PHOTON COUNTING DETECTORS FOR FILL STRUCTURE MEASUREMENTS AT VISIBLE WAVELENGTHS

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Abstract

When making accurate measurements of the relative populations of electron bunches in a storage ring, notably in light sources operating with only a single bunch filled, the method of time-correlated single photon counting gives the greatest dynamic range. The timing resolution and background noise level of the photon detector employed is critically important in determining the overall performance of the system; hitherto the best performance has been obtained detecting X-ray photons using avalanche photodiodes. On the SRS at Daresbury a visible light diagnostic station offers greater ease of access to instrumentation and operational advantages. A review is given of the detector types which have been employed, and the performances which can be obtained using visible light.

1 MEASURING ELECTRON POPULATIONS

A measurement is often needed of the relative populations of the different bunches in a storage ring electron beam. For instance, when a light source storage ring is operated in a user mode which requires only a single bunch to be filled, it is important to be able to distinguish the (unwanted) small populations in the other bunches. The total dynamic range for detection of a small bunch relative to a larger bunch is determined by 2 factors - the time resolution of the detection system and the background noise. The accepted technique which provides the best trade-off between these two requirements for electron storage ring measurements is Time-Correlated Single Photon Counting (TCSPC).

In the TCSPC method individual photons emitted from a source are timed against a reference signal synchronous with the source repetition rate [1]. A histogram of the number of events versus time will give a statistical picture of the time-structure of the source over many events. The reference signal can conveniently be taken from the storage ring RF timing signal, but may also be derived directly from a single bunch beam by using a stripline pickup.

Photon detection, which provides the other channel of the TCSPC system, may be accomplished using a variety of detectors sensitive to different photon wavelengths; generally X-ray or visible photons are detected directly, or X-rays indirectly using scintillators. Photomultipliers (PMTs), microchannel plates (MCPs) or avalanche photodiodes (APDs) have been used. The best dynamic range yet obtained is around 10^8, using an APD directly detecting X-ray photons around 10 keV [3].

2 VISIBLE LIGHT DETECTION

One factor determining the choice of photon counting system is the effort and equipment required to implement it – the ideal is a cheap, turnkey system which can be installed onto an existing beamline. Visible light diagnostic beamlines are an attractive option as most light sources possess one for other diagnostic purposes. With the correct design of beamline - such as at the Synchrotron Radiation Source (SRS) at Daresbury - continuous access to and operation of the diagnostic equipment can be maintained even during storage ring injection – this can greatly increase the flexibility and efficiency of making measurements.

To provide the photon channel for the system, three options for visible photon detection are presented here: these are systems based on PMTs, MCPs or APDs.

2.1 PMT-Based System

This is the type of system presently in use on the SRS at Daresbury Laboratory. A timing base must clearly be used, together with a tube with exceptional timing and noise characteristics. At present, one of the fastest low-noise tubes commercially available is the Photonis (Philips) XP2020 tube [4] which has a transit-time spread of 250ps (similar tubes have been manufactured in the past with slightly better characteristics but are no longer available). Coupled with the appropriate base [5] a dynamic range of greater than 10^5 for most neighbouring bunches can be obtained; this is partly dependent upon the tube temperature (which determines the noise rate of the photocathode), so tubes are generally cooled thermoelectrically [5]. However, artefact peaks arising from the first few dynodes are generally present, and are well correlated in time and magnitude with each real peak; artefacts associated with the largest bunches overlap certain time regions in the beam fill structure, reducing the dynamic range there, although this can be partly overcome using software analysis [5]. The transit-time spread, together with the resolution of the timing electronics (see Figure 1) means that the overall response time is such that very close bunches (within a few ns from the main bunch) have a reduced dynamic range. Whilst this is a restriction for storage rings with bunch spacings of 2 ns it is less so for lower RF frequencies than

500 MHz. The important response width parameter is not the usually quoted FWHM but the peak width at lower levels – these may not scale in a simple way from the FWHM, and must be measured (for instance see Table 2).

2.2 MCP-Based System

The MCP-based system electronics are similar to those for the PMT: a Hamamatsu R3809U integrated photocathode/MCP unit has been used at Daresbury [6]. Additional amplification and different discrimination are necessary to cope with the small, narrow output signal produced by the unit. Although the timing response of the unit is excellent (FWHM of 40 ps), it has similar dark noise characteristics to the PMT. In addition, it is relatively expensive and fragile compared to the PMT system. Overall, this makes it less attractive as an option than a PMT-based system.

2.3 APD-Based System

APDs have an advantage over PMTs in that artefacts are not present in the single photon response of the detector. Although APDs have been used with great success at X-ray wavelengths for timing measurements [2,3] the lower energy of visible photons means that the required amplification to detect them is much greater, generally increasing the dark noise to unacceptable levels. Recently, though, there have been developments in commercially available APD detectors, and both Hamamatsu (model C5331) [6] and EG&G Ortec (models SPCM-AQ) [7] now provide integrated detectors incorporating the APD, temperature compensated bias control and amplifier into a single unit. The EG&G models are particularly interesting as they also include discriminator circuitry to give a convenient TTL timing output, as well as their utilisation of very small area diodes (250 µm). Tests have been carried out at Daresbury using such a detector (model SPCM-AQR-13), which compares favourably in cost with the PMT, thermoelectric cooler and discriminator it replaces.

3 COMPARISON OF PMT AND APD-BASED SYSTEMS

The SPCM-AQR-13 is a mid-range detector which has similar quoted properties to the PMT system in use at Daresbury; these are summarised in Table 1.

Table 1:FWHM single photon response widths and dark noise levels for the APD and PMT detector. APD units with lower noise levels are available.

Detector	APD *(SPCM-AQR-13)*	PMT *(XP2020Q)*
Width [ps]	250	250
Noise [Hz]	140	40 (-2.3kV, -10°C)

The electronic layout used for the PMT and APD systems is shown in Figures 1 and 2. Using a single bunch beam with deliberately added small amounts of charge in the other bunches, a measure of the dynamic range, single photon response width and dark noise was made for the two systems; a comparison of two typical spectra is shown in Figure 3.

As expected, artefacts are not present in the APD spectrum and the dark noise is higher. For most of the bunches the dynamic range of the APD system is 10^4, though this could be improved with a lower-noise detector. However, the measured response widths for the APD system were not as expected (see Table 2), with much larger FWHM values than the quoted 250ps. This

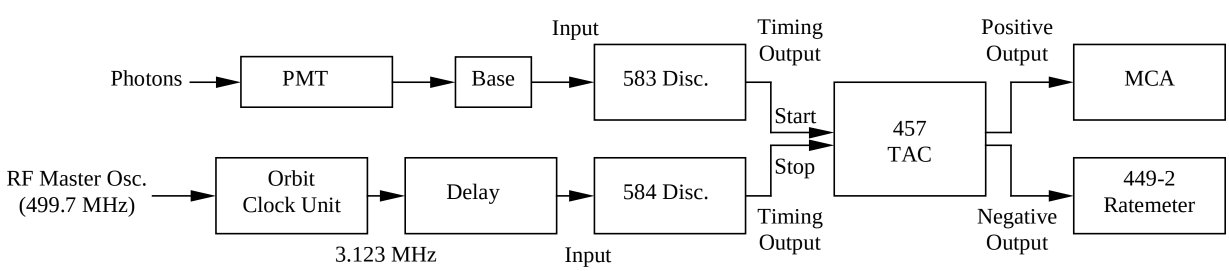


Figure 1. Layout of Photon Counting System based upon the XP2020 PMT. The orbit clock unit is a Daresbury-built unit; other NIM components are Ortec units [7].

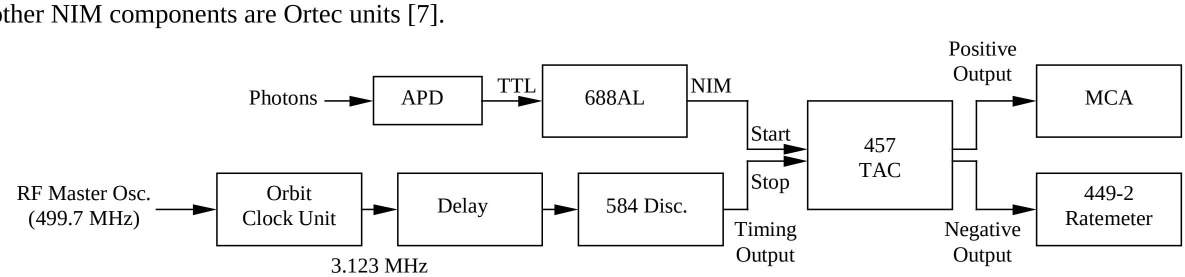
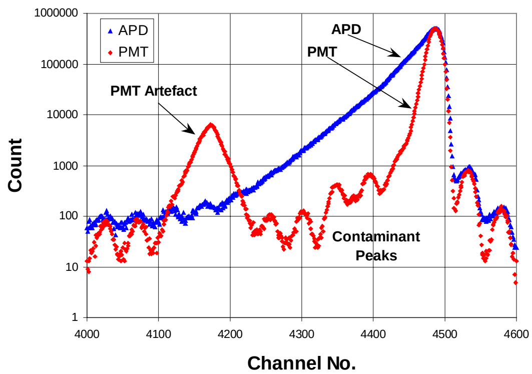


Figure 2. Layout of Photon Counting System based upon the SPCM-AQR-13. TTL to NIM conversion is performed using a LeCroy 688AL converter [8].

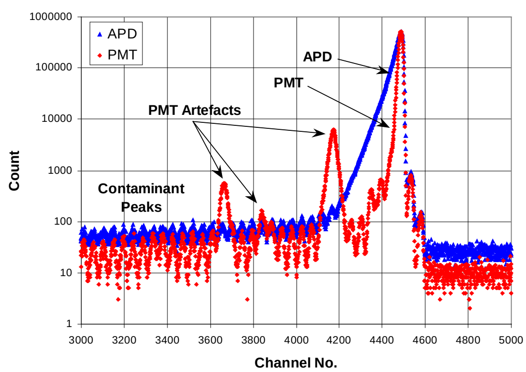
restricts the dynamic range within the first few ns from the main bunch.

Table 2: Single photon overall response widths for the APD and PMT-based systems.

Width	APD [ns]	PMT [ns]
FWHM	1.35	0.87
10^{-2}	7.43	2.30
10^{-3}	11.8	3.91



(a)



(b)

Figure 3. Comparison of spectrums measured using APD and PMT-based systems with the same stored beam. (a) is a close-up of (b). 23 channels corresponds to 1 ns.

4 DISCUSSION

The APD system as tested does not yield the expected timing resolution; this may have been due to a fault with the diode, and tests with alternative detectors will be carried out in the near future. However, for storage rings whose RF frequency is 50 MHz or lower, a system based on an APD is worth considering for a visible light beamline. If the time resolution issue can be resolved, these devices would be the best choice for any normal RF frequency, due to their relatively low cost, simplicity of use and probably greater ruggedness.

ACKNOWLEDGEMENTS

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