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Mode Selective Waveguide BPM

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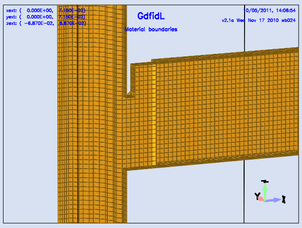
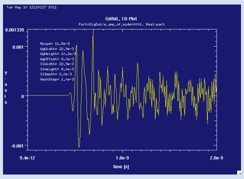
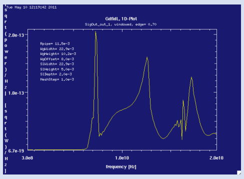
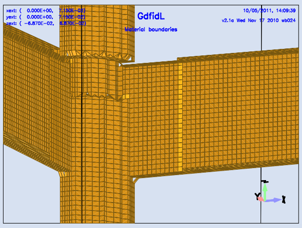
I propose a mode-selective waveguide Beam Position Monitor (BPM). It uses waveguide couplers arranged at the beampipe to create boundary conditions similar to those in slot-coupled cavity BPMs. This structure allows to couple to the differential beampipe mode co-propagating with the beam, and reject the usually much stronger monopole component of the field. As the full dynamic range of the processing electronics can be used for position measurements, and a waveguide is a native high-pass filter, such a BPM is expected to outperform stripline and button BPMs in terms of both spacial and time resolution. In this paper I give some details on the basic principle and the first simulation results and discuss possible ways of signal processing.

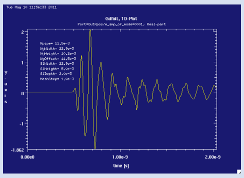
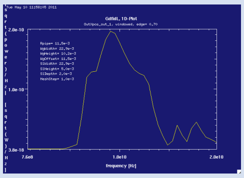


Signal and its spectrum produced by a window-coupled waveguide shown on the left.

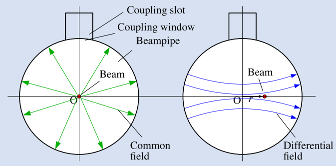
Simulations were done using GdfidL. A bunch carrying 1 nC of charge with a transverse offset of 1 mm was simulated. The beam pipe diameter was set to 23 mm, and standard WR-90 X-band waveguides. The signal produced by the window-coupled structure is shown above. There is clearly a short pulse similar to the signal produced by electrostatic pick-ups, created when the bunch enters and leaves the gap of the coupling window. The signal peak is around 1 mV (~500 μV in a 50 Ω cable. The frequency spectrum is composed of several peaks. The resolution is limited to about 70 μm (35 μV noise voltage in a 6 GHz bandwidth)



Signal and its spectrum produced by a waveguide with a slot sunken into the beampipe as shown on the left.

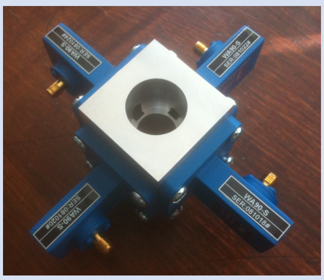
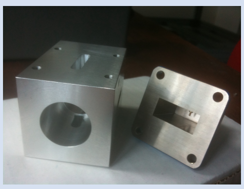
In an attempt of improving the beam coupling the coupling slots were sunken into the beampipe, creating a structure, which looks like a cavity BPM turned inside out. In this configuration the slot continues into the beampipe by a couple of mm in the part where it is not opened by the coupling window. This change alters the boundary conditions at the coupling window, virtually moving it inside the coupling slot and thus improving the coupling. The simulated signal for this case would peak to almost 1 V, which is comparable with the sensitivity of cavity BPMs. Importantly, the spectrum of the signal has a peak around 10 GHz, and is well contained within a 6 GHz bandwidth. The theoretical resolution limit in this case is about 35 nm.



Waveguides placed orthogonally to the beampipe with their longer side in the direction of the beampipe and coupling to the field of the beam through slots in the beampipe walls can be used for beam position measurement. When the beam is centred in the beampipe, there is no field gradient over the gap of the slot, meaning that the field is not coupled to the TE mode of the waveguide. A beam offset from the centre will create a differential field in the beampipe and a gradient over the slot's window.

$$i_w(b,\varphi_w,t) = -\frac{I_b(t)}{2\pi b}\left[1+2\frac{r}{b}\cos\varphi_w\right]$$

Representing the wall current as a series one gets the common and the differential modes traveling with the bunch in a circular beampipe. They represent, respectively, the position independent TEM wave, and the TE wave, whose wall currents, and hence the amplitude linearly depend on the position. This is the mode one wants to couple out, and it couples to the TE_{10} mode of the waveguide, which is its first passband.

Components (right) and assembly (left) of the prototype for cold tests

A prototype cavity for cold measurements in the laboratory was designed and has recently been manufactured. It uses 4 standard X-band waveguide-to-coax adapters with SMA connectors for coupling, and was machined of a single piece of aluminium using lathe cutting and milling only. A test bench with an antenna moving in transverse direction to simulate the beam is currently being set up for testing.

This preliminary study shows that waveguide BPMs can become high-resolution, high-bandwidth devices useful in many critical applications such as feedbacks. Below is a list of the features and questions that need to be answered:

- Output is a position-dependant, difference signal, the-oretical resolution below 100 nm
- Bandwidth only limited by the passband of the TE10 mode of the waveguide
- Simple design and fabrication, can use standard waveguide components
- Requires calibration, charge and phase reference – similarly to cavity BPMs
- Non-linearities, resonances, wakefields and effects on the optics produced by the reduced aperture need to be studied
- Interference signals traveling in the beampipe may be coupled
- Superposition of signals produced by closely spaced bunches needs to be investigated