**Calibrating the TAC and MCA**

PJHT 11/5/20

The Time-to-Amplitude Converter (TAC) has its range set from the front panel, typically 50 x 1000 nsec, or 50 μs. Short delays will produce a pulse near 0V high, and the longest delays will be near 10 V. The Aspec 927 MCA is a high-speed digitizer that places small pulses near 0 Volts near Channel 0, and large pulses near 10 V at Channel 16383. The TAC is a device that encodes the time difference between two pulses that arrive at its START input and its STOP input. If it receives a START and a STOP it will output a pulse whose height (voltage, from 0 to 10 V) corresponds to the time difference (from 0 to 50 μs, or whatever the range setting is on the TAC). In measuring the muon lifetime you will be making what is called a TAC spectrum, where the data in the MCA represent time differences between START and STOP inputs to the TAC. Physically it represents the time between when a muon gets stopped in the scintillator and when it decays—each event gives off a burst of light that gets amplified and then turned into NIM (nuclear instrumentation module) logic pulses by the constant-fraction discriminator (CFD). While we can estimate that 50000 ns = 16383 channels, for high-precision work we need to calibrate the TAC/MCA combination.

We work under the reasonable assumption that the pulses from the scintillations undergo the same analog signal processing on the way from the photomultiplier tube to the CFD. (Some experimenters use an LED embedded in the scintillator bucket to calibrate the entire timing sequence, but because there is no guarantee of a fixed pulse height, you'd need to check timing over a very broad range of pulse heights for either pulse). So we'll start with NIM pulses (the output of the CFD) and keep identical cabling between the CFD and the TAC (i.e., keeping the left and right output cables from the CFD as START and STOP) so that spurious relative delays are eliminated. At this point we introduce pairs of NIM logic pulses produced by a digital delay generator: by sending in pulse pairs of known difference in time delay, we can see where they appear in the MCA data memory. We have two digital delay generators for this purpose. Below describes the setup and operation of the Stanford Research Systems DG 535 4-channel digital delay generator. Be sure to turn it on 30 minutes before using it to let the temperature of the electronics stabilize.

First, using the DELAY button, push it until it says A = … and set A = T0 + 0000000. This sets the A output to begin the shortest time possible after the trigger or T0 edge. To move the cursor around the display, note that the keypad has green left and right arrows. Move the cursor over to the digit or character you want to change and then use the up and down arrows. Then set B = A + 000004 ns, to create a B output signal that appears 4 ns after the A delay. We choose 4 ns to mimic the logic pulses out of the CFD. Next make C = A + 500 ns, and finally D = C+ 4ns. Note that the difference between A and B or C and D is always 4 ns, whereas the difference between A and C is 500 ns. By changing the delay of C we can set a time difference between the A edge and the C edge.

Set the TRIGGER menu to internal and maybe 10000 counts per second. Technically the Line trigger option (60 Hz) has lower jitter, but it won't matter because we are taking lots of counts and a few picoseconds of delay dither will average out.

Now using the OUTPUT button, make sure that all the outputs (T0, A, B, C, D) are set for NIM, the appropriate logic family that gives pulses between 0 and -1 V. And make sure that all the outputs are set for 50 Ω, which is the characteristic impedance of our BNC cables, to avoid reflections.   The pulses should all be Normal, not Inverted.

Note that in addition to the A, B, C, D logic edges, you can also form short negative-going pulse differences via the A⊔B and C⊔D outputs at the appropriate BNC outputs.  Look on a fast oscilloscope on the 50 Ω setting and you should now see a 4 ns wide pulse from A⊔B on Channel 1 and a delayed C⊔D 4 ns wide pulse on Channel 2.  Verify that the two pulses are 500 ns apart.

Now connect these START and STOP signals into the TAC (using exactly the same cables that normally come from the CFD) and look at the MCA.  If you clear out and turn your MCA on, you should see a narrow pulse appearing near Channel # (500/50000)*16384.  Calibration then consists of varying the time delay between A⊔B and C⊔D and recording the TAC spectrum on the MCA.  Note that you only need to vary the C delay relative to A to get the time delays.  There's a simple automated procedure that allows you to ramp up the time delay between C and A:  push the DELAY button until you are on the C selection.  Then move the cursor over to the 5 (as in 500 ns) digit.  Using the down arrow, reduce this to 100 ns.  The MCA should show the TAC spectrum as you go to 400, 300, 200, and finally 100.  Now stop the MCA and clear it.  Turn it on ("GO").  With the cursor blinking under the 100 ns C delay, press 5 (the center button) and up arrow at the same time.  The delay generator will start to increment that digit, pausing for approximately 250 ms at each time difference.   You should see the MCA start to accumulate counts at 100, 200, 300… ns, which will fall approximately 33 channels apart.  Under each peak will be about 2500 counts, assuming the 10000 Hz TRIGGER rate that you set above.  Continue until you fill the screen out to the end.  Stop the MCA.  Stop the delay generator by hitting the DELAY button.  You can do this sweep going down in time delay by pressing the center button and the down arrow.

Because your MCA may be set to ignore some low count channels (go to Acquisition/MCB Properties and set the lower threshold channel number to avoid too much Dead Time), you may or may not see the 100 ns first time delay.  To identify your absolute time delay, pick a fixed delay, say 500 ns, and acquire a fraction of a second more data on the MCA.  Now you know in which channel a 500 ns delay falls, because it will be taller than the others.  All the other peaks should be 100 ns increments away from this.  At the very end of the MCA display you may find that the last few channels never get any counts, simply because the maximum analog height of the TAC pulse is less than the maximum value accepted by the MCA.  For example, if a 50 us TAC pulse is only 9.800 V tall, whereas the MCA is 10.000 V in its last channel, you'll find a dead region of (0.2 V)*(16384)/(10.0 V) = 328 channels at the end.  Ordinarily this is not important, but keep it in mind when you are averaging the background counts due to uncorrelated (and unstopped) muon events.

Save your calibration as ASCII SPE (human-readable characters).  Use a Python program to read in the data and create a channel number array, knowing that the big peak represents 500 ns.  Now find the approximately 500 peaks and plot them as Time Delay # vs. Peak Channel Number.  Find the best fit line and you've got a calibration that tells you how to convert from channel number into time delay.

It might be a good idea to save all this setup in the delay generator.  Press STORE 6, to store the parameters.  Then if someone else has changed things, you can always RECALL 6 to get back to your preferences.  Put a piece of masking tape atop the instrument to claim that configuration memory (initials and date).