Contents

Chapter 1

Theory stuff and intro

1.1 BPM generalities

1.1.1 BPM signal

1.1.2 Shorted striplines

1.2 Selected topics of network theory

1.2.1 Impedance matching

1.2.2 S-parameters

1.2.3 Time Domain Reflectormery

... 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 beamline and layout is described later.

Beams parameters: electrons, protons, laser

Beam	Charge		σ
	nC	ppb	ps
Proton beam	48	3×10^{11}	250
Electron beam	0.6	3.7×10^{9}	1

Table 1.1: Nominal beam parameters usually used for the AWAKE experiment operation.

Chapter 2

Detection of copropagating beams for AWAKE

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).

Outline of the problem: CONS: - two beams, sheilding each other - not ideal proton beam, HF components

PROS: - low repetition rate - single pass device

2.1 AWAKE instrumentation 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 TRIUMF[1]. 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 lenght of 120 and 124 mm, respectively.

[1]TRIUMF, Canada's Particle Accelerator Centre, Vancouver, BC, Canada, `https://www.triumf.ca/`

Readout electronics

GENERALITIES ON THE ELECTRONICS

2.2 Signal generation

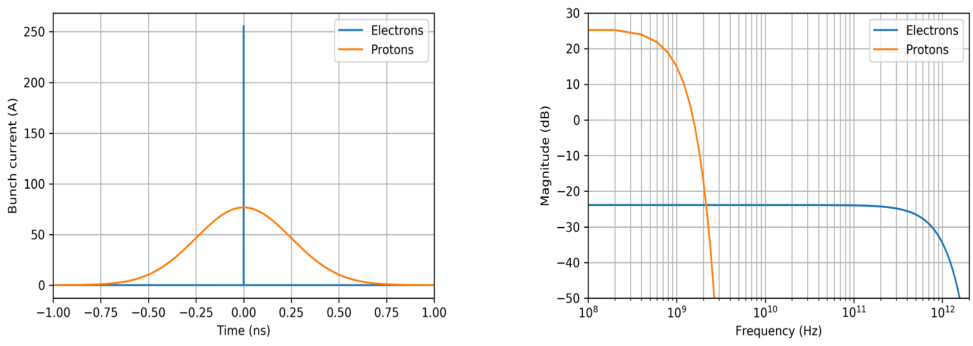
The signal is the convolution of the beam spectrum and the pickup response function (is it appropriate to speak of transfer function???). Some words on delta/sigma.

2.2.1 Pickup response

Lobes and BPM details for shorted striplines

2.2.2 Beam spectrum

In the AWAKE experiment a short electron bunch is propagating in close temporal and spacial proximity with a long proton bunch before entering the plasma cell. The beam parameters are reported in Tab. 1.1. Due to the different bunch length and charge, signals with different bandwidth and magnitude are expected from the two bunches. Figure 2.1 shows the time signals and the frequency spectrum of a 250 ps-sigma, 3e11 ppb proton bunch and a 1 ps-sigma, 600 pC electron bunch. From plot (b) it is trivial to see that around $\approx$ 2 GHz the power of the electron and proton bunch signal has equal strength. At lower frequencies the proton component dominates, while at higher frequencies the electron component has a higher power.



(a) (b)

Figure 2.1: The bunch in time (a) and frequency (b) with the paramters of the proton and electron bunch reported in Tab. 1.1.

Effect of a non-gaussian proton bunch. Extends more in spectrum.
It is reasonable to assume the electrons as gaussian (QUOTE)

2.2.3 Two beam effect

The spectrum is the sum of both, but different regions of the spectrum contain different level of information on the two beams.

Chapter 3

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 conduced assuming that the electron position did not drift in the shot with protons. The presence of protons blinds the present electron diagnostic.

3.1 Measurements

A number of measurements performed on BPM51 with and without beam

3.1.1 Electrode signals

with and without proton beam. Both 6.5 bit and 12 bit scopes.

3.1.2 VNA measurements

40 and 60 mm type

60 mm aperture model

60

40 mm aperture model

40

3.2 Electromagnetic simulations

A 3D simplified and parametric model was created in CST STUDIO SUITE® 2018 on the basis of the drawings provided by TRIUMF that were used for the series production. A new model was created from scratch instead of using the drawings in order to have the full control on the geometrical dimensions and gain in simplicity. This will be exploited when trying to optimise the design, as explained in Section 3.4. A comparison between the two showed that they agree within the mechanical tolerances provided in the design. The the CST model and its comparison to the TRIUMF drawings are shown in Fig. 3.1 and Fig. 3.2. 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 cilindrical 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 Ω, 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 lenghts 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.

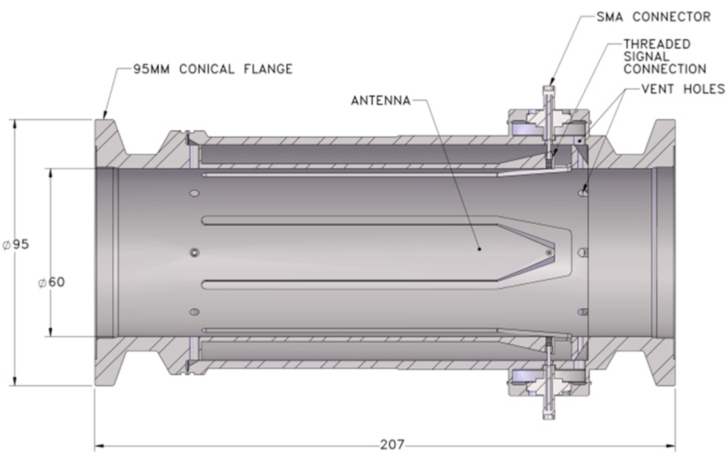
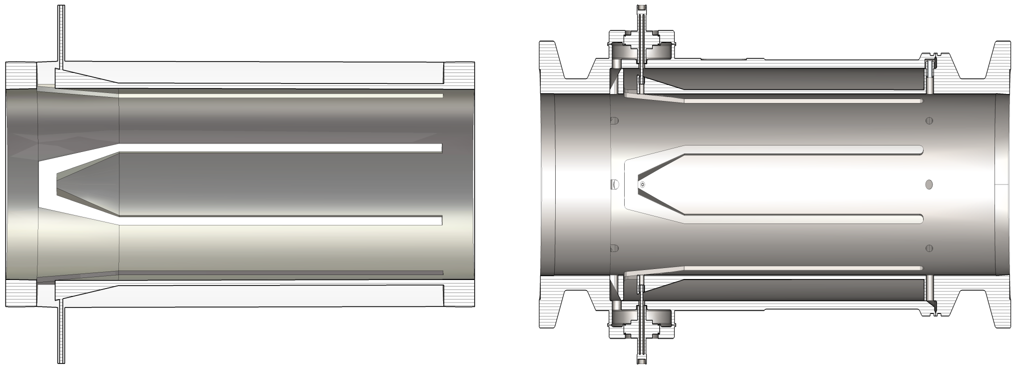


Figure 3.1: Schematic representation of a 60 mm aperture BPM[1].

3.2.1 Electrode signals

Wakefield time domain simulations have been conduced using CST in order to evaluate the stripline response to the beam excitation. This type of simulation



(a) CST model

(b) TRIUMF mechanical model

Figure 3.2: 3D models used in the electromagnetic simulations (a) and the original mechanical design (b).

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. 3.1.

Name	Charge		σ
	nC	ppb	ps
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 3.1: Beam parameters used in the wakefield simulations

3.2.2 Four-port device characterisation in simulations

Frequency domain simulations were carried out to characterise the BPM as a four port network, in order to compare to the VNA measurements carried out in the laboratory and in the tunnel. For simmetry reasons, it is sufficient to simulate half the structure obtaining anyway the full characterisation of the device including the cross-coupling between the electrodes.

3.2.3 Sensitivity studies to the beam position

Sensitivity study for a proton-like beam

3.3 Comparison between measurements and simulations

comp

3.4 Design optimisations

3.4.1 Impedance matching of the stripline termination

TDR studies showed that the impendance matching to 50 Ω 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 geomterical 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 code[1], but it had to be modified due to manufacturing constraints during the mechanical design phase[2]

3.4.2 Geometrical optimisation of the space behind the stripline

Same process, but for the

3.5 Conclusions

There is a need for high frequency systems: see the next two chapters

[1] https://www.ansys.com/products/electronics/ansys-hfss

Chapter 4

A high Frequency button BPM design

High frequency systems: something very HF, but not crazy, like 20 GHz.

Chapter 5

A sub-THz Cherenkov radiator-based BPM

A sub-THz Cherenkov radiator-based BPM. Super HF, and tests of the proof of principle at CLEAR

List of Figures

List of Tables

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.