ISBN: 978-3-95450-241-7 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2022-MOP08

DEVELOPMENT OF A WAVEGUIDE BPM SYSTEM*

A. Lyapin[†], W. Shields
John Adams Institute at Royal Holloway, University of London, Egham, UK

Abstract

A mode-selective waveguide beam position monitor (BPM) is under development. It is aimed primarily at electron linacs, although with its low impedance and wide bandwidth it could find alternative applications. In this paper we go over the design of the waveguide BPM system including the sensor and analog electronics, consider requirements to the digital processing and present some simulated results.

INTRODUCTION

Back in 2011, we reported on an idea of a mode-selective waveguide BPM, please, refer to [1] for full details and references to previous work. In a nutshell, we realised that waveguides can be made to selectively couple to the difference mode of the field travelling together with the beam by a special arrangement of coupling slots within the beampipe. At the same time, they suppress the common mode in a way similar to how selective coupling works in cavity BPMs and wakefield suppressing couplers in some accelerating structures. In this proceeding we report on a short project we ran recently that concentrated on advancing this idea towards a design of a complete BPM system. We also discuss the next steps towards a proof-of-principle test.

BENCH MEASUREMENTS

Previously a prototype waveguide BPM had been built for bench testing, Fig. 1. One of the tests carried out with this prototype since the last report was a linearity test. It was done by inserting an antenna into the beampipe to radiate a signal imitating the beam and measuring the transmission from the antenna to the outputs of the waveguide couplers. The aim was to demonstrate the linearity of the device by scanning the antenna position and looking at the corresponding change in the transmission from the antenna to the output port.

The result of this test is shown in Fig. 2. The plot presents the measured transmission coefficient on the complex plane. One can see that all the points lie on a straight line, so the position signal always comes in a certain phase, just like it is the case with cavity BPMs. This allows to separate the position signal from angle and reduce the out-of-phase noise and interference using a phase reference. The measured points corresponding to equal position steps are equidistant, which confirms the device's position linearity.

SENSOR DESIGN

With the encouraging results from bench testing we were able to start designing a prototype for beam measurements. As a starting point, we chose a beam aperture of 8 mm as with little or no modification this would be a fitting design for most undulator beamlines of Free Electron Lasers (FEL). It is also compatible with such a major accelerator project as the Compact Linear Collider (CLIC) and its former test facility now CERN Linear Electron Accelerator for Research (CLEAR), which makes CLEAR a perfect location for future beam tests. We decided to choose 15 GHz as the nominal processing frequency as it was compatible with the selected beampipe diameter. Also, at 15 GHz the waveguide BPM processing can share some parts with the complementary cavity BPM programme running at CLEAR.

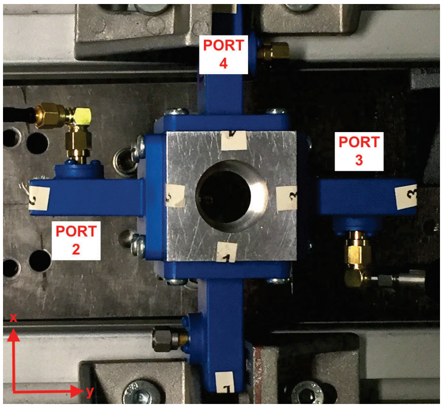

Figure 1: Prototype sensor on a test bench.

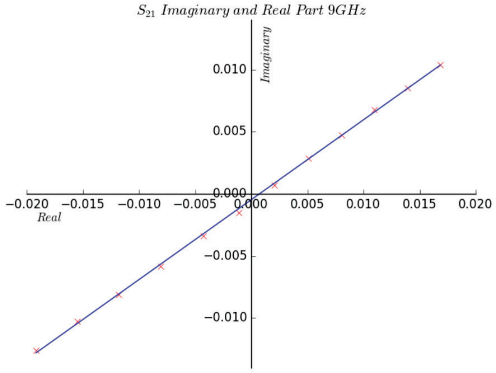

Figure 2: Port transmission measured with a moving antenna.

The design had thus been optimised for 15 GHz, which is roughly the middle of the chosen WR62 waveguide's passband. Using a Finite Difference Time Domain code GdfidL [2] we tuned the transmission of the difference mode of the beampipe into the output waveguide of the sensor. The resulting transmission curve is shown in Fig. 3. Depending on the chosen processing scheme, a wider or narrower part of the available bandwidth can be used, but up to 10 GHz bandwidth is available.

---

[*] Work supported by STFC Follow On Fund grant number ST/T003413/1
[†] alexey.lyapin@rhul.ac.uk

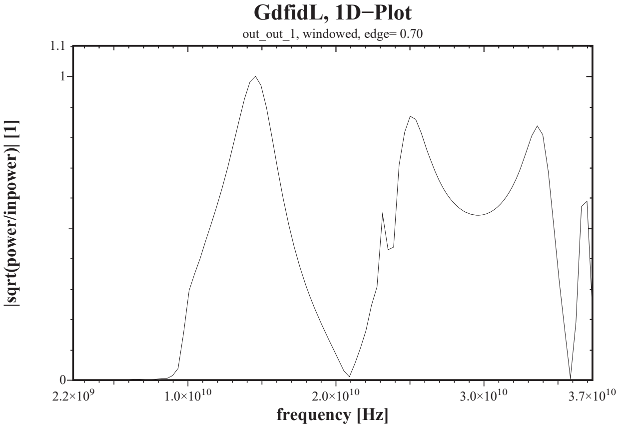

Figure 3: Coupling between the difference mode of the beam pipe and the output waveguide vs frequency.

The wide bandwidth of the waveguide sensor allows for it to be used with closely spaced bunches. One does not get any real boost in signal output (in contrast to cavity BPMs), but a long burst of pulses, such as the one computed for 100 bunches at CLEAR shown in Fig. 4, will produce distinct spectral lines, containing information on the average beam position and intra-beam offsets.

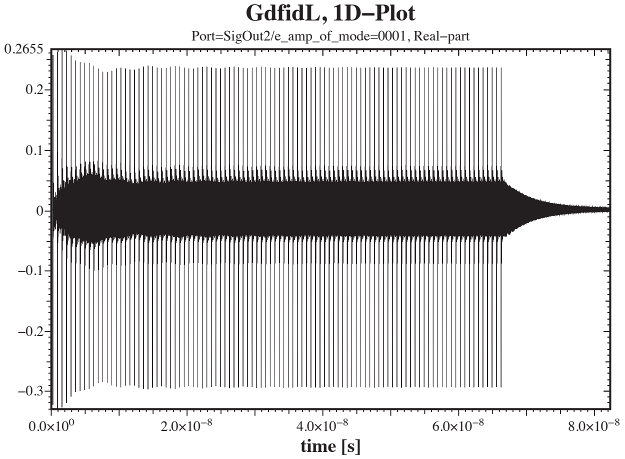

Figure 4: A burst of pulses generated by a long train of bunches.

VACUUM PROTOTYPE

The design of a vacuum prototype is reaching its final stages and is based around the application of radio frequency (RF) compatible vacuum seals [3]. The majority of machining can be done using conventional milling, although spark erosion may be required for the precision cuts of the coupling slots. A 3D view of the main block hosting the waveguide sensors is shown in Fig. 5. As in the figure, the beam would travel through a beampipe going in the vertical direction with output couplers on the sides of the block. Figure 6 shows a cross-section of the block revealing the arrangement of the coupling slot.

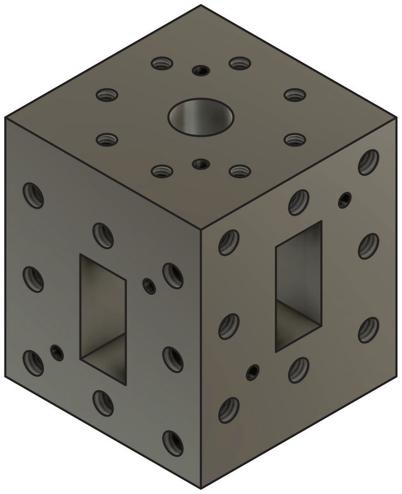

Figure 5: 3D view of the sensor block.

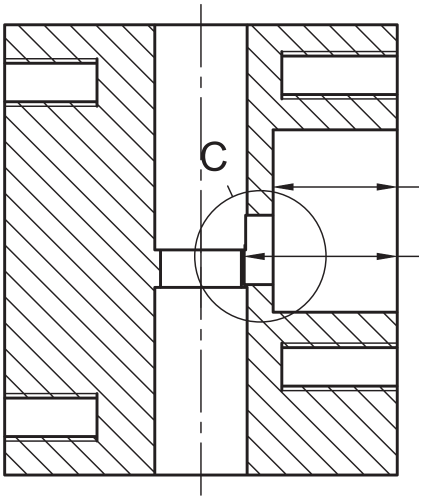

Figure 6: Cross-section of the sensor block showing the coupling slot opening into a section of the waveguide.

SIGNAL PROCESSING

Analogue Electronics

Analogue processing is fairly primitive at the moment and designed for flexibility and linearity rather than high sensitivity, Fig. 7. The chain includes a downconverting mixer followed by a wideband lowpass filter to suppress the high frequency components, primarily local oscillator signal leakage and up-converted input signal. Next there is an amplifier to boost the signal and curb the noise figure from further growth. A final bandpass filter is added to avoid aliasing of harmonics that may be produced by the mixer and amplifier during analogue to digital conversion. Cavity filters can be added to the input to suppress the image signal which may present a real issue with this broadband sensor. The electronics have been assembled in a modular format, Fig. 8, so that changes can be easily introduced and the bandwidth of the system modified during experiments.

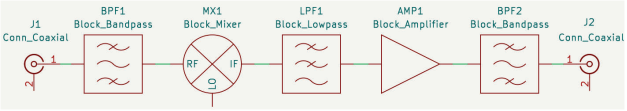

Figure 7: Block diagram of the processing electronics.

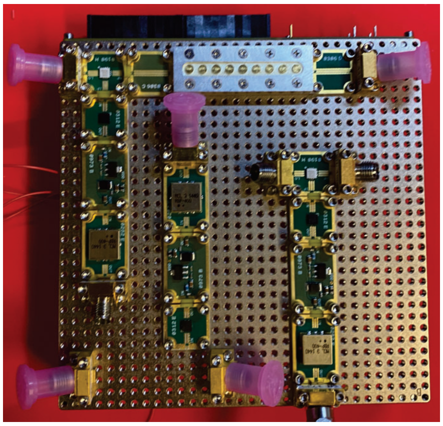

Figure 8: Modular signal processing electronics during the assembly.

Analogue to Digital Converter

The analogue to digital conversion is based on the Analog Devices' AD6676 [4] tunable bandpass $\Sigma - \Delta$ analog-to-digital converter (ADC) with up to 3.2 GSPS ADC clock rate. The interesting feature of this device is that it serves both as an ADC and an In-phase/Quadrature (I/Q) down-converter. Its output is decimated (up to 266 MSPS, 16 bit) complex data describing the amplitude and phase of the input signal. Traditionally, I/Q processing would be realised in an analogue circuit preceding the ADC. More recently, with the advances of high speed ADCs, this last stage would often follow the analogue to digital conversion. This novel converter removes the necessity of additional such processing altogether, which is beneficial to measurement systems, especially to those in which both the amplitude and phase of the signal need to be measured. At present, we are carrying out tests with an evaluation board built around the chip.

CONCLUSION

System design for a prototype waveguide BPM system is primarily complete, a prototype is underway and the subsystems are undergoing bench testing. Simulations show a promising performance in terms of sensitivity and bandwidth. This paper may be vague on detail, this is because the intellectual property (IP) rights have not yet been reserved, so we can not yet disclose the full details of the design. The next steps will involve finishing the prototype system and moving onto beam testing (which is subject to availability of further funding). Once the sensor is confirmed operational, we will start transferring the IP rights to a suitable partner for commercialisation. We are also considering an IP strategy in which the design would be open sourced. In this scenario, accelerator labs would be able to produce their own sensors with possibly a small licensing fee attached and kits for building the devices could be made available from the industrial partner alongside complete devices. Whether this will be possible will depend on various conditions including the funding source and industrial partnerships.

REFERENCES

[1] A. Lyapin, "Mode Selective Waveguide BPM", in *Proc. DIPAC'11*, Hamburg, Germany, May 2011, paper MOPD13, pp. 65–67.

[2] The GdfidL Electromagnetic Field Simulator, `http://www.gdfidl.de/`.

[3] VATSEAL vacuum RF seal technology from VATVALVE, `https://www.vatvalve.com`

[4] Analog Devices, AD6676 Wideband IF Receiver Subsystem, `https://www.analog.com/en/products/ad6676.html`