STREAK CAMERA CALIBRATION USING RF SWITCHES

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Introduction

The streak camera has been used to measure the bunch length since the ALBA storage ring commissioning in 2011. Previously, we developed an optical calibration system based on the Michelson interferometry. In this report, we show the electronic calibration system based on the work in DLS [1], and compare both calibration systems. Finally, we show measurements of the longitudinal impedance obtained with the new calibration.

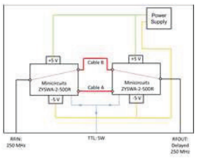
Electronic Calibration Kit

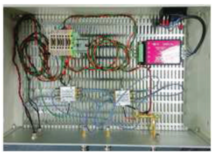
IDEA: delay the reference RF signal used for the fast sweep unit with respect to the synchrotron radiation.

-Guide the signal through cable A or B, which have a different length.

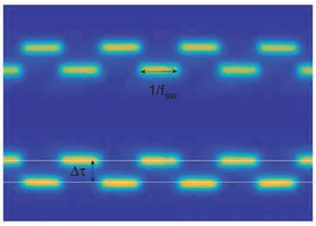
-Changing the cable path is done using RF switches (MC, ZYSQA-2-50DR)

-The difference cable length is inferred with the VNA, and measured with the SC





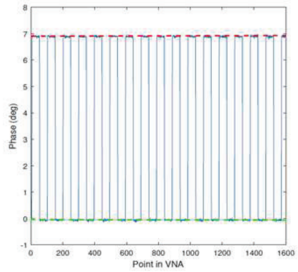
Example: Streak Image Using the Calibration Kit



- Horizontal scale is calibrated using $1/f_{sw}$
- Vertical scale calibrated using $\Delta\tau$.

Delay Characterization using the VNA

Cable time difference $\Delta\tau$ is inferred from the phase difference measured on the reference signal ($f_{rf}/2$ = 250 MHz) with the RF switches ON.



The cable delay difference is:

$\Delta\tau$ = 77.42 +/- 0.08 ps

Average for switching speeds between 10Hz and 4kHz (only 0.5% spread among them!)

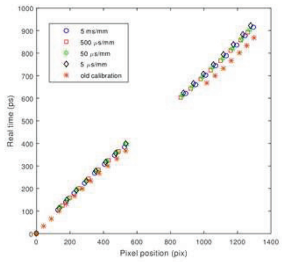
Calibration Results

Slow (Horizontal) Time Unit

- Differences ~10% are found wrt theoretical values
- Sweep speeds ~ns cannot be calibrated, since the typical switching time of about 10ns, according to the manufacturer

Sweep Speed	Cal. Factor, $\frac{\mu s}{pix}$	Theo. Factor, $\frac{\mu s}{pix}$
5 ms/mm	75.0 ± 0.5	70
1 ms/mm	15.6 ± 0.2	14
500 μs/mm	7.56 ± 0.15	7
100 μs/mm	1.60 ± 0.04	1.4
50 μs/mm	0.790 ± 0.02	0.7
10 μs/mm	0.163 ± 0.005	0.14
5 μs/mm	$(76.8 \pm 1.8)\times10^{-3}$	70×10^{-3}
1 μs/mm	$(16.2 \pm 0.6)\times10^{-3}$	14×10^{-3}
250 ns/mm	$(3.8 \pm 0.1)\times10^{-3}$	3.5×10^{-3}

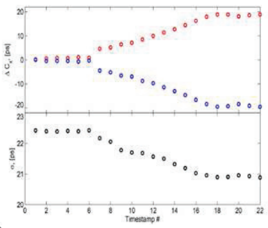
Fast (Vertical) Time Unit



- The most used sweep unit is the 50 ps/mm scale, whose non-linearities are corrected with the multi-linear scale
- Previously, this was calibrated with an optical delay line [2], which shows a small discrepancy related with the old experimental set-up.

Recovering an RF Cavity

- When one of the 6 RF cavities at ALBA trips, the available voltage decreases and the phase in the rest of the 5 cavities decreases to provide the beam with the necessary energy per turn.
- This is translated with an increase of the bunch length σ and a shift of the beam centroid ϕ.



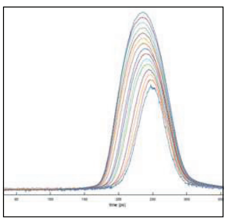
The crosscheck of this effect in the bunch length gives a very good agreement (~1%) with the measurements based on the rf power.

$$\frac{\sigma_2}{\sigma_1} = \sqrt{\frac{V_1 \cos\phi_1}{V_2 \cos\phi_2}}.$$

SC – Ratio	RF –Ratio
1.08 +/-0.01	1.092 +/- 0.005

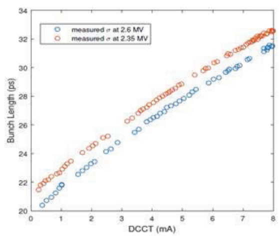
Longitudinal Impedance Measurements

Single Bunch Measurements at different rf voltages



Mountain Range plots between 0.5 and 8mA. The beam shape starts to deviate from the Standard Gaussian profile.

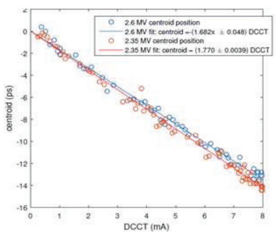
Exact solution solving Haissinsky Eq. (on-going)



Evolution of the bunch length for 2.6 and 2.35 MV, assuming a Gaussian profile.

Im(Z) could be inferred solving:

$$\left(\frac{\sigma}{\sigma_0}\right)^3 - \left(\frac{\sigma}{\sigma_0}\right) = \frac{\alpha_c \mathrm{Im}(Z_0^{\parallel}/n)_{eff}}{\sqrt{2\pi}(E/e)Q_{s0}^2(\omega_0\sigma_0)^3} \cdot I_B$$



Bunch centroid displacement with current for 2.6 and 2.35 MV.

The loss factor can be inferred from:

$$\Delta T_C = \frac{T_{rf}}{2\pi} \frac{k_{\parallel} T_0}{V_0 \cos\phi_s} I_B$$

ALBA parameters and results inferred from the analysis of the single bunch measurements using the SC:

mom. comp. factor, α_c	0.0088	
revolution period, T_0[ns]	896	
rf frequency, f_{rf}[MHz]	499.649	
energy, E[GeV]	2.987	
rf voltage, V_0[MV]	2.6	2.35
sync. phase, ϕ_s[°]	152.9	154.2
sync. tune,	0.0071	0.0066
bunch length, σ_0[ps]	18.75	20.26
loss factor, $k_{\parallel}$[V/pc]	14.1± 0.4	13.12 ±0.05
resistance, R[Ω]	935 ± 25	940 ± 5
Re($Z_0^{\parallel}/n$) [mΩ]	127±4	136±1

Conclusions and Outlook

We have implemented a calibration kit for our Streak Camera based on the electrical delay between two different cables, whose length is precisely measured with a VNA. The calibration kit allows almost on-line calibration in both the slow (horizontal) and fast unit (vertical). While the horizontal values are typically ~10% larger than the theoretical ones, in the vertical direction we found most convenient to use the slowest sweep speed (50~ps/mm) with a multi-linear calibration whose spread is very small (~0.5\%).

Several machine measurements are presented using the calibration results presented in this report. The bunch length evolution during the recovery of an rf cavity at ALBA showed a good agreement with the expectations. Moreover, longitudinal impedance measurements showed values consistent with other machines, although a more careful analysis of the result is foreseen in the near future.

References

[1] L.M. Bobb, A.F.D. Morgan, G. Rehm, *Streak Camera PSF Optimisation and Dual Sweep Calibration for Sub-ps Bunch Length Measurement*, IBIC'15, Melbourne (Australia), 2015.

[2] U. Iriso and F. Fernández, *Streak Camera Measurements at ALBA: Bunch Length and Energy Matching*, IBIC'12, Tsukuba (Japan), 2012.

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[4] http://www.optronis.com

[5] B. Bravo et al, *Calibration of the acceleration voltage of six normal conducting cavities at ALBA*, Proc. of IPAC15.

[6] R.Dowd et al, *Single bunch studies at the Australian Synchrotron*, TUPC010, Proc. of EPAC08.

[7] J.C. Bergstrom, *Jack's Book on Beam Instabilities*, Canadian Light Source Internal Note, 5.17.38.1 (2006)