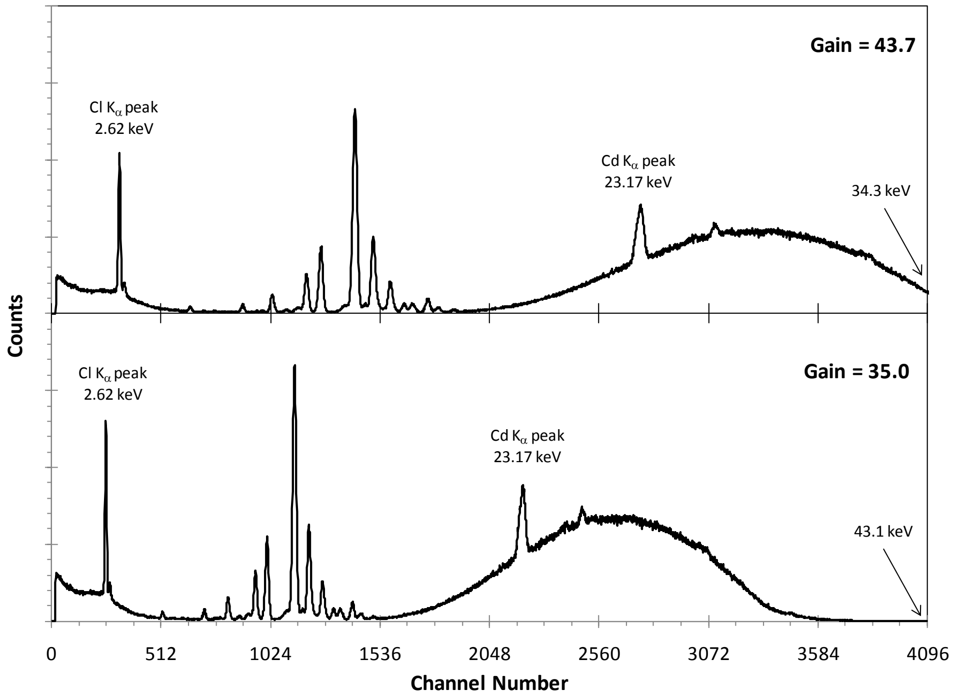
Understanding Gain in Amptek DPPs

How are the gain, full scale energy, and the energy calibration related?

The figure below shows an X-ray spectrum measured with the DPP set at two different gains. All other measurement conditions are identical. The diffe

- With the DPP set to a higher gain, 43.7 vs 35.0, the spectrum is visibly shifted to the right.
- The energy calibrations of the two are clearly different. In the lower (upper) spectrum, the Cd K_{α} peak is centered on channel 2201 (2740). The lower (upper) spectrum has a system conversion gain of 10.55 (13.17) eV/channel.

  Note that the centroid channel does not precisely scale with energy. There is, in general, a non-zero offset to the spectrum (channel zero is not exactly zero energy).
- The full scale energy, that corresponding to channel 4096 in these spectra are 34.3 and 43.1 keV. The higher DPP gain leads to lower full scale energy.
- The number of counts in each channel is lower on the top spectrum, by a factor of 0.8. Neglecting over-range events, the same number of counts is spread over more channels, so the number of counts per channel must be reduced.



How do I change the full scale energy?

Change the gain. The full scale energy is inversely related to the gain.

Why must I change the thresholds when I change the gain?

The purpose of the thresholds (fast and slow) is to separate signal pulses, due to radiation interactions, from noise fluctuations. Electronic noise makes the voltage fluctuate, and with an incorrect threshold, voltage fluctuations can be mistakenly recorded as valid counts or valid counts mistakenly rejected as noise.

If the slow threshold is too low, one measures a high count rate (even with no signal) and one observes many pulses at the lowest channels (far left of the spectrum). If the fast threshold is too high, one measures a high input count rate (even with no signal) and one frequently observes no spectrum if PUR is enabled (each signal pulse is followed by a noise pulse which the circuit interprets as pile-up).

The fast and slow thresholds are usually best set to just above the largest noise fluctuations. If the thresholds are set this way, and then the gain increases, then noise fluctuations will cross the thresholds and will be registered as signal pulses. To avoid this, always adjust the thresholds after changing gain. It is usually recommended after changing other parameters, e.g. peaking time, detector bias, etc.

How do I get a specific system conversion gain?

1. Record a spectrum using whatever gain setting has been commanded.
2. Perform an energy calibration, then find the energy of highest channel. In the lower plot above, this is 10.55.
3. Estimate the new gain desired for a particular full scale energy. In the lower plot above, if your goal is 10 eV/channel, then scale the gain down by a factor of 0.948 to 33.18.
4. Set the gain to the new value.
5. Record another spectrum, calibrate the new spectrum, and compute the new highest energy. Iterate as needed.

How do I get a specific full scale energy?

1. Record a spectrum using whatever gain setting has been commanded.
2. Perform an energy calibration, then find the system conversion gain (eV/channel). In the lower plot above, this is 43.1 keV.
3. Estimate the new gain desired for a particular full scale energy. In the lower plot above, if your goal is 40 keV, then scale the gain up by a factor of 1.08 to 37.71.
4. Set the gain to the new value.
5. Record another spectrum, calibrate the new spectrum, and compute the new highest energy. Iterate as needed.

Is the offset zero?

Not usually: channel zero typically does not correspond to zero energy. There is a baseline restoration (BLR) circuit in the DPP which keeps the baseline, the offset, from varying with time or count rate but it generally holds it to a non-zero value. To be specific, the BLR measures the negative noise fluctuations and keeps this rms value to zero.

This has some important implications. First, an energy of zero corresponds to a channel number comparable to the rms value of the electronic noise. Second, the offset of the energy calibration will change if the electronic noise changes. The rms noise (in channels) depends on gain, peaking time, HV bias, and many other parameters. Therefore, you should generally recalibrate if any of these parameters changes. Third, the thresholds (in channels) must be placed above both the noise and the offset. If you change anything which affects noise, thresholds should be retuned.

Can I make the offset zero?

Yes. The latest versions of the DPP include a "spectrum offset" command which essentially shifts the output spectrum by a commandable number of channels (it can be set to a fraction). If you do an energy calibration and discover that zero energy is at channel 33.4, then you can offset the spectrum by -33.4 channels. But if you change any parameter which changes the offset (e.g. gain, peaking time, HV bias) you must then correct the offset.

What gain should I use?

The energy range over which you want to measure should usually cover most of the channels in the MCA. If all of the pulses are near the bottom channels, there can be some loss of resolution. If many pulses are over-range, there can be some artifacts. Some processing software assumes a particular system conversion gain, e.g. 10 eV/channel.

What is the "System Conversion Gain"?

Gain is the ratio of the output of a system to its input. This seems simple but there are two distinct "gains" in the digital processor: the system conversion gain and the digital processor's voltage gain. Unfortunately, both of these may be referred to as simply "the gain," leading to confusion.

The *system conversion gain* is the eV/channel. It relates the system input, the energy deposited by a particle in units of energy, to the system output, the corresponding channel number in the output histogram. When you perform an energy calibration, you are measuring the system conversion gain. It is the slope in the linear regression for the energy calibration.

The system conversion gain is the product of several different terms, one of which is the digital processors' voltage gain. For a pulse depositing energy E_{dep} in a solid state detector, the output channel C is given by

$$C = \left(\frac{E_{dep}}{\varepsilon_{pair}}\right)\left(\frac{1}{q_e C_F}\right)\left(G_{Shape} G_{DPP}\right)\left(\frac{N_{chan}}{V_{\max}}\right)$$

where ε_{pair} is the energy required to produce an electron-hole pair, q_e is the charge on an electron, C_F is the feedback capacitance of the charge sensitive preamplifier, G_{shape} is a term related to the pulse shaping network and to the time profile of the detector current, G_{DPP} is the voltage gain of the digital processor, N_{chan} is the number of channels selected for the MCA (e.g. 1024, 2048), and V_{max} is the voltage corresponding to the highest MCA channel. The *digital processor gain* is only the G_{DPP} term. Some key points are:

- If you double G_{DPP}, then you double the system conversion gain and halve the full scale energy.
- The peaking time and flat top times may affect G_{shape}, depending on the detector.
- Changing the number of channels in the MCA will clearly affect the system conversion gain.

Digital processor voltage gain

G_{DPP} is the product of two terms. There is a coarse gain, which is set by analog amplifiers, and a fine gain, which is controlled digitally (to a precision of better than 1 part in 8192). The DPP permits a user to send either the coarse and fine gain separately or to send the total gain. With the latter option, the DPP computes the appropriate coarse and fine gain settings.

The coarse gain is set by resistors and op-amps. Even with precision resistors, the tolerance is about +/-0.2%, or 2 channels out of 1000. If you send a command to change total gain slightly, and the DPP changes coarse gain, the peaks may shift by 2 channels out of 1000. Different DPP units will exhibit comparable gain variations.

The DPP gain has a temperature coefficient of typically 0 to 60 ppm/^{o}C. In silicon, $\square_{pair}$ has a temperature coefficient of over 100 ppm/^{o}C while C_F can have a similar temperature coefficient. With an XR100 or X-123, if the temperature of the detector and feedback capacitor are held stable, detector bias is stable, etc. then the DPP gain variation is only ~30 ppm/^{o}C. If the detector temperature varies, large gain variations can be seen. Other systems may exhibit larger gain variations. In a Gamma-Rad5, the gain of the PMT is very important, and this is a strong function of temperature.