Notes on the data processing algorithms for Lyrtech cards.

ADC data into Custom code are 14 bits. D15 is connected to overflow and D14 copies D3 (sign). All 16 bits go into the trace and raw data. However, only 14 bits (d13:0) are used for MWD, and CFD code.

Signed to Unsigned code at start of MWD interprets the 14 ADC data bits D13:0 like this:

NB Positive and negative refer to data at the ADC which is same polarity as the front panel input in Lyrtech VHS-ADC (GRT4 inverts data between input and ADC).

	ADC data from ADC	If "positive" at ADC (pol = 0)	If "negative" at ADC (pol = 1)
+ve FS	01 1111 1111 1111	0x3FFF	0x0000
0	00 0000 0000 0000	0x2000	0x1FFF
0	11 1111 1111 1111	0x1FFF	0x2000
-ve FS	10 0000 0000 0000	0x0000	0x3FFF

So now there is no sign bit, but the data increase in the direction of the signal's increase.

Bipolar signals are handled correctly because 0v is coded as 0x2000 in both cases.

Processing of the data uses the Georgiev/Gast MWD code based on a VHDL implementation by Martin Lauer[1] (in collaboration with Ian Lazarus) for the GRT4 VME cards.

Two copies of the so-called MWD code operate on the result of the signed2unsigned process. One has minimal shaping times to act like a TFA and its output is fed into a CFD algorithm with fixed fraction (0.5) and fixed 50ns delay. The threshold is programmable. The second copy of the MWD code has programmable parameters and is used for energy calculation as follows:

Processing of data:

- Signed2unsigned produces 14 bits unsigned values 0 to 0x3FFF.
  (Input is ADC(13:0); Output is unsignedout(13:0) which feeds MWDin of mwdinstanz module which starts with decimation.)

- Decimation: increases 14 to 18 bits, no possible sign change: unsigned values 0 to 0xFFFC.
  (Input port called MWDin(13:0) receives MWDin(13:0) signal. Output port is DEC2MAUsig(17:0). Decimation factor is 4 (was 16 at times in the past, hence 18 bits out when only 16 are needed or used.).

- Moving window deconvolution (calculation is x[n]-x[n-M]+area*coeff).
  Use MAU to output delayed and mirrored copies of the DEC2MAU(15:0) signal. Subtract delayed value from current value and save both the difference and the carry bit. Within the MAU, accumulate the differences to make a 24 bit value, MAU2NORMsig(23:0) signal which represents the are under the pulse over integration length M, the MWD window. While the differences may be negative due to noise or on the tail of the pulse, the accumulated value (area) should always be positive because the input is always positive as a

[1] Martin Lauer's PhD Thesis, 2004 *"Digital Signal Processing for segmented HPGe Detectors: Preprocessing Algorithms and Pulse Shape Analysis" Available from:* http://cdsweb.cern.ch/record/811708?ln=en

result of the signed2unsigned unit. Maximum for MAU2NORM is 256 x 0xFFFC = 0xFFFC00. Subout can be + or – 65535 (0xFFFF).
MAU input port receives DEC2MAU(15:0) and shape_time controls difference and size of accumulated result. Output is called MAU2NORMSIG(23:0). The external subtraction unit takes 16 bits signals mau_inst and mau_del from MAU. After subtraction the difference is output as subout(15:0) with the carry (sign) bit in subout(16). To match the 24 bits of the multiplication, the subout signal becomes newsubout(23:0) where lowest 7 bits are 0.

- Multiplication to correct for decay time constant. The accumulator output is scaled by a multiplication factor derived from the decay time constant, the shaping time and the clock: decaytime = coeff / length = (1-exp(-M/tau)) / (M/dT). See table following which lists permissible combinations of Tau and M. Any value of Tau >20us is OK and cannot cause algorithm overflow. The ALU output is 24.24 bits but in fact can only be 16.24 because of the normalisation (coefficient depends how many samples we are correcting for, so must divide by M/dt) so we ignore the 8 MSBs (always 0) and include 8 of the 24 fractional bits making a 16.8 number (actually signed 15.8 with sign forced to 0) made up from bits 39 down to 17 of the multiplier output (23 bits) with the 24th bit being forced to 0 because we need a signed value to add to the signed difference in the last part of the MWD: x[n]-x[n-M]+area*coeff
Inputs are MAU2NORMSIG(23:0) and decaytime(23:0) resulting in ALUout(47:0) which becomes NewALU(23:0) with NewALU(23) = 0 and NewALU(22:0) = ALUout(39:17).

- Final part of deconvolution- signed addition of signed difference and unsigned corrected area resulting in a square pulse with a flat top (if the shaping time correction is done right).
Inputs are newsubout(23:0) and NewALU(23:0) with outputs MWDSIG(24:0) where MWDSIG(24) is the carry out (overflow) bit used to verify that the algorithm doesn't overflow/underflow and MWDSIG(23:0) is the signed value.

- Trapezoidal filter- Need to apply a low pass filter of length L to MWD result to reduce the noise. This is a simple "accumulate over a time window" moving average function and results in trapezoidal output (or triangular in the case that M= L). The subtraction element is signed because badly adjusted MWD can undershoot. Also need to allow 8 extra bits for the accumulation based on a 24 bit input signal. The ouput trapezoid should, however, be positive in the range 0 to 0x3FFFFFFF (max value of MWDsig is 0x7FFFFF because its 23 bits+sign, so max for trapezsig is 23+8 = 31 bits+sign (nominally signed but normally +)).
Input is MWDSIG(23:0) with output trapezsig(31:0).

- Optional baseline subtraction. The baseline is calculated by averaging the trapezsig signal between triggers and freezing the value for 2 shaping times following each trigger. By default the baseline is subtracted from the trapezoid value to give the pulse height but this can be turned off in the firmware. Baseline uses IIR exponential filter (there is also a MAU version which needs 8 bit values; iir needs only 4 so ignores top 4 bits). Values n= 0-15 represent 2**n in the iir filter, so 0 is no filtering, 4 is average of 16 values (typical value) and maximum 15 is 2**15 averages over 32768 updates. The update parameter defines how many decimated clocks (40ns) elapse between updates, so a typical value of 50 = 2us. A filter with average = 4 (16) and update = 50 (2us) averages over a period of 32us and the worst case (ave = 255x40ns = 10.2us x average =15 (32768)) averages over 0.33sec. This is the active time between pulses (the baseline is disabled for 2x shaping time, so at 10k cps and 8us shaping the baseline is disabled for a further 10k x 16us = 160ms.

- **A note on moving average unit (MAU)** which is used in several places in the energy calculation code- it is used for decimation, MWD window and the low pass (trapezoidal) filter. The MAU depends on correct initialisation- it must be initialised to 0 and then as the signal starts the accumulator adds the difference between the last (m'th) value and the new one (X(n)- X(n+m)) which initially is just X(n) while the window contains its initial value of zero so it sums all the incoming values until the window is full of M data values at which point the total is adjusted by the difference (X(n)- X(n+m)) between existing (non-zero) and incoming data to maintain the moving average. The limiting values are 0 and (M/dt) x maximum input, so the output data width must always be (log(M/dt)/log(2)) wider than the input data width.

A note on decaytime parameter. There is only 1 place in the algorithm where the user can insert a value which makes the calculation overflow (+/-) and that is the decaytime correction factor which has a 24 bit value (coeff x 2**24 where 0 < coeff <1). In fact values > 0x010000 could cause overflow of the data paths for maximum ADC value and maximum value of M (according to simulations). Therefore a table has been compiled to show the unsafe values of Tau and M. No sensible value causes overflow. Any value of Tau >=20us is totally safe for all values of M. The alg_overflow flag indicates whether the MWD signal has indeed been caused to overflow by an unreasonable Tau setting.

Table of permissible values of M and Tau

All values larger than 1/256 (i.e. table values above smaller than 256) are over-range
(based on simulation of extremes e.g. max ADC, max M, L)
The max permissible value of decaytime when M/dt=253 (M= 10us) and ADC = 2000 (-8191) is 010000.
In this case New ALU = 0x7F7E02 and Trapezoid = 0x3F7F41FF

		Tau (us)								
M(us)	M/dt		1	2	5	10	20	50	100	1000
0.25	6	OVR	OVR	OVR	OVR	Good	Good	Good	Good	
0.5	13	OVR	OVR	OVR	Good	Good	Good	Good	Good	
1	25	OVR	OVR	OVR	Good	Good	Good	Good	Good	
2	50	OVR	OVR	OVR	Good	Good	Good	Good	Good	
3	75	OVR	OVR	OVR	Good	Good	Good	Good	Good	
4	100	OVR	OVR	OVR	Good	Good	Good	Good	Good	
5	125	OVR	OVR	OVR	Good	Good	Good	Good	Good	
6	150	OVR	OVR	OVR	Good	Good	Good	Good	Good	
7	175	OVR	OVR	OVR	Good	Good	Good	Good	Good	
8	200	OVR	OVR	OVR	Good	Good	Good	Good	Good	
9	225	OVR	OVR	Good	Good	Good	Good	Good	Good	
10	250	OVR	OVR	Good	Good	Good	Good	Good	Good	