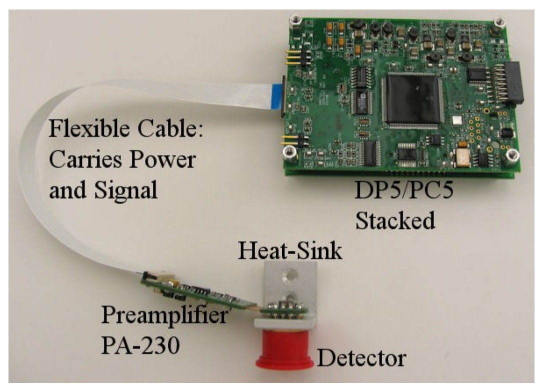
Grounding, Shielding, and Interference in Amptek Processors

Electromagnetic interference (EMI) is frequently a problem in radiation detection. The detector output is a very small current pulse, typically a few nanoamps with a duration of tens of nanoseconds. The preamp output is a small voltage pulse, typically a few millivolts in amplitude. Near these sensitive nodes, one often finds power supplies drawing large current (e.g. the high voltage supply for an X-ray tube), digital circuits which switch at high speeds, and other possible sources of interference. Grounding, shielding, and other techniques can be used to minimize interference, or when misapplied, can make it worse.

It is quite common for a user to assemble a system, start taking data, and to discover that the performance does not match expectations. The most common problems are trivial: cables or power supplies not connected, software improperly installed, or incorrectly configuration of the signal processor. Once these are solved, noise due to interference is the most common problem.

This application note provides a few suggestions for minimizing these problems with Amptek's X-ray detectors and signal processors. This is not an exhaustive treatment: there are too many possible sources of interference to cover them thoroughly. There are many excellent books and articles, listed in section 2, which provide a more general approach.

Amptek provides many different packaging options for its spectrometers systems, and the packaging configuration is very important in determining susceptibility to interference. The X-123, shown on the left below, puts the whole system (detector, preamp, signal processor, power supplies) inside a single, compact metal box with minimal external connections. It is well shielded with simple grounding and is usually least susceptible to EMI. The photo on the right below shows a board level solution. It has all of the same components, but the user provides packaging and interconnections. The user is responsible for shielding, and grounding. The board level solution requires more effort and expertise on the part of the customer.



1. General Suggestions

Grounding

Grounding is a subject which is surprisingly complicated and is often poorly understand. Improper grounds are responsible for more interference problems than any other condition. The key recommendations are:

- You should always have a connection to earth ground, for personnel safety.
- We recommend a single point ground, i.e. one and only one connection between the system ground and earth ground. It is usually best to ground either the preamp or the chassis of the spectrometer.
- Laptop computers are a common source of ground noise problems. Some laptops have very noisy power supplies, which inject large current pulses into their ground pin. We recommend isolating laptop power from earth ground.
- Pay close attention to the power return path for noisy equipment (e.g. high voltage power supplies for X-ray tubes, or stepper motors). Make sure that the return currents do not flow through the spectrometer's ground connections.
- If the detector and preamp are separate from the signal processor (e.g. when using an XR100 or PA210 preamp), connect the signal ground of the preamp to the signal ground of the processor using the lowest impedance feasible. It is usually best to connect the signal and chassis grounds to earth ground at the detector or preamplifier and isolate them elsewhere.

Cables

- Short cables are good. Customers often ask "How long can I make the cables before I get interference?" The answer is "It depends on the electromagnetic environment". Longer cables are more susceptible to EMI.
- Shielded cables are usually a good idea though it depends on how they are grounded. Recommended practice is to send a signal, particularly the small preamp output, through a shielded cable which is grounded at the preamplifier (tied to preamp signal ground) and floating at the amplifier input. Signal ground should be provided separately.
- When transmitting noisy signals, i.e. those with high current fluctuations, it is best to use a shielded cable with the return on the outside. Twisted pair may also reduce coupling.

Shielding

- For shielding to be effective, you must understand the source of the interference and the receiving portion of the circuit. In general, we recommend shielding preamplifiers (put a shield around the preamplifier and connect it to the preamp's signal ground).
- We also recommend shielding noisy power supplies. A switch mode power supply may require shielding. The high voltage power supply for an X-ray will, most often, require shielding.

Thinking about interference

Any electromagnetic interference problem involves three components: a source or transmitter, a coupling mechanism, and a receiver. To solve an interference problem, you can (a) reduce what is transmitted, (b) reduce the coupling, or (c) reduce the sensitivity of the receiver. To solve the problem, you must first identify the transmitter, and identify how it is coupling, and identify which portion of the circuit is sensitive. Only then can you identify which component to tackle.

2. References

Many papers and textbooks have been written on grounding, shielding, and interference. We strongly recommend that you refer to these sources. We have a few we particularly suggest (the recommendations in this application note come from these references).

Web resources

Analog Devices, Inc. has published several application notes on grounding, shielding, and interference which are available online. Their focus is on integrated circuits, rather than systems, but they still provide a very nice introduction to the main issues.

- *Understanding interference-type noise: How to deal with noise without black magic*. http://www.analog.com/library/analogDialogue/bestof/pdf/16_3.pdf
- AN-345, *Grounding for low- and high-frequency circuits*, by Paul Brokaw and Jeff Barrow
- AN-202, *An IC amplifier user's guide to decoupling, grounding, and making things go right for a change*, by Paul Brokaw
- AN-347, *Shielding and guarding: How to exclude interference-type noise*, by Alan Rich
- MT-95, *EMI, RFI, and Shielding Concepts: A Tutorial*

Radiation detection texbook

Helmut Spieler has written a textbook on radiation detection. Chapter 9 is entitled *"Why things don't work"* and most of the chapter concerns grounding and shielding for semiconductor radiation detectors. It is an excellent reference.

- Spieler, Helmut, **Semiconductor detector systems**, Oxford press, 2005

Standard electrical engineering textbooks

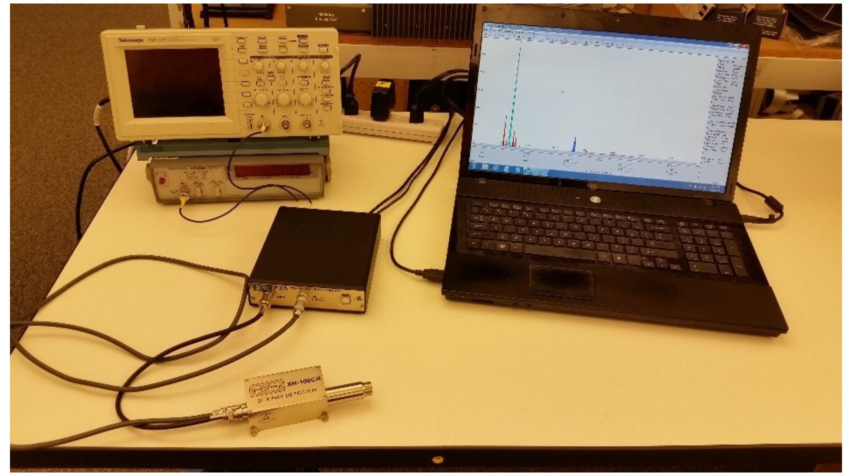
Electromagnetic interference is a common problem in electrical engineering. There are several standard reference textbooks. Their advice is generally good for radiation detection systems.

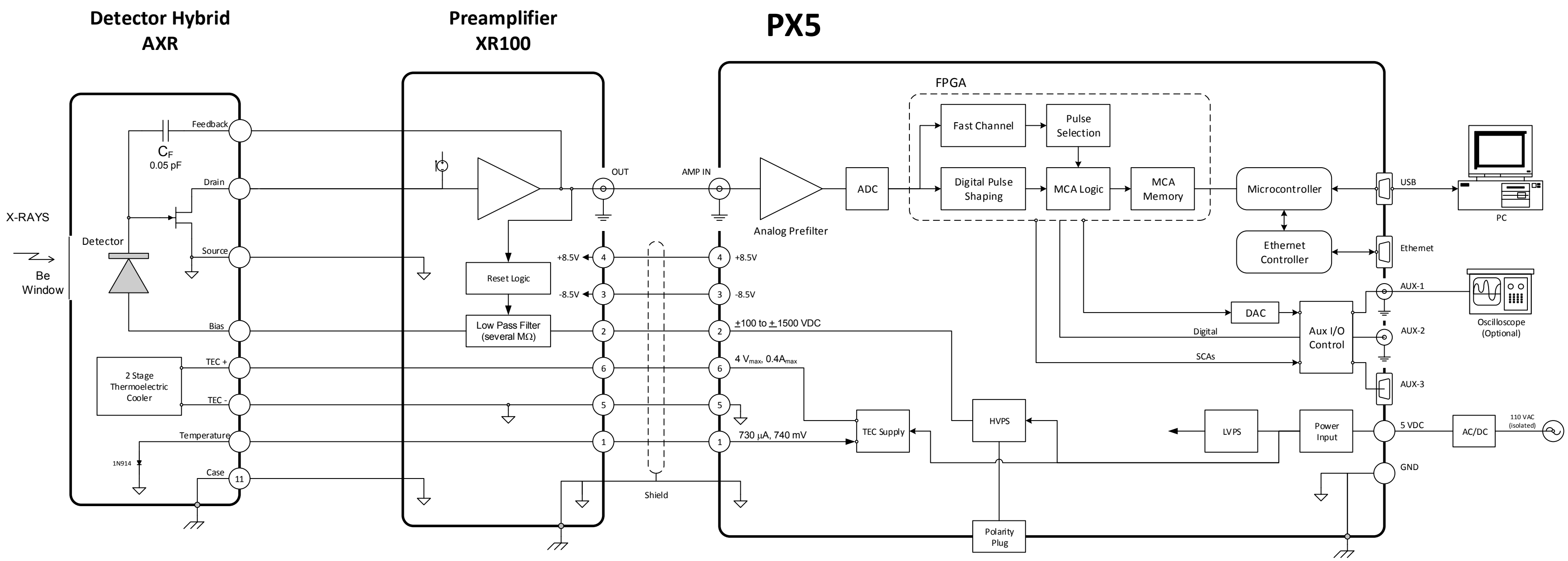
- Morrison, Ralph, **Grounding and Shielding Techniques**, John Wiley & Sons, New York, 1998.
- Ott, Henry W., **Noise Reduction Techniques in Electronic Systems**, 2nd ed., John Wiley & Sons, New York, 1998.

3. XR-100 with PX5

Amptek's XR100 detector/preamplifier with the PX5 signal processor and power supply is commonly used in laboratory and benchtop settings. A typical setup is shown to the right. Because the components are in shielded boxes, with shielded cables, it is immune to much interference. Grounding can be a concern, due to the connections between the boxes and from the PX5 to auxiliary equipment.

The block diagram below summarizes the connections in this system, in a typical configuration while the photo shows a typical setup. Note that there are several different detector configurations available; this is a generic illustration. Refer to the PX5 and XR100 manuals for more details, including specific pinouts for the connectors.





Notes and recommendations for XR100/PX5

Detector and preamp

- The signal ground is the source of the input JFET. This is connected to the ground plane of the XR100.
- The case of the TO-8 can be regarded as the sensor chassis ground. It is connected to the XR100 box (chassis ground). In most detectors, the TO-8 case is connected to a detector pin, which connects to the XR100 ground plane.
- The TEC power return is tied to the XR100 ground plane.
- The XR100 ground plane is tied to the XR100 box (chassis ground) and to the shields of the BNC and the LEMO.
- It is usually best to connect the XR100 box to ground and to have this be the single point ground.

PX5

- The BNC for the amplifier input and the LEMO from the XR100 both connect to the chassis of the PX5 and to the ground plane of the PX5 board.
- On the PX5 back panel, there is a ground plug and ground connections on the two BNCs, the USB, the AUX3 connector, and the 5VDC power. These are all tied to PX5 signal and chassis ground.

Connections

- The AC/DC power supply provided by Amptek is isolated: the power return is not connected to ground.
- The USB ground is tied to PX5 ground. This is frequently tied to ground in a computer, so can create a ground loop.
- If the AUX connectors are tied to oscilloscopes or other test equipment, and this is grounded, a ground loop is formed.

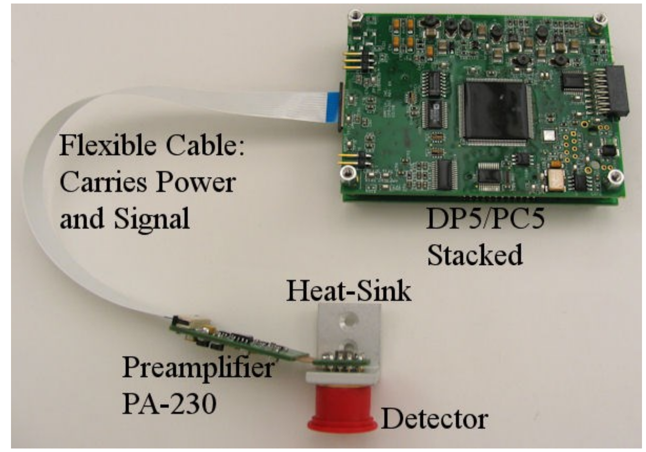
Other

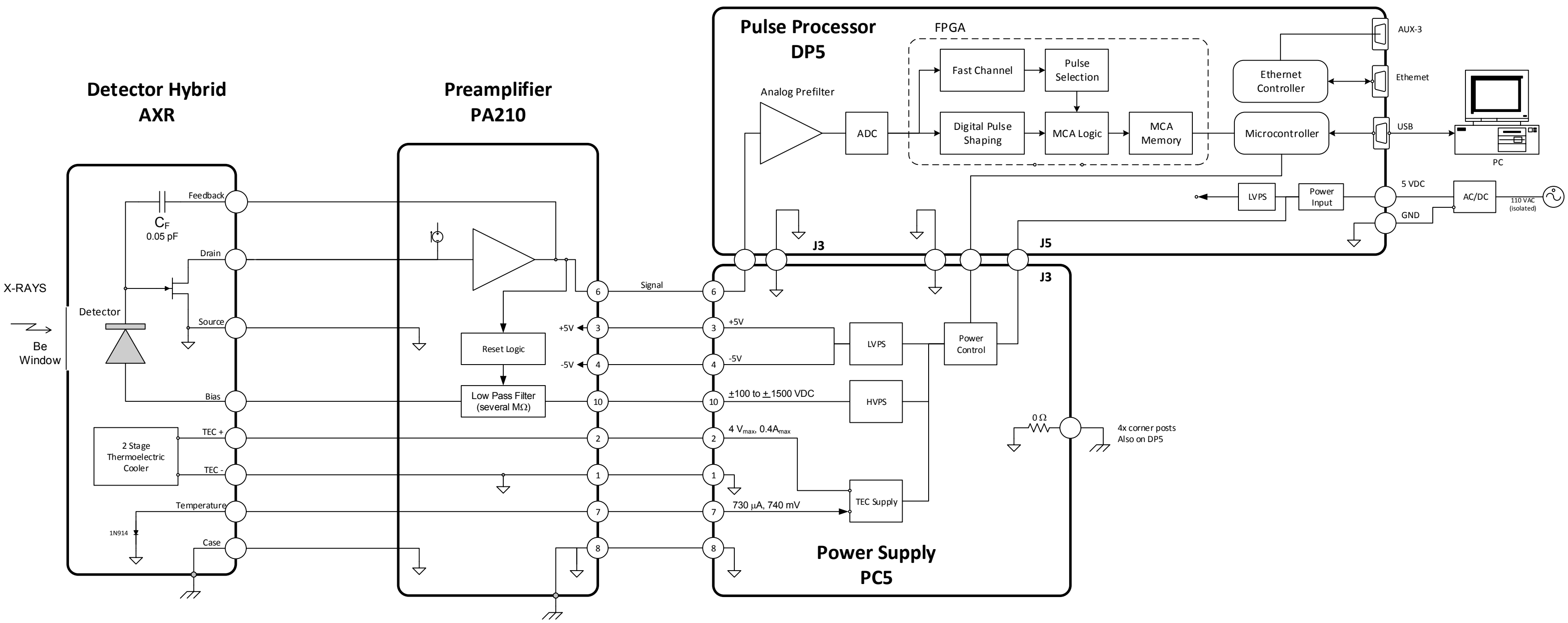
- We have found that LCD screens, often used in laptops or oscilloscopes, to be a source of noise (the boost regulator needed to power the LCD may emit radiation).

4. PA210 with DP5 and PC5

Amptek's PA210 detector/preamplifier with the DP5 signal processor and PC5 power supply is intended for use by OEMs, integrating the boards into instruments. Because the components are in unshielded boards with unshielded cables, this configuration is most susceptible to interference and grounding.

The block diagram below summarizes the connections in this system, in a typical configuration while the photo shows a typical setup. Note that there are several different detector and preamplifier configurations available. Note also that the connectors have more pins than are shown here. Refer to the PA210, DP5, and PC5 manuals for more details, including specific pinouts for the connectors.





Notes and recommendations for PA210/DP5/PC5

Detector and preamp

- The signal ground is the source of the input JFET. It is connected to the ground plane on the PA210 preamp board.
- The case of the TO-8 detector package is chassis ground. In most Amptek detectors, this is connected to a pin 11 and is connected to the preamp ground.

  In the FastSDD™, the case is not tied to a pin and board ground. A separate connection from the TO-8 case to preamp ground is recommended for the FastSDD™.
- The TEC return current is not connected to ground in the detector or preamp. It is grounded in the PC5.
- We strongly recommend that the preamplifier be shielded. Amptek provides an aluminum housing or a custom housing can be made. This housing should be tied to the preamplifier ground plane.
- For good cooling and hence low noise, it is vital that the detector be attached to a good heat sink. Good heat sinks are usually electrical conductors; in many cases, this means that the detector case is electrically tied to the heat sink. We have seen many cases where large ground current flow through here, e.g. due to a nearby X-ray tube. In these cases, it is advantageous to electrically isolate the detector package and the threaded stud, using thermally conductive but electrically isolating materials.

PA210 to PC5 connection

- An 8 inch, ten pin, shielded flex cable is the standard connection between the preamp and the PC5. Longer cables can be used but are more susceptible to interference noise. Shorter cables may also be used.
- The ten pin connector from the PA210 brings over signal ground (often tied to detector case ground) and separately the TEC return, which is grounded on the PC5.

DP5 and PC5 - grounding

- The DP5 and PC5 signal grounds are connected via the signal connector (J3 on the DP5) and via a large connector (J5 on the DP5).
- In addition, each board has four mounting holes through which studs are usually placed. Each hole (and stud) can be connected to the board's ground plane via an adjacent zero ohm resistor, or the resistor can be removed to isolate the stud. These can studs tie the board grounds together and can ground the stack.
- One approach is to ground the stack using one stud and to remove the other six resistors. If the DP5/PC5 stack and the preamp are separately grounded, a ground loop is formed. A second approach is to completely isolate the DP5/PC5 stack and ground the preamp (or vice-versa).
- The 5 VDC ground pin is tied to the ground plane on both DP5 and PC5. If a non-isolated supply is used, a ground loop is formed. Amptek's AC/DC supply is isolated so does not ground the system.
- The USB connection is tied to the DP5 ground plane so can form a ground loop. The AUX connection are referenced to the DP5 ground plane so can form ground loops.

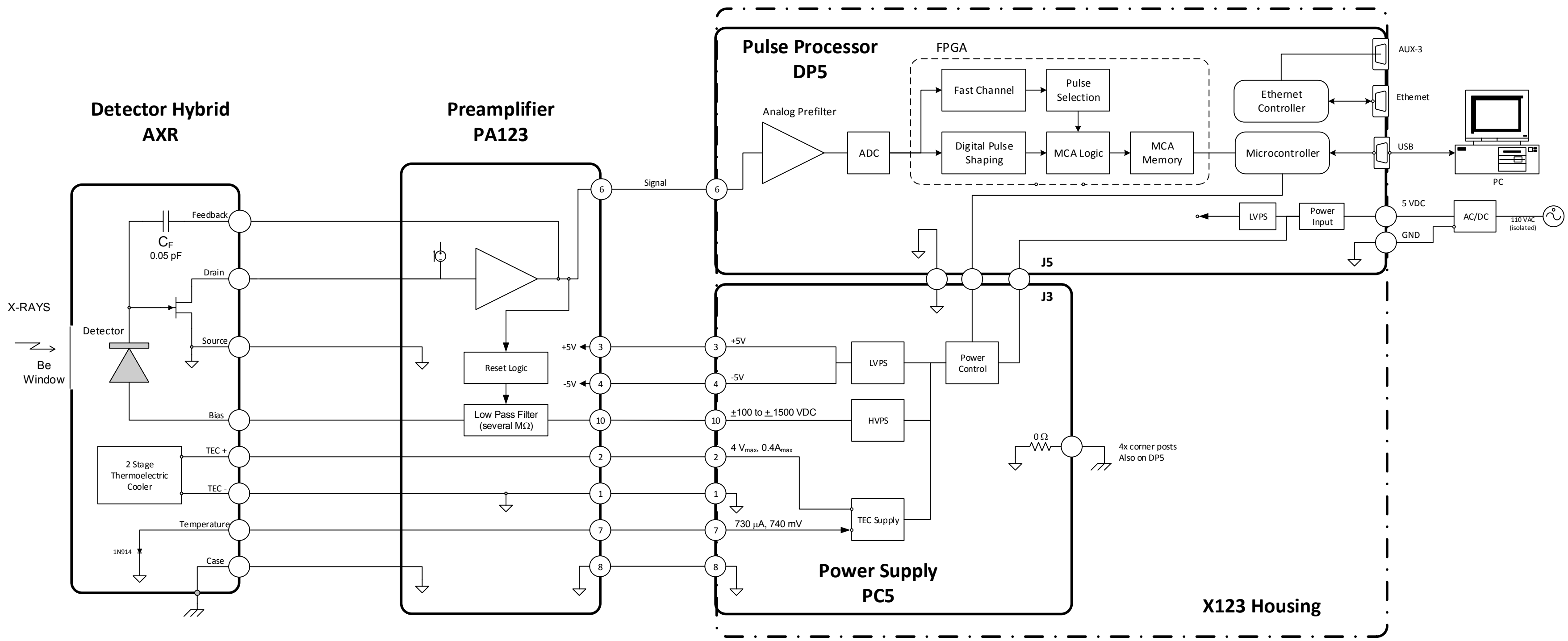
DP5 and PC5 – other issues

- We recommend shielding the DP5/PC5 stack.

5. X-123

Amptek's X-123 is a complete spectrometer. It is essentially a packaged version of the detector/preamplifier with DP5 and PC5. Because it is in a single metal box, it is often less susceptible to interference and grounding that Ammptek's other products.

The block diagram below summarizes the connections in this system, in a typical configuration while the photo shows a typical setup. Note that there are several different detector configurations available; this is a generic illustration. The block diagram is nearly identical to that already shown. The preamp has a different part number and the DP5/PC5 are in a metal housing but otherwise it is essentially unchanged.



Notes and recommendations for X123

Detector and preamp

- The signal ground is the source of the input JFET. This is connected to the ground plane of the XR100.
- The case of the TO-8 can be regarded as the sensor chassis ground. It is connected to the X123 housing (chassis ground). In most detectors, the TO-8 case is connected to a detector pin, which connects to the XR100 ground plane.

DP5/PC5 in its housing

- Internally, the DP5 ground plane is tied to a single metal stud and thus to the housing. The PC5 ground plane is also tied to a single metal stud and to the housing. The stud and screw nearest the extender provides this single ground connection.
- We recommend a single point ground. If one location is to be used, this mounting screw nearest the extender is best.

Connections

- The AC/DC power supply provided by Amptek is isolated: the power return is not connected to ground.
- The USB ground is tied to PX5 ground. This is frequently tied to ground in a computer, so can create a ground loop.
- If the AUX connectors are tied to oscilloscopes or other test equipment, and this is grounded, a ground loop is formed.

Other

- We have found that LCD screens, often used in laptops or oscilloscopes, to be a source of noise (the boost regulator needed to power the LCD may emit radiation).

6. Other Information

The pulse shaping network functions as a bandpass noise filter. It is optimized for filtering the broadband intrinsic noise at the preamplifier input, primarily white current noise from the detector's leakage current and white voltage noise from the preamplifier. This filter will also affect the response of the circuit to interference, whether conducted via the ground or through other mechanisms.

The plot below shows the transfer function of the digital processor's noise filter, for representative settings. There are two pulse shaping channels; the "slow" or "shaped" channel is used for pulse height spectroscopy while the "fast" channel is used for timing and pile-up rejection. The curves here are for a 2.4 μs peaking time in the slow channel, with a response peaking near 70 kHz, and for a 0.1 μs peaking time in the fast channel, with a response peaking near 1 MHz. The curves scale inversely with the peaking time. The circuit will respond to ripple or interference (ground loops, radiated, microphonic) as shown here.