UNDERSTANDING ACQUISITION TIME, LIVE TIME, AND ALL THAT

What is the difference between "real time", "accumulation time", and "live time" in Amptek's DPPs? How do you measure "dead time"? How do you measure "live time"? These questions are very frequently asked. Many users are accustomed to methods traditionally used in analog MCAs to measure these quantities. There are fundamental differences to the way these are measured in Amptek's digital processors.

Key Points

- In a traditional analog MCA, the ratio of the livetime to the realtime indicates the fraction of counts which were not measured because pulses overlapped (dead time per pulse). The livetime is used to determine input count rate.
- In Amptek's DPPs, the ratio of livetime to accumulation time (not real time) indicates the fraction of counts not measured due to pulses overlapping.
- The best way to determine the input count rate in Amptek's DPPs is to use the measured input count rate rather than the estimated livetime or dead time.
- The input counts, slow counts, and accumulation time are displayed in the Info Pane of the DPPMCA software. They are also stored in the footer at the bottom of the .MCA files.

Why don't you measure the livetime just like the analog MCA I have used for years?

- First, Amptek's DPPs pauses data acquisition at various times; the real elapsed time does not equal the time when counts can be acquired. To find accurate count rates, the count totals must be divided by the measurement interval – and this does not equal real time.
- Second, Amptek's algorithms can accurately measure the pulse height for pulse much more closely spaced than in analog system. The throughput with an Amptek DPP is much higher than for an analog system at the same input count rate and shaping time. But the traditional analog livetime measurement method (stopping the clock when the signal is above threshold) does not work properly.
- Third, analog MCAs estimate input count rate from only the slow, shaped pulses. Amptek's DPPs have a high performance fast channel so they can directly measure the input count rate. The livetime is really only useful as a method to estimate the input count rate. Analog systems measured the livetime and estimate the input count rate. Amptek's DPPs measure the input count rate, not the livetime.

For more information on why we uses these algorithms, please refer to a paper we published in 2009: Redus, R.H., A.C. Huber, D.J. Sperry, *Dead time correction in the DP5 digital pulse processor*, IEEE Nucl. Sci. Symp. Conf. Rec., Oct 2008, pp 3416 - 3420 (2009).

Definitions for Amptek's Processors:

Real Time

- In Amptek's digital processors, the **real time** is the actual time which has elapsed between starting and stopping a measurement. It equals the time interval measured on your watch.
- The digital processor stops acquiring data for brief intervals during a measurement (discussed below). No counts are measuring when acquisition is paused, so dividing counts by the real time does not give the correct count rate.
- The measured real time is unaffected by counts or no counts, pile-up losses, or data acquisition being paused by readout, gate inputs, or preamplifier resets.

When is acquisition paused? When the spectrum is transferred from the FPGA memory into the microcontroller, it is paused for anywhere from 113 microseconds to 2.5 milliseconds depending on how many MCA channels are used. It is paused when the spectrum is sent to the computer via the USB, RS232, or Ethernet interface (2 to 20 milliseconds depending on MCA channels). It is paused following each preamplifier reset (the duration of the pause is set by the reset lockout parameter) and if the GATE input is used and is off.

What is the "dead time fraction" in data acquisition due to these pauses? This is not a constant but depends on many parameters. For a preamp with resistive feedback and no gate, it can be as low as 113 microseconds. With a reset preamp, the rate of resets (and hence dead time) depends on input count rate and input spectrum.

Acquisition (a.k.a. Accumulation) Time

- In Amptek's digital processors, the **acquisition time** (a.k.a. **accumulation time**) is the actual elapsed time during which counts are measured.
- To measure the acquisition time, the clock is paused during the intervals when data acquisition is stopped. The acquisition time is meaningful for computing count rates.
- **Dividing the counts by the acquisition time yields the correct output count rate (R_{out}).**
- The acquisition time does not correct for overlapping pulses, i.e. the dead time per pulse. It is not the "live time".

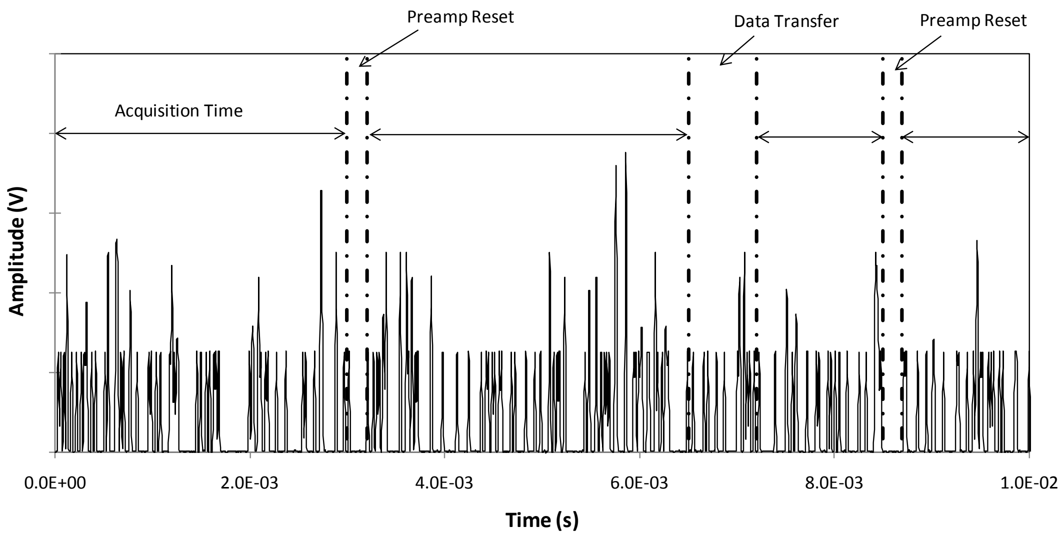

Figure illustrating acquisition time and real time. In this interval, the real time is 10 milliseconds. No counts are measured during the two preamp resets or during the data transfer interval, so the acquisition clock is gated off during these times. The acquisition time in this example is 9.89 milliseconds.

Total Counts and Total Count Rate

- **Total count** is the total number of pulses accepted in the spectrum using the slow channel. It is the number of output counts.
- To register in total counts (and the spectrum), a pulse must (1) have peak height exceeding both the slow threshold and LLD, (2) have peak height not exceeding the highest channel, (3) be separated in time from other pulses by more than the dead time per pulse, and (4) not have been rejected by PUR, RTD, or GATE logic.
- The **total count rate** is the output count rate, R_{out}, equal to total counts divided by acquisition time.

Input Counts and Rate

- **Input count** is the total number of counts measured using the fast channel. To show up in fast counts, the pulse height must not exceed the fast threshold (there is no upper limit) and pulses must be resolved in time.
- The reported **input rate** an estimate of R_{in}, It equals the measured fast channel count rate, input counts divided by acquisition time. For T_{fast}=100 ns, the error is <1% for R_{in} <100 kcps.
- A corrected input rate can be computed from the measured R_{fast} and the pulse pair resolving time, T_{fast}, using the formula below. This is accurate to 0.5% for R_{in} < 500 kcps. This calculation is not carried out in DPPMCA.

$$R_{est} = \frac{R_{fast}}{1 - R_{fast} T_{Fast}}$$

Dead Time

- The **dead time** shown in the DPPMCA information pane is computed from R_{in} and R_{out}. It is not measured using a live time clock but is computed from the number of counts lost from the slow channel:

$$DT = \frac{R_{fast} - R_{slow}}{R_{fast}}$$

- Note that this calculation includes count losses from all sources, not just pulse overlap. Counts may be rejected because they are over-range in the slow channel or rejected by RTD. Their loss is quantified in the reported dead time.

Livetime

- The **livetime** reported in Amptek's MCA files is computed. It represents an estimate of the total time that the DPP could have been acquiring counts.
- It is computed from the real time, and from the ratio of total counts to input counts as

$$T_{live} = T_{accum} \left(\frac{N_{tot}}{N_{fast}} \right)$$

- Note that the ratio of the livetime to realtime reported in the MCA file is not an indicator of pulses lost to pile-up and overlapping pulses:

$$\frac{T_{live}}{T_{real}} = \left(\frac{T_{accum}}{T_{real}}\right)\left(\frac{N_{tot}}{N_{fast}}\right)$$

Example

The table below illustrates how the quantities are related for some hypothetical examples.

Measured	Input Cts	N_{fast}	100,000	150,000
	Total Cts	N_{slow}	80,000	85,000
	Accum Time	T_{accum}	17.23	16.70
	Real Time	T_{real}	20.00	20.00
Computed	Output Rate	N_{slow}/T_{accum}	4,643	5,090
	Input Rate	N_{fast}/T_{accum}	5,804	8,982
	Dead Time Fraction	$1 - (N_{slow}/N_{fast})$	20.0%	43.3%
	Livetime	$T_{accum}\ (N_{slow}/N_{fast})$	13.78	9.46

Background Information: Live Time Clocks

- In nuclear electronics, there exists a minimum amount of time that must separate two interactions for them to be recorded as two separate events. This minimum separation time is the **dead time per pulse.** Because X-rays and radioactive decays happen randomly, interaction times are random, so even at low count rates there is some probability that events will not be counted. It can be important to know the true rate of radiation interaction, R_{in}, which will always be less than R_{out}. There are many different ways to estimate R_{in}.[1]
- In conventional analog signal processors, the dead time per pulse is very well defined. It usually includes the total duration of the shaped pulse and is dominated by ADC digitization time. Analog processors generally use have only a slow (shaped) pulse to estimate R_{in}. The best solution for an analog system is a live time clock. This is gated off for the duration of the pulse dead time (and may actually run backward during pile-up inspection intervals). The **total live time** is the elapsed time during which additional counts could be measured. In the analog processors, dividing the counts by the total live time yields the most accurate estimate of R_{in}.
- A digital processor has a much shorter dead time per pulse, i.e. much higher throughput under identical conditions. This is because Amptek's DPP has no time require to digitize the peak amplitude and the dead time per pulse is less than half that of the analog pulse. However, the dead time per pulse is not as well defined, making a live time clock less accurate. Fortunately, Amptek's digital processors include a high performance fast shaping channel with low dead time losses. Amptek's processors do not currently measure a "live time" analogous to that of analog shapers but instead measure the rate in the fast channel, R_{fast}, which is used to estimate R_{in}.

[1] A general discussion of dead time losses can be found in several references. One is *Radiation Detection and Measurement*, 4th Ed, by G.F. Knoll, published by John Wiley and Sons, 2010, pp 121-128 and 655-664. A second is *Quantitative X-ray Spectrometry*, 2nd Ed, by Jenkins, Gould, and Gedcke, published by Marcel Dekker, 1995, on pages 190-199