# BPM DESIGN FOR THE ALBA SYNCHROTRON

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*Abstract*

ALBA is a 3 GeV, low emittance, 3rd generation Synchrotron Light Source that is in the construction phase in Cerdanyola, near Barcelona, Spain. Vertical beam sizes down to few microns will require beam stabilities on the submicron level. The Beam Position Monitors (BPMs) have to be designed in order to provide reliable and accurate beam position readings. Simulation and computational codes have been used to optimise, for a given vacuum chamber dimension, the BPMs design. The optimisation has taken into account the usual sensitivity and intrinsic resolution parameters, but as well, the wakefield loss factor of the buttons. Due to the storage ring small vertical vacuum chamber dimension and the high design current, the beam power deposited in the buttons is becoming a concern due to the thermal deformation effects that can introduce errors at the submicron level. A compromise between a higher intrinsic resolution from one side, and a low power deposited by the beam in the buttons from the other, define the final buttons dimensions.

## INTRODUCTION

The ALBA facility includes a LINAC, a full energy 249.6m Booster, a 268.8m Storage Ring (SR) and their respective two transfer lines. A total of 171 BPMs will be installed for beam orbit measurement, distributed as follows:

- 1 at the end of the LINAC
- 3 in the LINAC to Booster transfer line (LTB)
- 44 in the Booster
- 3 in the Booster to SR transfer line (BTS)
- 120 in the SR

To perform tune measurement, diagnostics and multi-bunch instabilities detections, 2 extra BPMs will be placed in the Booster and 3 in the storage ring.

The aim of this document is to show the followed approaches leading to the definition of the BPMs.

## STORAGE RING BPM

BPM blocks are planned to be directly welded on the vacuum chamber section, with no flanges or bellows. Four button-type capacitive pickups will be mounted in each block. Figure 1 shows a SR BPM block and the button pickup.

The SR vacuum chamber, at the BPMs place, has a vertical aperture of 28mm and a width of 72mm. Theoretical calculations based on Matlab code* were performed to determine the ideal button electrode diameter according to these dimensions. The studied diameters were: 10.3mm, 7mm and 4mm.

*www.cells.es/Divisions/Accelerators/RF_Diagnostics/Diagnostics/Tools

### *BPM Sensitivity*

To obtain the horizontal and vertical sensitivities ($S_x$ and $S_y$), a widely used method known as Delta over Sum is used [1].

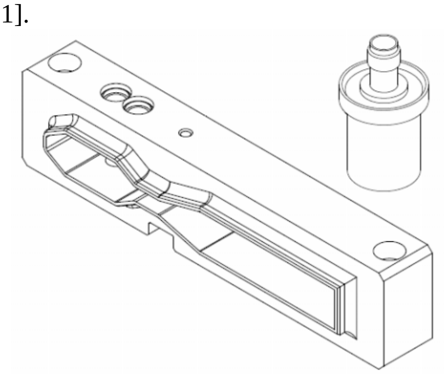

Figure 1: SR BPM block and button pickup.

Sensitivity mainly relies on the electrodes diameter and the distance from them to the electron beam. The vertical position of the buttons is fixed due to the chamber height and the horizontal separation is 18.1mm, which is mainly defined by the available space. The obtained Delta/Sum curves for the vertical plane are shown in Figure 2.

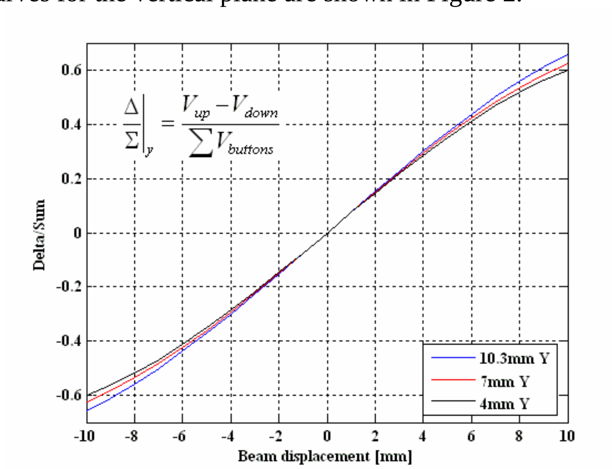


Figure 2: Vertical Delta/Sum curves for 10.3mm (blue), 7mm (red) and 4mm (black) buttons.

The slopes of these curves at no beam displacement give us the $S_y$ of the buttons. $S_x$ is obtained the same way and all results are shown in Table 1.

Table 1: $S_x$ and $S_y$ for the three different button diameters

| | 10.3mm | 7mm | 4mm |
|---|---|---|---|
| **$S_x$ [mm$^{-1}$]** | 0.077 | 0.080 | 0.083 |
| **$S_y$ [mm$^{-1}$]** | 0.077 | 0.075 | 0.074 |

No major differences in sensitivities are found for the studied buttons diameters.

### *Buttons Intrinsic Resolution*

The intrinsic resolution ($\sigma_{int}$) is the resolution obtained at the buttons level considering only the thermal noise (not including the electronic induce noise). That will be the maximum achievable resolution of the system, and it'll be reduced while we introduce other elements on the readout process of the BPMs. It is related to the beam induced signal caught by the buttons as [1]:

$$\sigma_{\text{int}} = \frac{b}{2\sqrt{2}} \frac{1}{\sqrt{SNR}} \quad (1)$$

*b* is the distance button-beam; and *SNR* stands for the ratio between induced signal (P) and thermal noise ($N_{th}$).

The induced signal (P) on the button depends on the button capacitance, which is defined from its geometrical dimensions [2]. One can then obtain the available power at the input of the processing unit, which is shown in Figure 3.

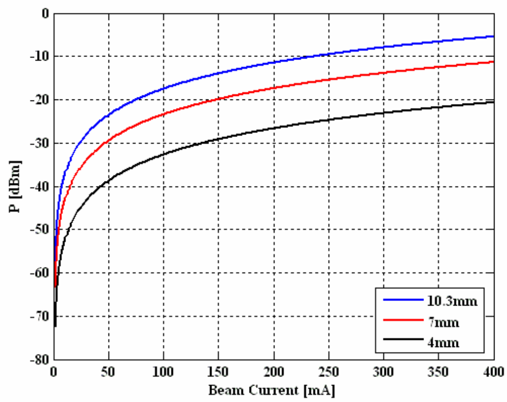


Figure 3: Button delivered power vs. beam current.

Thermal noise ($N_{th}$) of the readout depends on the measurement bandwidth (Bw) as $N_{th}$=kTBw (k, Boltzmann constant; and T, temperature)

Considering a Bw of 4kHz, that is the expected one for fast orbit measurement system, one can obtain, with equation (1), the intrinsic resolution achievable for each button, as shown in Figure 4.

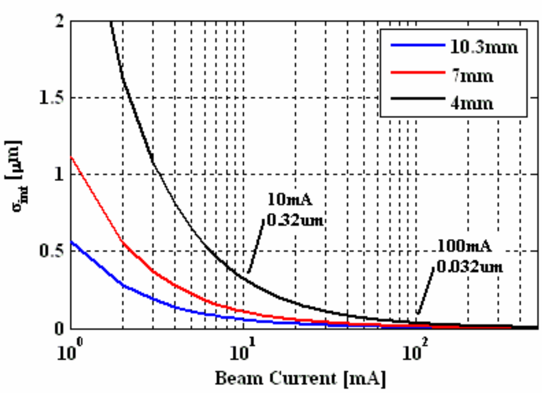


Figure 4: Intrinsic resolution vs. beam current @ 4kHz.

The $\sigma_{int}$ variation is one order of magnitude per beam current decade, as the power of the induced signal (P) depends on the square of the beam current, and the $\sigma_{int}$ to the square root of the SNR (equation 1).

Table 2 shows the values found at 4kHz Bw (fast orbit) and three different beam currents: 0.1mA (single bunch current), 10mA and 100mA.

Table 2: Button characteristics @ 4kHz Bw

| | | 10.3mm | 7mm | 4mm |
|---|---|---|---|---|
| **Capacitance [pF]** | | 3.9 | 2.7 | 1.6 |
| **$\sigma_{int}$ [μm]** | **0.1mA** | 6 | 11 | 32 |
| | **10mA** | 0.06 | 0.11 | 0.32 |
| | **100mA** | 0.006 | 0.011 | 0.032 |

For currents > 10mA we are already at sub-μ and for 100mA the difference is negligible if we consider that the noise of the electronics has to be added up.

## OPTIMISATION OF THE BPM SHAPE

In order to optimise the BPMs in respect to low power losses, high signal transmission and proper impedance matching, its geometry has to be adapted, in particular the diameter and the thickness of the button.

The value of the diameter is exposed to conflicting requirements. A small value reduces power losses, but also the signal transmission. The losses are reduced due to the higher frequency of the electromagnetic mode trapped at the button, that reduces the coverage of the impedance spectrum by the bunch spectrum (see figure 6). The signal transmission is reduced due to the lower induced signal (see figure 3). But priority was given to the reduction of the power losses as long as the transmission would not be reduced below an unacceptable level.

The same applies for large values of button thickness, although power losses and signal transmission are less sensitive to it than to diameter changes.

In addition the inner radii of the axial-symmetric geometry of the pick-up were adapted to match with the impedance of 50Ω (in order to keep the geometry simple this criteria was not in all cases respected as it would have led to a conic form of the shell of the button above the ceramics).

Power losses were calculated for different values of diameter and thickness of the button as given in Table 3. GdfidL [3] was used for the calculation of the losses and as well as for the calculation of the transmission of signals through the buttons and vacuum chamber entries via the S-parameters.

Table 3: Power losses [W] of a BPM block in multibunch mode (bunch length 4.6mm)

| | 10.3mm | 7mm | 4mm |
|---|---|---|---|
| **thickness 2.5mm** | 5.11 | 1.75 | 0.25 |
| **thickness 4 mm** | 3.82 | 1.32 | 0.19 |

Although the lower losses are given by a button diameter of 4 mm, the 7 mm button was chosen for further optimisation since the former would have reduced too strongly the transmission through the button.

In the second optimisation stage some details of the 7mm button were varied to further reduce the power losses, increase the transmission, as well as the ratio of transmission to reflection. The transfer impedance† was used also as a criterion, which is defined as the ratio of output voltage of the button to the beam current, calculated from the S-parameters [2]

$$Z_t = \frac{S_{31}}{S_{21}}\sqrt{Z_0 \cdot 50\Omega} \qquad (2)$$

with $Z_0$ as characteristic impedance of the vacuum chamber, $S_{31}$ as transmission through the buttons and $S_{21}$ through the exit of the vacuum chamber.

Figure 5 shows that the ratio of transmission to reflection at 500 MHz is the largest for a button with a gap of 0.3 mm between its electrode and its shell. Additionally the corresponding BPM-block has a power loss in multibunch mode of only 0.76W (Figure 6). Its transfer impedance of 0.4Ω is at an acceptable level.

The effect of 120 BPM blocks of this type on the β–weighted transverse impedance budget was analyzed. The quality factor of the resonances is by far not high enough to drive longitudinal or transverse coupled bunch instabilities. The effective β–weighted vertical impedance is 0.012kΩ and the horizontal one is 0.013kΩ.

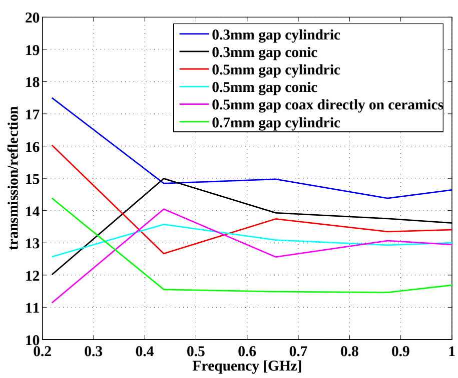


Figure 5: Ratio of transmission to reflection of different buttons. The one of 0.3mm gap and cylindrical form has the best ratio at 500MHz.

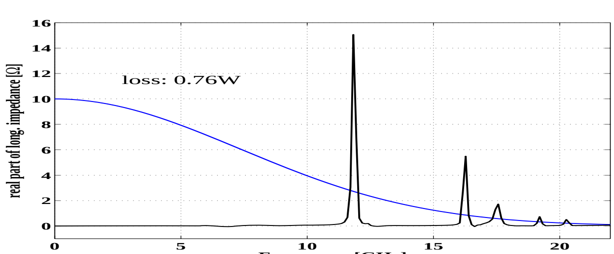


Figure 6: Coverage of the bunch spectrum (bunch length 4.6mm) with the real part of the longitudinal impedance of the chosen BPM.

## BOOSTER BPM

The buttons of the BPM blocks will have 14mm diameter electrodes and will be placed in a 45° symmetry from axis, Figure 7.

†Not to be mixed up with the coupling impedance

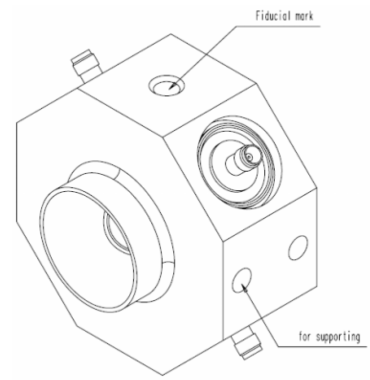


Figure 7: Booster BPM block.

### *Sensitivity and Intrinsic Resolution*

Similar calculations were done for the ALBA Booster BPMs and the results are reported in the Table 4.

Table 4: Booster BPMs specs at 0.1mA and revolution frequency Bw (1.2MHz)

| | |
|---|---|
| **$S_x = S_y$ [mm$^{-1}$]** | 0.093 |
| **Capacitance [pF]** | 3.2 |
| **P [dBm]** | -72 |
| **$\sigma_{int}$ [µm]** | 45.5 |

Due to the big button electrodes, the induced signal (P) leads to a quite good intrinsic resolution at 1.2MHz Bw. No problems regarding heating are expected because of the low beam currents in the ALBA Booster.

## SUMMARY

In Table 5 the main characteristics of the selected Storage Ring BPM buttons are shown.

Table 5: Storage Ring BPMs characteristics

| | |
|---|---|
| **Buttons Diameter [mm]** | 7 |
| **Buttons Thickness [mm]** | 4 |
| **Buttons Gap [mm]** | 0.3 |
| **Capacitance [pF]** | 2.7 |
| **Sx [mm$^{-1}$]** | 0.080 |
| **Sy [mm$^{-1}$]** | 0.075 |
| **Long. Loss factor [V/pC]** | $2.35 \cdot 10^{-3}$ |

## REFERENCES

[1] S.R. Smith, "Beam Position Monitor Engineering", AIP Conference Proceeding 390 (1996), p.50-65, 7th Beam Instrumentation Workshop.

[2] F. Marcellini, M. Serio, M. Zobov, "DAFNE Broad-Band Button Electrodes", INFN-LNF, Accelerator Division, Frascati, January 16-1996.

[3] W. Bruns, GdfidL, www.gdfidl.de