

## A HIGH DYNAMIC RANGE BUNCH PURITY TOOL

B.Joly, G.A.Naylor. ESRF, Grenoble, France.

### Abstract

The European synchrotron radiation facility uses a stored electron beam in order to produce x-rays for the study of matter. Some experiments make use of the time structure of the x-ray beam which is a direct reflection of the time structure in the electron beam itself. Avalanche photo-diodes have been used in an x-ray beam in a photon counting arrangement to measure the purity of single or few bunch filling modes. Conventional techniques measuring the photon arrival times with a time to analogue converter (TAC) achieve dynamic ranges in the  $10^{-6}$  range. We report here the use of a gated high count rate device achieving a measurement capability of  $10^{-10}$ . Such high purity filling modes are required in synchrotron light sources producing x-ray pulses for experiments looking at very weak decay signals as seen in Mossbauer experiments..

measurement of the main pulse and subsequent pulses. By applying a gate to the discriminator the incoming photon counts can be accepted or de-validated. A gate can then be applied to only allow counts during a specified period after the main pulse. These validated counts are then at a rate much less than 1 per revolution and so the trace becomes linear again but with a much greater sensitivity (up to 10 orders of magnitude below the intensity of the main pulse. Since the main pulse now has an amplitude much higher than the subsequent pulses to be counted (due to the fact that it represents many photons) the gate can only be applied some 10-20ns after the main pulse due to the decay and possible oscillations following the main pulse. Such a diagnostic is then not useable for determining the population in neighbouring electron bunches but is very sensitive to occupancy in bunches more than 20ns following the main pulse up until the neighbouring pulse prior to the next main pulse.

### 1 INTRODUCTION

An avalanche photodiode, collects scattered x-ray photons from an x-ray absorber on an unused bending magnet beam-line (fig 1, 2) and is used to measure bunch purity in few bunch modes. The x-ray photons collected by the photodiode create a hundred to a thousand carriers which are then multiplied by avalanche in the junction. An avalanche photodiode is chosen with a thin (10 $\mu$ m) depletion layer to achieve a fast time response (HAMAMATSU model S5343SPL, ref 1). The subsequent electric pulse is amplified (fig 3) and sent to a photon arrival time electronic acquisition time (fig 4).

Such an acquisition system is frequently used in high dynamic range time resolved user experiments (ref 2) and can be used in two different operating regimes:

1) Low count rate mode where the probability of detecting a photon is much less than one per main pulse revolution. The arrival time of all photons is stored and a profile of the time dependent x-ray emission is determined and hence the electron bunch intensity profile as a function of time determined with a very high dynamic range (fig 4). Since photon pile up is rare the plot is fairly linear and accurate with moderate acquisition times (a few minutes) over around 6 orders of magnitude. This is an important diagnostic tool in determining the purity of the main bunch with respect to neighbouring bunches.

2) High count rate where the probability of detecting a photon from the main pulse is much more than one. In this case there is a great non-linearity between the

### 2 DIAGNOSTIC CONFIGURATION

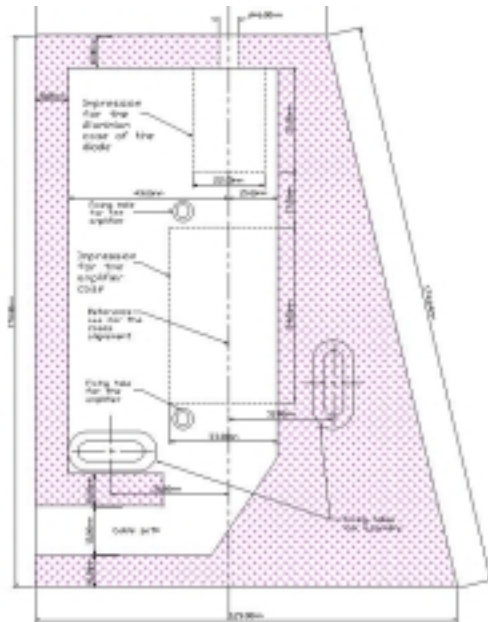


Figure 1: Avalanche photo-diode in lead shielding

A bunch purity diagnostic tool using the first mode of operation is installed on beam line D19. This paper concerns the performance of a bunch purity diagnostic used in the second counting mode. A high count rate is achieved on the D4 beam line (fig 1) using a beryllium window to allow the high flux of Cu K alpha fluorescence photons to be detected. As seen in figure 5, an aluminium

window will effectively transmit a moderate flux of Compton scattered photons from the Cu absorber surface.

The cross section for x-ray interaction with the copper surface is however much higher via the photo-electric emission than for Compton scattering. The remaining excited Cu<sup>+</sup> ion (electron removed from an inner shell) can decay by auger emission or by the re-emission of an x-ray fluorescence photon. Assuming there to be not to much delay in the fluorescence emission (due to the very short excited state lifetime of the Cu<sup>+</sup>) this fluorescence is still characteristic of the temporal profile of the electron bunch (though in practice may lead in part to the tail of the main pulse detected by the avalanche photodiode.

Figure 2: Avalanche Photodiode

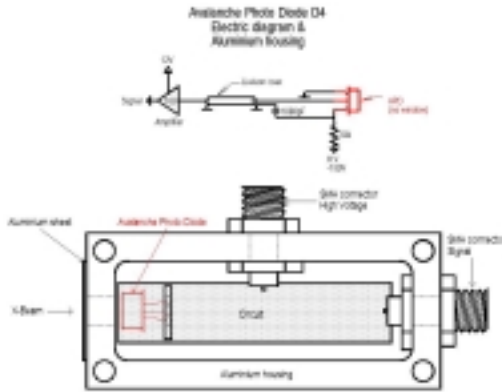
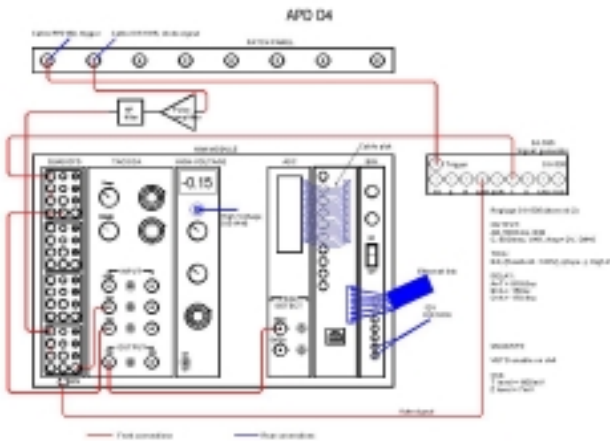


Figure 3 Time to analogue converter



A significant fraction of the incident scattered x-rays is then scattered in-elastically into Cu K alpha x-rays at an energy below the peak of the bending magnet emission. These photons will be heavily attenuated by the aluminium window yet strongly transmitted by a beryllium window. The avalanche photodiode must be protected within a thick lead housing to prevent erroneous

counting from x-rays scattered from other sources than the Cu absorber surface (that would not have the correct timing) as well as Bremsstrahlung gamma rays coming directly from the electron beam impacting residual gas atoms in the storage ring.

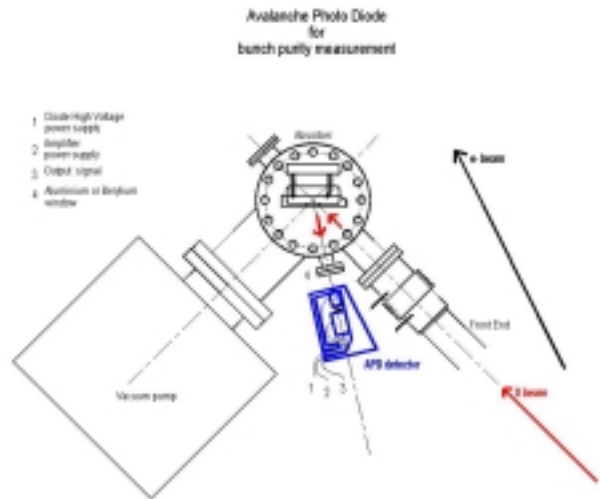


Figure 4 Collection of scattered x-rays on beam port

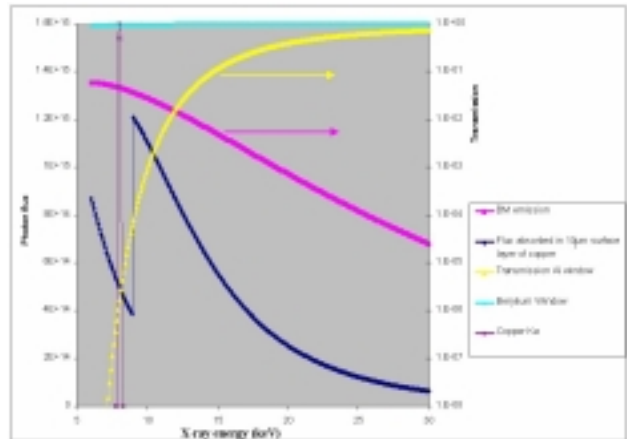


Figure 5 Cu Ka line transmitted by Be window.

### 3 MEASUREMENTS

The received count rates as a function of time must be calibrated at low current so as to avoid non-linearity effects due to photon pile up. This is done by injecting a low current in a multibunch mode (one third filling) and looking at the trail off in intensity of the bunches at the end of the pulse train. The count rate was calibrated by injecting 20mA of 2/3<sup>rd</sup> fill and scraping down to 0.4mA. The count rate in the 150ns window was 1600per sec equivalent to 50Hz/µA or 16Hz/pC. This corresponds to a count rate of 50 times that on D19.

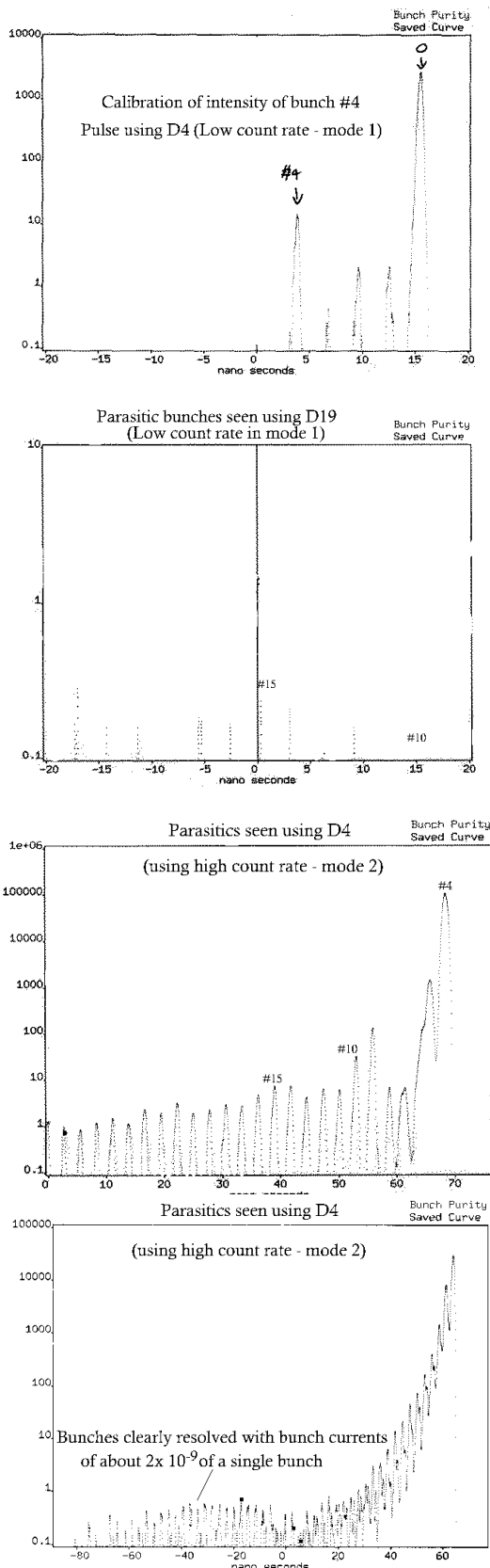


Figure 7 Resolution of  $10^{-9}$  in high counting mode

The beam was further scraped down to 3Hz within the 150ns period. This corresponds to a remaining current of 1nA per bunch. A single bunch was injected as a reference pulse (#0). With a fill of 10mA this would correspond to parasitic bunches each at  $10^{-7}$  of the main pulse. Figure 2 and 3 show the visualization of these parasitic bunches using D4 and D19. While barely detectable on D19 using the counting mode i) these pulses are easily visible with the high count rate device D4 using mode ii) described above. The detector D4 can usefully determine the purity ratio of bunch #4 to bunch #0 by lowering the count rate using an attenuator to be in the linear counting regime with no pile up. The purity detector D4 is then able to detect the ratio of the parasitic bunches #10 and #15 to the weak pulse #4 in the high count rate regime. Pulses with an intensity of  $10^{-9}$  of the intensity of a single bunch can be detected in this way.

#### 4 CONCLUSIONS

The Avalanche photodiode on D19 gives a good linear detection of the bunch purity and is sensitive to parasitic bunches immediately following the main pulse with a detection limit of about  $10^{-7}$  or 1nA per bunch in absolute terms (3pC). The D4 avalanche photodiode is heavily saturated by the main pulse and successive ripples on the signal prevent correct counting during the 20ns period immediately following the main pulse. The D4 APD does have greater sensitivity allowing parasitic bunches at the  $10^{-9}$  level to be easily measured in a 200s-integration period. Further tests measuring the total count rate within the 150ns gate window and using a high count rate gives a resolution in the  $10^{-9}$  range in single bunch and the  $10^{-10}$  range in 16 bunch. The mode of operation i) is therefore able to detect impurities down to  $10^{-6}$  while mode ii) allow the impurity detection limit to be extended from  $10^{-6}$  to  $10^{-7}$ .

#### 5 ACKNOWLEDGEMENTS

Discussions with R.Rueffer and J.L. Revol have been essential in the development of this diagnostic tool.

#### 6 REFERENCES

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