

Contents

| | | |
|----------|--|----------|
| 1 | Theory stuff and intro | 1 |
| 1.1 | BPM generalities | 1 |
| 1.2 | Selected topics of network theory | 1 |
| 1.2.1 | Impedance matching | 1 |
| 1.2.2 | S-parameters | 1 |
| 1.2.3 | Time Domain Reflectormery | 1 |
| 1.3 | Simulation codes | 1 |
| 1.3.1 | CST STUDIO SUITE® | 1 |
| 1.4 | The AWAKE experiment | 1 |
| 2 | The present AWAKE eBPM system | 2 |
| 2.1 | Equipment description | 2 |
| 2.1.1 | Beamline and diagnostic | 2 |
| 2.1.2 | Electron BPMs | 2 |
| 2.2 | Beam spectrum | 3 |
| 2.2.1 | Gaussian beams | 3 |
| 2.2.2 | Real beams | 3 |
| 2.3 | Measurements with beam | 3 |
| 2.3.1 | Electrode signals | 3 |
| 2.3.2 | VNA measurements | 3 |
| 2.4 | Electromagnetic simulations | 3 |
| 2.4.1 | Electrode signals | 4 |
| 2.4.2 | Four-port device characterisation in simulations | 4 |
| 2.4.3 | Sensitivity studies to the beam position | 5 |
| 2.5 | Design optimisations | 5 |
| 2.5.1 | Impedance matching of the stripline termination | 5 |
| 2.5.2 | Geometrical optimisation of the space behind the stripline | 5 |
| | List of Figures | 6 |
| | List of Tables | 7 |
| | Bibliography | 8 |

Chapter 1

Theory stuff and intro

1.1 BPM generalities

1.2 Selected topics of network theory

1.2.1 Impedance matching

1.2.2 S-parameters

1.2.3 Time Domain Reflectometry

... and equivalence of TDR to S-parameters

1.3 Simulation codes

1.3.1 CST STUDIO SUITE®

Time domain, F and Wakefield simulations

1.4 The AWAKE experiment

Aim of the experiment on the conceptual level (beams + plasma). The beam-line and layout is described later.

Chapter 2

The present AWAKE eBPM system

AWAKE uses a copropagating electron and proton beam. The proton beam has a repetition rate of 10 Hz, while the proton beam from the SPS comes with time intervals in the order of the minute(s).

The simultaneous, shot-by-shot, measurement of the position of the electron and proton beams is desirable. All the experiments so far conducted assuming that the electron position did not drift in the shot with protons. The presence of protons blinds the present electron diagnostic.

2.1 Equipment description

2.1.1 Beamline and diagnostic

Description of the SPS beamline, of the electron beamline and general other instrumentation installed (including the proton BPMs).

2.1.2 Electron BPMs

The electron beam position monitoring system of the AWAKE facility was developed at TRIUMF¹. It is composed by shorted stripline-type beam position monitor, and the readout electronics in charge of the signal processing.

Beam position monitor

Two types of beam position monitors are installed in the beamlines. In the electron beamline 40 mm aperture BPMs are used, while in the common beamline the 60 mm aperture model is used. The working principle is the same and they differ mostly on the mechanical dimensions. The coverage angle is 38 degrees, with a longitudinal length of 120 and 124 mm, respectively.

¹TRIUMF, Canada's Particle Accelerator Centre, Vancouver, BC, Canada, <https://www.triumf.ca/>

Readout electronics

GENERALITIES ON THE ELECTRONICS

2.2 Beam spectrum

Intro to section.

2.2.1 Gaussian beams

2.2.2 Real beams

2.3 Measurements with beam

A number of measurements performed on BPM51 with and without beam

2.3.1 Electrode signals

with and without proton beam

2.3.2 VNA measurements

40 and 60 mm type

2.4 Electromagnetic simulations

A 3D parametric model was created in CST STUDIO SUITE® 2018 on the basis of the drawings provided by TRIUMF. The comparison between the CST model and the drawings is shown in Fig. 2.1 and Fig. 2.2. It is important to note that none of the vacuum feedthrough was modeled in CST, as it is inaccurately reported also in the technical drawings as it constitutes industrial secret. In the simulations the signal is collected from the striplines through waveguide ports placed at the end of coaxial lines. The central cylindrical pin of the coaxial line is retained at the design value, while the surrounding vacuum diameter was selected in order to match the line impedance to $50\,\Omega$, in order to avoid unwanted reflections.

The beam position monitor geometry is transversely symmetric. Whenever possible, this has been used to reduce the computing time, imposing boundary conditions.

The simulations regarded mostly calculating the signal response to the beam excitation with different bunch lengths and the full characterisation of the device as a four port network, calculating the scattering parameters. The former is realised via wakefield simulations, and the latter via frequency domain simulations.

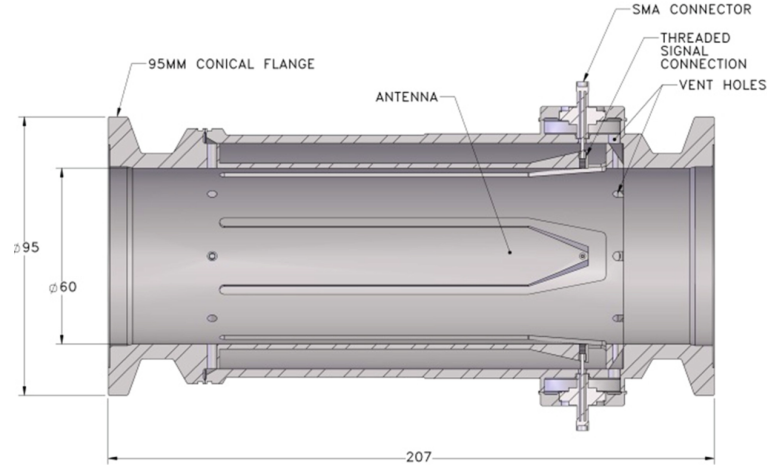


Figure 2.1: Schematic representation of a 60 mm aperture BPM[1].

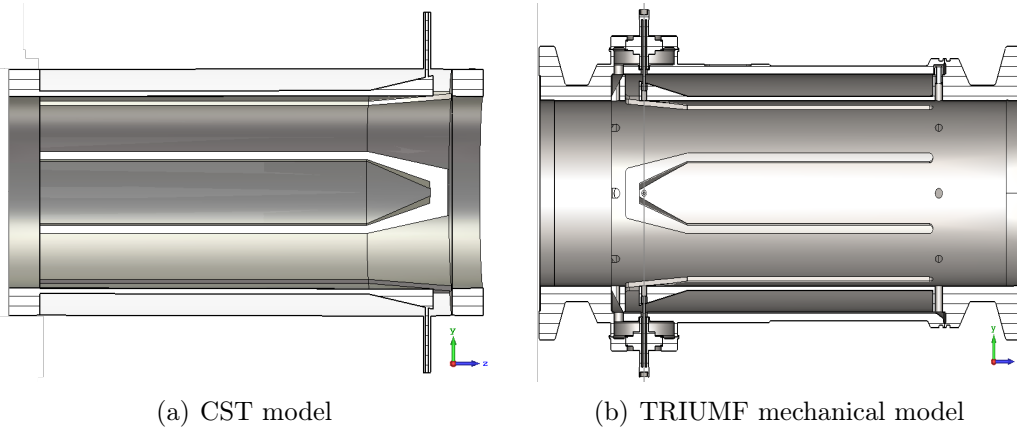


Figure 2.2: 3D models used in the electromagnetic simulations (a) and the original mechanical design (b).

2.4.1 Electrode signals

Wakefield time domain simulations have been conducted using CST in order to evaluate the stripline response to the beam excitation. This type of simulation assumes a Gaussian beam. The beam parameters were chosen starting from the nominal proton beam used in the experiments, and the charge and bunch length was gradually decreased until reaching the electron beam parameters. Using wakefield simulation it is not possible to simulate both beams travelling in the vacuum pipe together. The simulated beam parameters are reported in Tab. 2.1.

2.4.2 Four-port device characterisation in simulations

Sparam sims

| Name | Charge | | σ ps |
|-----------------|--------|--------------------|----------------|
| | nC | ppb | |
| Proton beam | 48 | 3×10^{11} | 250 |
| Proton beam/10 | 4.8 | 3×10^{10} | 25 |
| Proton beam/100 | 0.48 | 3×10^9 | 2.5 |
| Electron beam | 0.6 | 3.7×10^9 | 1 |

Table 2.1: Beam parameters used in the wakefield simulations

2.4.3 Sensitivity studies to the beam position

Sensitivity study for a proton-like beam

2.5 Design optimisations

2.5.1 Impedance matching of the stripline termination

TDR studies showed that the impedance matching to 50Ω of the striplines is not sufficiently optimised. In the attempt of understanding if this could be the source of the resonant response of the device, an geometrical optimisation of the tapered part of the stripline has been carried out. This is realised via parametric time domain simulations, observing the variation of the TDR response. Successively, a wakefield simulation was carried out with the improved geometry, comparing the electrode signal to the unoptimised version.

Something something ...

Mention that in the development phase, this geometry was optimised using the ANSYS® HFSS™ electromagnetic simulation code², but it had to be modified due to manufacturing constraints during the mechanical design phase[2]

2.5.2 Geometrical optimisation of the space behind the stripline

Same process, but for the

²<https://www.ansys.com/products/electronics/ansys-hfss>

List of Figures

| | | |
|-----|--|---|
| 2.1 | Schematic representation of a 60 mm aperture BPM[1]. | 4 |
| 2.2 | 3D models used in the electromagnetic simulations (a) and the original mechanical design (b). | 4 |

List of Tables

| | | |
|-----|---|---|
| 2.1 | Beam parameters used in the wakefield simulations | 5 |
|-----|---|---|

Bibliography

- [1] S. Liu, V. Verzilov, W. Farabolini, S. Doebert, and J. S. Schmidt, “Development of the AWAKE Stripline BPM Electronics,” *Springer Proc. Phys.*, vol. 212, pp. 237–242, 2018.
- [2] V. Verzilov. Private communication. March 2019.