in kcps) field on the right side of the display will show a non-zero value. A Region of Interest (ROI) is automatically selected: it is based on the largest peak and is the contiguous set of MCA bins with contents greater then half the peak bin's contents. These bins appear with yellow fill. If the largest peak is NOT the calibration energy, you must delete this ROI and define one that spans the calibration peak. See the Appendix on defining ROIs. The ROI is used to fit the peak position (and FWHM) needed to fine tune the DXP gain to achieve the proper calibration. Note: The text box in Figure 2.3 shows that, after these first startup approximations, the first ROI is 5431.5 eV, which is quite different from the calibration energy of 5900 eV.

The next step is to perform an energy calibration and refine some of the DXP parameters. Select the menu item DXP-->Reconfigure:

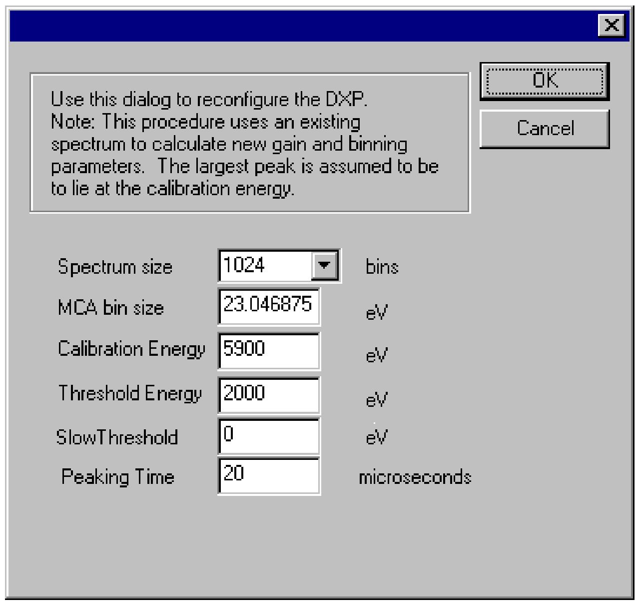


Figure 2.4: DXP-->Reconfigure Dialog

You may fill the fields with values you want: Spectrum size can be up to 14000 -- it does not need to be a power of 2. The MCA bin size can be any value, perhaps 10 eV. The other fields are the same as described for the Setup dialog. The Peaking Time can be any value between 0.5 and 80 μsec: the software will use the nearest match. Accepting the values (click OK) adjusts the internal DXP parameters to achieve the desired MCA bin size, threshold energy and peaking time. For example, adjusting to a convenient 10 eV/MCA channel gives

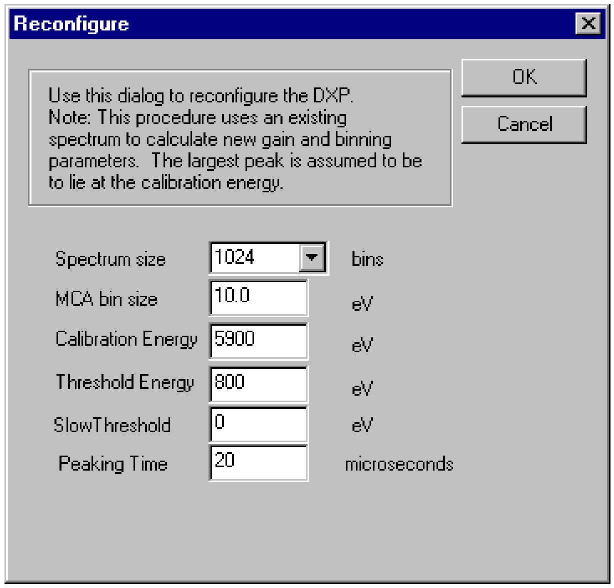


Figure 2.5: DXP-->Reconfigure Dialog after adjustment

Use the Update button to display the new spectrum. The following alert box may appear

Figure 2.6: An annoyance to ignore

If the highest peak in the spectrum is the calibration peak, you can simply select the menu item “ROI->Delete All” and then click Update. Otherwise, you will need delete the ROI and redefine it -- see Appendix. You should acquire reasonable statistics (>100k events in peak) If the fitted peak position under <E> in the text box agrees with the calibration energy, the DXP is said to be calibrated. Otherwise, you must again perform DXP-->Reconfigure. This time, there is no need to change any of the fields -- accepting the values simply iterates on the gain calibration. After calibration, with 10 eV/MCA choice, the display may look something like the following (linear scale):

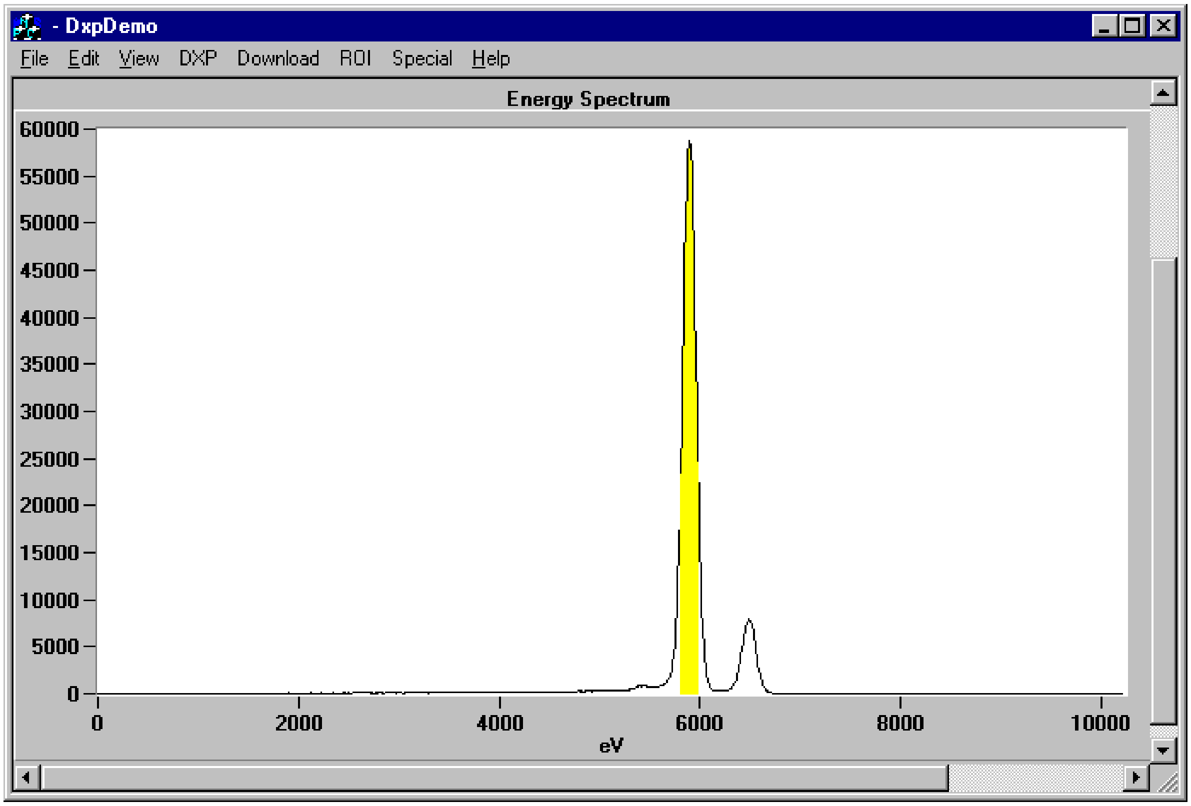


Figure 2.7: Main window after DXP-->Reconfigure (Linear Scale)

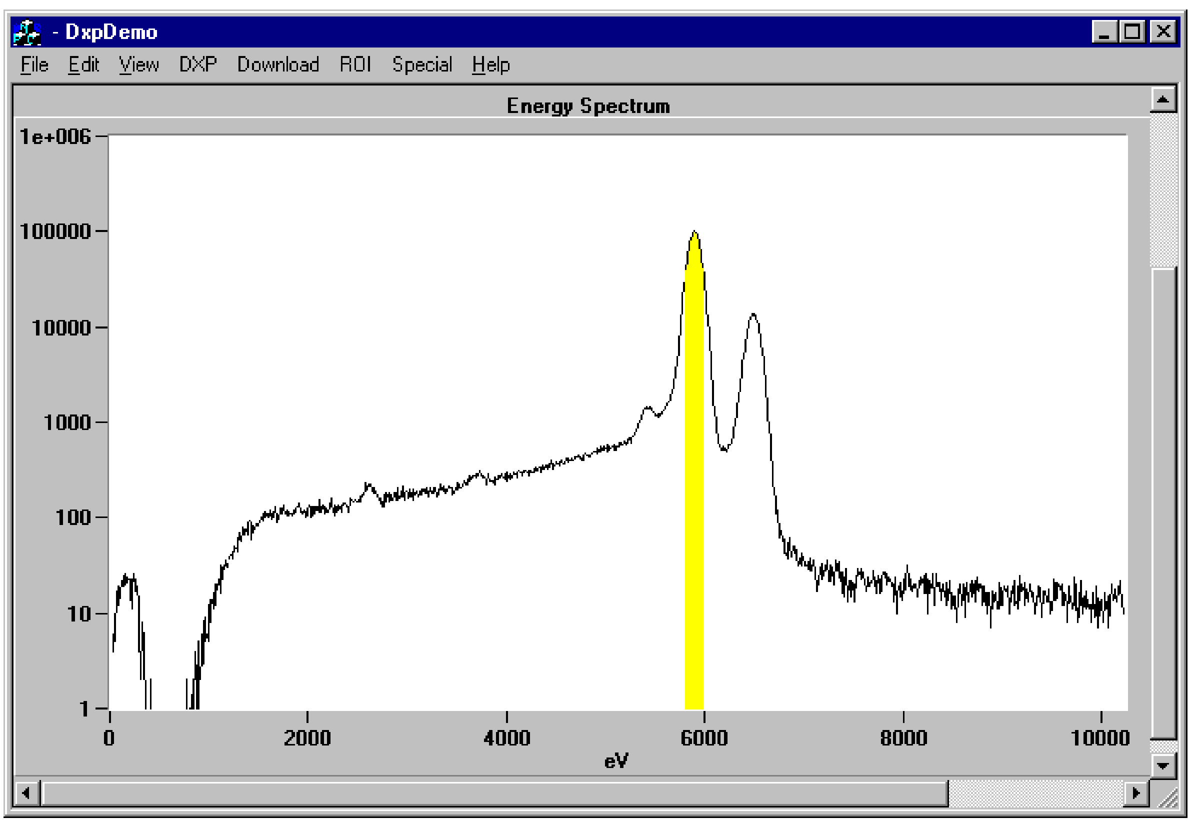


Figure 2.8: Main window after DXP-->Reconfigure (Log Scale)

View-->Baseline: The baseline histogram shows what the FiPPI output looks like when there are no X-rays present. Figure 2.9 shows the baseline histogram for a good quality detector . The high energy tail arises from partial charge collection events that do not satisfy the X-ray selection requirements. Crudely speaking, that which is not an X-ray can be considered baseline. Ideally, this display should be Gaussian shaped, and this sample shows Gaussian behavior over almost 3 decades.

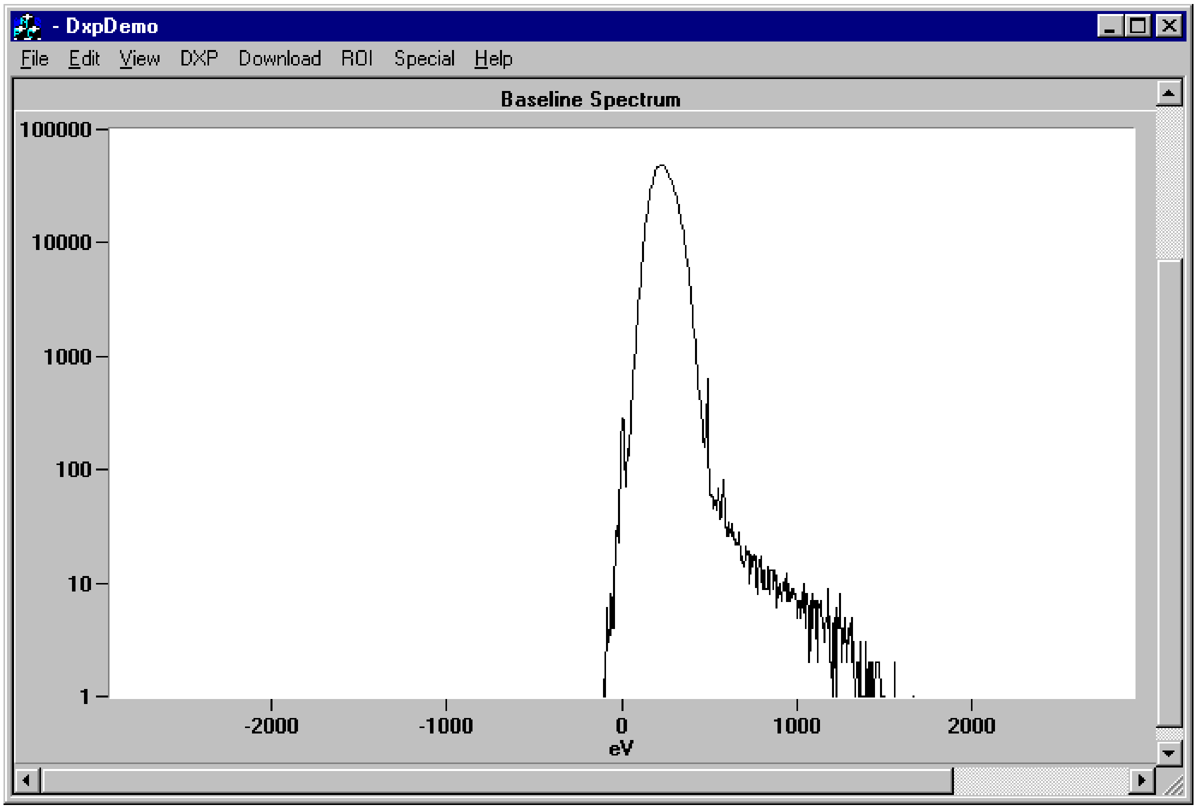


Figure 2.9: Baseline histogram (Log scale)

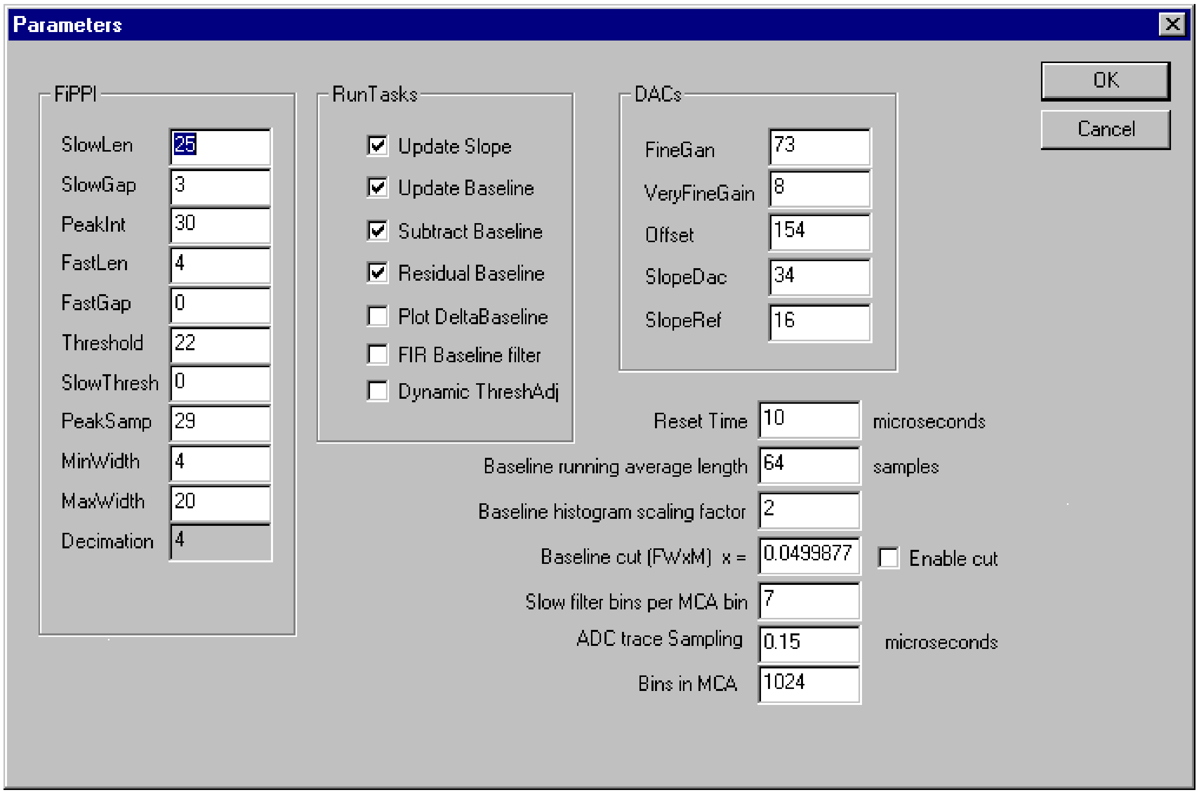


Figure 2.10: Edit-->Params dialog

At this point, you may wish to fine tune some of the parameters. These can be found on the Edit-->Params dialog, shown in Figure 2.10. What follows is description of some of parameters:

- **FiPPI Parameters:** These parameters are described in the DXP users manual (except Slow Threshold). Some of these may require small amounts of tweaking to get best performance.

If you are working at low energies, you may want to adjust FastLen (default value= 4):
Increasing this value will allow you to lower your energy threshold. Here are the rules to keep in mind:

If FastLen --> C*FastLen then:

✓ Threshold --> C*Threshold (keeps energy threshold unchanged)
✓ MaxWidth --> MaxWidth + 2*(C-1)*FastLen
✓ Subject to the following limits:
✓ Fastlen < 32
✓ Threshold < 256
✓ Maxwidth < 250

After making these adjustments, you can go back to DXP-->Reconfigure and enter a smaller Threshold Energy value. For example, suppose the energy threshold is 1000 eV and the DXP gain is set for 142.9 eV/ADC (this is displayed on the upper left hand side of the main page -- Figure 2.3) Here are the default FiPPI values:

FastLen = 4
Threshold = 56
MaxWidth = 20

The following set of parameters are equivalent in terms of Threshold Energy (still 1000 eV), but the fast filter peaking time (used in peak detection and pileup inspection) 800 nsec instead of 200 nsec.

FastLen = 16
Threshold = 226
MaxWidth = 44

Now you can acquire spectra at reduced values of the threshold by adjusting Threshold Energy in the DXP-->Reconfigure dialog. Warning: if you use DXP-->Setup, the default values of FastLen=4 and MaxWidth=20 will be restored.

Slow Threshold invokes a second discriminator that is applied to the slow trapezoidal filter output, extending the detection range well below 1000 eV. The dead time per event significantly higher for events detected in this manner, and also can vary significantly between events of the same energy. Because of this, soft x-ray throughput will be attenuated and the statistical accuracy within this range degraded. This will be a very small effect at low count rates, but can become quite serious at rates approaching the point of maximum throughput. In other words, under these conditions peak counts in the low-energy range should not be directly compared with peak counts at higher energies. For this reason we recommend disabling the Slow Threshold by setting it equal to 0 in most cases.

- **Other Parameters:**
  - ✓ RunTasks: Normally the top four boxes should be checked.
  - ✓ DACs: These should not be adjusted under normal conditions
  - ✓ Reset Time: Default=10 μsec: this is the blanking time (data not used, baselines not acquired) after resets are detected. Maximum=4000μsec. Use a scope to determine the best value for your detector/preamp system.

- **Baseline adjustments:** how the baseline is collected can have a significant effect on energy resolution:
  - ✓ Baseline running average: Default=64: This is the number of baseline samples that are averaged for the baseline correction. Minimum value is 2 maximum value is 32767. Smaller values of this variable track changes in the baseline better, but suffer from larger statistical variations. Larger values do not track real shifts in the baseline well. You can use View-->Baseline History to evaluate the effect of this parameter. Non-optimal value of this parameter will hurt resolution. Optimal value is detector dependent.
  - ✓ Baseline histogram scale factor: Default = 2. This parameter controls the scaling of the baseline histogram (View-->Baseline, see Figure 2.9) The baseline spectrum bin size scales like 2**(bin factor). If the Baseline cut (next item) is not enabled, the DXP performance does not depend upon this factor. Minimum value = 0, maximum = 16
  - ✓ Baseline cut (FWxM) x: Default = disabled. This cut restricts the baseline values used in the running average to be close to average. This cut is based on the baseline histogram. For example, a cut made at x=0.1 on the baseline histogram shown in Figure 2.9 would limit baseline samples in the range [344,768] eV from being used in the running average. This cut eliminates the tail events from entering the running average calculation. Warning: At the present time, the baseline cuts (e.g. 344,768 eV) are computed only when the peak bin in the baseline histogram reaches 64k. When this happens, the histogram contents are scaled down by a factor of 2. The rate at which this updating occurs depends on the baseline histogramming scale factor and the actual value of the baseline FWHM -- this can range from once per second to once a minute. This is usually only a problem when the cut is first enabled or disabled, when a parameter that affects baseline is changed (e.g. gain or peaking time) or if the detector baseline wanders around on a time scale comparable to the reset time. This will be addressed in the future.

Measuring the Detector/Preamp Gain: The best way to measure this is to put a tee on the scope input (use high impedance), connect one end of the tee to the DXP and the other end of the tee to the preamplifier output. If the preamp signal is carried on the DB9 connector, then you could simply plug the scope directly into the DXP's BNC without a tee. If the preamp output passes through zero volts, you can keep the scope DC coupled, otherwise AC coupling will help.

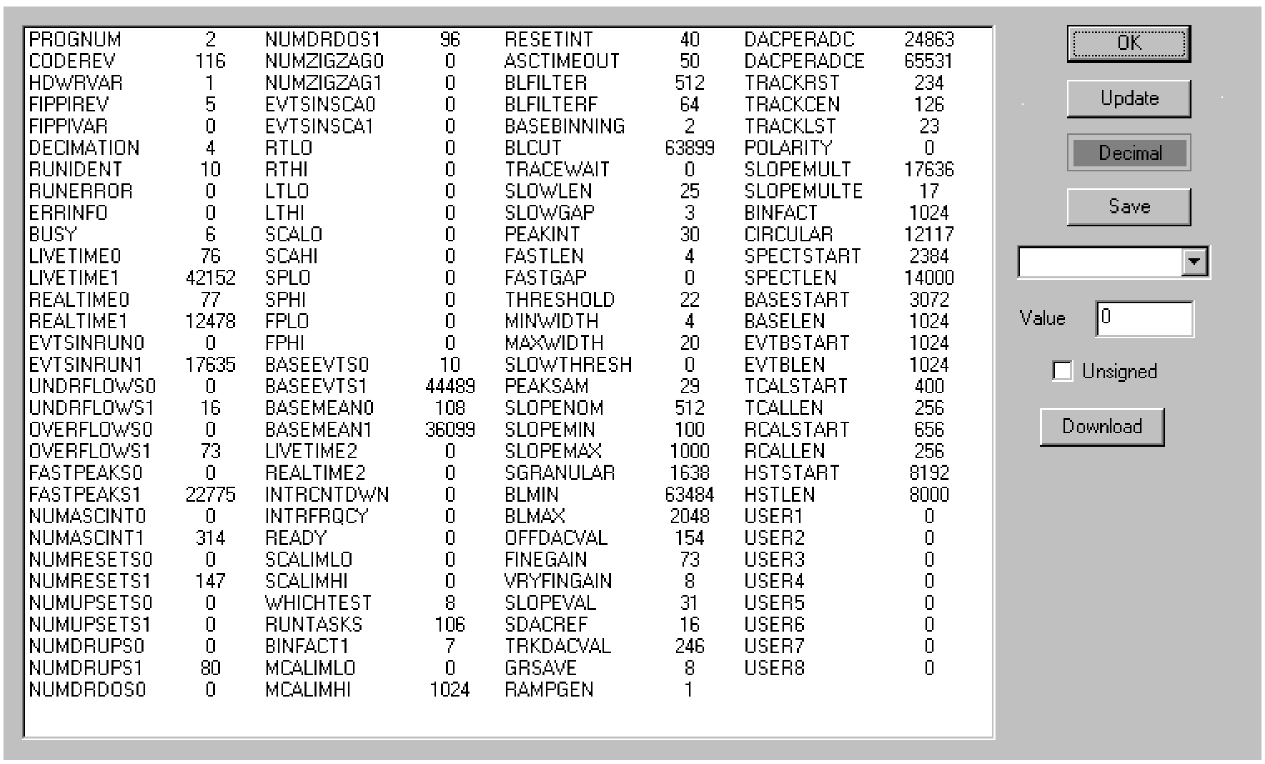
Set the time base to 10 μsec per box and the vertical gain to say 10 mV/box. Trigger the scope on edge transitions with the appropriate polarity. Measure the step height for x-rays of known energy. For example if the step height for an Fe-55 source is 30 mV then the detector gain would be 30/5.9 = 5.1 mV/keV.

Region of Interest (ROI) : The ROI is used to choose bins for fitting peak positions and widths (FWHMs). The Menu item ROI-->Delete All will delete all ROI(s) from the spectrum. If no ROI's are defined, the program will use the largest peak to define a ROI. To add an ROI use ROI-->Add: a dialog will appear for entering the energy you want to associate with the ROI (e.g. energy of a line). The dialog is dismissed when <Return> is typed. Then select the ROI with the mouse as follows:

1. Position the mouse ABOVE the middle of the peak you want to select
2. Press and hold the left mouse button
3. SLOWLY move the mouse towards the left edge of the ROI. Bins will acquire a yellow fill as they are added to the ROI.
4. Move the mouse to the right edge of the ROI -- again, bins added to the ROI will acquire a yellow fill.
5. Release the left mouse button. You are done.

You may add up to 20 ROIs. The first one (labeled 0 in the text box) is the calibration energy used in DXP-->Reconfigure. To delete a single ROI, use the cursor (Click on the "Cursor" button located on the upper left side of the main window) to select a ROI and then use ROI-->Remove. Each time the spectrum is updated the bins in each ROI are fit to a Gaussian and the peak position and FWHM are calculated and displayed in the text box. Also displayed are the ROI bin limits and counts in each ROI.

The full parameter set: For debugging purposes it is useful to be able to report all the DXP's control parameters and internal code variables used to record runtime statistics. These can be found from the View -> Parameters menu. This view is also useful in determining sets of operating parameters to download to the DXP when operating from other systems than DxpDemo program.



PROGNUM	2	NUMDRDOS1	96	RESETINT	40	DACPERADC	24863
CODEREV	116	NUMZIGZAG0	0	ASCTIMEOUT	50	DACPERADCE	65531
HDWRVAR	1	NUMZIGZAG1	0	BLFILTER	512	TRACKRST	234
FIPPIREV	5	EVTSINSCA0	0	BLFILTERF	64	TRACKCEN	126
FIPPIVAR	0	EVTSINSCA1	0	BASEBINNING	2	TRACKLST	23
DECIMATION	4	RTLO	0	BLCUT	63899	POLARITY	0
RUNIDENT	10	RTHI	0	TRACEWAIT	0	SLOPEMULT	17636
RUNERROR	0	LTLO	0	SLOWLEN	25	SLOPEMULTE	17
ERRINFO	0	LTHI	0	SLOWGAP	3	BINFACT	1024
BUSY	6	SCALO	0	PEAKINT	30	CIRCULAR	12117
LIVETIME0	76	SCAHI	0	FASTLEN	4	SPECTSTART	2384
LIVETIME1	42152	SPLO	0	FASTGAP	0	SPECTLEN	14000
REALTIME0	77	SPHI	0	THRESHOLD	22	BASESTART	3072
REALTIME1	12478	FPLO	0	MINWIDTH	4	BASELEN	1024
EVTSINRUN0	0	FPHI	0	MAXWIDTH	20	EVTBSTART	1024
EVTSINRUN1	17635	BASEEVTS0	10	SLOWTHRESH	0	EVTBLEN	1024
UNDRFLOWS0	0	BASEEVTS1	44489	PEAKSAM	29	TCALSTART	400
UNDRFLOWS1	16	BASEMEAN0	108	SLOPENOM	512	TCALLEN	256
OVERFLOWS0	0	BASEMEAN1	36099	SLOPEMIN	100	RCALSTART	656
OVERFLOWS1	73	LIVETIME2	0	SLOPEMAX	1000	RCALLEN	256
FASTPEAKS0	0	REALTIME2	0	SGRANULAR	1638	HSTSTART	8192
FASTPEAKS1	22775	INTRCNTDWN	0	BLMIN	63484	HSTLEN	8000
NUMASCINT0	0	INTRFRQCY	0	BLMAX	2048	USER1	0
NUMASCINT1	314	READY	0	OFFDACVAL	154	USER2	0
NUMRESETS0	0	SCALIMLO	0	FINEGAIN	73	USER3	0
NUMRESETS1	147	SCALIMHI	0	VRYFINGAIN	8	USER4	0
NUMUPSETS0	0	WHICHTEST	8	SLOPEVAL	31	USER5	0
NUMUPSETS1	0	RUNTASKS	106	SDACREF	16	USER6	0
NUMDRUPS0	0	BINFACT1	7	TRKDACVAL	246	USER7	0
NUMDRUPS1	80	MCALIMLO	0	GRSAVE	8	USER8	0
NUMDRDOS0	0	MCALIMHI	1024	RAMPGEN	1		

Figure 2.11: View -> Parameters shows all DXP control parameters and internal code variables.

Input Data Quality: If there is some problem with the detector, the DXP card, or the connection between the two (particularly ground loop problems or high frequency noise pickup) then no amount of refining parameter settings will produce a good spectrum.

ADC Trace: The first test of data quality is to look at an ADC trace. Use View-> ADC to capture a trace of input signal values as seen at the ADC. It should look approximately as shown below, without any spikes or other odd behavior. High frequency spikes are often due to picking up computer noise, particularly from monitors with large EMF emissions.

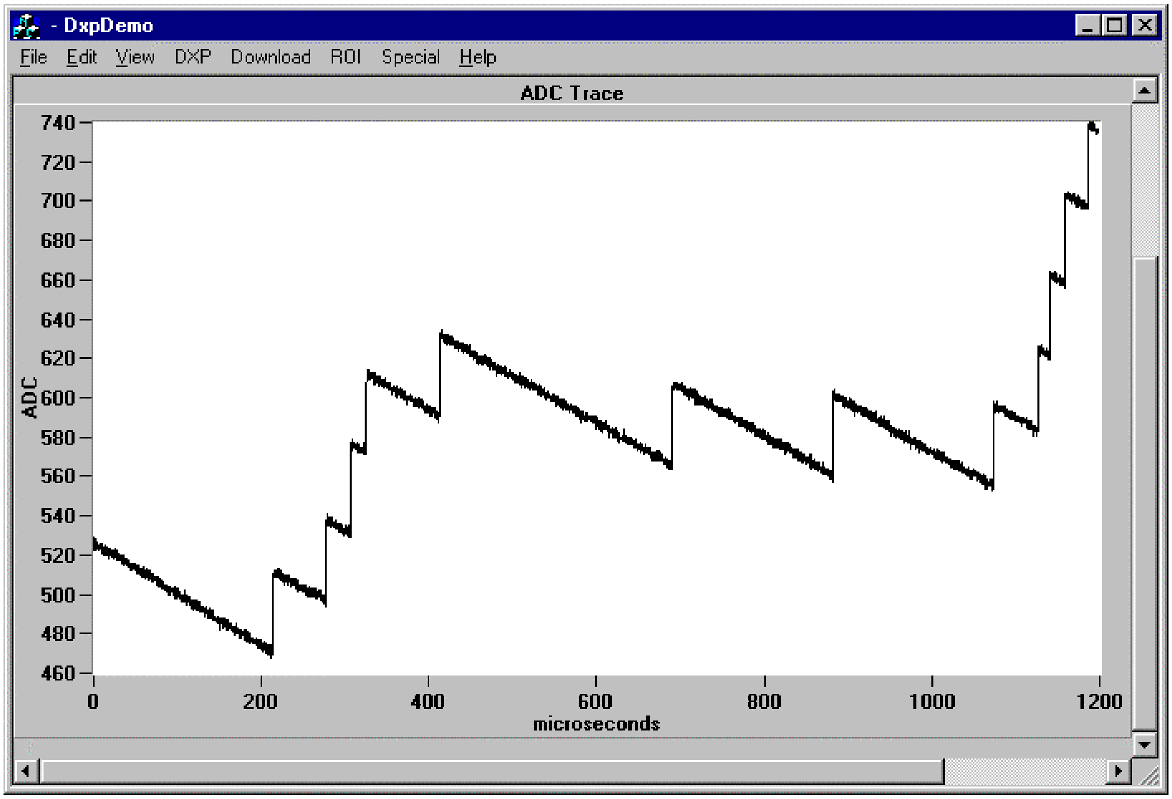


Figure 2.12: ADC input from a good quality Pulsed Optical Reset Preamplifier.

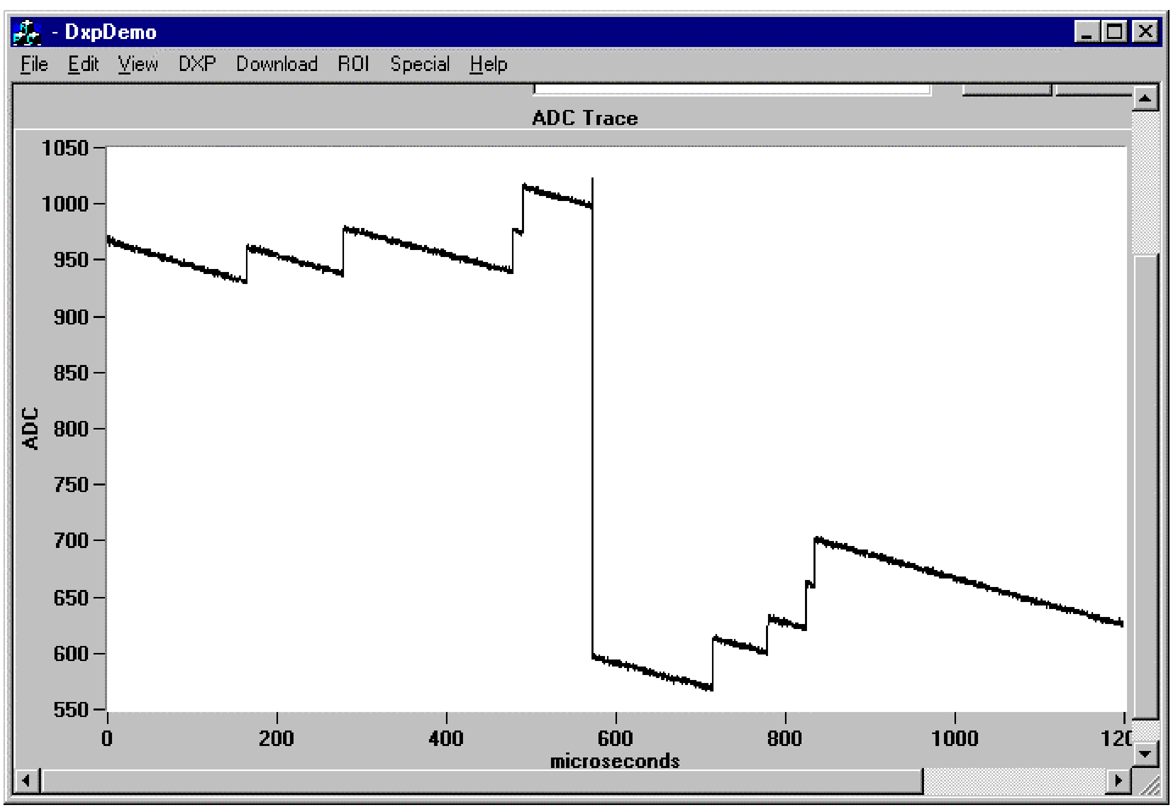


Figure 2.13: Same as Figure 2.12, but showing a tracking step correcting a drift out of range

Baseline History: The next test is to look at View -> Baseline History, which will capture about 50 ms of baseline values. Ideally, this should be a curve of white noise whose width is the same as the baseline width. Most detectors are not particularly ideal, as may be seen from a pulsed optical reset detector below. Each time (two instances in Figure 2.13) the preamplifier resets it goes through a significant change in leakage current (due to optical stimulation of traps in the first FET Gate Oxide) which causes the baseline to move. At these relatively slow frequencies the baseline tracking can keep up pretty well and there is not too much degradation in resolution. At much higher counting rates, however, the problem becomes more serious and can significantly degrate resolution. Problems caused by resetting are best addressed using the Reset Time and the Baseline Running Average parameters described above.

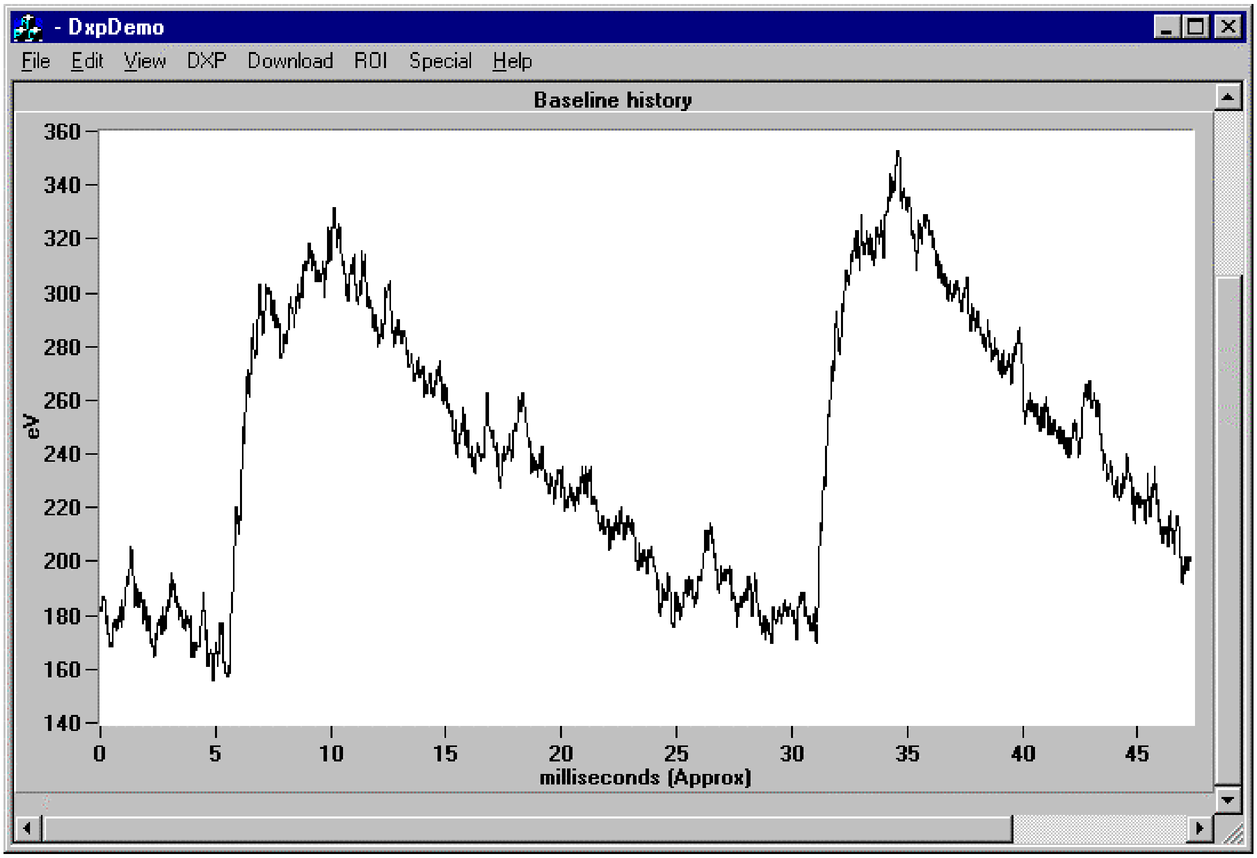


Figure 2.14: Baseline history from a pulsed optical reset preamplifier. This figure shows a particularly bad case.

3. Digital Filtering Theory, DXP Structure and Theory of Operation:

The purpose of this section is to provide the DXP user with an explanation of its operation which is deep and complete enough to allow the module to be used effectively yet not so filled with detail as to become cumbersome. A further level of detail is required for those who wish to engage in developing control programs for the DXP and this is provided in subsequent sections.

This introduction is divided into three parts. In the first, we examine the general issues associated with using a digital processor to extract accurate x-ray energies from a preamplifier signal and detect and eliminate pile-ups. In the second section we then describe how these general functions are specifically implemented in the DXP. This leads rather naturally to a discussion of the parameters used to control the DXP's functions: that is, those digital values which replace knob positions in analog systems. In the third section we the proceed to describe strategies both for selecting reasonable starting parameter values and for adjusting their values to optimize performance in particular situations.

3.1. 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 as shown in Figure 3.1a. Here the detector D is biased by voltage source V and connected to the input of amplifier A which has feedback capacitor C_f. In resetting preamplifiers a switch S is provided to short circuit C_f 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 shined on the amplifier A's input FET to cause 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 the preamplifier following the absorption of an x-ray of energy E_x in detector D is shown in Figure 3.1b as a step of amplitude V_x. When the x-ray is absorbed in the detector material it releases an electric charge $Q_x = E_x/\varepsilon$, where ε is a material constant. Q_x is integrated onto C_f, to produce the voltage $V_x = Q_x/C_f = E_x/(\varepsilon C_f)$. Measuring the energy E_x of the x-ray therefore requires a measurement of the voltage step V_x in the presence of the amplifier noise σ, as indicated in Figure 3.1b.

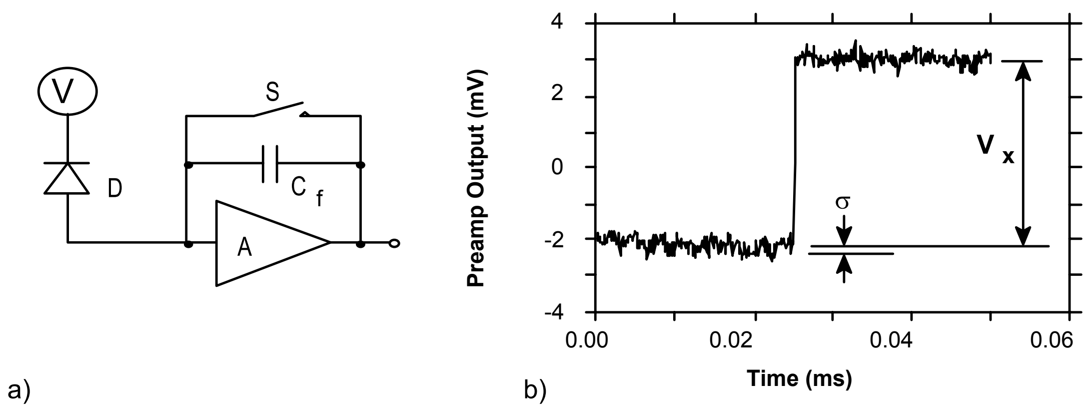


Figure 3.1: a) Charge sensitive preamplifier with reset; b) Output on absorption of an x-ray.

3.2. X-ray Energy Measurement & Noise Filtering:

Reducing noise in an electrical measurement is accomplished by filtering. Traditional analog filters use combinations of a differentiation stage and multiple integration stages to convert the preamp output steps, such as shown in Figure 3.1b, 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.

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 3.2. The data displayed are actually just a subset of Figure 3.1b, which was digitized by a Tektronix 544 TDS digital oscilloscope at 10 MSA (megasamples/sec). 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 3.2, averages are computed over the two regions marked "Length" (the "Gap" region is omitted because the signal is changing rapidly here), and their difference taken as a measure of V_X. Thus the value V_X may be found from the equation:

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

Equation 3-1

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

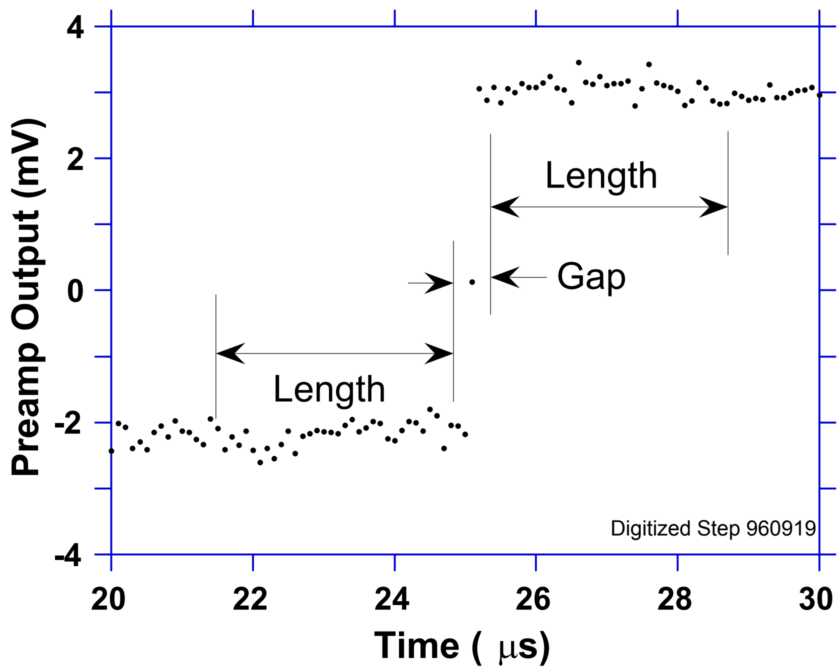


Figure 3.2: Digitized version of the data of Figure 3.1b in the step region.

The primary differences between different digital signal processors lie in two areas: what set of weights $\{w_i\}$ is used and how the regions are selected for the computation of Equation 3-1. 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 the most information about its height, they should be most strongly weighted in the averaging process. How one chooses the filter lengths results in time variant (the lengths vary from pulse to pulse) or time invariant (the lengths are the same for all pulses) filters. Traditional analog filters are time invariant. The concept behind time variant filters is that, since the x-rays arrive randomly and the lengths between them vary accordingly, one can make maximum use of the available information by setting Length to the interpulse spacing.

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. 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 3-2

where the filter length is L and the gap is G. The factor L multiplying $V_{x,k}$ arises because the sum of the weights here is not normalized. Accommodating this factor is trivial for the DXP's host software. In the DXP, **Equation 3-2** is actually implemented in hardwired logic by noting the recursion relationship between $V_{x,k}$ and $V_{x,k-1}$, 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 3-3

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 3-2 actually gives the best estimate of V_x in the least squares sense. This, of course, is why triangular filtering has been preferred at high rates. Triangular filtering with time variant filter lengths can, in principle, achieve both somewhat superior resolution and higher throughputs but comes at the cost of a significantly more complex circuit and a rate dependent resolution, which is unacceptable for many types of precise analysis. In practice, XIA's design has been found to duplicate the energy resolution of the best analog shapers while approximately doubling their throughput, providing experimental confirmation of the validity of the approach.

3.3. 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 3-2 and Equation 3-3. The result of applying such a filter with Length L = 20 and Gap G = 4 to the same data set of Figure 3.2 is shown in Figure 3.3. 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. 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* . Their peaking time is typically twice this and their pulses are not symmetric so that the basewidth is about 5.6 times the shaping time or 2.8 times their 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.

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.

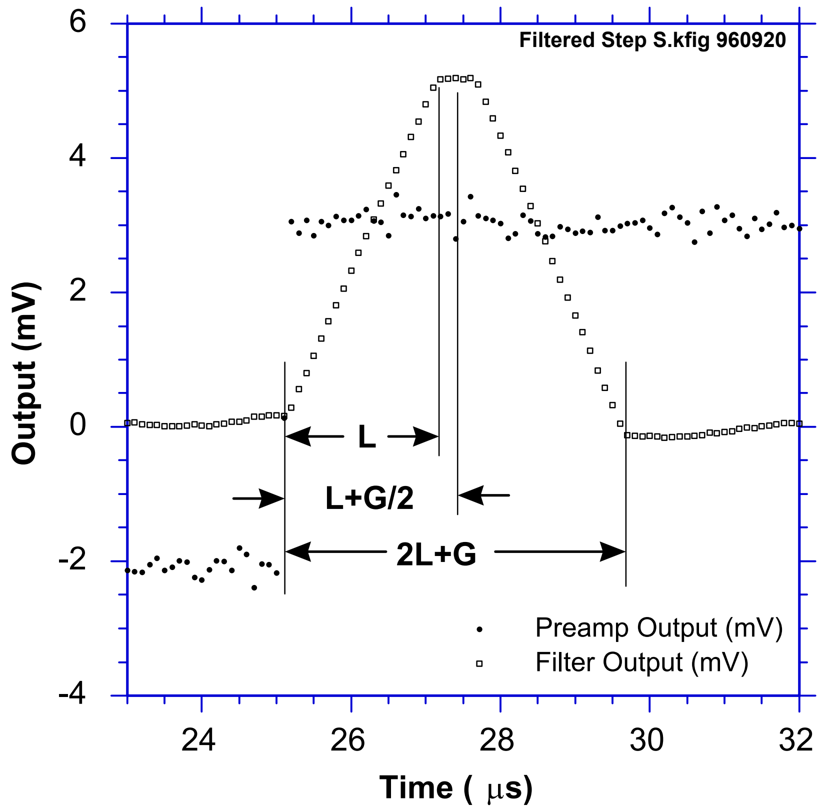


Figure 3.3: Trapezoidal filtering the Preamp Output data of Figure 3.2 with L = 20 and G = 4.

3.4. Baseline Issues:

Figure 3.4 shows the same event as is Figure 3.3 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 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 3-4

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, however, 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 3-2. 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 will be σ_e, this means that multiple baseline measurements will have to be averaged. In the standard DXP operating code this number is 64, which leads to the total noise shown in Equation 3-5.

$$\sigma_t = \mathrm{sqrt}(\ \sigma_f^2 + (1+1/64)\sigma_e^2)$$

Equation 3-5

This results in less than 0.5 eV degradation in resolution even for very long peaking times when resolutions of order 140 eV are obtained.

In practice, the DXP initially makes a series of 64 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. 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 also cause the x-ray spectrum to be distorted and which should be fixed.

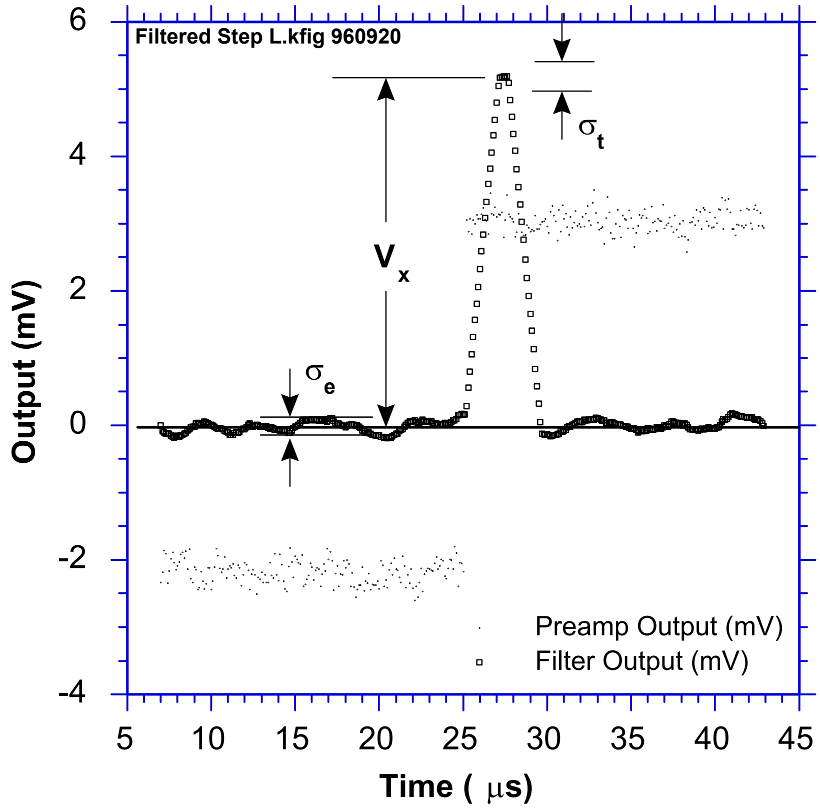


Figure 3.4: The event of **Figure 3.3** displayed over a longer time period to show baseline noise.

3.5. X-ray Detection & Threshold Setting:

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.

In the DXP the peak detection and sampling is handled as indicated in Figure 3.5. In the DXP two trapezoidal filters are implemented, a *fast filter* and a *slow filter*. The fast filter is used to detect the arrival of x-rays, the slow filter is used to reduce the noise in the measurement of V_X, as described in the sections above. Figure 3.5 shows the same data as in Figure 3.1 - Figure 3.4, together with the normalized fast and slow filter outputs. The fast filter has a filter length $L_f = 4$ and a gap $G_f = 0$. The slow filter has $L_s = 20$ and $G_s = 4$. Because the samples were taken at 10 MSA, these correspond to peaking times of 400 ns and 2 μs, respectively.

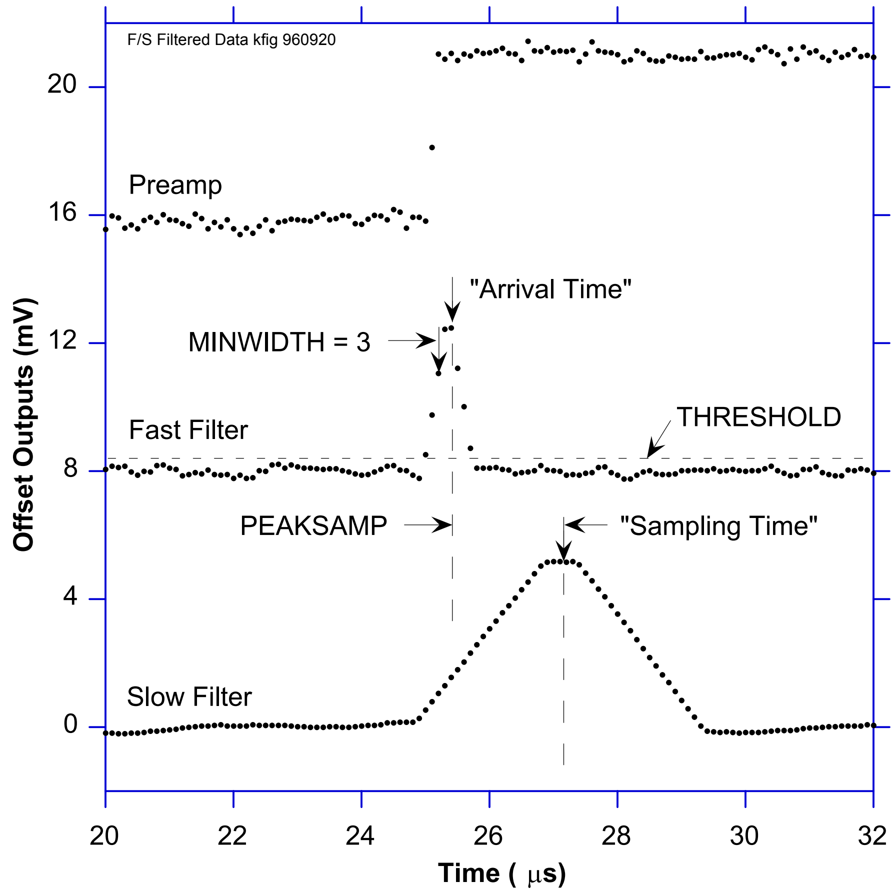


Figure 3.5: Peak detection and sampling methods in the DXP digital processor.

The arrival of the x-ray step (in the preamp output) is detected by digitally comparing the fast filter output to the digital constant THRESHOLD, which represent a threshold value. Once the threshold is exceeded, the number of values above threshold are counted. If they exceed a minimum number MINWIDTH, then the excursion is classified as a true peak and not a noise fluctuation. Once the MINWIDTH criterion has been satisfied, the DXP finds the arrival of the largest value from the fast filter (which becomes the pulse's official "arrival time") and starts a counter to count PEAKSAMP clock cycles to arrive at the appropriate time to sample the value of the slow filter. Because the digital filtering processes are deterministic, PEAKSAMP depends only on the values of the fast and slow filter constants and the risetime of the preamplifier pulses. The slow filter value captured following PEAKSAMP is then the slow digital filter's estimate of V_X.

3.6. Energy Measurement with Resistive Feedback Preamplifiers

In previous sections, the pulse height measurement was shown for the case of pulsed reset preamplifiers. The pulsed reset scheme is most often used for optimum energy resolution x-ray detectors. Other detectors use a continuous reset which we refer to as "resistive feedback" or "RC feedback", where the reset switch in Figure 3.1a is replace by a large value resistor, giving a exponential decay time of typically 50 µsec. The RC 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.

Where analog shaping amplifiers typically have a "pole-zero" adjustment to cancel out the exponential decay, the DXP uses a patented exponential decay correction to achieve good energy resolution without a pole-zero correction. Figure 3.6 and Figure 3.7 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 slow filter measurement, 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.

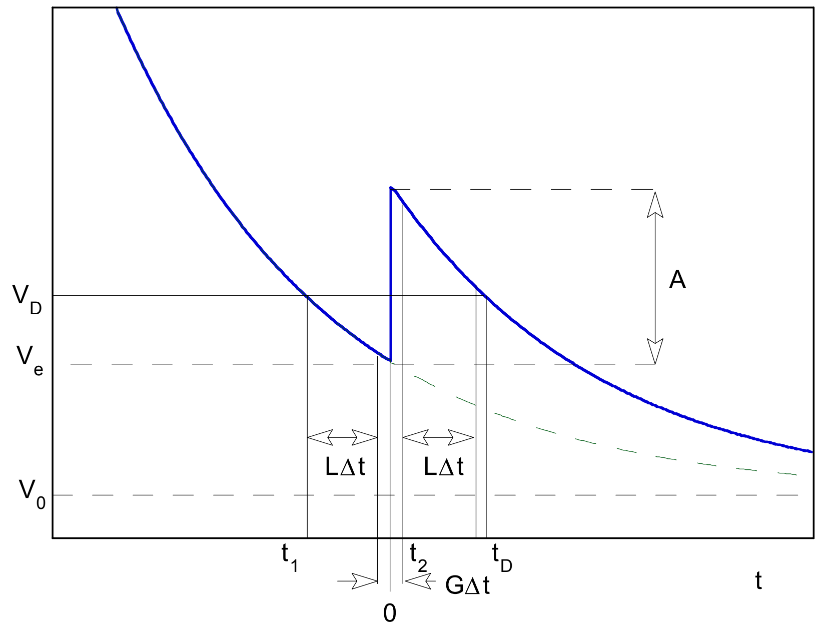


Figure 3.6: RC preamplifier output voltage. An x-ray step occurs at time t=0.

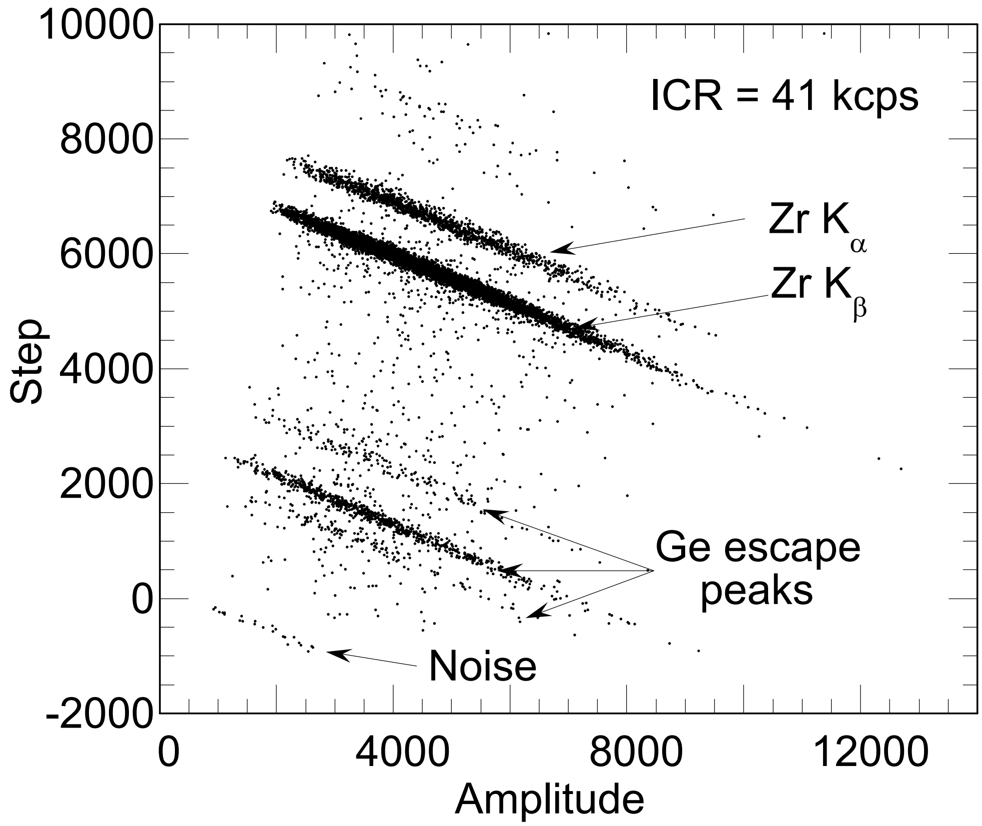


Figure 3.7: Correlation between step size and amplitude for Zr Ka x-ray events measured with the DXP-4C.

As Figure 3.7 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 3-6

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 TAURC). The decay time TAURC is in units of 50 ns clock ticks, and is measured with an exponential fit (for example, using the program DxpRCSetup). At the start of an acquisition run, the DSP calculates RCFCOR using the following approximate expression:

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

The above expression is valid for peaking times less than about TAURC/2. Alternatively, RCFCOR can be determined empirically in a special test run from a linear fit of data as in Figure 3.7.

3.7. Pile-up Inspection:

The value V_X captured will only be a valid measure of the associated x-ray's energy provided that the filtered pulse is sufficiently well separated in time from its preceding and succeeding neighbor pulses so that their peak amplitudes are not distorted by the action of the trapezoidal filter. That is, if the pulse is not *piled up*. The relevant issues may be understood by reference to Figure 3.8, 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 3.8 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 §3.6.

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 3.8, 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.

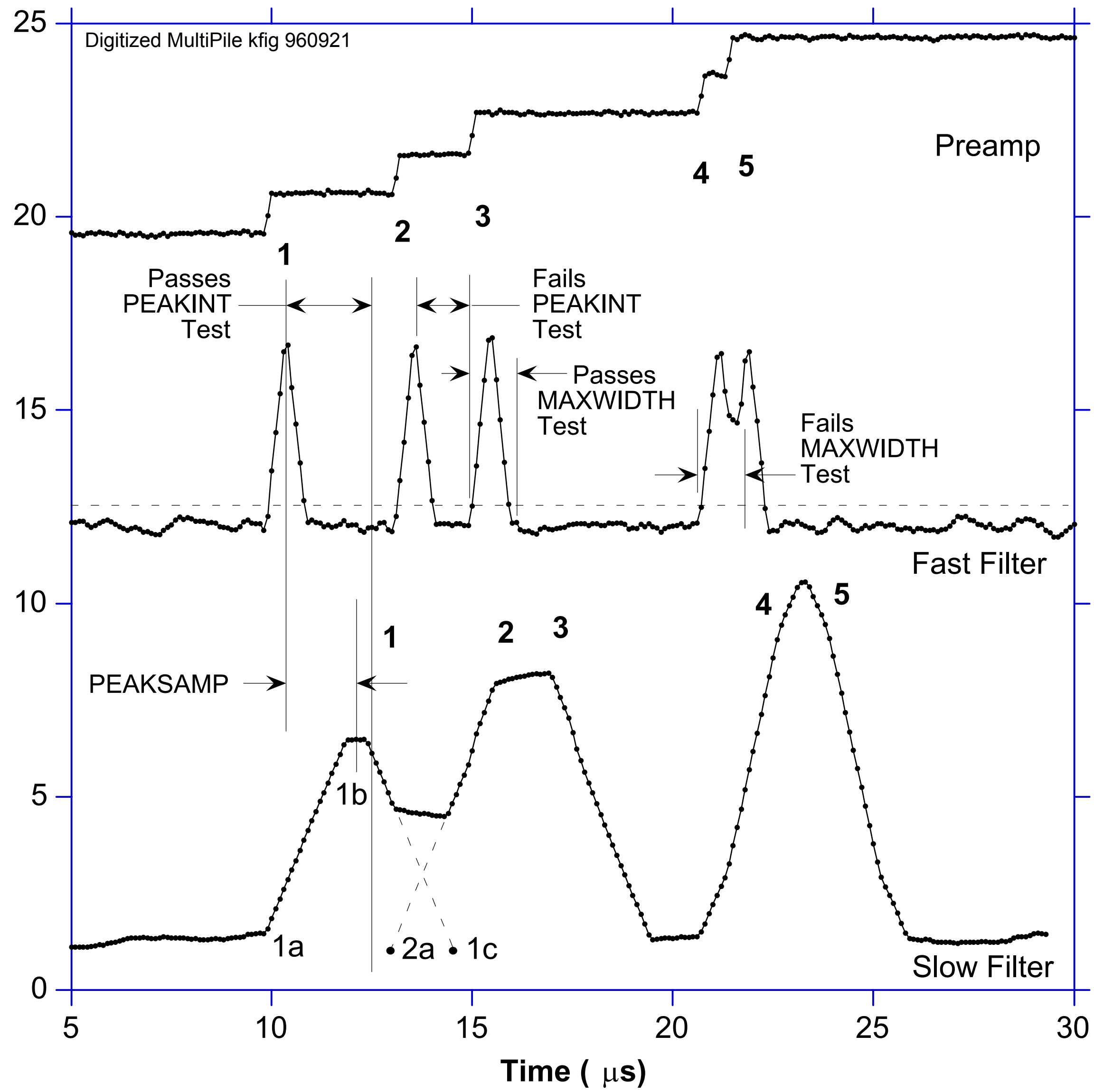


Figure 3.8: A sequence of 5 x-ray pulses separated by various intervals to show the origin of both slow channel and fast channel pileup and demonstrate how the two cases are detected by the DXP.

3.8. 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 actual time LIVETIME for which data was collected, 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 3-7. These values can then be used to make deadtime corrections as discussed in the next section.

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

Equation 3-7

3.9. Throughput:

Figure 3.9 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 edge. Intensity was varied by scanning a pair of slits across the input x-ray beam so that its harmonic content remained constant with varying intensity.

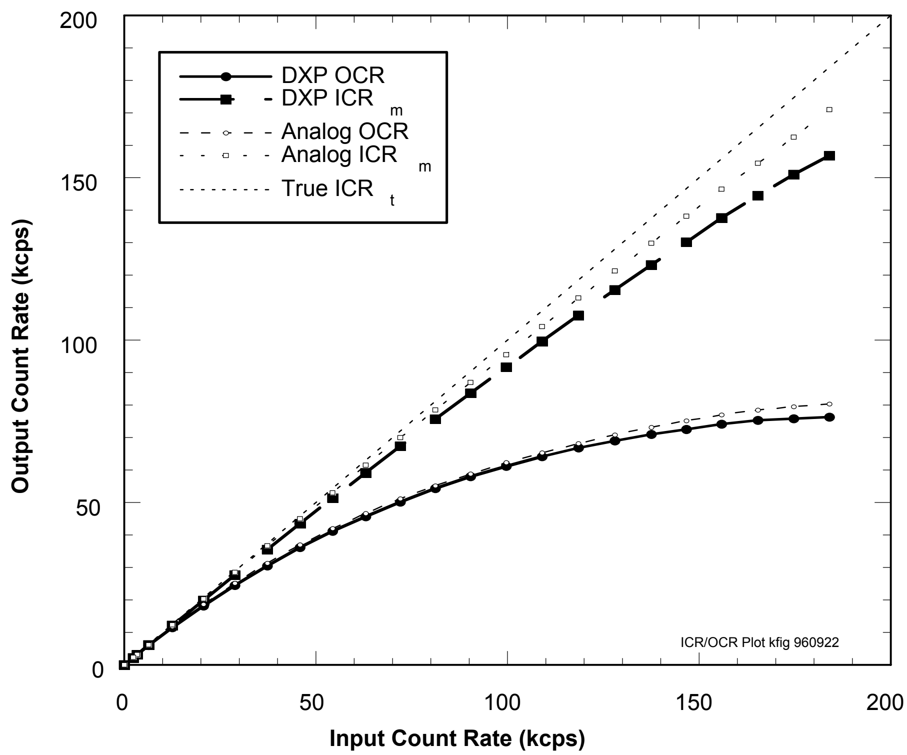


Figure 3.9: Curves of ICR_m and OCR for the DXP using 2 μs peaking time, compared to a common analog SCA system using 1 μs peaking time.

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 3.1: 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 [Ref. 4], is given by:

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

Equation 3-8

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's shown in Table 3.1. 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 3-8 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 the ICR, or

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

Equation 3-9

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

Table 3.1 illustrates a very important result for using the DXP: the slow channel deadtime is nearly the minimum 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.

3.10. Dead Time Corrections:

The fact that both OCR and ICR_m are describable by Equation 3-8 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 3-10

Looking at Figure 3.9, it is clear that a first order correction can be made by using ICR_m in Equation 3-7 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 3-11

Then, for each recorded spectrum, the associated value of ICR_m is noted and Equation 3-11 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 3-8. 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. The fact that the DXP provides highly accurate measurements of both LIVETIME and ICR_m therefore allows it to produce accurate spectral measurements over extremely wide ranges of input counting rates.

4. DXP Saturn Hardware Description

4.1. Organizational Overview:

The DXP channel architecture is shown in Figure 4.1, 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.

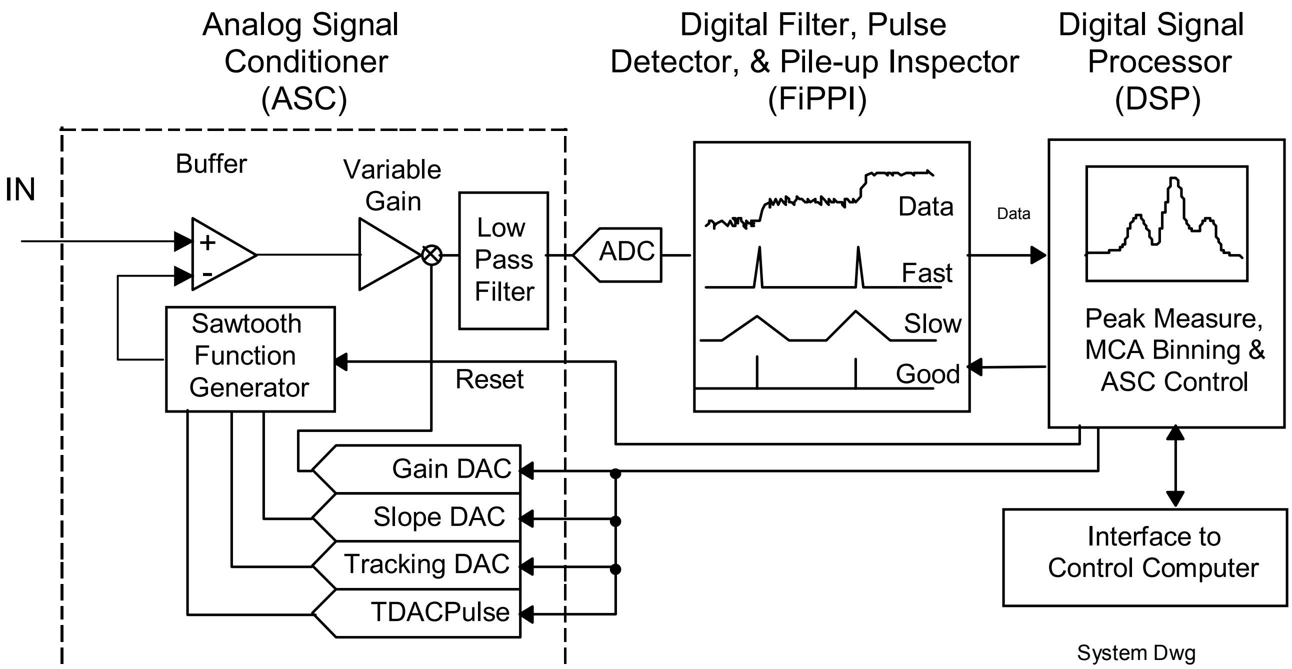


Figure 4.1: Block diagram of the DXP channel architecture, showing the major functional sections.

4.2. 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 10 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 10 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 §3.5. 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 Fig. 3.1), 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 4-1

For a typical high resolution spectrometer, N must be 14 to 15. However, 14 bit ADCs operating in excess of 10 MSA are very expensive, particularly if their integral and differential non-linearities are less than 1 least significant bit (LSB). At the time of this writing a 10 bit 20 MSA ADC costs less than $10, while a 14 bit 5 MSA ADC costs nearly $500, 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 4.2. 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, which 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 4.2. 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 achi3eve 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 4.2) within the ASC input range.

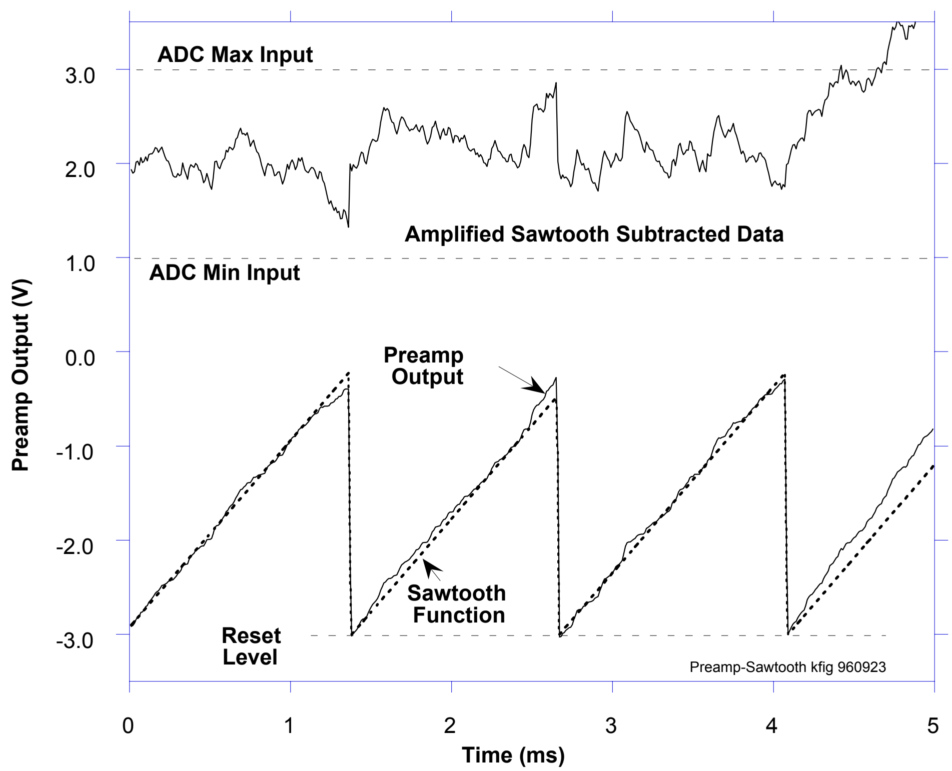


Figure 4.2: A sawtooth function having the same average slope as the preamp output is subtracted from it and the difference amplified and offset to match the input range of the ADC.

Occasionally, as also shown in Figure 4.2, 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 pulsing 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.

4.3. 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 §3. 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} 0.5 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 1.2 µs and the maximum throughput according to Eqn. 3.9 would be 310 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 §3.2, 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 all 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 be reprogrammed for special purposes, although this process is non-trivial and would probably require XIA contract support.

4.4. 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-2181 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 5 describes in detail the DSP operation, its tasks, and parameters which control them.

The ADSP-2181 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.

4.5. Interface to the Host Computer:

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 through the XiaSystems DLL on Windows 95/98/NT platforms. In this way a programmer needs to know very little about the interface specifics.

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 upload...) 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.

0x0000 - 0x3FFF	DSP Program memory	Contains the DSP instructions and 24-bit data
0x4000 - 0x7FDF	DSP Data memory	16-bit data, including the parameters memory
0x7FE0 - 0x7FFF	reserved	
0x8000	Control Status Register (CSR):	

bit	access	Name	Meaning
0	r/w	RunEnable	Disable(0) or Enable(1) data acquisition
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

0x8001-0x8002	Diagnostic or special purpose registers
0x8003	FiPPI configuration register

5. DXP Saturn DSP Code Description

5.1. 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 upload 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 (Variant #0) provided with the DXP Saturn is for typical x-ray fluorescence spectroscopy using a pulsed reset preamplifier. Additional program variants, listed in Table 5.1, are available for other applications, including hardware diagnostics. Other specialized measurements, including: 1) x-ray mapping; 2) Quick XAFS scanning; 3) switching between multiple spectra synchronously with an experimentally derived signal (e.g. "Phased locked EXAFS"); and 4) time resolved spectroscopy (e.g. "multi-channel scaling"). The variants which have been released to date are described in Section 5.11. Several other variants have been developed for particular customers and may be made available upon request.

Variant	Name	Standard Application/Configuration
0	X10P	General x-ray spectroscopy data acquisition for pulsed reset preamplifiers Single MCA per channel with up to 8K bins
1	X10PRC	General x-ray spectroscopy data acquisition for RC feedback preamplifiers Single MCA per channel with up to 8K bins
2	X10PDIAG	Hardware diagnostics, for testing purposes

Table 5.1: DSP Software Variants

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 an 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.

5.2. Program Flow

The flow of the DSP program is illustrated in Figure 5.1. 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.

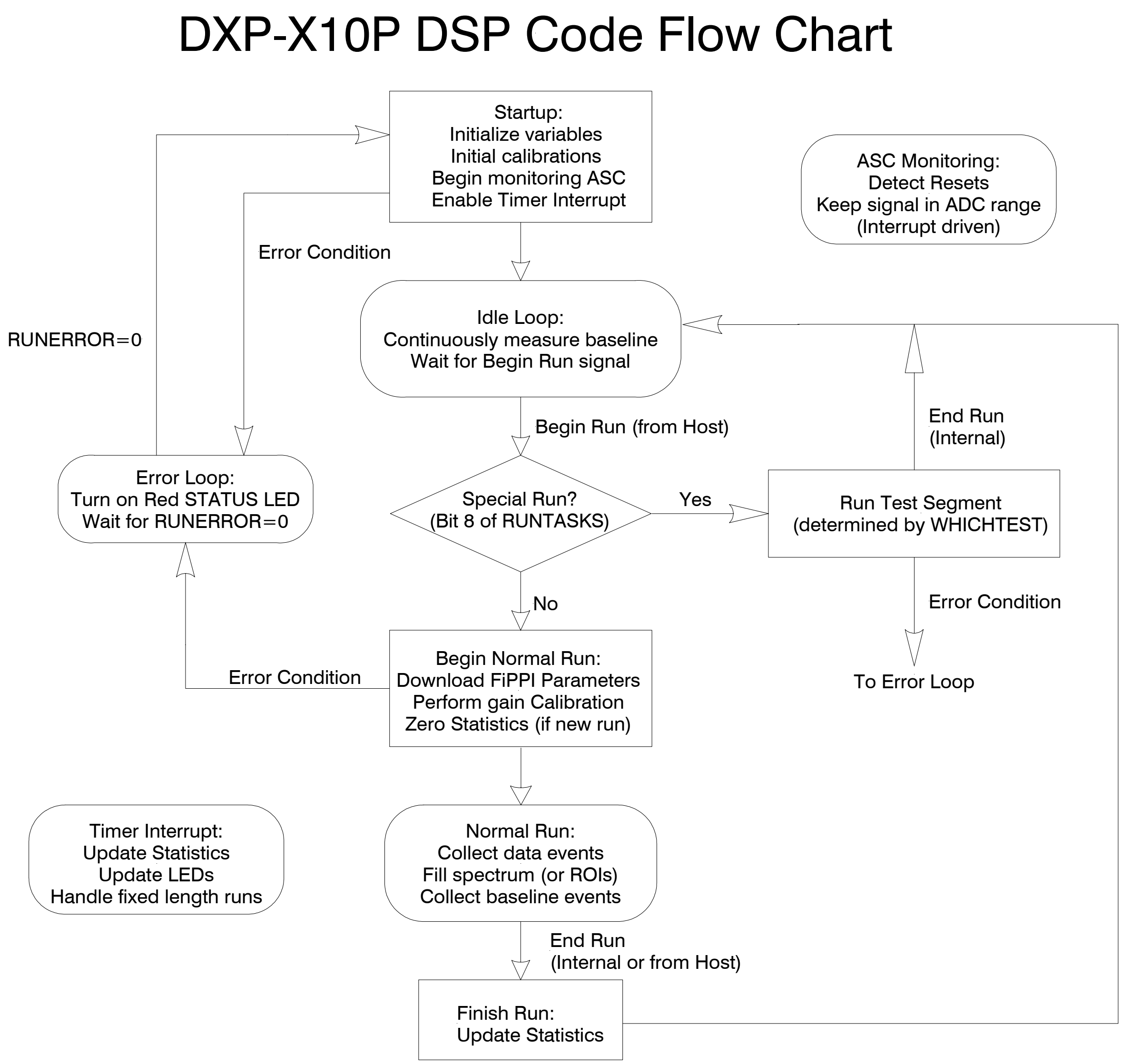


Figure 5.1 DSP code flow diagram

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). Normally, the special runs 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.

5.3. Initialization

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

1) Setup internal DSP control registers
2) Zero spectrum and data memory, then initialize parameters to default values.
3) Set ASC DACs to initial default values
4) Initialize FiPPI and download default filter parameters
5) 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.
6) 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.

5.4. Event Processing

There are two primary tasks performed during a normal data-taking run: event processing and baseline processing. These tasks are described in detail below.

5.4.1. Run Start

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

7) Sets the desired gain (by setting the GAINDAC and the HIGHGAIN relay). If the gain has changed, the TrackDAC calibration is redone (for reset detectors only).
8) 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).
9) Downloads the specified FiPPI parameters (SLOWLEN, SLOWGAP, etc) to obtain the desired peaking time.
10) Updates the internal calibrations with the new gain and FiPPI values.
11) 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.

5.4.2. 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.

5.4.3. 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.

5.4.4. 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.

5.4.5. 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 ful 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.

5.5. 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 1/64. 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.

5.5.1. 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 5-1

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 (1/64)*2**15 = 2**9 = 512.

5.5.2. 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.

5.5.3. 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. 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 in use.

The baseline histogram is only filled during a normal datataking 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.

5.5.4. 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. The user can choose to include the slope baseline in the mean by clearing the residual baseline bit (6) in RUNTASKS.

5.5.5. 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.

5.6. 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 5.4 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.

5.6.1. ASC Monitoring

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

12) Detects Resets (pulsed reset detectors only)
13) Adjusts the slope generator to match the event rate (pulsed reset detectors only)
14) Adjusts the offset value to keep the signal in range (RC feedback detectors only)
15) 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.

5.6.2. Timer Interrupt

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

16) Update the run statistics EVTSINRUN, LIVETIME, REALTIME and FASTPEAKS (only during a run).
17) 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.
18) 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.

5.7. 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 5.2: 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.

5.8. 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 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	Continuously write baseline values to baseline history circular buffer (DEFAULT)	Disable writing baseline values to baseline history circular buffer
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 5.3: Data acquisition tasks controlled by the DSP parameter RUNTASKS.

5.9. 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	RESET calibration (measure TRACKRST)
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 5.4: Special tasks and test segments that can be selected with the DSP parameter WHICHTEST.

5.10. 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.

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	DAQ 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	
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).
HIGHGAIN	Parameter	High gain relay setting
INPUTENABLE	Parameter	Input Enable relay setting
ASC Control Parameters and Calibrations (pulsed reset 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
TAURC	Parameter	Preamplifer decay constant, in 25 ns units (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 5.5: Summary of DSP parameter definitions

5.10.1. 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 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 real time or live time, the units are 800 nanosecond intervals.

5.10.2. Setting the slow filter parameters (SLOWLEN,SLOWGAP)

In general the user does not modify these parameters directly, but through the host software routine SetAcquisitionValues (See Appendix).

The DXP uses a trapezoidal filter, characterized by the peaking time, T_p, and flat-top time, T_f. The peaking time is determined by the SLOWLEN and DECIMATION values. DECIMATION is automatically sensed by the DSP and should not be modified. For T_p and T_f. in µsec, the following gives the value of SLOWLEN and SLOWGAP:

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

The user will want to be able to choose the peaking time based on resolution and throughput requirements. Throughput (output count rate, OCR, divided by input count rate, ICR) is given by exp(-τ*ICR) where, to a good approximation, the pulse-processing deadtime $\tau = 2Tp+T_f$ is the pulse basewidth. The dependence of resolution on peaking time is detector specific. Typical values of SLOWGAP are 6 for the 0-bit decimation FiPPI and 3 for the others. Different detectors may work best with slightly different values.

5.10.3. Setting the fast filter parameters(FASTLEN,FASTGAP)

In general the user does not modify these parameters directly, but through the host software routine SetAcquisitionValues (See Appendix).

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_f’ = fast flat-top time in µsec:

$$FASTLEN = 20*T_p'$$
$$FASTGAP = 20*T_f'$$

Typical values of these parameters are FASTLEN=4 and FASTGAP=0. While these are reasonable values for most users, some may want to make FASTLEN larger in order to trigger at lower values (see beloe) or shorter to run at higher rates.

5.10.4. Setting the pulse detection parameter (THRESHOLD,MINWIDTH)

In general the user does not modify these parameters directly, but through the host software routine SetAcquisitionValues (See Appendix).

X-rays are identified when the fast filter output (in units of ΔADC*FASTLEN) goes above threshold. This threshold can be expressed in energy units once the DXP conversion gain, G_{DXP} = number of ADC counts per keV at the DXP input, is known. For an energy threshold E_{th} in keV,

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

The conversion gain is discussed below. The MINWIDTH parameter is used for noise rejection: It is the minimum number of time bins the fast filter is above threshold. A typivsl value that works with FASTLEN=4 is MINWIDTH=4.

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

In general the user does not modify these parameters directly, but through the host software routine SetAcquisitionValues (See Appendix).

MAXWIDTH is used to reject pulse pile-up on a time scale that is comparable to FASTLEN. The idea is that wide pulses are really two or more normal width pulses that are separated in time, but not enough for the fast filter to go below threshold. 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 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 = 2 or 3.

5.10.6. Setting Gain parameters (HIGHGAIN, GAINDAC)

In general the user does not modify these parameters directly, but through the host software routine SetAcquisitionValues (See Appendix).

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. The ADC range is one volt full scale. .Two guidelines are suggested for the internal gain setting:

19) 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).
20) 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 ADC channels.

The parameters HIGHGAIN and GAINDAC set the coarse and fine internal amplifier gain. The overall gain can be expressed as follows:

Gtot = Gin * Ghigh * Gvar * Gbase

where

Gin : input stage gain = roughly 2 or roughly 4 depending on setting of jumper JP102
Ghigh : High Gain relay setting = 1 for low gain, 4 for high gain
Gvar : variable gain setting = 1 to 100 depending on GAINDAC setting
Gbase : baseline gain = 0.0285

Overall, the internal gain can range from 0.057 V/V to 45.56 V/V.

The coarse gain is set either low (HIGHGAIN=0) or high (HIGHGAIN=1); this setting controls a relay which offers a factor of 4 difference in gain between the high and low gain settings.

The fine gain control is a 16 bit DAC which sets the gain of a variable gain amplifier which is linear in dB". The gain setting accuracy is approximately one bit(or 0.00061 dB = 0.007%). The relationship between Gvar and GAINDAC is:

Gain (in dB) = (GAINDAC/65536) * 40 dB
Gvar = 10**(Gain(in dB)/20)

In addition to the programmable gain control, a jumper (JP102, located in the corner of the board, next to the input BNC connector) chooses an input stage gain of either roughly 2 (with the jumper away from the edge of the board) or roughly 4 (with the jumper towards the edge of the board). The exact gain of this stage depends on the output impedance of the detector preamplifier:

Gain = 2k /((1k or 500) + Output Impedance))

5.11. DSP Program Variants

5.11.1. MCA acquisition with pulsed reset preamplifiers (variant 0)

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

Firmware files:

Program file name:	X10P0106.HEX
Fippi file names:	FXPDxx0_ST.FIP (x=0,2,4,6)

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

5.11.2. MCA acquisition with resistive feedback preamplifiers (variant 2)

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

Firmware files:

Program file name:	X10PRC0103.HEX
Fippi file names:	F02X10PxG.FIP (x=0,2,4,6)

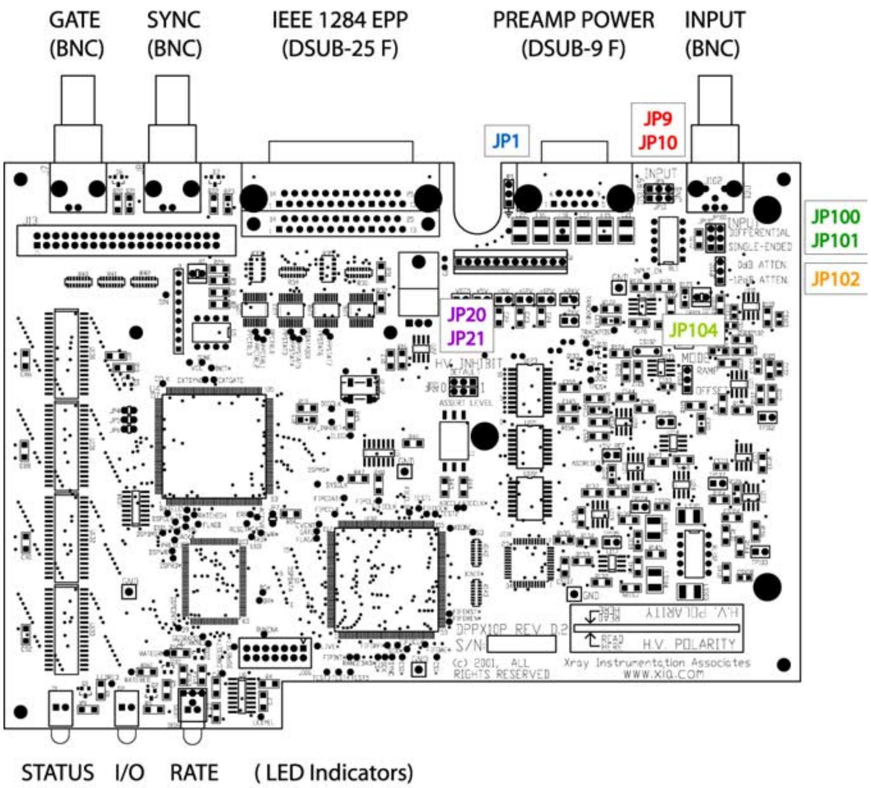
Additional parameters (described in Section 5.10):

TAURC	Exponential decay time in 50 ns units.
RCFCOR	Correction factor (calculated automatically at start of run if TAURC not 0)

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

Appendix A: DPP-OEM Revision D.2

This addendum 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.



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

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 EPP 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

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

Power Consumption:

DPP-X10P Only (preamplifier power consumption NOT INCLUDED)					
		Standby		**Active**	
Name	*Voltage*	*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**