

# DIODE DOWN-MIXING OF HOM COUPLER SIGNALS FOR BEAM POSITION DETERMINATION IN 1.3-GHz- AND 3.9-GHz-CAVITIES AT FLASH\*

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## Abstract

Beam excited signals available at the HOM coupler ports of superconducting accelerating cavities cover a wide frequency range and carry information about (amongst others) the transverse beam position. Down-mixing these signals using detector diodes is a mean to measure the time dependence of the power leaving the HOM coupler with standard and non-specific oscilloscope technology. Experiments undertaken at the accelerator modules ACC1 and ACC39 at FLASH demonstrated the possibility to extract beam position data out of low-frequency signals sampled with such a setup. These experiments as part of an ongoing study are described together with mathematical details of the evaluation scheme.

## INTRODUCTION

The excitation of wake fields in accelerator cavities by the beam is an unavoidable effect, which may lead to harmful consequences concerning cooling demands and beam quality. Therefore many cavity designs include specific Higher Order Mode (HOM-) couplers intended to lead beam deposited fields out of the cavity. It is common practice to terminate these couplers externally with resistive loads in order to dump the beam-excited high-frequency signals. Research of the past decade (e.g. [1-4]) demonstrated the possibility also to deduce beam properties, mainly the transverse beam position, from HOM coupler signals, trying to avoid the need of beam position monitors. Typically this is done with dedicated electronic hardware [3] that replaces the terminating dumps. It filters out all but those signal components from two distinct orthogonal dipole mode polarisations. Modes of dipole type are preferred since some of them interact strongly with the beam and since their signal amplitude depends (in good approximation) linearly on the beam's distance to the cavity's axis of rotational symmetry. This implies the need of well-tuned narrow band filters, down-mixing stages including a local oscillator and mixers and, for final read-out, analog-digital-converters.

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## CONCEPT

Starting from the idea to avoid the need of a local oscillator we investigate the possibility to replace most of the specific hardware listed above by a broadband radio frequency detector diode like it is illustrated in Fig. 1. This diode is intended to operate as a mixing instance that produces a low-frequency signal by combining at least two, but typically a large set of spectral lines of the HOM-coupler signal. Since different polarisations of fields are to be expected at slightly different original frequencies (which is a consequence of the non-ideal rotational symmetry of the cavity) their contributions should appear at different places in the down-mixed spectrum. If furthermore both polarisations have a non-vanishing coupling to the HOM-coupler under consideration the down-mixed signal is therefore expected to carry information about the beam-position in both transversal coordinates.

Abandoning the primary narrow-band filters obviously will lead to a superposition of several high-frequency signals, each associated to a certain mode frequency and decay time. After down-mixing an even more complicated temporal dependence is to be expected. This demands for an evaluation scheme capable to distinguish dominant contributions in a large set of measurements. Following [3] we apply the Singular Value Decomposition (SVD-) technique as a black-box solution, implemented e.g. in *Mathematica*© [5].

The SVD reduces the low-frequency time-domain signal, typically consisting of several thousands of sample points, to a small set – in most cases not more than ten – of amplitudes, but it performs no correlation to any physical parameter. This is done in a second evaluation step. It is one main purpose of this paper to demonstrate that this correlation of SVD-amplitudes of diode down-mixed HOM-signals with the transversal beam coordinates is of *linear* type.

## EXPERIMENTAL SETUP AND PROCEDURE

Following the description above we connected AGILENT 423B detector diodes with the HOM couplers of DESY-FLASH [6] modules ACC1 (some) and ACC39 (all), as shown in Fig. 1. This was done at a switchboard neighbouring to the accelerator using the firmly installed cable connections. These cables introduce a signal damping of -10 dB ... -15 dB. Coaxial 3dB attenuators

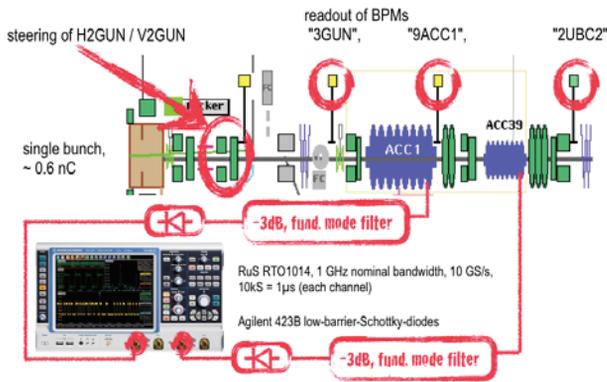


Figure 1: Main experimental components. Sketch of FLASH setup taken from DOOCS [7] display. Signals taken from the HOM-couplers (multiplexing switch not shown) are filtered to suppress fundamental mode components, down-mixed in the RF detector diodes and sampled using a standard oscilloscope.

were used mainly in order to protect the diodes against potential electrostatic charging (even though there was no evidence for such). As matter of experimental experience additional filters were needed in order to suppress the 1.3 GHz-/3.9 GHz-fundamental mode signal, which dominates the HOM-coupler signal in spite of the coupler's own fundamental mode notch filters. At ACC1 MiniCircuits VBF-1575+ band passes were used, which have their main transmission close to the frequency range of the first dipole mode passband. For ACC39 high pass filters MiniCircuits VHF-4600+ demonstrated to be well suited. Unlike ACC1 (and all other accelerating modules of FLASH) with several clearly cavity-localised HOMs the cavities of module ACC39 are strongly coupled through the beam pipe for almost all HOMs [8]. This typically reduces the beam-mode interaction and makes the identification of modes, which are well suited for individual detection, a difficult task [9]. Therefore we experimentally tried to feed at ACC39 a HOM spectrum with a very wide range into the diode.

Signal detection and data storage was performed using a Rohde&Schwarz RTO1014 oscilloscope. In comparison with other brands it turned out that a 10 GS/s sampling rate and a best sensitivity of 1mV/div with a digitising step of  $\sim 40 \mu\text{V}$  were important assets in this application. (If multibunch operation also is intended, a memory depth sufficiently large to capture one entire bunch train (e.g.  $400 \mu\text{s} \times 10 \text{GS/s} = 4 \text{MS}$ ) is needed.)

Triggering of the oscilloscope was performed without external source, directly using the diode signal. When operating simultaneously on both modules ACC1 and ACC39 the signal of the former was used.

Different vertical offsets of the beam, which was accelerated in ACC1, were achieved by adjusting two steering magnets. For each setting the measurements of three beam position monitors (BPM) of FLASH were

read out from the DOOCS system and saved together with the down-mixed HOM signals. In one series of 25 measurements signals from ACC1, cavity 8, HOM coupler 1 and ACC39, cavity 4, HOM coupler 2 were observed simultaneously. In a second set of 31 measurements the signals of all 8 HOM couplers of ACC39 were captured sequentially with a single diode, using an additional multiplexing switch.

## EVALUATION

Taking an entire ensemble of  $N_s$  down-mixed signals (Fig. 2, there  $N_s=25$ ) as input for a SVD procedure results first in a set of dominant signal forms ("SVD vectors", Fig. 3). Further the SVD determines a matrix of the weights of all SVD vectors in all signals. Let  $\mathbf{U}$  be a submatrix of it, taking only a reduced set of the first  $N_v$  most dominant vectors, thus  $\mathbf{U}$  being of dimension  $N_s \times N_v$ . Fig. 4 illustrates that often very few vectors (there  $N_v=4$ ) are sufficient to reconstruct the raw signals very well.

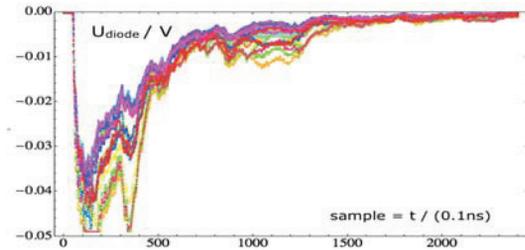


Figure 2: Set of 25 diode down-mixed signals from ACC39, cav. 4, co. 2, each belonging to a steerer setting.

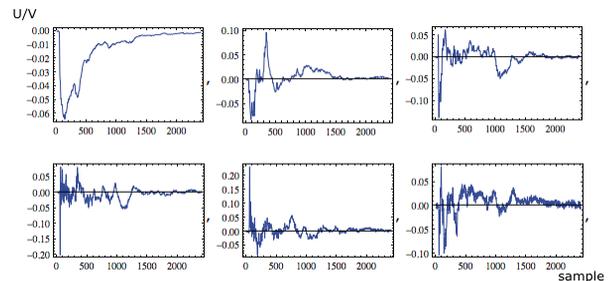


Figure 3: Dominant 6 signal forms of the set of Fig. 2.

Let  $\mathbf{M}$  denote the matrix of BPM read outs, containing x- and y-measurements in front and behind the module under consideration ("3GUN" and "9ACC1" in case of ACC1, "9ACC1" and "2UBC2" for ACC39).  $\mathbf{M}$  contains in its four columns four values for each steerer setting and therefore is of dimension  $N_s \times 4$ . In order to find a correlation between the SVD weights  $\mathbf{U}$  and the physical parameters  $\mathbf{M}$ , a linear dependence is assumed, which is expressed as a  $N_v \times 4$  - matrix  $\mathbf{S}$ . Then the correlation would read like

$$\mathbf{M} = \mathbf{U} \cdot \mathbf{S} \quad (1)$$

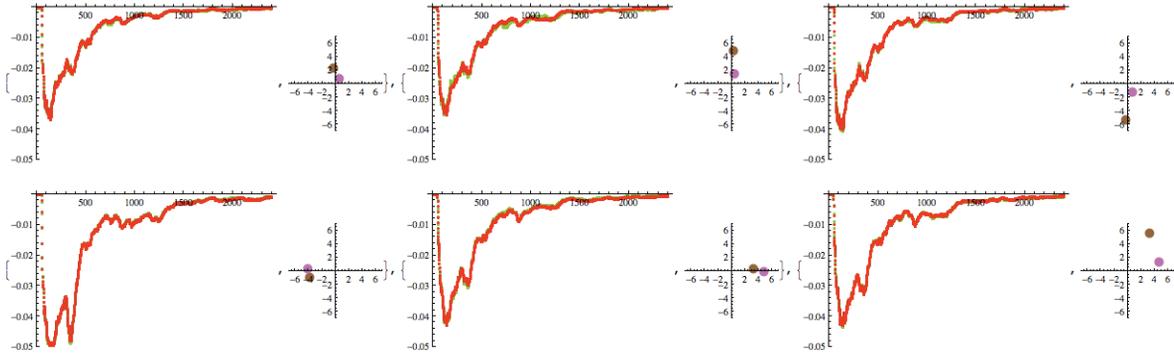


Figure 4: Reconstruction of six freely chosen original signals from Fig. 2 (green, mostly hidden) using the superposition of the first four SVD vectors, together with BPM read outs (in mm, magenta "2UBC2", brown "9ACC1").

This can be understood as a group of four (since both  $\mathbf{M}$  and  $\mathbf{S}$  have four columns) overdetermined matrix-vector-equations, which have a well-known best solution (using a least-square norm):

$$\mathbf{S} = (\mathbf{U}^T \cdot \mathbf{U})^{-1} \cdot \mathbf{U}^T \cdot \mathbf{M} \quad (2)$$

Once  $\mathbf{S}$  is computed the comparison of both sides of (1), i.e. the predicted and the measured BPM read outs, will show how well the assumption of linearity is justified, and how many SVD vectors are needed (see Figures 5a, b).

## CONCLUSION

The capturing of HOM signals using an unspecific diode detector was successfully demonstrated. This especially holds for the FLASH-ACC39-module in spite of its strong cavity-cavity coupling and its lack of well distinguishable spectral components. Applying the SVD procedure in combination with a linear regression demonstrates that the assumption of a linear correlation between SVD vector amplitudes and beam position coordinates is well justified. The number of SVD vectors needed is significantly higher than 4, indicating that more physical parameters besides the transversal beam position and momentum are hidden. Furthermore it is remarkable that informations about both transversal coordinates can be extracted from a single HOM coupler, even not in the same quality at all couplers of a module.

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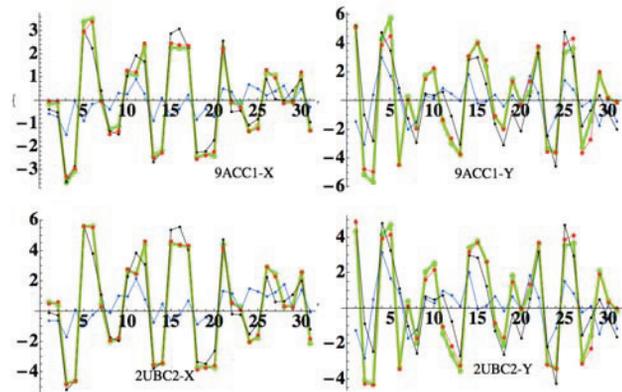


Figure 5a: Comparison of measured (green) and reconstructed BPM read outs in mm for a set of 31 experiments (index as x-value). Signals were taken from ACC39, cav. 4, coup. 2. Blue corresponds to 5, black to 7 and red to 10 SVD vectors used for reconstruction. Whereas the latter reaches very good coincidence in almost all points the first fails totally.

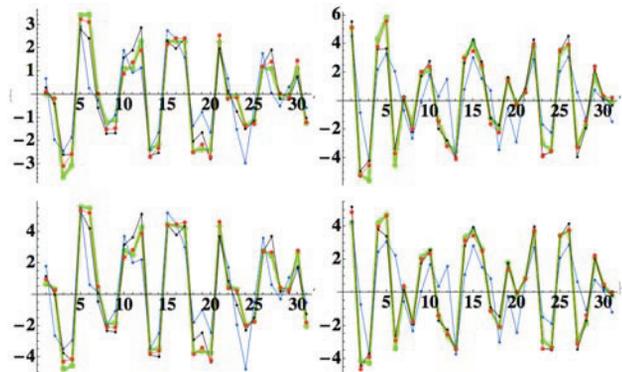


Figure 5b: Like 5a, but signals taken at ACC39, cav. 3, coup. 1. Here reconstruction even with 5 SVD vectors show some poor correlation to the reference, much better with 7 and again best with 10 vectors. This illustrates that the quality of reconstruction in principle depends on the properties and location of the coupler.