The Implementation of a Down Conversion Orbit Measurement Technique on the Daresbury SRS

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Abstract

Precision orbit measurement with global and local feedback control of position has become a basic requirement in many storage rings around the world. The production of stable, accurate and repeatable processed beam position signal voltages is an absolute necessity if any feedback system is to be successful. As part of a project to improve the SRS orbit stability a further development of BPM signal processing techniques has been pursued, involving amplitude detection of hybrid pre-processed sum (Σ) and difference (Δ) signals, derived locally. The new RF signal processing and detection electronics are housed in a single compact unit which, mounted locally at each BPM, is the basic building block of the installed system and provides full parallel signal processing over a beam current range of 1-500mA. A distributed 16-bit digital multiplexer provides high resolution readout. The use of LabVIEW® for automated calibration checks of each processor unit confirms stable measurement (<±5 μm) over a minimum dynamic range of 26 dB, and subsequent beam performance tests demonstrate extremely high measurement resolution (<1 μm). The system is flexible and provides the front-end video bandwidth required to support alternative functions such as first turn and injection diagnostics.

1. INTRODUCTION

Synchrotron radiation sources throughout the world are undergoing significant changes with regard to the provision of closed orbit control[1]. A similar situation has arisen for the SRS at Daresbury. The requirement to implement a new distributed high precision position measurement technique that has the flexibility to support a number of general BPM functions, geared to the task of orbit correction in both local and global feedback systems[2] has now been realised. The system includes facilities for tune measurement and dynamic injection beam response and has been constructed entirely in house, at modest cost. The principal requirement of the hardware is to provide a 10 fold improvement in measurement precision over the previous system and to give position over a wide dynamic range of stored beam current to within ±5μm, with a repeatability of <1μm. This has been achieved using a new down conversion[3] approach, which allows low frequency processing to provide filtered DC outputs for adjacent ADC digitisation[4]. This new system is designed to be compatible with considerable portions of the installed equipment, and is based on the amplitude detection of pre-processed sum (Σ) and difference (Δ) signals derived locally at each BPM monitor using passive 180° hybrids.

2. PREVIOUS ELECTRON BPM SYSTEM

2.1 Basics

The SRS has a series of 16 horizontal and 16 vertical BPM pickup vessels installed, one of each type in each machine straight. Button type pickups are installed within these vessels, and the signals from these are cabled directly to combining 180° passive hybrids, used to provide sum (Σ) and difference (Δ) output signals directly adjacent to the monitor vessels. These signals were then switched in pairs using a distributed coaxial multiplexer and extensive cabling network to a single narrow band detector[5] tuned to the 500Mhz fundamental RF beam component. Previous performance figures were:

Resolution	≈ 30μm
Stability/Repeatability	≤ 100μm
Detector Sensitivity	≈ 0.5mA.mm (10dB noise margin)
Minimum Current	≈ 15mA
Dynamic Range	≈ 10dB

These figures were dominated by the performance of the detector and its cabling/switching system, which fall short of current standards.

2.2 Operation

Operational advantages are gained from a hybrid based system. Processing the sum (Σ) and (Δ) signals means that a stable electrical measurement centre, independent of beam intensity, is defined. Purely passive 180° hybrid devices ensure a linear response with regard to beam current, and a dynamic range limited only by the sensitivity of the installed system and detector. As such, a stable measurement of beam offset about the survey beam orbit is made using the signal processing system as a zero beam offset detector. This approach is especially useful if the BPM vessels are mounted separately to the major machine vessels, and can be aligned to the survey beam orbit. The multiplexed central detector responded equally to single and multi-bunch beams in the range 20-500mA. The useable dynamic range of stable detector performance was limited to a maximum of 10dB, which was maintained by a series of expensive switched attenuators (6dB steps), controlled automatically from the stored beam total current monitor.

The new detector addresses these limitations, but maintains all good points from the previous system.

3. New BPM Processing Electronics

3.1 Overview

The new detector electronics is housed in a specially designed multi-compartment RF case. The unit has two channels, allowing it to cater for one horizontal and one vertical BPM input per straight. The inputs are initially filtered through narrow band-pass filters, centred at 500Mhz. in order to filter out orbit harmonics. The filtered input signals are then down-converted to low frequency, where they are low-pass filtered, and detected using a fast comparator and multiplication stage. Two selectable gain ranges provide for multi and single-bunch SRS operation. A single unit (excluding input filters) can be seen below in Figure 1.

Figure 1. New Daresbury Distributed BPM Processor Unit.

Major Specifications for the system are:

Dynamic Range	10-400mA :low gain 1-40mA :high gain
Position Sensitivity	$\leq$ 0.05mA.mm
Resolution	$\leq 10\mu m$
Stability (over fill period)	$\leq 20\mu m$
Absolute Cal. Accuracy	$\leq 100\mu m$, rms

3.2 Down Conversion Stage

The down converter stage is a direct derivative of the previous phase sensitive amplitude detector system and is shown in Figure 2. The hybrid pre-processed sum (Σ) and difference (Δ) signals are filtered using commercial narrow band-pass ($\approx$1%) filters, designed to Daresbury specification. These are necessary to suppress the 3Mhz orbit frequencies generated when the SRS is operated in single bunch mode. These filtered signals are passed into the inputs of the down converter stage along with a local oscillator (Lo) signal, set at 500.5MHz i.e. 500kHz above the machine frequency. Due to BPM signal levels available, no amplification is required. A high output low noise RF amplifier is used for the local oscillator drive to provide sufficient constant levels for the RF mixer.

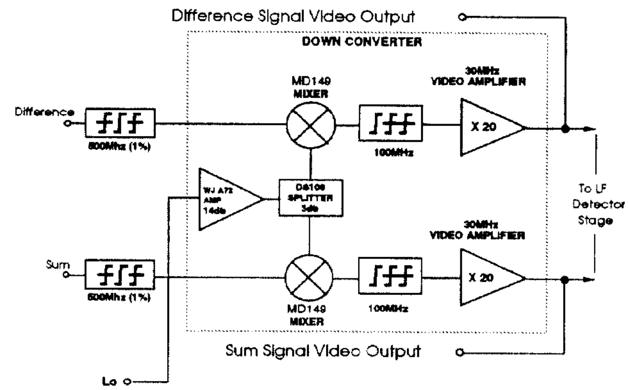

Figure 2. Down Converter Stage

The use of this basic building block as a two channel frequency converter, shows the following performance, with a noise figure of 3dB (Figure 3).

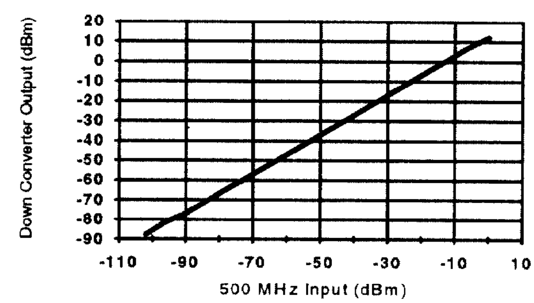

Figure 3. Response of Down Converter Stage (IF = 500kHz)

This stage also provides facilities such as direct measurement of beam tune components, and allows wide-band injection studies by switching in different local oscillator frequencies, such as a master oscillator signal.

3.3 Low Frequency (LF) Phase Sensitive Detector Stage

Once the input signals are frequency down converted maintaining all amplitude components, they are fed via internal coaxial couplings and video amplifiers to the key component of the new system, shown in Figure 4. A commercial, wide-band analogue multiplier (AD539) is configured as a dual channel phase sensitive detector, which processes both the sum (Σ) and difference (Δ) channels from each BPM monitor. Using the larger sum (Σ) signal input channel to drive a fast (ecl) amplitude comparator, a synchronous reference signal is generated for use with the multiplier. This ensures constant amplitude and phase (<<5° change) over an input range of some 20 to 3000mV (peak) at the multiplier inputs. Gain selection amplifiers are multiplexed into the multiplier input chains to allow low gain multi-bunch (x2) and high gain single-bunch (x20) operation. The overall dynamic range of the units however is restricted to typically 30dB in this application to allow operation from low power ±5.0 Volt linear supplies.

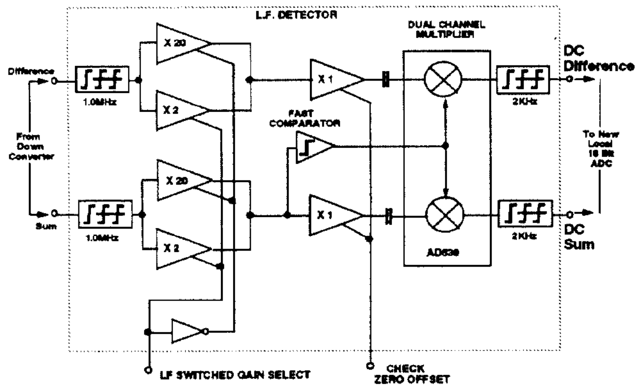

Figure 4. Dual Channel Low Frequency Detector

4. Testing and Commissioning

4.1 LabVIEW® Overview

Due to the number of units required, it was necessary to develop a fast simple automated bench testing technique to allow commissioning and calibration of each complete processor. This need was met by use of the graphical data acquisition software LabVIEW®[6] from National Instruments. Virtual Instruments (VIs) were written to control several GPIB instruments, which simulate beam signals, measure the BPM processor responses and present the calibration data graphically.

4.2 Bench Test Results

The wide dynamic operating range of the detector is illustrated below in Figure. 5, which shows one channel response in multi-bunch mode, the output expressed in terms of beam offset. Signal levels (Δ/Σ) corresponding to 1.6mm offset in the new detectors are used to illustrate the response of the LF detector for real storage ring pickup vessels, and demonstrates the resolution over the full working range.

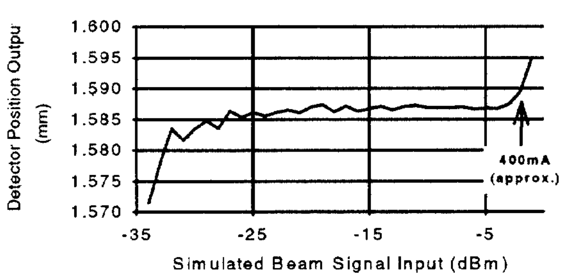

Figure 5. LabVIEW® Automated Data Processor Response

4.3 Installed Operational Performance

The new processing installation has now been completed and all 16 BPM processors are installed and connected to their dedicated 16 bit ADC units. This has allowed testing with beam, and also accelerator physics experiments to begin to assess the new processors usefulness for global horizontal feedback. Data acquisition software has been completed which allows data to be taken from all 16 horizontal and vertical BPMs simultaneously. Of particular importance is the horizontal noise performance. Figure 6. below shows 600 horizontal plane readings taken over 10 minutes with a 250mA stored 2.0GeV user beam.

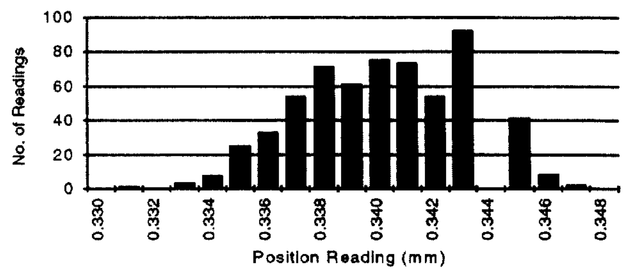

Figure 6. With-Beam Data Showing Typical Noise (BPM H9)

Analysis of data taken shows that typical horizontal BPM rms noise is only 3μm, which is to be compared with the horizontal electron beam size of ≈1.0mm (sigma).

5. Conclusions

The new down conversion technique has proved to be a great success for the detection of beam position. Performance targets from the original specification have been met or exceeded, and system commissioning time was greatly reduced by the essential use of LabVIEW® for accurate processor calibration. Operational use of the detector system is now making the correction of beam position extremely simple and reliable. The associated local ADC system has realised a significant improvement in reading speed, facilitating the implementation of global feedback, and the possibility of orbit correction during ramping. The processor units are simple and reliable, low power, low cost, ruggedised and suitable for use with future storage rings due to the method of operation. Work is in hand to obtain first turn injection signals from the processing units.

6. Acknowledgments

J.R. Alexander for technical support during the system commissioning. Dr. D.E. Poole for advice and guidance. A.R. MacDonald for help in areas of equipment construction and testing. T. Cosgrove for his assistance with prototyping.

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