

Electromagnetic Simulations for the PETRA III BPMs

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1. Introduction

1.1. PETRA III:

PETRA III is a new high-brilliance synchrotron radiation source to be built at DESY, Hamburg [1]. Planned to start operation in 2009, the facility will have 14 beam lines spread along one eighth of its circumference. 40 to 960 bunches with a current of 100 mA and an emittance of 1 nm-rad will be circulated at 6 GeV. The topping up operation will ensure a stable beam.

235 beam position monitors (BPM) of button type with several different designs will be built in the various chamber sections of the accelerator. These monitors have been studied through various methods, such as measurements on button models, analytical calculations and simulations of the electromagnetic fields. This report presents simulations made with two electromagnetic field codes, MAFIA [2] and Microwave Studio [3], on the characteristics of these BPMs. The results for a few types of monitors are shown.

1.2. BPM characteristics

Most of the vacuum chamber along the PETRA III circumference has elliptical cross-section of various dimensions. The pickups of the BPMs are placed up-right (UR), up-left (UL), down-right (DR) and down-left (DL) (see Fig. 1).

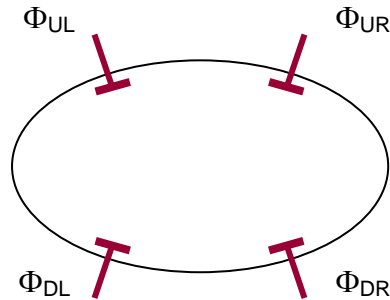


Figure 1: Schematic of a typical BPM for PETRA III

Through combination of the signals Φ at these buttons, excited by the beam, one gets signals, Φ_H and Φ_V , proportional to the horizontal and vertical beam offsets from the chamber center (eqs. (1)):

$$\begin{aligned}\Phi_H &= \frac{\Phi_R - \Phi_L}{\Phi_R + \Phi_L} = \frac{(\Phi_{UR} + \Phi_{DR}) - (\Phi_{UL} + \Phi_{DL})}{\Phi_{UR} + \Phi_{DR} + \Phi_{UL} + \Phi_{DL}} \\ \Phi_V &= \frac{\Phi_U - \Phi_D}{\Phi_U + \Phi_D} = \frac{(\Phi_{UR} + \Phi_{UL}) - (\Phi_{DR} + \Phi_{DL})}{\Phi_{UR} + \Phi_{UL} + \Phi_{DR} + \Phi_{DL}}\end{aligned}\quad (1)$$

The monitor constant is defined as the slope of Φ_H and Φ_V at the chamber center:

$$\frac{1}{\mathbf{K}_H} = \frac{\partial}{\partial \mathbf{x}} \Phi_H(\mathbf{x} = 0, \mathbf{y} = 0), \quad \frac{1}{\mathbf{K}_V} = \frac{\partial}{\partial \mathbf{y}} \Phi_V(\mathbf{x} = 0, \mathbf{y} = 0) \quad (2)$$

From here one can calculate the measured beam offset with a good approximation over a certain range as:

$$\mathbf{x} = \mathbf{K}_H \Phi_H, \quad \mathbf{y} = \mathbf{K}_V \Phi_V \quad (3)$$

In conjunction with the characteristic of the electronics used with a BPM, K gives the resolution of the monitor.

Another characteristic of a BPM is the coupling of the beam to the pickups, which tells how much signal is delivered by a pickup for a given beam.

2. Electrostatic Simulations

Although they cannot give a full picture of the signals from a BPM, electrostatic simulations can lead to the monitor constant and information on the coupling factor. We use MAFIA for such simulations [2].

2.1. Method

In most cases a 2D model is sufficient to calculate the monitor constant and a relative coupling factor. Fig. 2 shows the model of a BPM for the damping wiggler section of PETRA III. The chamber profile is flat with rounded ends, with dimensions 120mm×30mm. The background is defined as perfect conducting, while the chamber is defined as vacuum. The four pickups are defined as being of different materials, all perfect conductors, but with the possibility to define a different potential applied to each of them.

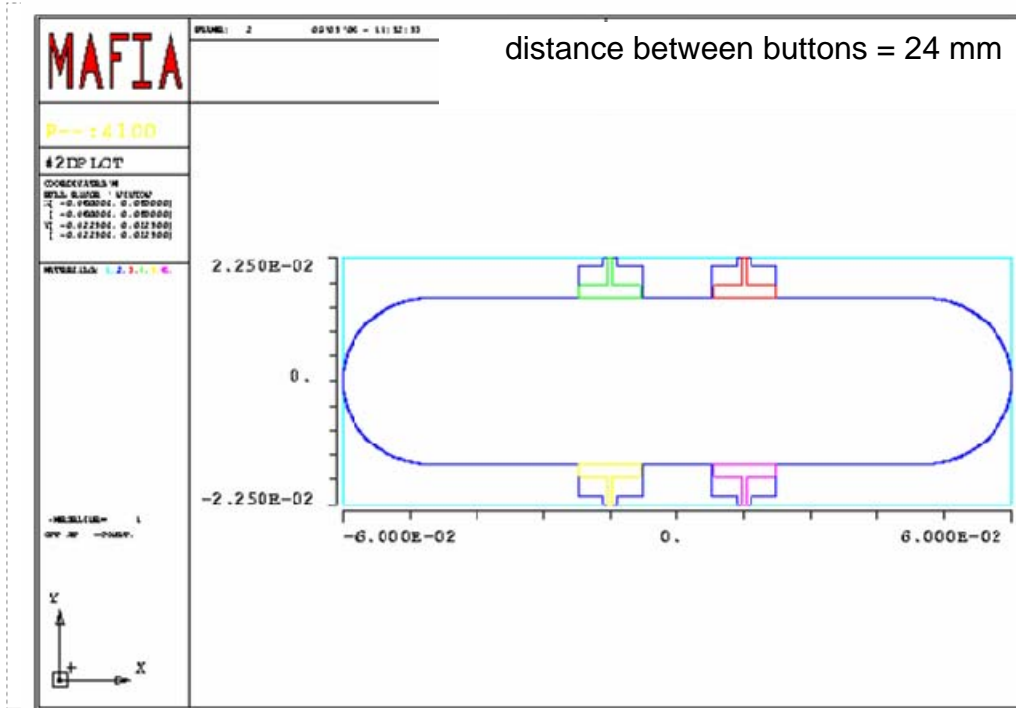


Figure 2: 2D model of a BPM for the damping wiggler section

We apply 1V at one of the buttons, while we keep the others at 0V, and calculate the electric field distribution. By considering the symmetry of the model, one can then calculate the field for the case of applying 1V at each of the pickups individually. By combining the

four results, based on reciprocity, one can then calculate Φ_H and Φ_V , and from here the monitor constants, K_H and K_V .

We define the coupling factor between the beam and the pickups, as the voltage at the middle of the vacuum chamber when applying 1V at one of the pickups. Although this number will not give us the signal amplitude for a real beam, one can compare in this way the signals for various monitors. For example, based on experience, 10 % indicates a strong coupling for the PETRA III monitors [4].

2.2. BPM for the damping wiggler section

Fig. 3 shows results for the BPM for the damping wiggler section. The equipotential electric field lines when applying 1V at the UR-pickup are shown in plot a, as well as the voltage along the vertical and horizontal cross-sections through the chamber center (plots b and c respectively). At the chamber middle one obtains 0.1V, or a coupling of 10 %. The locations where 0.01V is found delimit approximately the range where a signal can still be measured. A more relaxed range for voltage above 0.02V still indicates a rather large position range.

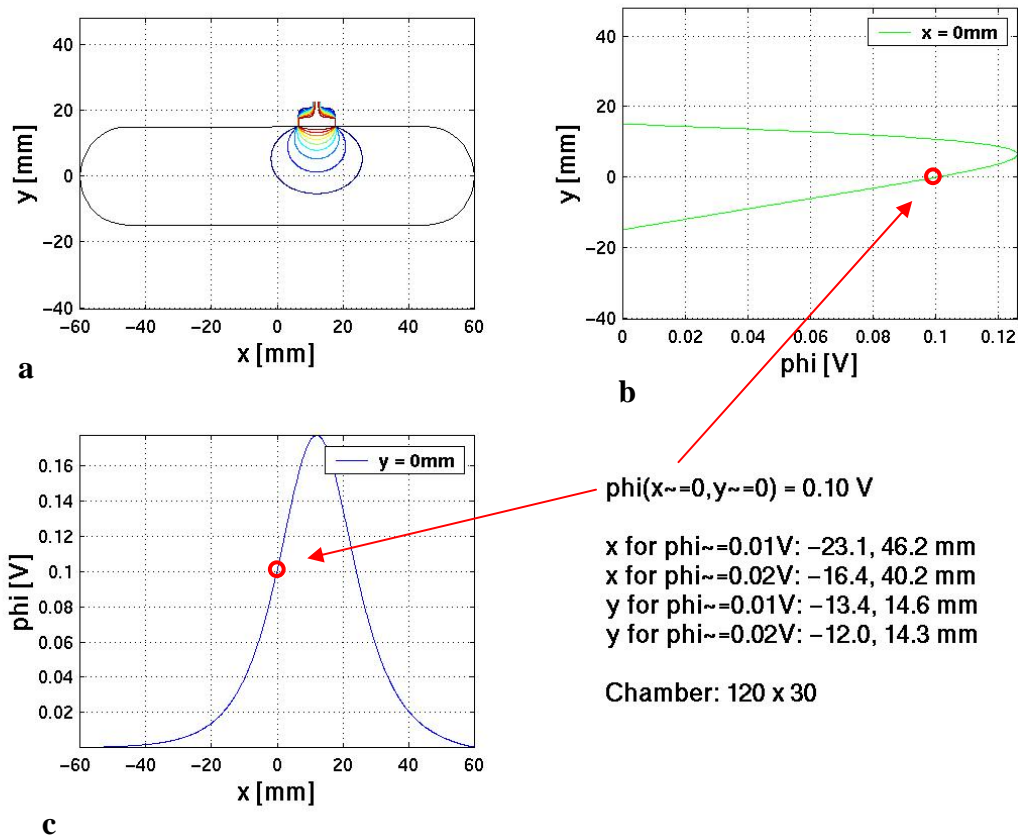


Figure 3: Potential of the electric field when applying 1 V on the UR pickup. a: equipotential field lines; b: potential along vertical cross-section and c: potential along horizontal cross-section of vacuum chamber

Fig. 4 shows Φ_H and Φ_V in the chamber cross-section, while Fig. 5 plots the same quantities along the horizontal and vertical axes. The monitor constants are: $1/K_H = 0.08 \text{ mm}^{-1}$ and $1/K_V = 0.06 \text{ mm}^{-1}$. For a horizontal beam position resolution of $1 \mu\text{m}$ one needs $8 \cdot 10^{-5}$ resolution in Φ_V , (given by the electronics).

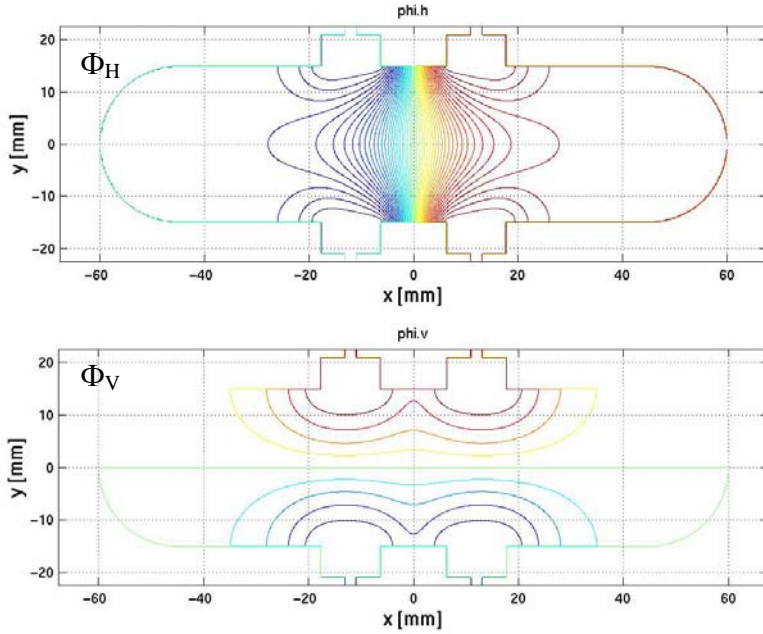


Figure 4: Φ_H and Φ_V in the transverse section of the vacuum chamber.

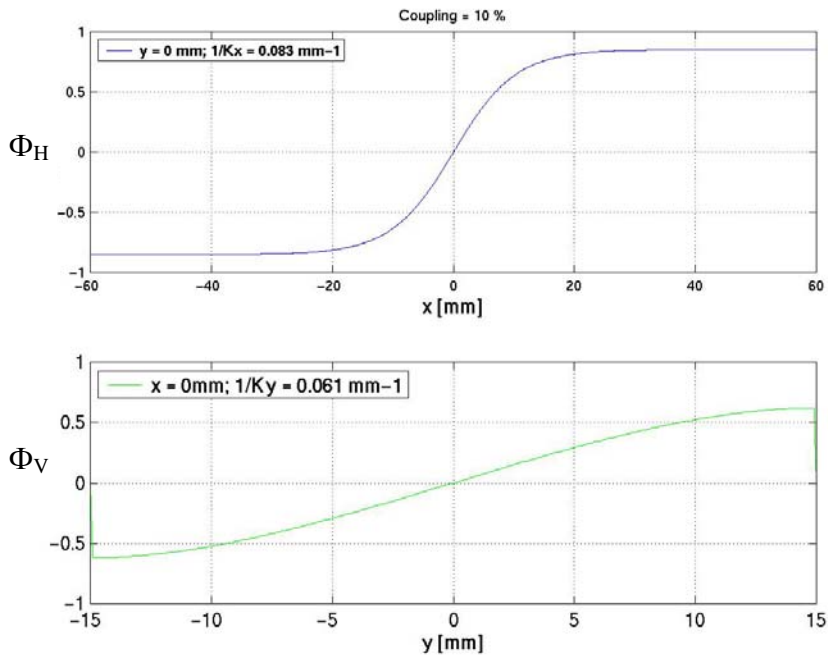


Figure 5: Φ_H and Φ_V along the horizontal and vertical cross-sections through the center of the vacuum chamber.

Various horizontal distances between the two upper and lower pickups have been considered. Table 1 shows the results for several values. A distance of 31 mm gives a somewhat low coupling, with very different monitor constants for the 2 transverse directions. While a distance of 20 mm gives equilibrated monitor constants in both directions, it is harder to realize mechanically. Therefore a distance of 24 mm has been chosen for this monitor.

Table 1: Monitor constants and coupling factors for various distances between the pickups

Pickup distance	1/Kx [mm-1]	1/Ky [mm-1]	Coupling [%]
20	0.074	0.070	12
24	0.083	0.061	10
31	0.093	0.045	7

2.3. Coupling between pickups

Another concern with button type BPMs is the coupling between the pickups. A strong coupling may lead to the mixture of reflections from one pickup into the signal of another pickup. This is particularly critical for the BPM in the narrow undulator chamber with dimensions 66mm×11mm. In this chamber the pickups have to be longitudinally displaced with respect to each other due to mechanical reasons.

We attempt to extract information about the coupling between the button with a MAFIA electrostatic simulation. For this we look at a 2D model of a section through the 4 pickups. Note that the width of the model is therefore larger than the chamber width. We apply 1V at the UR pickup and define the UL pickup as vacuum (Fig. 6-a). Then we look at the field profile along vertical sections through the chamber middle (Fig. 6-b) and through the left pickups (Fig. 6-c). The field through the left buttons suggests a coupling of the UR pickup to the UL one of ca. 0.009 %, which is negligible, as compared to the coupling for this monitor of the pickup to the beam of 23 %.

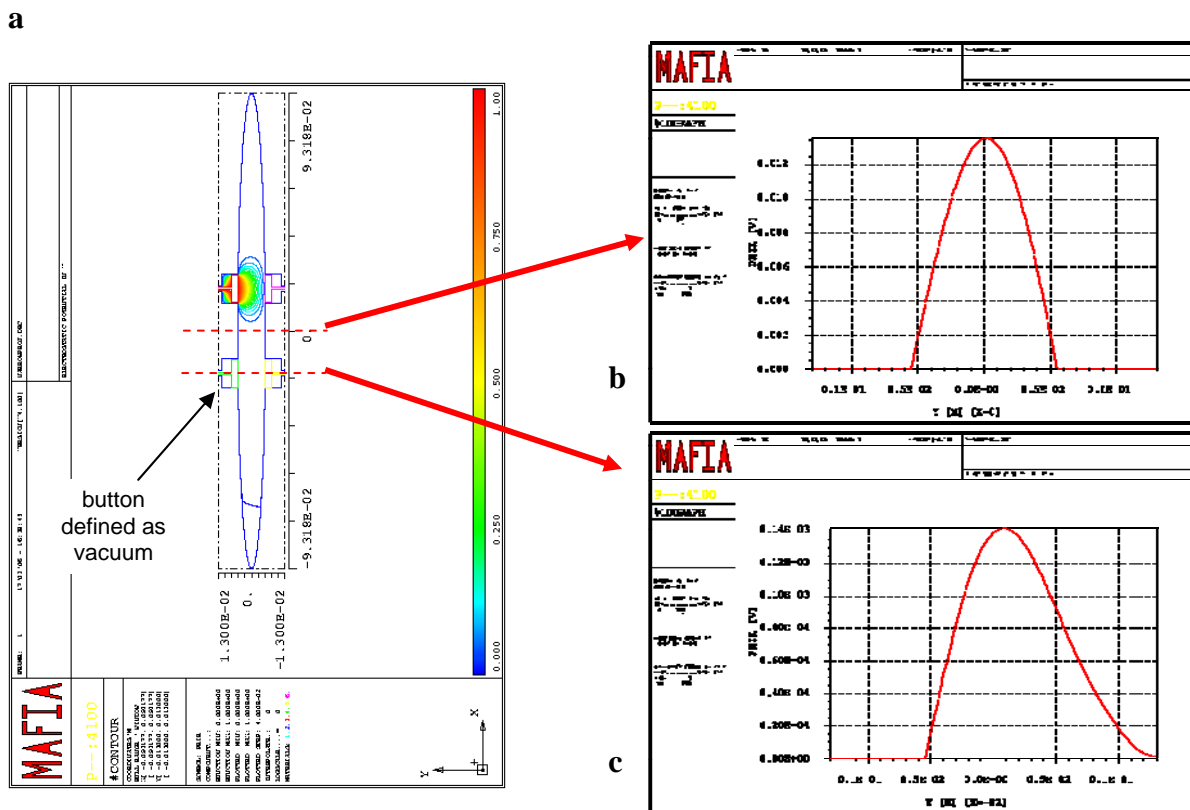


Figure 6: Coupling between UR and UL pickups of a BPM for the undulator chamber. Potential for 1V applied at the UR button: a: in 2D monitor cross-section; b: along vertical cross-section through chamber middle and c: along vertical cross-section through UL pickup.

A similar reasoning leads us to a coupling of the UR to the DR button of 10 %, (Fig. 7) comparable to the coupling to the beam, which seems unreasonable. Moreover, RF measurements on a model with 4 real pickups show a coupling between the UR and DR buttons of -45 dB, or 0.6 % at 500 MHz [5].

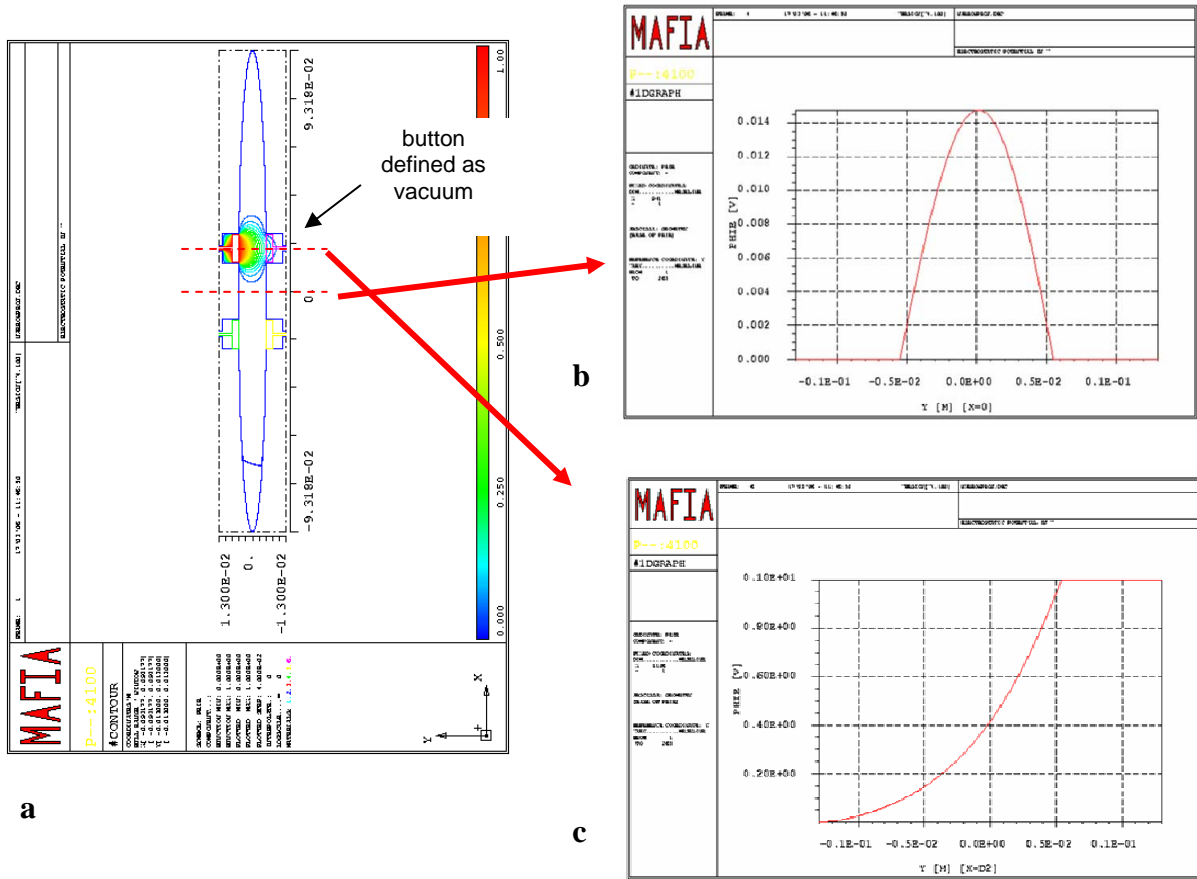


Figure 7: Coupling between UR and DR pickups of a BPM for the undulator chamber. Potential for 1V applied at the UR button: a: in 2D monitor cross- section; b: along vertical cross-section through chamber middle and c: along vertical cross-section through DR pickup.

Therefore another simulation, taking into account the RF character of the system, has been made with Microwave Studio.

3. RF Simulations

3.1. Frequency domain simulation: S-parameters

In order to calculate the coupling between two opposite buttons in the narrow undulator chamber described in section 2.3, we model first in Microwave Studio (MWS) [3] two pickups in a flat vacuum chamber (Fig. 8-a). We define a waveguide port at the end of each antenna.

The S-parameter for these two ports can then be obtained directly from the simulation. The results are shown in Fig. 8-b. S₂₁ at 500 MHz is about -50 dB, in relatively good agreement to the RF measurements.

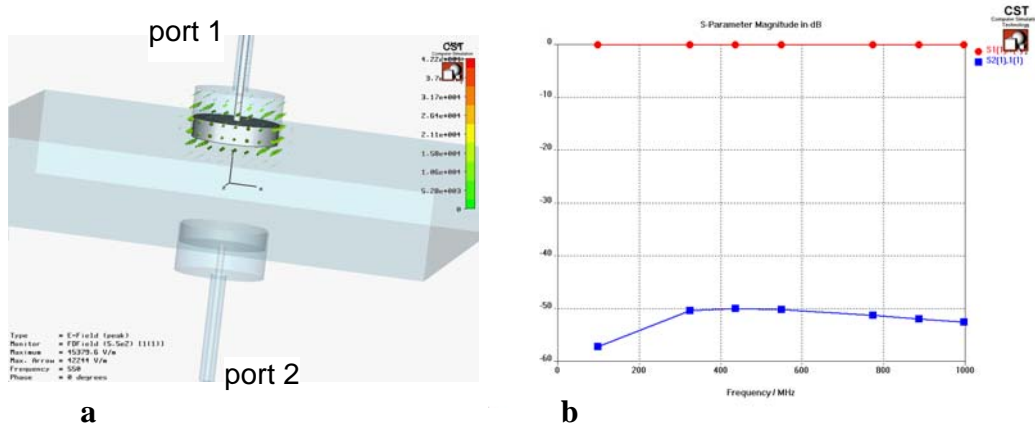


Figure 8: a: MWS model of 2 opposite pickups for the BPM for undulator chamber; b: S-parameters between the two pickups (normalized to 50 Ohm)

A more complex simulation of the BPM for the undulator chamber in time domain is shown in the next section.

3.2. Time domain simulation

3.2.1. Coupling between buttons

Fig. 9 shows a 3D model of the undulator vacuum chamber with the four BPM pickups. The ends of the pickups are defined as ports, while the two ends of the vacuum chamber are assigned either electric or magnetic boundary conditions. A Gaussian source is considered at port 1. The response at the other ports is then calculated.

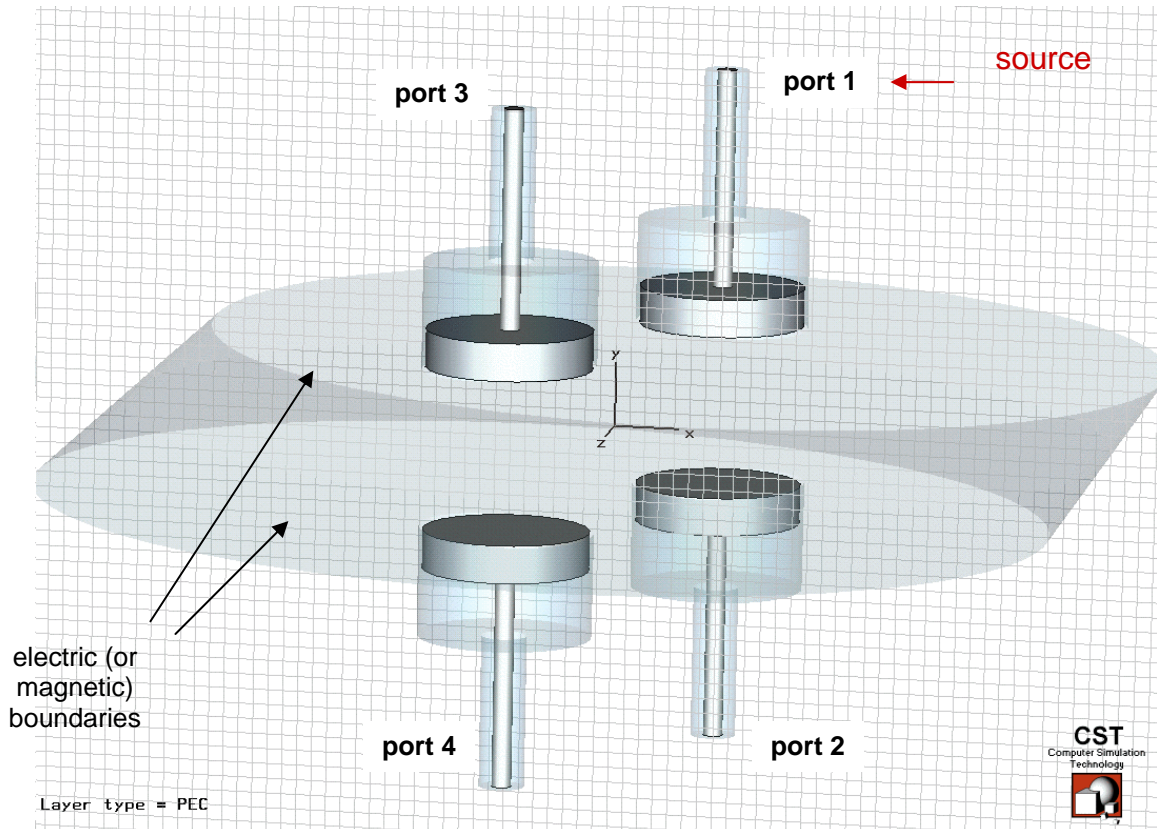


Figure 9: MWS model of the BPM for the undulator chamber for time domain simulations. Each pickup ends with a port. A Gaussian source is applied at port 1 (UR).

The results of the time domain simulation are shown in Fig. 10. The upper plots (a and b) show the transmission parameters to each of the 3 ports, in linear and logarithmic scale. S21, the transmission to the opposite pickup, is -45 dB at 500 MHz, in very good agreement to the RF measurement. Fig. 10-c shows the exciting current (i1, in red) and the reflection at port 1 (green). The response at the other ports is shown in plot d.

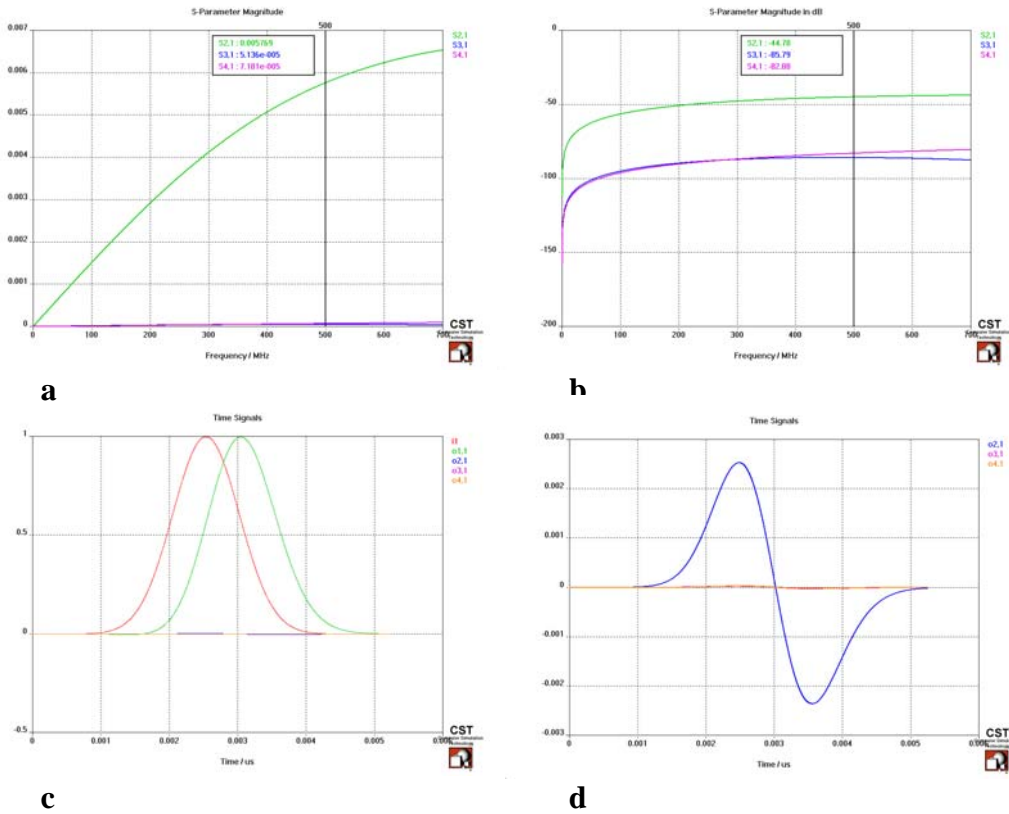


Figure 10: Results of the time domain simulation in Fig. 9. a: S-parameters between each of the ports in linear scale; b: same in dB; c: exciting current and reflection at port 1; d: response at ports 2-4.

3.2.2. “Beam” simulation

A simulation of an electron bunch with Gaussian profile is attempted by using a discrete port along a line on the axis of the vacuum chamber (port 5 in Fig. 11). A current source with a Gaussian time profile (with amplitude equal to 1) is defined on this line. Note that, unlike for a real bunched beam, in the model the current rises and decays at the same time in all points of the line.

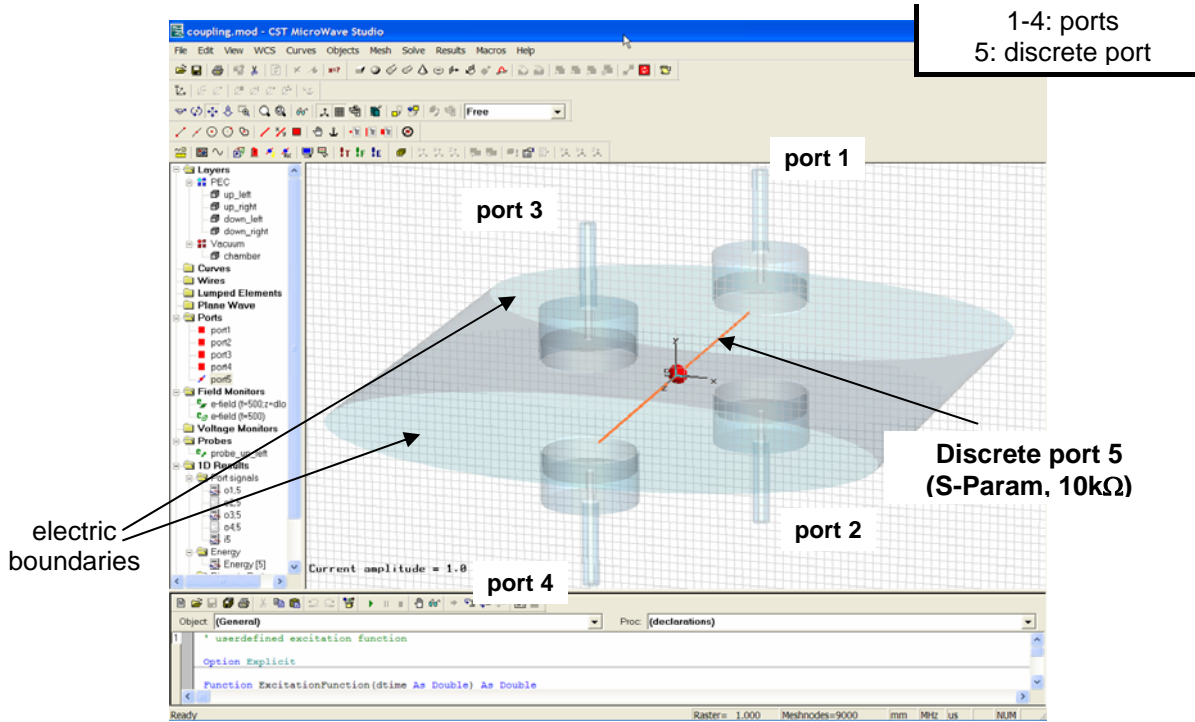


Figure 11: “Beam” simulation with MWS. The “beam” is simulated by a discrete port along the axis of the vacuum chamber.

Fig. 12 shows the results of the simulation. The time response at the 4 pickups is shown in the left graph (a), while the S-parameters are shown in plot b. Note that the time response is not as expected from a real bunch, due to the fact that in our model the current does not propagate along the axis. The meanwhile available Particle Studio [6] simulation code can overcome this difficulty in future simulations.

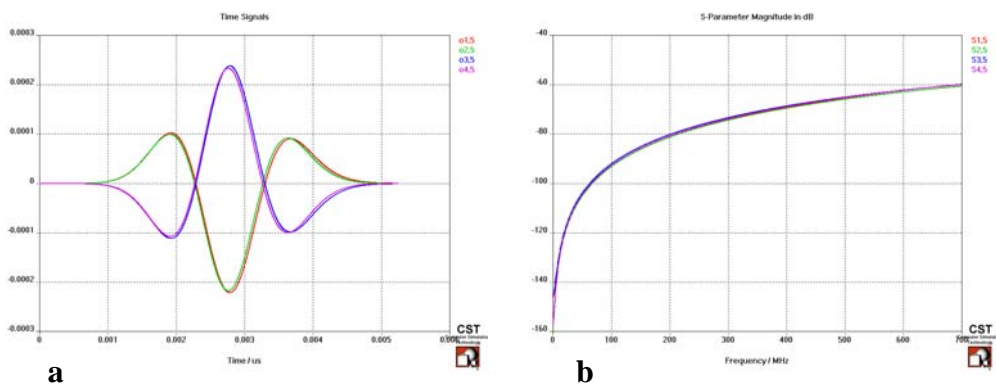


Figure 12: Results of the “beam” simulation. a: time signals at the 4 ports at the pickups; b: S-parameters.

4. Summary

Various BPMs for PETRA3 have been simulated with electromagnetic field codes in order to study their behavior. Relatively simple 2D electrostatic simulations with MAFIA deliver the monitor constants, and can be used to optimize the geometry of the position monitors. The same type of simulations also gives information on the coupling of the button pickups to the beam.

In order to study the coupling between buttons and to simulate the signals generated at the pickups by a particle beam, a simulation of the electromagnetic fields has to be made. A 3D model of a BPM in a narrow vacuum chamber has been built in Microwave Studio for this purpose. The S-parameters between the ports of various pickups have been obtained. A very good agreement with RF measurements has been obtained.

The attempt to simulate a beam by using a current source on a discrete port along the axis of the model gave unrealistic result for a propagating bunch. For a more realistic simulation of the beam, Particle Studio will be used in future simulation.

5. Acknowledgements

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6. References

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