DEVELOPMENT OF THE S-BAND BPM SYSTEM FOR ATF2

A. Lyapin*, B. Maiheu, M. Wing, University College London, UK
S. Shin, Fermilab, Batavia, IL, USA
Y. Honda, T. Tauchi, N. Terunuma, KEK, Ibaraki, Japan
A. Heo, E.-S. Kim, H.-S. Kim, Kyungpook National University, Daegu, Korea
R. Ainsworth, A. Aryshev, S. Boogert, G. Boorman, S. Molloy,
Royal Holloway, University of London, Surrey, UK
D. McCormick, J. Nelson, G. White, SLAC, Menlo Park, CA, USA
D. Ward, University of Cambridge, UK

Abstract

The ATF2 international collaboration is intending to demonstrate nanometre beam sizes required for the future Linear Colliders. An essential part of the beam diagnostics needed to achieve this goal is the high resolution cavity beam position monitors (BPMs). In this paper we report on the S-band system installed in the final focus region of the new ATF2 extraction beamline. It only includes 4 BPMs, but they are mounted on the most critical final focus magnets squeezing the beam down to 35 nm. We discuss both the design and the first operational experience with the system.

INTRODUCTION

The new extraction beamline of ATF2 (Accelerator Test Facility, KEK, Japan) [1] required large beam aperture submicron resolution BPMs for the final focus magnet system due to large (compared to the rest of the beamline) beam size in the final focus region – right where it will be squeezed to achieve the target 35 nm at the interaction point. Standard C-band BPMs with a beam aperture of 20 mm [2], used throughout the extraction beamline, would not be suitable in that case, so we had to design a larger size cavity with a 40 mm beam aperture in order to instrument the 4 final focus magnets. Our C-band design was modified for that purpose and scaled to a lower frequency of 2.9 GHz, which is in the S-band of microwaves.

S-BAND CAVITIES

The design was sketched up by our UK team working on a similar high resolution S-band BPM for the energy measurements [3], and then the KNU group took over. As our C-band cavities, the S-band cavity is circular with four coupling slots in one of its flat surfaces for coupling the dipole mode and rejecting monopole modes. The design frequency was 2878 MHz, but in attempts to match the decay time of the dipole mode to about 150 ns needed for processing it shifted to 2890 MHz, which does not affect the performance of the system as the Local Oscillator (LO) frequency can be changed to keep the same frequency going into the digitisers (see the next section). The cavity provides about 0.5 V/mm/nC sensitivity, so that sub-micron resolution can be achieved with it as it was done with a similar system and a similar beam during our experiments at SLAC [4].

The mechanical design and manufacturing was done by KNU basing on experience of KEK (Japan) and PAL (Korea). The cavities were made of oxygen free copper and brazed together at temperatures reaching 900 $^\circ C$. A minimum amount of brazing material was used to avoid it from leaking into the cavity, which could result in an altered frequency and perturbations leading to cross-coupling. The cavities were mounted on the same support as the final focus magnets, as close to them as possible to allow for beam alignment of the magnets (fig. 1).

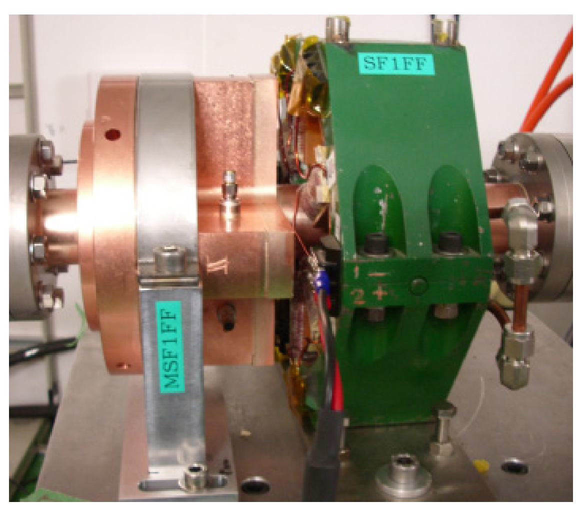

Figure 1: One of the S-band cavities in an assembly with a final focus magnet in the ATF2 extraction beamline.

* al@hep.ucl.ac.uk

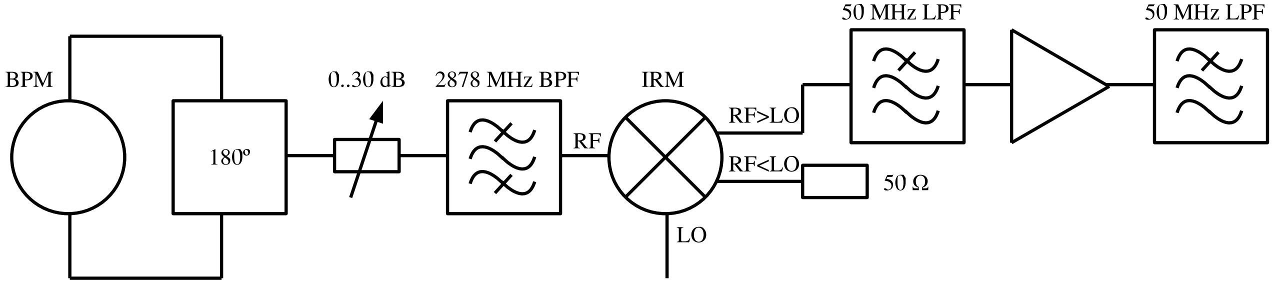

Figure 2: Simplified schematic of the S-band signal processing electronics.

ELECTRONICS AND SIGNAL PROCESSING

Our electronics uses a single stage mixer down-converting the BPM signal from 2.9 GHz to 20–30 MHz (fig. 2). The signals from the opposite couplers can be combined in a 180 °-hybrid to gain up to 3 dB of the signal level. The sensitivity of the electronics is adjusted for different ranges of the beam offsets with a remotely controlled attenuator at the front end, providing up to 30 dB attenuation. It is followed by a band pass filter centred at the dipole mode frequency of the cavity rejecting the out-of-band noise.

The signal is then processed by an Image Reject Mixer (IRM), which rejects the noise around the image frequency passing through the front-end [5]. The image frequency is symmetrical to the dipole mode frequency with respect to the LO and is therefore mixed down to the same frequency as the useful signal and can have some impact on it. The output of the mixer contains both the down- and the up-converted components of the signal, so a low-pass filter follows the mixer in order to suppress the up-converted component. It also filters out the RF signal leaking through the mixer directly from the input to the output. A low frequency amplifier compensates for the losses in the other components and provides a total gain of the electronics of 10–12 dB. Another low-pass filter further suppresses all the unwanted signals including harmonics generated by the amplifier and prevents aliasing in the digitisers further down the processing chain.

The signal is digitised at 100 or 120 MHz (with the internal clock generated by the digitiser or external clock locked to the ATF2 RF system respectively) by Struck SIS3301 8-channel VME digitisers. Further processing is done digitally in the software.

The electronics were assembled in 19” rack cases from SMA connectorised commercially available components (fig. 3). For better energy efficiency the power supply was assembled in a separate case and different supply voltages distributed to all the modules using multi-core cables. The attenuators and the amplifiers providing the LO power for the mixers are controlled by a National Instruments PCI-6259 DAQ card installed in a PC running Windows. Custom made boards in each electronics module (seen in fig. 3 to the left) provide interface between the DAQ and the electronics hardware. The DAQ card is also used for monitoring environmental data in the system such as temperatures, supply and control voltages etc.

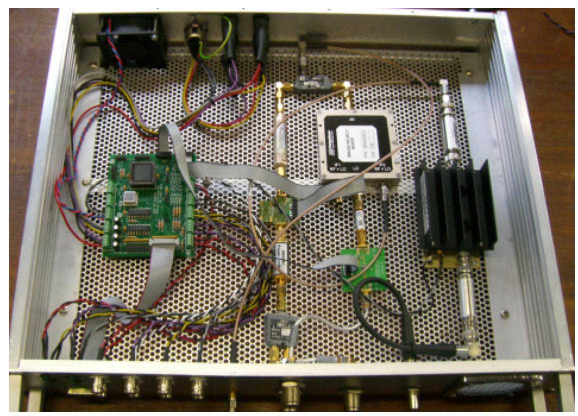

Figure 3: One of the S-band electronics modules with its lid open.

In the software the digitised BPM signal is down-converted again down to the baseband in order to extract the envelope. For that the LO frequency is matched to the frequency of the signal measured using either the Fourier transform or waveform fitting. A digital equivalent of an In-phase/Quadrature mixer (I/Q-mixer) creating a vector representation of the signal is used for down-conversion in order to extract the phase. A Gaussian filter is then applied to both I and Q components to suppress the up-converted component and reduce the noise bandwidth. The resulting waveform is sampled around its peak and during the calibration, when the BPM is moved together with the magnet on a precision stage or the beam position is changed in known steps, the amplitudes for every position and the phases measured at this point are averaged to get the scale and the phase rotation for the offset signal. The calibration parameters are then used for calculating the beam offset. Some details of this processing can be found in [4, 6].

INSTALLATION AT ATF2

At ATF2 the electronics were installed in a rack outside the extraction line tunnel (fig. 4) with 30 m long cables connecting them to the cavities. We measured around 14 dB attenuation with these cables, which is higher than our current electronics gain and so gives a negative total gain. For achieving sub-micron resolution we hope to replace them with lower loss cables and improve the total signal-to-noise ratio in the nearest future. For the same purpose, low-noise amplifiers can be installed in the front-end of the y-channels later in the commissioning when the beam is stable and a better resolution can be achieved for the more important vertical direction in which a 35 nm beam size is to be demonstrated.

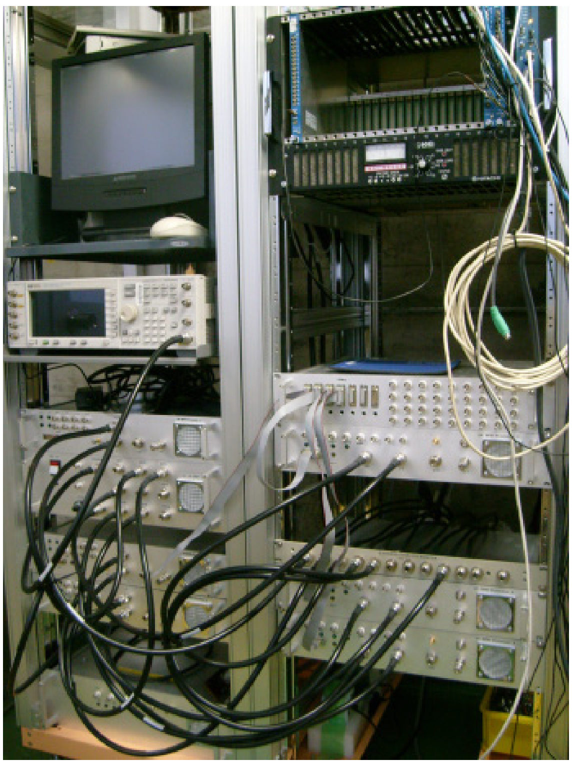

Figure 4: S-band electronics system in a rack at ATF2.

The system is now under commissioning at ATF2. We checked the appearance of the waveforms visually and did not notice any anomalies such as monopole mode transients or any other mode-mixing issues (fig. 5). It takes the signal about 300 ns to decay by a factor of 3, which means a decay time of about 150 ns, as per design.

The system is currently being integrated in the ATF2 BPM readout system. Once this is done, we will be able to calibrate the system using movers supporting the final focus magnets and begin its operation.

SUMMARY

A large beam aperture S-band cavity BPM system was designed and installed in the ATF2 final focus region to satisfy the stay-clear requirements in that part of the beamline and provide diagnostics for the final focus magnet system. Initial tests show no issues and the system is now being integrated into the ATF2 readout to allow for further commissioning, calibration, resolution and stability measurements, and finally normal exploitation.

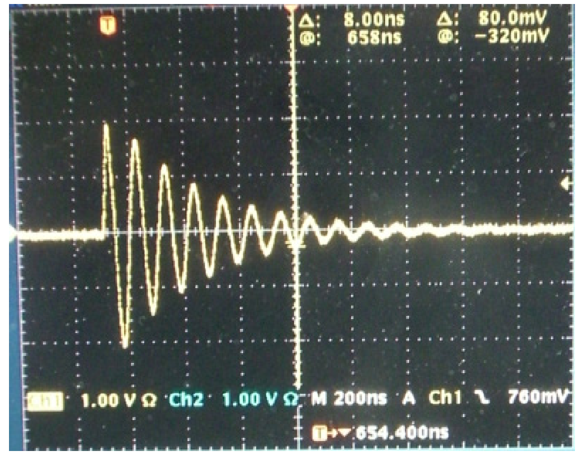

Figure 5: First beam generated signals seen from the S-band system.

REFERENCES

[1] The ATF2 collaboration, ATF2 (Accelerator Test Facility) proposal, 2006, `http://lcdev.kek.jp/ /ILC-AsiaWG/WG4notes/atf2/proposal/`

[2] S. Molloy et al., Development of the C-Band BPM System for ATF2, these proceedings

[3] A. Lyapin et al., A Prototype S-Band Cavity BPM System for the ILC Energy Spectrometer, EUROTeV-Report-2008-072

[4] M. Slater et al., Cavity BPM system tests for the ILC energy spectrometer, Nuclear instruments and Methods, 2008, 10.1016/j.nima.2008.04.033

[5] B. Henderson, J. Cook, Image-Reject and Single-Sideband Mixers, Watkins-Johnson Company Tech-Notes, Vol. 12 No. 3, May/June 1985, `http://rfwireless.rell.com/pdfs/TN_WJimage.pdf`

[6] S. Walston et al., Performance of a high resolution cavity beam position monitor system, Nuclear Instruments and Methods, 2007, 10.1016/j.nima.2007.04.162