A PROPOSAL OF A SINGLE COUPLER CAVITY BEAM POSITION MONITOR

A. Lyapin*, University College London, UK
S. T. Boogert, Royal Holloway, University of London, Surrey, UK

Abstract

Cavity beam position monitors (CBPM) made a significant progress in the last 10 years with an entire nanobeamline relying on them being currently commissioned at ATF2 (KEK). The major improvement was the introduction of the mode selective coupling allowing for efficient rejection of unwanted monopole modes. We propose another step towards creating a simple and cost effective CBPM - a cavity using just one coupler (instead of 2 or even 4) to couple out both polarisations of the dipole mode. The x and y signals are then split in the mixing stage of the electronics, so that only one expensive high-frequency electronics front-end is used for both x and y. A very good separation of the x and y signals can be achieved with a reasonable performance mixer assembly. In this paper we present the concept and provide some simulation results proving this processing scheme.

INTRODUCTION

CBPMs have been in use for almost 50 years, the whole of the SLAC linac is instrumented with rectangular S-band BPMs, but a lot of progress has been made in the last decade following the first nanometre-level resolution measurement [2]. Around the same the same time the group led by V. Balakin proposed the mode selective coupling [1]. Earlier designs were using antennae inserted directly into the cavity, which were coupling out all possible modes of the cavity picking up a lot of monopole mode background, sometimes prevailing over the dipole mode signal by orders of magnitude. Using coupling slots at one of the flat walls of the cavity (as shown in Fig. 1 (left) it is possible to reduce the monopole mode leakage by 40-60 dB.

With the new mode-selective cavities resolution of 20 nm was systematically achieved during NanoBPM experiments at KEK [3]. Micrometre level stability was measured during our experiments at SLAC [4], which may be improved very soon as the main source of drifts was identified. The entire new extraction beamline of the ATF2 facility, which is now under commissioning and aiming at nanometre beam sizes, relies on a range of CBPM systems [5, 6, 7].

Nevertheless, not all the problems are yet completely solved for CBPMs, among them the cross-talk between the channels measuring the x and y position and the high fabrication costs of the cavities and electronics. Our proposal is aimed at these problems and may help making CBPMs more reliable and affordable.

* al@hep.ucl.ac.uk

BASIC PRINCIPLES

A bunch of charged particles travelling through a microwave cavity excites a signal represented by a number of cavity modes. If the bunch has an offset from the centre of the cavity, the first dipole mode is excited among the others, and the bigger the offset, the higher is the dipole mode amplitude. Coupling that signal out with slots arranged to the x and y axes we would ideally get the x and y components of the beam offset. In practise, though, the dipole mode is always affected by small perturbations of the cavity's geometry splitting it into two polarisations, usually not aligned to the x and y as shown in Fig. 1 (left), resulting in a cross-talk. These perturbations can be compensated by mechanical tuners and the polarisations realigned to the geometrical axes, but the tuners must be included in the mechanical design adding extra time and cost to the fabrication process.

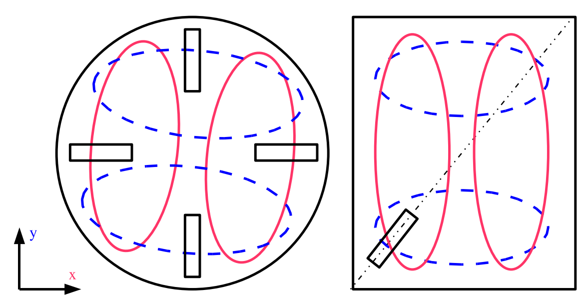

Figure 1: Magnetic fields of the dipole mode in a cylindrical and a square-shaped cavity.

Another approach is to introduce a strong perturbation into the cavity's geometry to force the two polarisations to align to the cavity's x and y, the most brutal form of which would be a rectangular cavity as shown in Fig. 1 (right). The polarisations can be coupled out separately with the same arrangement of the slots hence the cross-talk is small.

The perturbation also results in a frequency split between the polarisations. That means that they can be put into one electronics channel, providing they can later be separated efficiently. We propose to use a single slot for coupling both polarisations. It has to be aligned to the cavity's diagonal line in order to minimise its own impact on the rotation of the polarisations. The coupling can be made symmetrical in order to preserve the mutual alignment of the

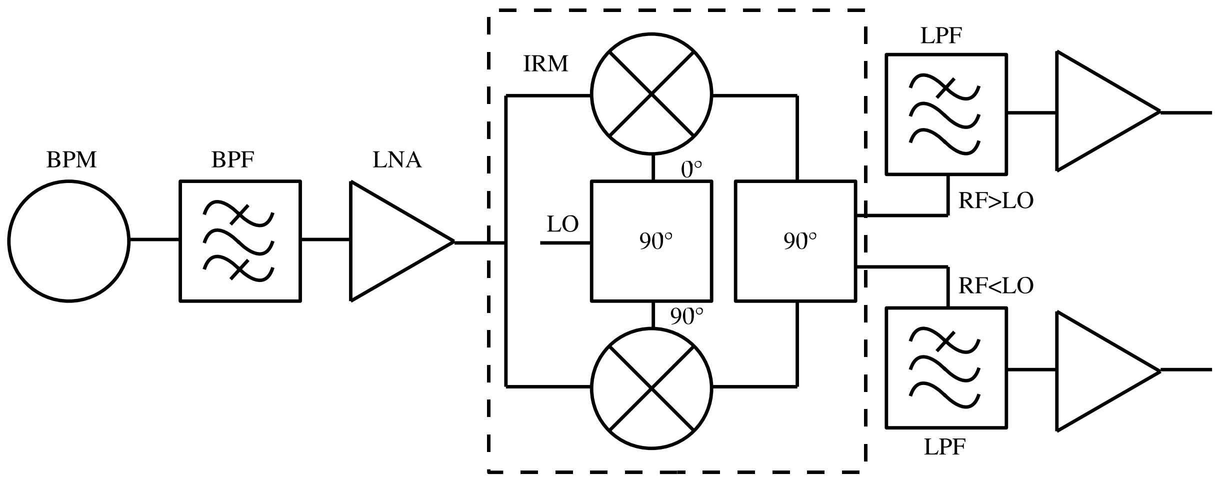

Figure 2: Processing scheme that can be used for separating the signals from a single-coupler CBPM.

mechanical and electrical centres of the cavity. The combined two-frequency signal is then coupled into a coaxial cable trough a short section of a waveguide adaptor and delivered to the processing electronics. Below we show how both signals can be processed in one electronics channel and then separated.

THE PROCESSING SCHEME

We propose a processing scheme using an Image Reject Mixer (IRM) [8] to process the BPM signal containing a mixture of both polarisations. IRM uses two identical mixer circuits to process the signal, but the Local Oscillator (LO) signal is supplied to them with a 90 ° phase difference. Assuming that the LO frequency is exactly between the two polarisations peaks, we have at the mixer outputs

$$\frac{A}{2}\cos\omega_{IF}t + \frac{B}{2}\cos\omega_{IF}t \tag{1}$$

$$\frac{A}{2}\sin\omega_{IF}t + \frac{B}{2}\sin\omega_{IF}t, \tag{2}$$

where A and B are the amplitudes of the both polarisations and ω_{IF} is the down-converted frequency. Passing through the hybrid at the RF>LO output the signals in the lower arm of the IRM gain an additional 90 ° phase delay:

$$\frac{A}{2}\cos\omega_{IF}t - \frac{B}{2}\cos\omega_{IF}t, \tag{3}$$

so that in combination with the signals from the upper arm they give

$$A\cos\omega_{IF}t. \tag{4}$$

Similarly, at the RF<LO output we only have the signal produced by the other polarisation.

In case the frequency after down-mixing is the same for both polarisations, the isolation between the two polarisations depends on the image rejection properties of the IRM – usually at least 20-30 dB. Better results can be achieved if the frequencies of the down-mixed signals are separated by a few bandwidths of the cavity, see Fig. 3. In that case the signal produced by the other polarisation can easily be filtered out after the conversion to the baseband adding another 20-30dB isolation depending on the separation and the bandwidth of the signals and the filter.

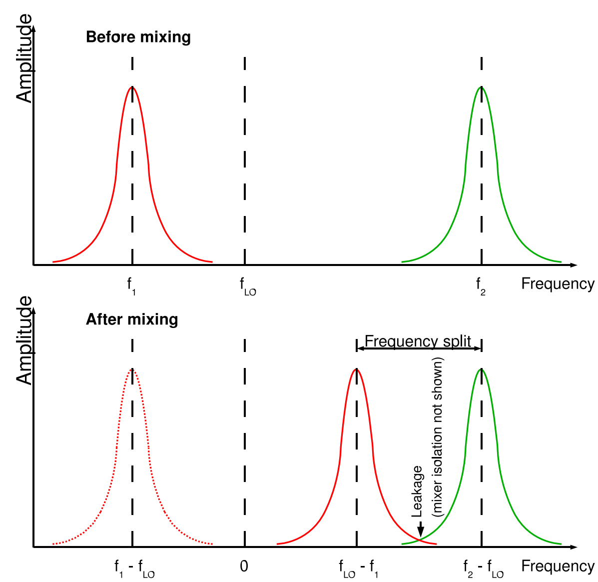

Figure 3: Frequency conversion in the IRM mixer electronics.

SIMULATION RESULTS

For simulating the cavity response and processing electronics we used our in-house code ABSim (A BPM Simulation) [9], which simulates the BPM response from the first principles. The beam position was varied by 0.1 mm RMS centred at 0.5 mm. We included the electronics and digitiser noise in the simulation and verified it against the measured performance for the typical setup of our previ-

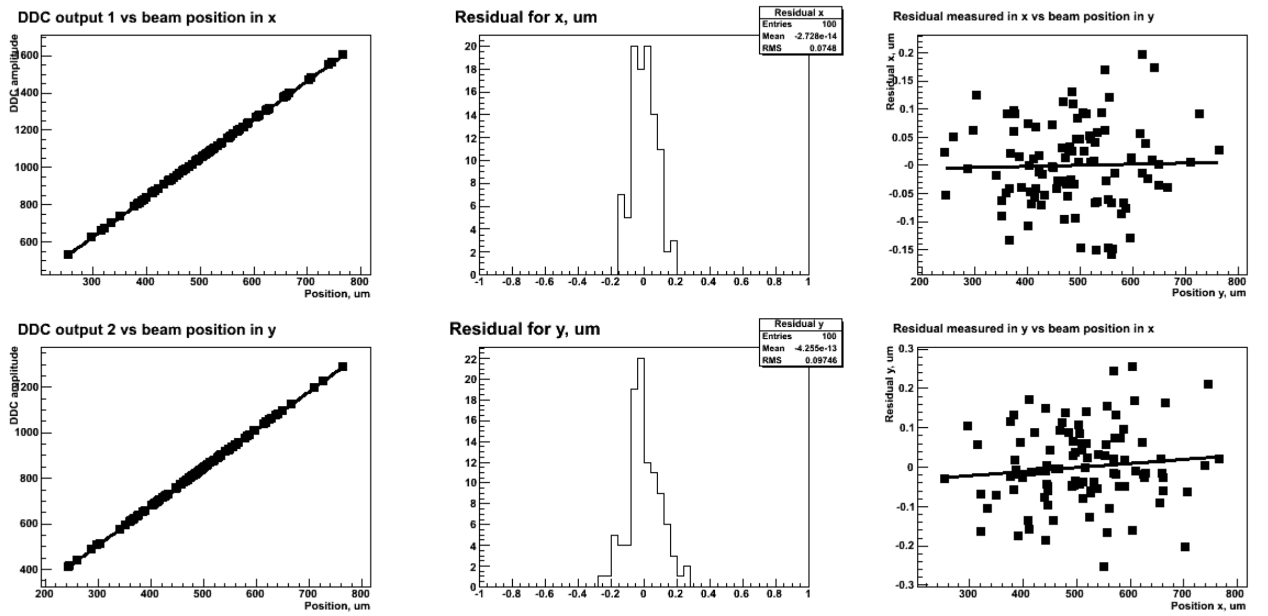

Figure 4: Results of an ABSim simulation: Processed signal amplitude versus beam position (left); Residual between the reconstructed and the real beam position (middle); Correlation between the orthogonal directions (right).

ous experiments [4]. We then ran the simulation for the proposed system and obtained sets of beam positions and corresponding BPM responses as would be seen in the digitisers.

To process the simulation results we used a typical digital signal processing including digital down-conversion to the baseband and filtering. We picked one sample of each waveform located close to the maximum of the processed signal and plotted them against the beam position for calibration (Fig. 4, left). We then compared the beam position measured for each bunch with the true bunch position in order to get a resolution estimate from their residual (Fig. 4, middle).

First setting the frequencies of both polarisations so that they were mixed down to the same frequency we discovered that, given the settings we used, the software introduces a phase error of 1-2° typical for a reasonable quality IRM. This error resulted in a cross-talk of around 1%, or 40 dB isolation. When the applied a frequency split of 10 MHz between the downmixed signals, we saw almost no corellation between the x-signal and y-position and vice versa (Fig. 4, right). The isolation estimate for this case was 80 dB, and the resolution returned to 100 nm we previously simulated for a conventional system (with 0.7 V/mm/nC BPM sensitivity and 10 dB total electronics gain).

SUMMARY

We proposed a novel CBPM design rejecting the internal cross-coupling between the x and y channels of the cavity and reducing the fabrication costs. A suitable signal processing scheme was also discussed. Our simulations showed that 80 dB isolation between x and y can be achieved without any visible degradation of the system's performance, although such processes as inter-modulation need double-checking. Our future efforts will be focused on real life tests of this new approach, including beam experiments.

REFERENCES

[1] V. Balakin et al. Experimental test of Beam Position Monitor for Linear Collider, http://www.vlepp.serpukhov.su/engl/bnl/bpm.html

[2] T. Slaton et al., Development of Nanometer Resolution C-band Radio Frequency Beam Position Monitors in the Final Focus Test Beam, LINAC98, 1998

[3] 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

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

[6] A. Lyapin et al., Development of the S-Band BPM System for ATF2, these proceedings

[7] A. Heo et al., Nanometre Resolution Beam Position Monitor for the ATF2 Interaction Point Region, these proceedings

[8] 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

[9] A. Lyapin, B. Maiheu, S. Boogert, ABSim – A BPM Simulation Software, in preparation