TB-5 User Manual

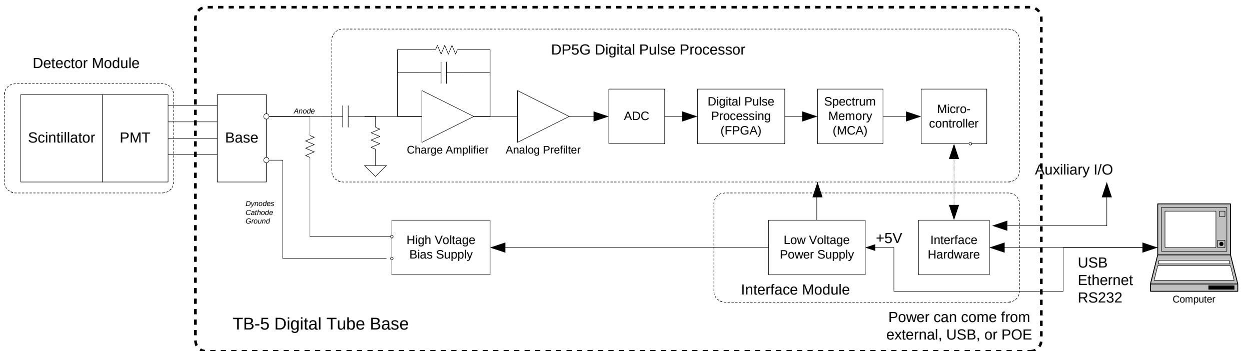
AMPTEK, Inc. 14 DeAngelo Drive, Bedford, MA 01730-2204 USA

+1 781 275-2242 Fax: +1 781 275-3470 www.amptek.com sales@amptek.com

1 Introduction

1.1 TB-5 Description

Amptek's TB-5 is a digital tube base. It contains a digital pulse processor, low voltage power supplies, a high voltage power supply, and a standard 14-pin PMT tube base. It connects to a user-supplied PMT/scintillator module. It reads out the spectrum (via USB, Ethernet, or RS232 interfaces) and includes a List Mode and several auxiliary interfaces, including single channel analyzers. A block diagram of the TB-5 is shown below.

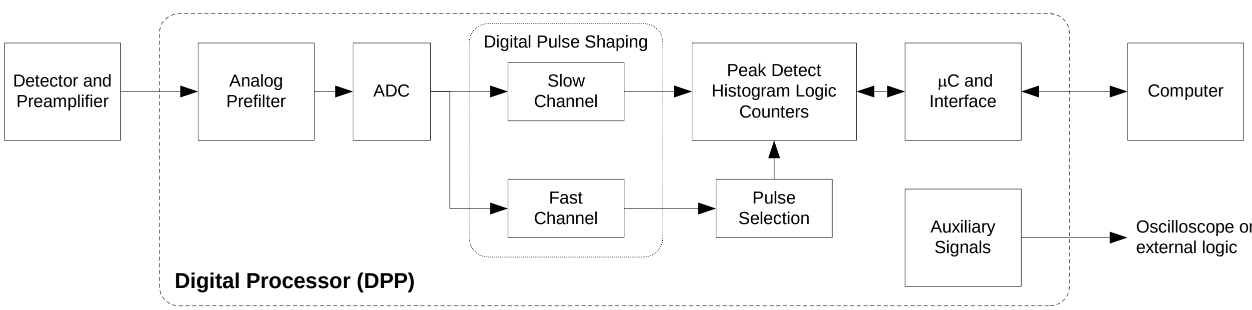


The TB-5 includes the DP5G digital pulse processor, with a new release of the firmware. For information on the DP5G board, please refer to the "DP5G User Manual", located on the CD. The new firmware includes two additional control parameters, described in this document.

The TB-5 includes a high voltage power supply to bias the PMT and an interface board which includes low voltage power supplies and communications connectors. Like the Gamma-Rad5, it can communicate over USB, Ethernet, or RS232. The possible power sources include an external +5VDC supply, USB, and PoE. Amptek's DPPMCA software is used to control and communicate with the TB-5. It is important to use the most recent release, ver 1.0.0.16 or later, to access all parameters.

1.2 DP5 Family

Amptek has a family of products built around its core DP5 digital pulse processing technology, designed for pulse height spectroscopy. It was originally designed for the detection of ionizing radiation, principally X-ray and gamma-ray spectroscopy. A generic system, illustrated below, includes (a) a sensor, a.k.a. detector, (b) a charge sensitive preamplifier, (c) analog prefilter circuitry, (d) an ADC, (e) an FPGA which implements pulse shaping and multichannel analysis, (f) a communications interface, (g) power supplies, (h) data acquisition and control software, and (i) analysis software.



The core DP5 technology shared by all the systems includes the ADC, the FPGA, the communication interface, and the data acquisition and control software. All products in the DP5 product family include nearly the same digital signal processing algorithms, the same communication interfaces (both the primary serial interfaces and the auxiliary I/O), and use the same data acquisition and control software. The DPPMCA software package is a complete, compiled data acquisition and control software package used across the family; Amptek also offers an SDK for custom software solutions.

The products in the DP5 family differ in the sensor for which they are designed, which leads to changes in the analog prefilter, power supplies, and form factor. They also differ in their completeness: some of Amptek's products are "complete", with elements (a) through (i), while others offer only a portion of the functionality for the user to integrate into a complete system.

1.3 Options and Variations

High speed and low speed

The TB-5 is available using either a 20 MHz or 80 MHz ADC. The 20 MHz ADC is sufficient for NaI(Tl), where the count rate and timing are limited by the decay time constant of the scintillator, and it draws less power than the 80 MHz option. The 80 MHz ADC can be operated at 20 MHz but still draws more power. It is recommended for use with faster scintillators.

Analysis Software

The TB-5 is supplied with Amptek's standard DPPMCA data acquisition and control software. In addition, the SODIGAM analysis software may be purchased to do quantitative analysis of the gamma-ray spectra. SODIGAM processes the spectra to determine both the radioisotopes and their activity in a sample.

PMT Pinout

The standard TB-5 has been designed for a particular PMT pinout (described in section 3.2), i.e. dynode bias voltages. Custom PMT pinouts can be accommodated through design of a custom HVPS divider board. Contact Amptek for pricing of such custom systems.

2 Specifications

2.1 Spectroscopic Performance

The spectroscopic performance is determined by the scintillator material and the PMT. The performance obtained with a NaI(Tl) scintillator and the TB-5 is equivalent to that shown in the Gamma-Rad5 manual. For a 76x76 mm NaI(Tl), Amptek typically measures <7% FWHM at the 662 keV line of ^{137}Cs.

2.2 Processing, physical, and power

Several of the Gamma-Rad5 specifications differ from those in the "User Manual for the DP5 Product Family". Specifications not listed here are unchanged from the standard in the family.

Pulse Processing Performance	
Gain Settings	Four software selectable coarse gain settings are available: 3 MeV full scale to 750 keV full scale. Fine gain is adjustable between 0.75 and 1.25. System gain can also be changed by changing the HV on the PMT.
Pulse Shape	Trapezoidal, software selectable from 0.8 to 102.4 μs. The flat top has 63 software selectable values for each peaking time. For NaI(Tl), T_{peak} is usually set to 2.4 μs and T_{flat} to 1.0 μs, with a pulse shape similar to an analog 1 μs shaping time.

	The fast channel, used for pile-up rejection and pulse shape discrimination, has a pulse pair resolving time of 0.25 or 0.5 µs.
Pile up interval	This is approximately equal to the sum of T_{peak}, and T_{flat}, and the scintillator time constant.
Gain Stabilization	The gain from the NaI(Tl) and PMT is well known to vary with temperature. A software gain stabilization algorithm is available.
Maximum Count Rate, Dead Time, and Throughput	With the typical configuration, T_{peak}=2.4 µs, the maximum input count rate is 1.5 x 10^5 cps with a throughput of >50% and good baseline stability and pile-up rejection. At T_{peak}=0.8 µs, the maximum input count rate is 2 x 10^5 cps.
Custom Configuration	The DP5G is set at the factory for either a 20 MHz or 80 MHz clock. For NaI(Tl), the 20 MHz is standard, yielding the specifications listed above. The 80 MHz setting allows for peaking times down to 0.1 µs in the slow channel and 0.05 µs in the fast channel but draws more power. The 80 MHz setting is recommended for custom scintillation materials with faster decay times, fast pulse shape discrimination, or other unique requirements. Contact Amptek for more information.

Physical	
Dimensions	2.44 in (dia) x 4.0 in; 62 mm (dia) x 102 mm
Weight	8.4 oz; 240 g

Power	
Nominal Input	@ +5 VDC: 165 mA (0.85 W) typical , 20 MHz ADC, USB interface 190 mA (1.0 W) typical , 20 MHz ADC, Ethernet 80 MHz ADC adds 30 mA (typical)
Maximum Input	300 mA @ +5 VDC
Input Range	+3 V to +6.4 V
Power Source	USB bus for USB interface External DC PoE for Ethernet interface

3 Mechanical Interface

3.1 Dimensions

4" (102 mm) x 2.44" (62 mm)

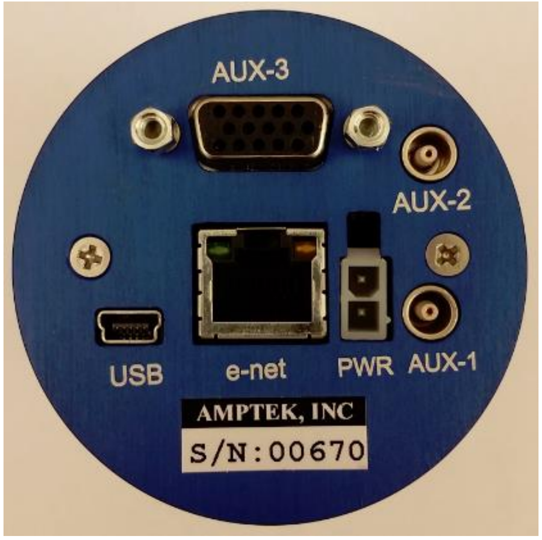
3.2 PMT Connector

Standard base for 2" diameter, 14 pin, 10 stage detectors.

If the HV is set to any value, the supply divides it as shown below, where ΔV=HV/13.

Pin #	Name	Pin #	Name
1	Dynode 1 – 3 ΔV	8	Dynode 8 – 10 ΔV
2	Dynode 2 – 4 ΔV	9	Dynode 9 – 11 ΔV
3	Dynode 3 – 5 ΔV	10	Dynode 10 – 12ΔV
4	Dynode 4 – 6 ΔV	11	Anode– 13ΔV
5	Dynode 5 – 7 ΔV	12	No Connect
6	Dynode 5 – 8 ΔV	13	No Connect
7	Dynode 7 – 9 ΔV	14	Photocathode

3.3 Communication and AUX connectors



USB

Standard USB 'mini-B' jack.

Ethernet

Standard Ethernet connector (RJ-45). Supports PoE.

AUX-1 and AUX-2

LEMO connector, P/N Lemo EPK 00.250.NTN.

AUX-3

15 socket high-density D connector which includes (a) the lines for a serial RS232 interface, (b) the AUX_OUT_1 and AUX_OUT_2 digital input/output lines, and (c) the 8 SCA outputs. The RS232 lines connect to a MAX3227.

Pin #	Name	Pin #	Name	Pin #	Name
1	GND	6	GND	11	SCA7
2	RS232-TX	7	AUX_OUT_1	12	SCA1
3	RS232-RX	8	AUX_OUT_2	13	SCA2
4	SCA6	9	SCA8	14	SCA3
5	SCA5	10	SPARE	15	SCA4

PWR

A +5 VDC adapter is provided, which is needed only when using Ethernet or RS232. When using USB, the USB bus provides the power. Newer units include PoE. If the Gamma-Rad5 is to be connected to an external power supply the connector information is below:

Molex 39-30-1020, Digi-Key WM1351-ND

Mates with Housing: Molex 39-01-2020, Digi-Key WM3700-ND

Terminal: 16 ga. – Molex 44476-3112, Digi-Key WM1913-ND

18-24 ga. – Molex 44476-1112, Digi-Key WM1914-ND

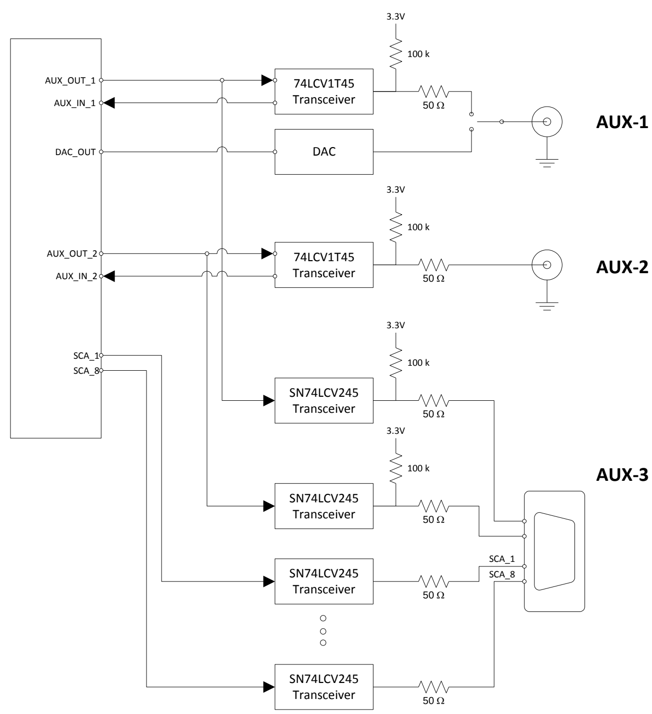
4 Electrical Interface

4.1 Communications Interface

The USB and Ethernet interfaces are unchanged from those of the standard DP5 family.

AUX-1

This is a primary auxiliary input/output connector. It can be configured as (1) the analog output, (2) the AUX_OUT_1 digital output, or (3) the AUX_IN_1 digital input. AUX-1 can be used for diagnostic purposes by displaying analog outputs, e.g. shaped pulses or the ADC input. It can be used as a digital input, e.g. to count pulses from a 3He neutron monitor. It can also be used as a digital output, e.g. as an output count indicator. A software controlled switch selects between the DAC output and a bidirectional digital transceiver (SN74LVC1T45) with 50 ohm series impedance and a 100 k pull-up resistor.



AUX-2

This is a digital input/output connector. It can be configured as (1) the AUX_OUT_2 digital output; (2) the AUX_IN_2 digital input; or (3) the Gate input. It is connected to a bidirectional transceiver (SN74LVC1T45) with a 50 ohm series resistance and 100 k pull-up.

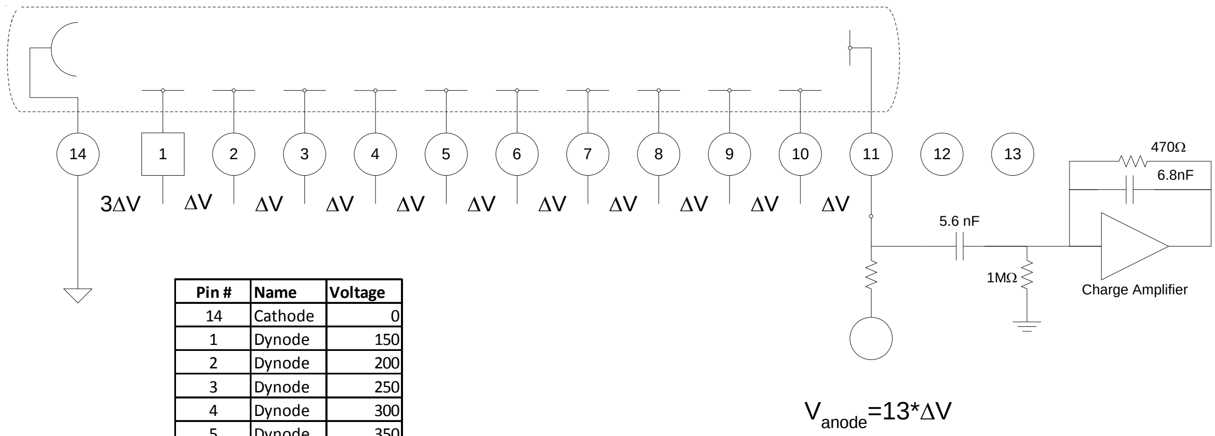
4.2 High Voltage Power Supply

The high voltage power supply is an active network, using a Cockcroft-Walton multiplier with each dynode connected directly to one stage of the multiplier. This provides both much better power efficiency and much better stability at high count rates than conventional resistive or transistor bias networks.

The schematic below shows the bias scheme used in the standard TB-5. It is a positive HV supply, with the photocathode (pin 14) grounded. The first dynode (pin 1) has three times the voltage drop of subsequent stages. The anode is AC coupled into a charge amplifier located on the DP5G.

The user commands a single HV value, which is the bias on the anode. The table below shows the voltages at each stage for one example bias, 650V on the anode.

Note that pins 12 and 13 are "NO CONNECT".



Pin #	Name	Voltage
14	Cathode	0
1	Dynode	150
2	Dynode	200
3	Dynode	250
4	Dynode	300
5	Dynode	350
6	Dynode	400
7	Dynode	450
8	Dynode	500
9	Dynode	550
10	Dynode	600
11	Anode	650

Amptek can fabricate connectors with a custom pinout. Please contact Amptek for details.

4.3 *Power Interface*

Absolute Maximum Power Supply Voltage +6.0 VDC

Absolute Minimum Power Supply Voltage +4.0 VDC

Input power outside this range will damage DP5 components.

5 Design

5.1 *Summary*

The TB-5 consists of several subassemblies: (1) Amptek's PMT HVPS boards, and (2) the electronics assembly, consisting of Amptek's DP5G digital pulse processor for scintillation spectroscopy and Amptek's PCG LVPS & I/O boards.

5.2 *Scintillator and PMT*

The customer must supply the scintillator/PMT module and must ensure compatibility with the specifications given above. If the PMT pinout differs from that shown above, contact Amptek to inquire about customization.

5.3 *DP5G and PCG*

The electronic assembly inside the TB5 consists of Amptek's DP5G signal processor and the PCG power supply and interface cards. These are both documented in a separate User Manual for the DP5G so will not be discussed in detail here.

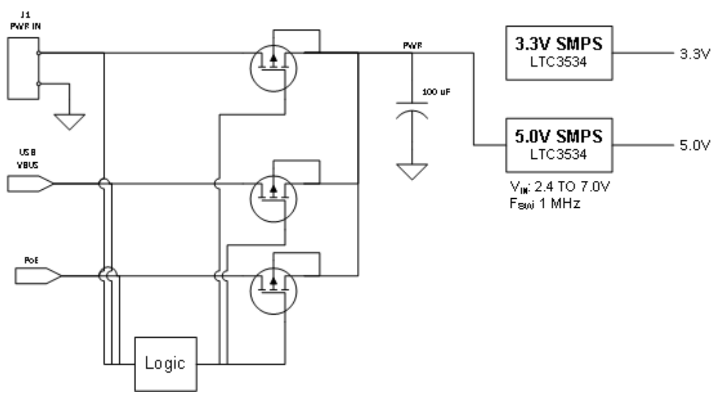
The DP5G provides the signal processing function. It is in the DP5 family but has been optimized for use in scintillation spectroscopy. The primary change is that the analog prefilter includes a charge sensitive preamplifier. The current pulse which is output from the scintillator is fed directly to this charge amplifier; its voltage pulse is then input to the ADC. This schematic is shown in the DP5G User Manual.

The DP5G uses the same basic pulse shaping logic but the ideal settings are slightly different, due to the characteristics of the scintillator and PMT. There are two major changes. First, the light output from the scintillator decays exponentially with time, with a time constant that depends on the scintillator material. This means that the input pulses have an infinite impulse response, rather than the finite impulses from a semiconductor detector. This alters the dead time and pile-up properties. Second, the high gain of the PMT means that electronic noise is negligible, so the noise properties of the pulse shapers are much less important. These points alter the optimum processor settings. See section 6.1 of this document for a detailed discussion on optimizing the processor for various scintillators.

The PCG board provides the low voltage power supplies and the communication and auxiliary connectors. This board is discussed in the DP5G manual.

5.4 Power supplies

The low voltage power supplies are on the PCG board. As shown below, and discussed in the DP5G manual, the input power (USB, PoE, or external) is switched by a MOSFET into low voltage switching power supplies. The 3.3V supplies the DP5G, while the 5V supplies the HV power supply.



The TB-5 utilizes a priority power controller. If power is available at the DC power input, that will be used to power the TB-5. If that isn't available, then USB power is used, if available. PoE is only used if external power and USB power aren't available.

The high voltage power supply is a Cockcroft-Walton, in which each stage is connected directly to a PMT dynode. This approach provides the most stable biasing, making gain independent of count rate, and is the most efficient, for the lowest power dissipation.

6 Application Advice

6.1 Configuring the TB5 for a particular scintillator

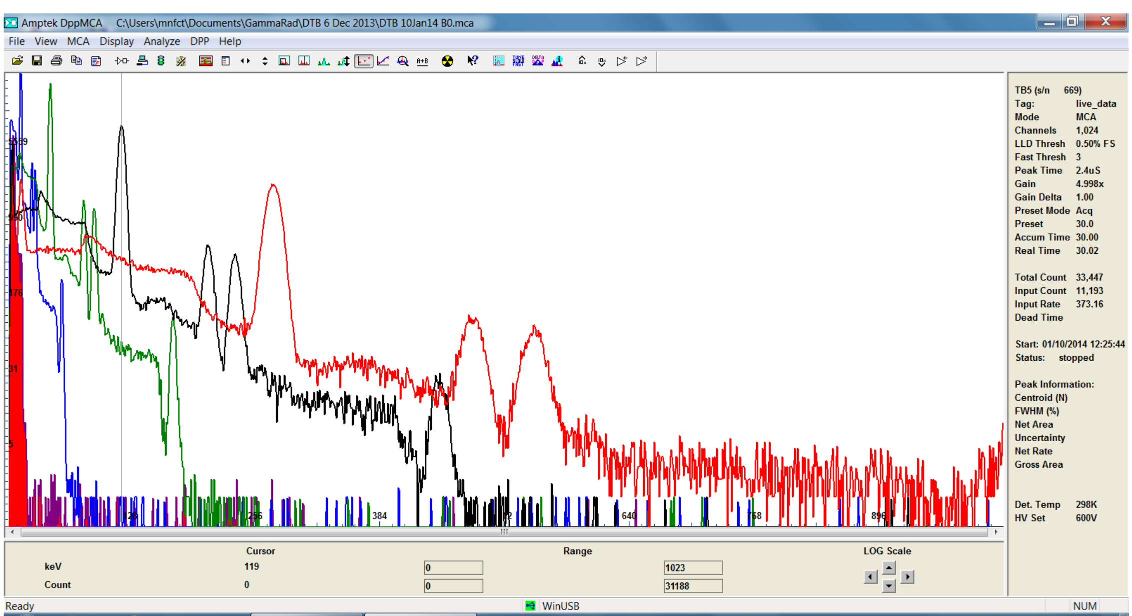
Each TB-5 is tested at Amptek using a NaI(Tl) scintillator coupled to a PMT, measuring a ^{137}Cs spectrum. After testing, the HV bias is set low and then the configuration used in the test is stored in EEPROM in the TB-5. When you connect to the TB-5, this configuration is automatically loaded and used.

You will need to change some of the parameters to obtain good performance with your scintillator/PMT module. The following parameters often require adjustments:

- **High voltage bias**: Every PMT has a slightly different gain versus bias curve. Even among "identical" PMT/scintillator modules, the HV bias will generally need to be changed to obtain consistent spectra. There is also a "gain" parameter in the signal processor. We recommend adjusting the HV bias for large changes in gain, then using the processor's gain parameter for fine tuning.
- **Pulse shaping parameters**: There are several different parameters which control the pulse shaping: T_{peak}, T_{flat}, T_{fast}, T_{scint}, T_{PUR}. The optimum settings will vary with the scintillator material. Adjusting these will primarily affect pile-up so they are most important at high count rates. In many cases, they will not need adjusting.
- **Thresholds**: There are two "thresholds" in the logic: a slow threshold (used in pulse height analysis for the main spectrum) and a fast threshold (used in the fast channel, for pile-up rejection and for measuring input count rate). The ideal setting can be a function of the system gain (including HV bias) and of the pulse shaping so they should be adjusted after the other parameters are set.

High Voltage

The figure below shows spectra taken from a single NaI(Tl)/PMT/TB-5 setup, using DPPMCA, at HV bias settings of 600V, 700V, 800V, 900V, and 1000V. The source consisted of 1 μCi ^{137}Cs and 1 μCi ^{60}Co. When the TB-5 was first turned on, at 600V, only a few counts were seen in the lowest channels. The system gain increased by about a factor of 2.5 for every 100V bias.



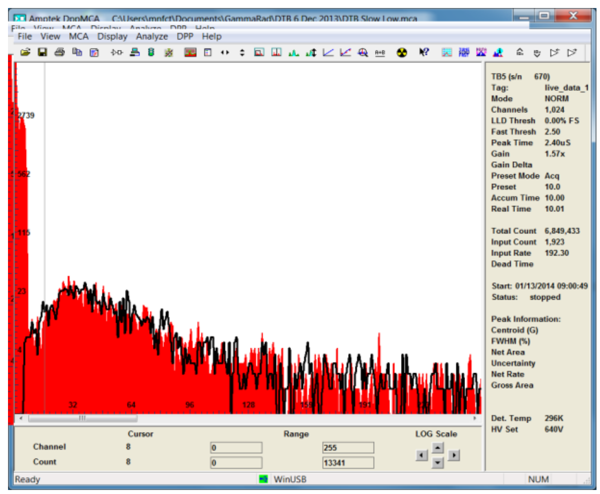
Procedure: We recommend beginning at a HV setting around 600V, with an analog gain around 5. Put a source in front and increase HV in 100V steps until the photopeaks are within a factor of two of the correct channels. The HV and/or analog gain can be further refined to get the desired range. The DPPMCA "Calibrate" button can be used to calibrate the energy scale. Its use is documented in the DPPMCA HELP.

Thresholds

The TB-5, like Amptek's other digital processors, has both a "fast" and a "slow" channel. The slow channel is optimized for good resolution; it is the input to the pulse height analysis. The fast channel is optimized for separating counts; it is input to the fast counter (to determine true input count rate) and to the pile-up rejection circuitry. Both channels have thresholds. The slow threshold functions as both a low level discriminator (pulses below it are rejected) and is used in the peak detect circuit. The fast threshold is purely a low level discriminator in the fast channel. For best performance, these should be set just above the electronic noise.

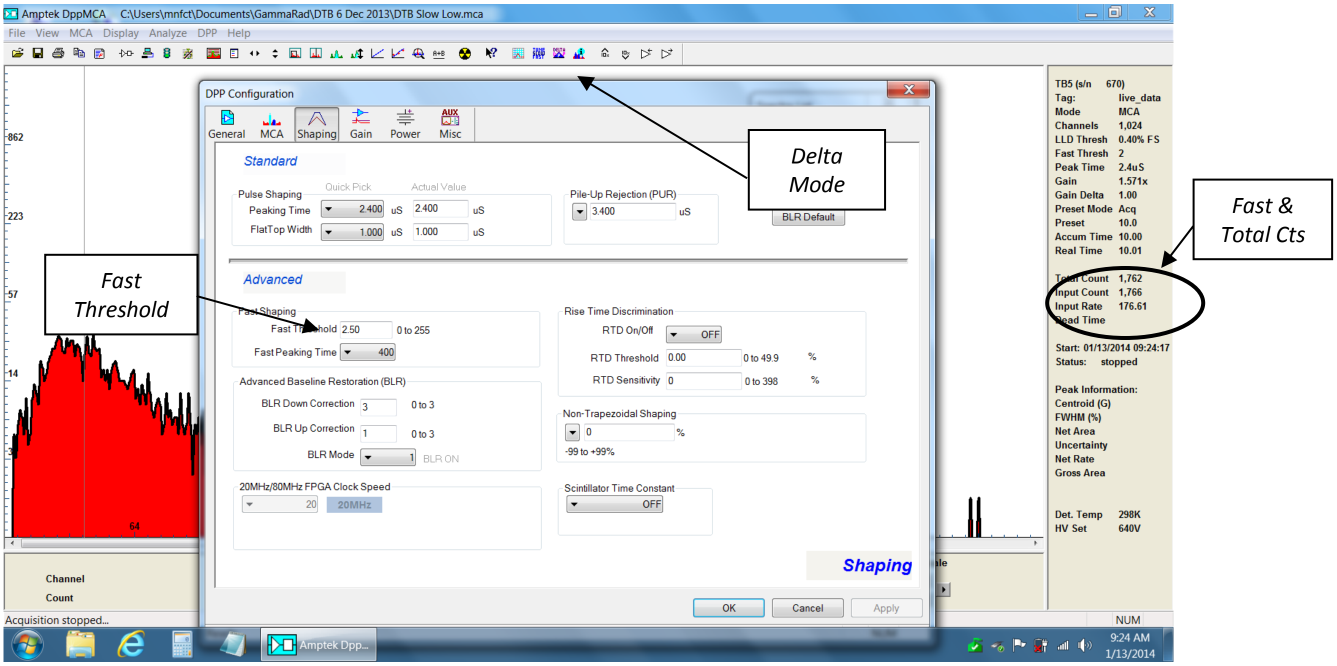
The DPPMCA software includes an "autotune threshold" function to set these above the noise but the current algorithm does not work well for scintillators so manual adjustment is recommended. The current algorithm raises the thresholds until the total rates above threshold is only 1 cps, assumed to be noise. The background radiation in a scintillator is generally above this, causing the algorithm to fail. Therefore, we do not recommend use of "auto-tune" with the TB-5. An improved version will be released in the future.

Procedure: First, set the slow threshold. To do this turn off "pile up rejection" (if the fast threshold is incorrect, it will affect pile-up rejection and thus the observed spectrum). Remove all sources and observe the spectrum. Manually place the threshold just high enough to avoid noise counts, as illustrated in the spectrum to the right. The filled red spectrum has the slow threshold too low, so noise fluctuations are recorded as real pulses. The black trace shows natural background in our lab.



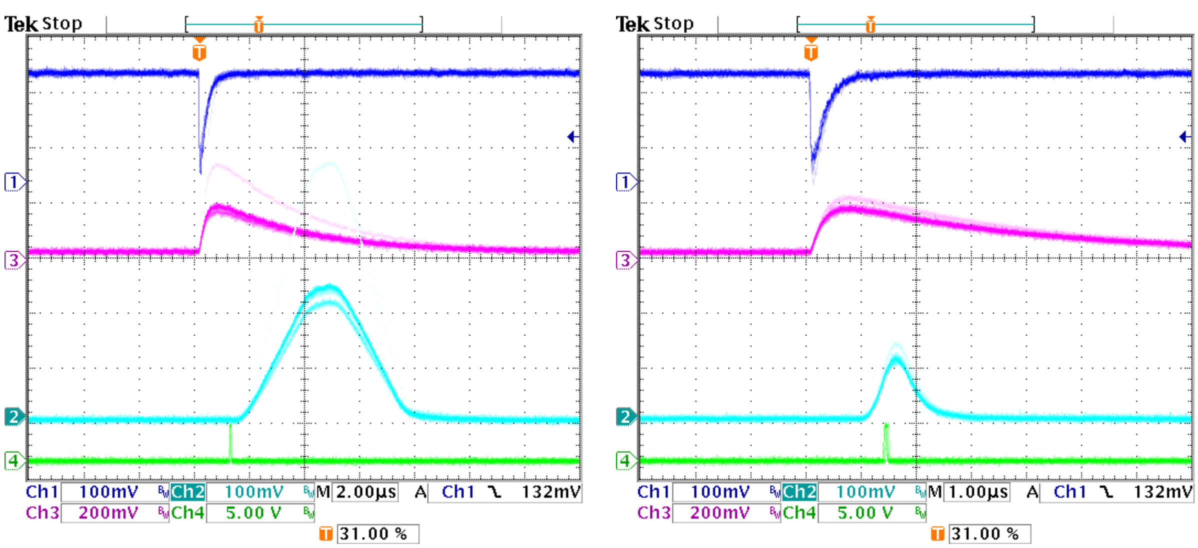
You can manually set the threshold either by placing the cursor in the correct channel and pressing the "F8" key or by opening the "Acquisition Setup" dialog to the "MCA" tab and entering a value.

Second, set the fast threshold. To do this, put the system into "delta mode", where the data are updated without integrating, making it easy to see changes. Compare the "Total counts" and "Fast counts", in the Info Pane. If only background radiation is present, the two should be very similar. If the "Fast counts" are much higher (lower) than the "Total counts", then adjust the Fast threshold higher (lower). After tuning, place a stronger source to get a few kcps rate and verify that the "Fast counts" are higher than the "Total counts".



Pulse Shaping

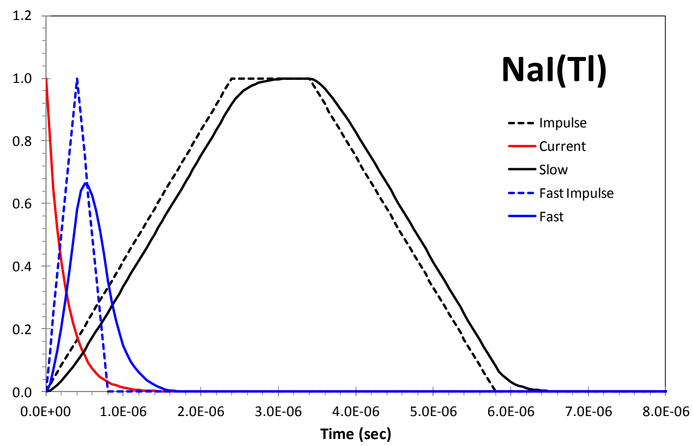
The figure below shows oscilloscope traces taken with a TB-5. The dark blue trace is the current output from the PMT while the magenta traces show the output from the charge amplifier. The light blue trace shows the shaped output (left) and fast output (right), for T_{peak}=2.4 µs, T_{flat}=1.0 µs, and T_{fast}=0.4 µs. The green trace shows the ICR output, a fast channel trigger. The light blue traces can be seen on the AUX1 output and the green trace on the AUX2 output. The others are internal to the TB-5.



Peaking time, flat top, and fast channel shaping

A shorter peaking and flat top duration will lead to a shorter duration pulse but one cannot shorten them arbitrarily without loss of performance. The scintillator has a characteristic time constant or time constants; the shaped pulse will be nonzero for several times these time constants. For the best, overall performance, we recommend a peak time and flat top several times longer than the scintillator time constant. The user may shorten these and the spectrometer will still function and indeed will give good energy resolution. But pulses will occur on the tails of preceding pulses, and this can affect resolution, stability, and even triggering (if a small pulse occurs on the tail of a large one, it may not be detected).

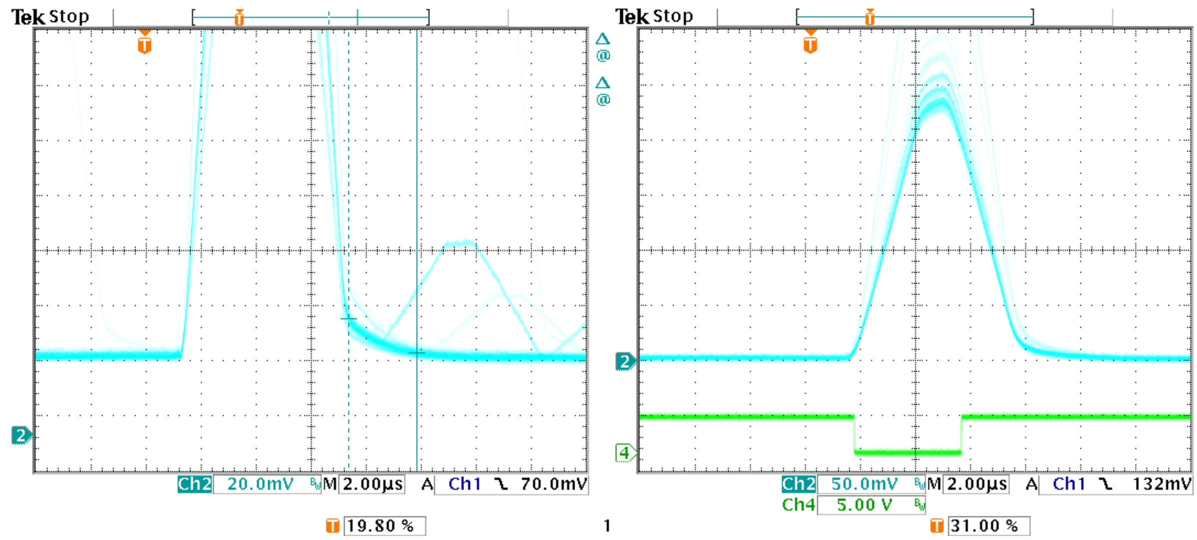
The basic trapezoidal shaping used by most digital pulse processors, including Amptek's TB-5, was originally designed for use with semiconductor or solid state detectors (SSDs). There is an important difference in the signals produced by a scintillator versus an SSD: in an SSD, the current flows for a finite time, the time required for the carriers to cross the detector. This is a finite impulse. In a scintillator, the optical current decreases exponentially with time (or as the sum of exponentials). This is an infinite impulse and it lengthens the shaped pulse. The plot below shows the computed response for a finite current (dashed) and for a NaI(Tl) time constant (solid curve). The difference can be important, if a low energy photon is on the tail of a much larger event.



Pile-up inspection interval

By default, the digital processor in the TB-5 uses a pile-up inspection interval which is the sum of T_{peak} and T_{flat}. This is the appropriate interval for a detector with a finite impulse but does not entirely account for the tail arising from the infinite impulse of the scintillator. The oscilloscope trace on the left below illustrates the difference. The dashed vertical line marks where the end would be for a finite response; the slow component in the NaI(Tl) leads to a tail of about 2 μs longer. To accommodate this, a non-standard pile-up inspection interval can be commanded in Amptek's firmware. Using an interval longer than the default will reduce the throughput somewhat while also reducing pile-up. The user must determine the optimum for any given application.

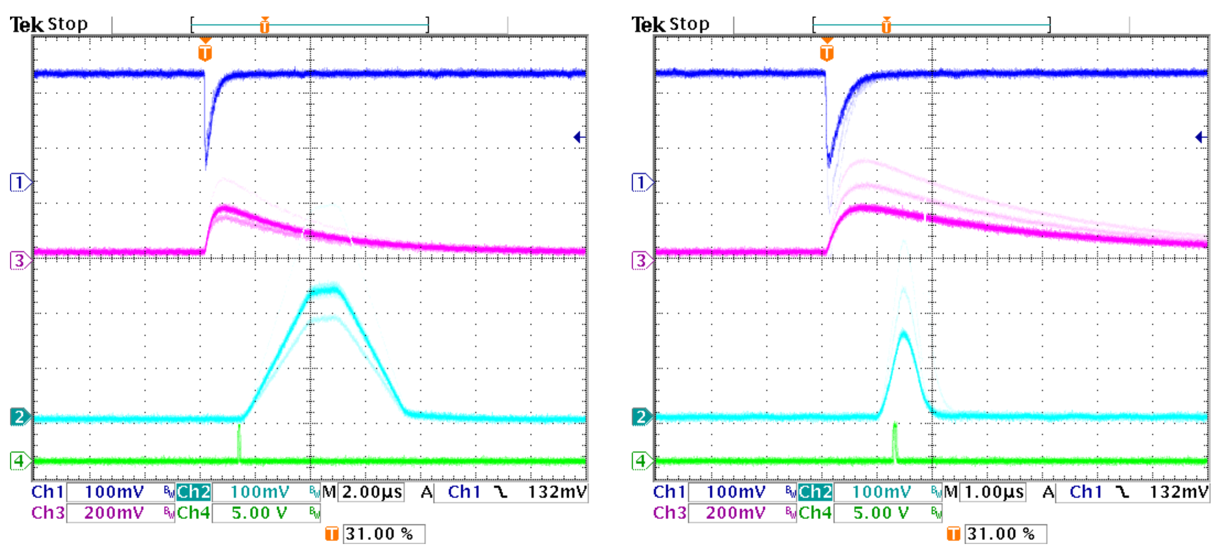
Procedure: In the DPPMCA software, go to "Acquisition setup", the "Shaping" tab. Use the PUR box to set a particular value, in microseconds. This should be the complete PUR interval: T_{peak}, plus T_{fast}, plus the "tail" interval. Then click "Apply". Note that, there is a maximum allowable value; this varies with peaking time.



Oscilloscope traces showing pile-up with shaped pulses. Left: Illustration of extended interval due to scintillator time constant. The dashed cursor shows where the shaped pulse would terminate with a finite impulse; the solid cursor shows where the pulse tail is negligible with the scintillator. Right: The green trace shows the output of "ONE SHOT", an AUX output signal used in the pile-up rejection logic, indicating the end of the pile-up inspection interval.

Scintillator time constant

Amptek has introduced a new processing parameter which reduces the effect of this tail. Termed the "scintillator time constant", it can correct the shape for an exponential decay. Most real scintillators have two or more time constants and this algorithm only corrects for one time constant. The plots below show the shaped and fast outputs after correction (for NaI(Tl)); note that the shape is closer to a trapezoid, the tail is reduced, and the fast channel pulse is narrower. Note also that the fast channel pulse is larger; this correction effectively increases the gain of the fast channel.



Procedure: To use the scintillator time constant, go "Acquisition setup", to the "pulse shaping" tab. Set the "scintillator time constant" to the nominal value of the primary time constant of the scintillator, in nanoseconds. For NaI(Tl), for example, set this to 230. Then click "apply". Note: Because the gain of the fast channel has increased, the fast threshold will need to be increased as well. When the scintillator time constant is first applied, the fast rate usually increases dramatically due to (false) noise triggering. To view the effect of this change, connect an oscilloscope to AUX1 and set the DAC output to the shaped or fast signals. You can observe the light blue and green traces above (the dark blue and magenta are observed at nodes inside the TB-5 package).

7 Technical Questions and Contact Information

For all technical questions, please contact the factory:

Amptek Inc.
14 De Angelo Drive
Bedford, MA 01730 USA
+1 781 275 2242
Fax: +1 781 275 3470
Email: sales@amptek.com
Web: http://www.amptek.com

8 Warranty

AMPTEK, INC. warrants to the original purchaser this instrument to be free from defects in materials and workmanship for a period of one year from shipment. AMPTEK, INC. will, without charge, repair or replace (at its option) a defective instrument upon return to the factory. This warranty does not apply in the event of misuse or abuse of the instrument or unauthorized alterations or repair. AMPTEK, INC. shall not be liable for any consequential damages, including without limitation, damages resulting from the loss of use due to failure of this instrument. All products returned under the warranty must be shipped prepaid to the factory with documentation describing the problem and the circumstances under which it was observed. The factory MUST be notified prior to return shipment. The instrument will be evaluated, repaired or replaced, and promptly returned if the warranty claims are substantiated. A nominal fee will be charged for unsubstantiated claims. Please include the model and serial number in all correspondence with the factory.