List Mode, Streaming Mode, and other advanced data acquisition modes

Amptek's digital pulse processors are usually operated in multichannel analyzer (***MCA***) mode: the output is a histogram of the pulse heights recorded during the acquisition interval. MCA mode produces pulse height spectra, the typical outputs of digital pulse processors. There are up to 8k pulse height channels and MCA mode can operate at output rates of several Mcps. In most applications, the count rate is constant and data must be acquired for seconds or more; the readout time for a spectrum packet is 5 millisec for 1k channels over USB (longer for more channels or other interfaces). MCA mode is sufficient for the vast majority of applications, where count rates are constant and acquisitions are seconds or longer, but there are a few cases where it is not adequate.

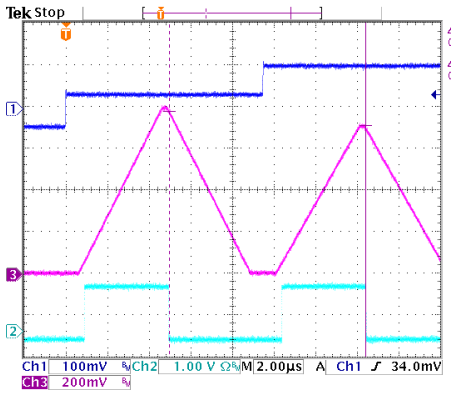
- In some applications, the user needs to know the time of each pulse, to better than tens of milliseconds.
- In some applications, the spectrum is not constant but changes on a time scale of milliseconds or less. For example, when doing on-line measurements of objects on a conveyor belt, the spectrum may only be acquired for a few milliseconds (and not synchronized with the DPP).
- In some applications, very short acquisition times are needed. In a mapping application, for example, one needs to measure a spectrum at each (x,y) coordinate. To obtain an image of 1k x 1k pixels in a reasonable time, acquisition times of milliseconds may be needed.

To meet these special cases, Amptek has implemented several features in its DPPs, including advanced acquisition modes.

- Some timing information is available in standard DPP features. A ***Gate*** input allows a user to synchronize acquisition start and stop with external hardware. A multichannel scaling or **MCS mode** produces an output histogram, like MCA mode, but the channels represent time instead of height; this yields a measure of pulses versus time. There are also single channel analyzers (or ***SCAs***) which allow external hardware to directly and immediately measure pulses in various pulse height channels.
- In ***List Mode***, instead of summing the data into a histogram, the DPP stores the pulse height and time of each event, creating a list of time and pulse heights. This list is then transferred to the computer. There is much more data to be transferred: each event now has 16 (or 32) bits of data. So List Mode is limited to <100 kcps (sustained). To use List Mode, a user typically needs to customize demonstration software provided by Amptek.
- In **Streaming Mode**, instead of producing a list in memory and transferring it to the computer, the DPP writes the amplitude to a custom parallel port on the DPP. The user can obtain both time and amplitude of each pulse with no limitation from the data transfers; it can operate at several Mcps. To use Streaming Mode, a user needs to develop the hardware to read the parallel port (usually implemented in an FPGA).

Frequently asked questions

How does pulse processing affect the data acquisition modes?



They are independent, effectively pipelined. The pulse processing logic in the FPGA, which implements the pulse shaping, baseline restoration, pileup rejection, and so on operates continuously on the digitized signal. It determines the pulse height for every pulse. The oscilloscope trace on the right illustrates its operation: the dark blue trace shows the output of the preamplifier, while the magenta trace shows the shaped pulse. The light blue trace shows the peak detect circuit looking for the peak amplitude; the dashed line shows when the DPP logic determined the peak. All of this logic operates continuously and independent of the readout mode.

The data acquisition modes determine what to do with that peak amplitude. In MCA mode, the peak amplitudes get stored in the histogram: a counter in memory is incremented. The Gate input determines if a particular peak is stored; in MCS mode, the time of the pulse is used for the histogram. In List Mode, the time and amplitude are written to the array; in Streaming Mode, the amplitude is written to the parallel port. So all of the normal signal processing occurs in all of the data acquisition modes. They have the same pulse height resolution; maximum count rates and sum peak intensity are determined by the signal processing parameters. The pulse shaping parameters and configuration options are discussed in the DPPMCA help file and in various application notes from Amptek.

What are the data transfer times?

These are discussed in section 3.4 of the "*Amptek Digital Products Programmer's Guide.*" In MCA mode, data are accumulated into an array in the FPGA. When a command is sent to read the array, there are two steps. First, the data in the "live" array is written to a "readout" array; data acquisition must be stopped for this transfer, then is restarted. With a spectrum of 2k channels and an 80 MHz ADC clock, this requires 650 µs. Second, the readout array is formatted and transferred to the computer. With a 2k spectrum over USB, this requires 7.5 milliseconds (slower over RS232 and Ethernet). Note that one can request a spectrum at any time but USB commands are not real time; latency depends on the amount of USB traffic. If you request a spectrum at some time, it's difficult to know how long it will take the OS to process the request and send it to the DPP. Similarly, commands to start and stop data acquisition are not real time.

Do all Amptek DPPs support these modes?

Not necessarily. All Amptek DPPs support MCS mode and auxiliary I/O functions, including the Gate, ICR, and at least one SCA output. But the firmware to implement List Mode requires considerable FPGA resources; some firmware revisions, with special signal processing features, do not include List Mode. Some DPPs do not contain the hardware needed for Streaming Mode. The list below summarizes what is available.

PX5 Both list and streaming mode are available in FW 6.06.06/FP 6.00 and later

DP5 Both modes were introduced in FW 6.06.06/FP 6.00. List mode was removed in FW 6.09.09/FP 7.03 to make room for some advanced signal processing features.

DP5G Same as DP5

DP5X List mode is available in all versions. Streaming mode is not available.

DPXSM List mode is available in versions. Streaming mode is available.

Section 6.1.2 of the Programmer's Guide has more information on the different firmware versions which support these modes and some changes that were made to these modes in different releases.

MCA Mode

As noted above, MCA mode produces a histogram or array showing the number of valid X-ray pulses within each pulse height channel or window. The table to the right shows typical data: there were 59 pulses with a peak amplitude corresponding to channel 545. This particular snip is taken from a spectrum of 2048 channels which had been acquired for an accumulation time of ten seconds.

Channel	Counts
540	50
541	47
542	43
543	51
544	49
545	59
546	55
547	57
548	70
549	80
550	80
551	91
552	64
553	81
554	91
555	92
556	59
557	104
558	106
559	102
560	103
561	90
562	87
563	108

The pulse height corresponds to energy. For information on how to calibrate the relation, please refer to DPPMCA Help. For information on the meaning of acquisition time, real time, dead time, etc in Amptek's DPPs, please refer to the application note "Understanding acquisition time and live time in Amptek's DPPs."

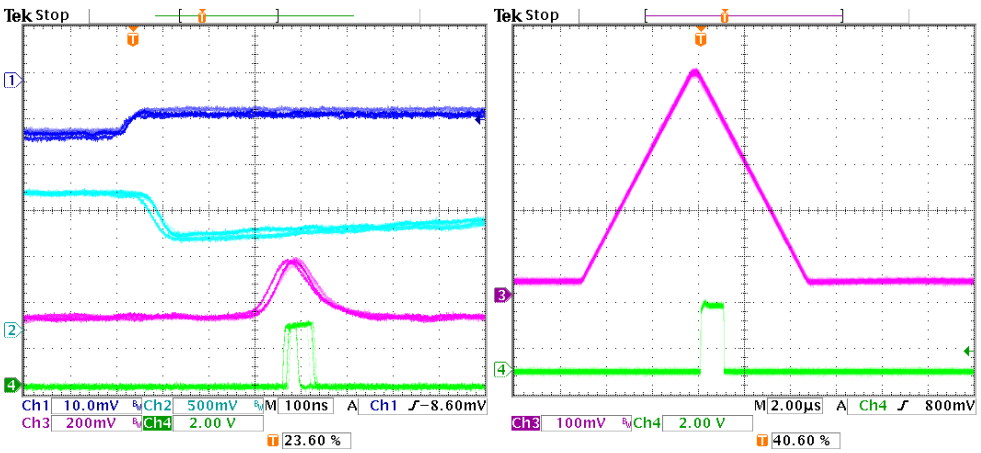
AUX I/O: Gate, ICR, SCAs

There are auxiliary inputs and outputs built into all of Amptek's DPPs. The details of which connectors are used for what and how to command them vary from one DPP to the next but are all described in the standard user manuals. A few are relevant for this discussion.

Gate: The Gate is used to synchronize data acquisition with external hardware, i.e. starting data acquisition when a beam is turned on. This is needed since the USB command to start acquisition has non-deterministic timing. Essentially, one begins with the Gate disabled, sends the USB command to start acquisition, and then enables the Gate. One then disables the Gate, sends the command to stop acquisition, and then reads the spectrum. Operation of the Gate is described in an application note, "Understanding the Gate in Amptek DPPs." The Gate can be used on a pulse by pulse basis; at the time the FPGA logic detects a peak, the logic checks the status of the Gate input and rejects the pulse if Gate is disabled.

ICR: ICR (Input Count Rate) is an auxiliary logic output produced by a comparator operating on the fast channel. Any pulse which exceeds the fast threshold will generate an ICR logic pulse, which is typically a few clocks wide. This is used in the FPGA to measure the input count rate and in the pile-up reject logic. It can also be connected to external logic, to directly measure the instantaneous input count rate or to synchronize with external hardware. The timing of the pulse is shown below; note that there is a pipeline delay between the actual X-ray interaction and the time of the fast logic pulse.

SCA: The SCA (single channel analyzer) is an auxiliary logic output produced by a window discriminator operating on the slow channel; there are eight independent SCAs in Amptek's DPPs If a pulse has a peak amplitude within the SCA range (which is set in software), there will be an SCA logic signal generated. This can be used, for example, to measure the instantaneous rate of pulses in some photopeak. Its rising edge is at the time the peak is detected. Its width is commandable to 0.1 or 1 µs.



Left: Oscilloscope trace of the ICR output (in green). The magenta trace shows the fast channel output which triggers this. Note the pipeline delay from the preamp edge, in dark blue. Right: Oscilloscope trace of the SCA output (in green). The magenta trace shows the slow channel shaped pulse; if the peak amplitude is within the window of the corresponding SCA, there will be an SCA logic pulse.

MCS Mode

MCS (multichannel scaler) mode is used to measure counts versus time instead of pulse height. The output array looks just like an MCA array, but the channels correspond to time bins. The time for each bin can be set from 10 milliseconds to 655.35 seconds, in increments of 10 milliseconds. For finer time intervals, List Mode or Streaming Mode should be used. The counts are recorded through the standard pulse shaping logic; the DPP applies the SCA8 window discriminator to the slow channel pulses, so only counts pulses falling in the commanded amplitude range for SCA8.

List Mode

In List Mode, for each radiation interaction, the processor records both the pulse height and the time of interaction. The processor generates a list of such data and then transfers this list, over the standard interfaces, to the computer. This can be useful in various applications:

- One can synchronize the events with external hardware.
- One can implement a double buffer scheme, e.g. to separate fast and delayed neutrons in a pulsed beam application.
- One can synchronize with an imaging system where the position of the detector is known as a function of time. Samples are often scanned in an SEM or µXRF, yielding a spectrum at each pixel.
- One can synchronize data for samples moving on a conveyor belt, where each sample is measured for a short period of time, with asynchronous starts and stops.

In List Mode, each event which passes all acceptance criteria (PUR, RTD, Gate, thresholds, etc) will be recorded. The pulse heights are recorded to 14 bits resolution (16k channels). The time of each event is recorded to a precision of either 0.1 or 1 us (software selectable). The time base can be synchronized using an external timing pulse (e.g. a 1 pulse per second pulse), which resets the List Mode timer. For each event, a "buffer select" logic bit is also stored, indicating the state of an external signal.

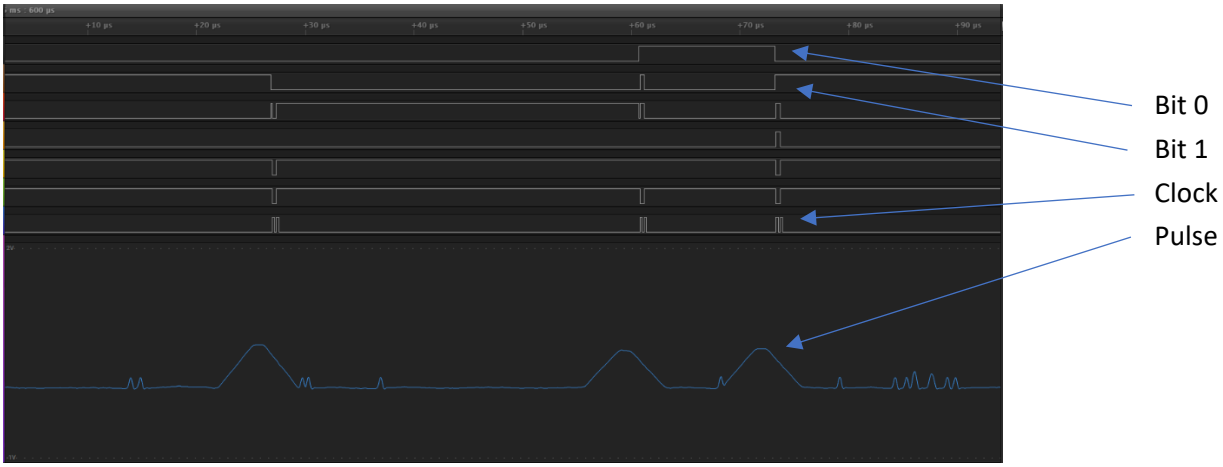
The maximum count rate that List Mode can support is limited by the interface. Theoretically, USB can sustain 150 kcps but this depends on software implementation. The demonstration software supplied by Amptek sustains 100 kcps over USB. Ethernet (RS232) is limited to 12 kcps (2 kcps).

The digital processors provide a second version of List Mode, the 16-bit List Mode. In this mode, instead of associating a time tag with each event, a time tag is inserted in the data list at either a 1 kHz or 10 kHz rate. This mode allows a maximum count rate of about 240 kcps over USB. This mode is appropriate when the user does not need the time of each interaction but in the events recorded with a 0.1 to 1 ms window, e.g. in a scanning system with a suitable dwell time.

Amptek provides a demonstration program which reads the data in both List Modes; its use is described in a separate application note. List Mode applications are inherently custom, so the user should expect to tailor the software in this demonstration program to achieve the needed outputs. List Mode is described in more detail in section 6.1 of the "*Amptek Digital Products Programmer's Guide.*"

Streaming Mode

Streaming mode is essentially a hardware equivalent to List Mode. Every time a valid event is recorded, the complete pulse height is sent to a parallel output port (the SCA output lines are reconfigured into this parallel bus). User supplied external hardware can read the pulse height and then combine this with timing and synchronization information. The advantage of Streaming Mode is that it's not limited to the USB bandwidth; it can support the highest count rates the shaping electronics will support, well over 1 Mcps. The disadvantage is that the user must develop hardware rather than software. This is typically implemented in an FPGA.



The image above, taken from a mixed signal oscilloscope, illustrates Streaming Mode operation. The bottom trace shows three shaped pulses; the upper traces show the logic outputs. The data are transmitted over two clock periods, with a 1 bit strobe to indicate a valid pulse was measured, 7 bits of pulse height, and a 1 bit LSB/MSB indicator. The values are written in the clock cycles immediately after the digital processor has detected a valid event so are delayed relative to the radiation interaction. This delay includes the peaking time, the flat top, and certain pipeline delays. The delay depends on the configuration settings of the digital processor so should be measured by the user. Streaming Mode is described in more detail in section 6.2 of the "*Amptek Digital Products Programmer's Guide.*"