Applications of the Scanwell Systems Timing Alignment Probe

Introduction: “Timing alignment” of a PET scanner refers to the estimation of the individual time offsets of each detector so as to ensure that each time a pair of γ-rays is detected in coincidence, their times of arrival are actually recorded as identical. Accurate timing alignment allows a narrower coincidence timing window in order to reduce random count rates. In modern time-of-flight enabled PET scanners, timing alignment is even more important to improve the localization of each positron along the line of response to enhance the accuracy and rapidity of convergence of the image reconstruction.

Scanwell Systems has recently commercialized a novel device for performing the timing alignment of a PET scanner. Scanwell Systems’ unique, patented* PET Scanner Central Timing Alignment Probe detects the positron decay of 22Na atoms just before each positron annihilates with an electron producing two 511 keV γ-rays. The time between the positron decay and the detection of the γ-ray by any of the PET scanner’s crystals is the “time offset” which must be associated with all γ-ray detections by that crystal. Although originally developed for timing alignment of complete PET scanners, the device has other applications which make it interesting to those laboratories working to develop PET detectors, and novel PET systems.

The Source and Theory of Operation: A 3.7 MBq 22Na point source is embedded in a small cylinder of plastic scintillator using a proprietary process developed by radio-chemists at Eckert & Ziegler Isotope Products. As each 22Na atom decays, the positron’s kinetic energy is absorbed in the plastic scintillator prior to the formation of positronium with an electron and annihilation to produce two 511 keV γ-rays. The energy is immediately released from the plastic scintillator as a very fast light flash which is detected with a fast photo-multiplier. These pulses are like the “ticks from a reference clock” with respect to which the times of pulses from detected γ-rays can be measured.

Applications:
- Routine quality control: efficiency, crystal ID mapping, and timing offset estimation of PET scanners.
- Quality control during the assembly of PET detectors during manufacture.
- Physics experiments in labs. developing novel PET detectors or complete PET scanners.
- Initial setup and verification of PET scanners.

Application in PET Detector Development and Verification:
- The measurement of intrinsic spatial resolution and count-rate performance are two of the fundamental tests performed in PET detector physics laboratories when evaluating new detectors. The 3.7 MBq 22Na source used in Scanwell timing probe has a very small diameter, < 1 mm and the low average positron energy of 22Na reduces the blurring effects of positron range compared with 68Ge. Likewise the half-life, (2.3 years of 22Na compared with 9 months for 68Ge) makes the source useful for a much longer time. Similarly, in places where quality control must be done on each PET detector manufactured or tested, the Scanwell timing probe can be used to provide a simultaneous crystal identification image and an accurate estimate of the apparent arrival time of the γ-rays being detected as described below. (No license is required for the 22Na in this certified device)
- In most PET detector experiments the source must be placed between two detectors in order for the two collinear γ-rays to be detected. This makes it almost impossible to collect flood histograms of the counts from all crystals in a detector block and, at the same time, measure their arrival times. We have performed experiments in which the signal from the probe’s CFD was used as the “start” input of a TAC and the signal from various PET detector blocks was used as the “stop” input of the TAC. An image of the counts recorded by the crystals in the block gave an image similar to that used in conventional setup scans to assign counts in the flood histogram to specific crystals. The TAC signal was used to separate these by ‘observed arrival time’. An appropriate experimental setup is shown in figure 2 where an ADC and workstation are used to collect events in “list-mode” which include both the point of interaction on the block detector and the time after annihilation when the gamma ray was detected. These studies showed that there are significant differences in “apparent arrival time” among the crystals. Some of these differences could be attributed to the way the detector readout was performed, others may be due to the difference in transit times among the block’s PMTs due to using bias different voltages to adjust the PMT gains.
- Examples of these experiments are shown here. The experimental configuration is shown in figure 2. The apparent γ-ray arrival times in each crystal are shown in figure 3. There are a few crystals which appear to
If the voltage across a PMT is reduced to compensate for higher gain, the electron transit time is also reduced. A 100 volt drop in applied voltage delays the output signal by about 1 nanosecond.

Block diagram of complete experimental setup which allows the acquisition of both γ-ray interactions within a crystal block and the apparent delay in arrival time of the γ-ray in the detector under test since the positron annihilation.

The apparent arrival times of γ-rays in a HiReZ 13x13 LSO detector block. The group of crystals in the right front quadrant have later arrival times probably as a result of the PMT under this group having a higher gain, and operated at a lower voltage to compensate for its high gain.

be “late” for no obvious reason, however those in one quadrant are later than the others due perhaps to the longer transit time of one of the four PMTs. The transit time vs bias for a typical PMT used in PET detectors is shown in figure 4. It appears that lowering the anode voltage (commonly done to match the PMT gains) also increases the electron transit time, since the electrons will move more slowly when the voltage is lower.


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