

# ALIGNMENT MONITORS FOR AN X BAND ACCELERATING STRUCTURE

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## Abstract

Currently an X band traveling wave accelerator structure is under development in a collaboration between CERN, PSI and ELETTRA. At PSI and ELETTRA, it will serve for longitudinal phase space compensation at the respective FEL projects, where CERN will use it to test break down limits and rates in the high gradient regime. The design employs a large iris,  $5\pi/6$  phase advance geometry, which minimizes transverse wake field effects while still retaining a good efficiency. In addition, we plan to use an active monitoring of the beam to structure alignment and to include two wake field monitors coupling to the transverse higher order modes. These allow steering the beam to the structure axis giving a higher precision than mechanical alignment strategies. Of special interest is the time domain envelope of these monitor signals. Local offsets due to bends or tilts show up as distinct patterns, which should be easily detectable via basic measurements.

## INTRODUCTION

Within the context of the GLC and NLC projects, a considerable effort has been going on in developing high power X band RF systems for high energy  $e^+e^-$  colliders[1]. After the conclusion of these projects, the recent decision by CLIC to change their principal RF frequency from 30 GHz to an European X band frequency near 12 GHz has given a renewed push to X band development. A big RF structure fabrication and testing program involving major laboratories around the world is under way.

A relatively new application for X band technology is in free electron lasers. LCLS compensates nonlinearities in the longitudinal phase space with an X band structure in order to improve bunch compression. The European FEL projects SPARC, FERMI@ELETTRA and PSI-XFEL also plan to employ it for the same purpose. In that context, a collaboration between CERN, PSI and ELETTRA has been set up to develop suitable structures. While being operated at the PSI-XFEL and the FERMI FEL, an ultra long performance test also important for CLIC, these are also going to be submitted to break down tests at CERN.

Looking at the PSI-XFEL, beam voltages up to 30 MeV are required using only a limited power in the order of 40 MW at the structure, which means a fairly efficient structure. On the other hand, the beam has a relatively modest energy of 250 MeV, so that we are relatively sensitive to transverse wakes. So we need to make a good compromise between a high shunt impedance, generally associated with low apertures, and a low transverse kick, demanding the

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opposite. The structure will have no HOM damping. But two wake field monitors are foreseen to align the structure to the beam and to minimize transverse kicks.

The monitor use TE type coupling to the dipole modes in the structure to reject the fundamental as well as higher order longitudinal modes. A special feature is, that we also make use of the fact that wave propagation inside the RF structure is relatively slow at a few percent of the speed of light. The spread out pulse response of the wake monitors not only contains information about the offset but also about higher order misalignments as structure tilts. So basic measurement procedures using only the envelope of the output signal are possible.

## FUNDAMENTAL MODE PROPERTIES

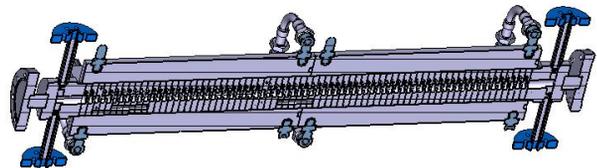


Figure 1: Cut through X band accelerating structure.

For both ELETTRA and PSI specifications, a single structure with 750 millimeter active length is the most appropriate solution. The NLC structure type H75 ( $5\pi/6$  phase advance) has been chosen as the most suitable candidate for the testing program. The original H75 design, with all iris aperture, thickness and ellipticity of the iris varying along the structure, provides an accelerating gradient of 65 MV/m for 80 MW input power and was successfully tested up to 100 MV/m with a SLAC mode launcher [2, 3], which we also use here. The relevant parameters are summarized in Table 1.

Table 1: Structure Specifications

Beam Voltage	30 MeV
Max. Power	29 MW
Iris diameter	9.1 mm (avg.)
Wake field monitors	up/downstream
Operating temp.	40 deg. C
Fill time	100 ns
Repetition rate	100 Hz

## WAKE FIELD MONITOR

To measure the beam offset inside the structure, we couple to the lowest dipole mode. Minimum perturbation of the fundamental mode and maximum information in the output signal, easily post processed, are the principal design criteria. Where and how to couple, what to expect as a signal is shown in the following.

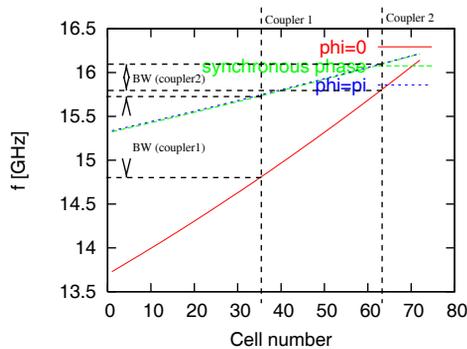


Figure 2: Limits of lowest dipole band and synchronous frequency versus cell number. Also shown the location of the wake field couplers with their respective bandwidths.

The distribution of bandwidths and synchronous frequencies of the lowest dipole band inside the whole structure (Fig. 2) shows three characteristic frequency bands. Dipole modes in the region of 15.3 to 16.1 GHz will be trapped modes, localized in the inside of the structure, where there are cells propagating these frequencies. These trapped modes start in an upstream cell with a field distribution corresponding to a  $\pi$  mode and continue with a decreasing phase advance to the downstream cell, where it goes to zero. The coupling with the beam is most pronounced in the cell, where the resonance corresponds to the synchronous frequency and phase. Resonances below 15.3 GHz ( $\pi$  mode of cell 1) extend from the input coupler to the cell where the phase advance goes to zero. Most of these modes will have weak kick factors, since their frequency does not correspond to one of the synchronous frequencies. The last region contains high kick modes above 16.1 GHz, their fields extend into the output coupler.

With this in mind and assuming, that introducing the monitors will not distort this modal pattern, we are able to choose suitable locations for the wake field monitors. Dipole wakes excited by offsets in the upstream half of the structure correspond to modes which are concentrated in the middle of it. Actually, if we put a monitor in cell 36, it will have a bandwidth of 14.8 to 15.7 GHz (the width of the dipole band in cell 36), the corresponding modes have their synchronous phases in the upstream half and will signal offsets there. For the downstream coupler, we are restricted by the width of the dipole band – a reasonable compromise is cell 63, which sees wakes excited in cells 40–63.

What are the design criteria for the monitor? In order to effectively measure offsets, the wake monitor should reject signals coming from all monopole modes, fundamental as well as higher ones. These are best suppressed by selectively coupling to the transverse electric components of the hybrid dipole modes, something achieved by a suitable orientation of the coupling waveguide.

One option is to use radially oriented waveguides coupling head-on to the cell and a second to have a waveguide in parallel to the beam axis being side coupled, similar to the design of the damped detuned structure, but coupling only to one select cell. Side coupling has the advantage,

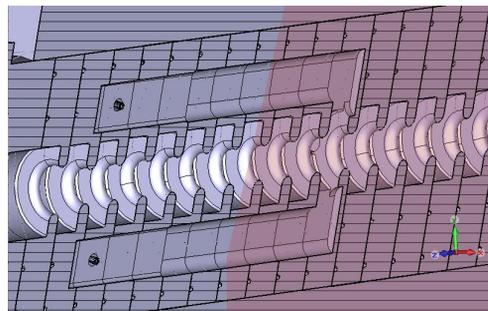


Figure 3: Cut through structure showing the geometry of the downstream wake monitor cell.

that we can have a longer waveguide damping down any residual signal from the fundamental mode, which may enter due to mechanical misalignments. Also, there is enough space to integrate a transition from the waveguide to coaxial and use a standard 50  $\Omega$  vacuum feedthrough to connect the front end. We chose this option, the coupler design is similar to the HOM coupled cells of the damped detuned structures, the difference being that we couple only to one cell and have the wave guide electrically shorted on one side (Fig. 3).

The coupling strength corresponds to a loaded Q of around 800 for a zero phase advance of the dipole and gives sufficient signal amplitudes. The effect on the fundamental mode parameters is only minor: A 10 % drop in group velocity and Q, the R/Q stays virtually unchanged.

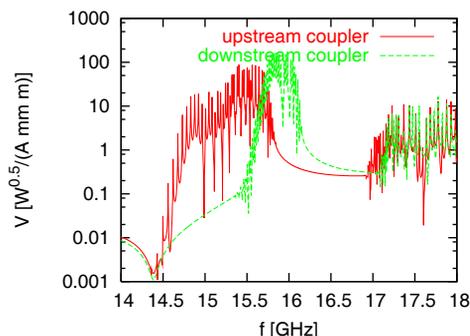


Figure 4: Output signals from up- and downstream monitors vs. frequency.

The wake monitor signals shown in the following were obtained from a dual resonator equivalent circuit, where the elements of the resonators describing the TE and TM components of the hybrid dipole mode and their mutual couplings are fitted from the results of numerical computations. (See [4] for more details, and [5] for special modifications used). Figure 4 shows the signal spectra computed for the up- and downstream couplers. As can be expected from the previous discussion, we see two distinct frequency bands corresponding to the synchronous frequencies in the two parts of the structure.

Of special interest is the time domain evolution of the transverse wakes. A given dipole mode is excited by the beam dominantly in the 'synchronous' cells, where his resonant frequency corresponds to the synchronous one. The mode does not build up instantaneously, but the energy de-

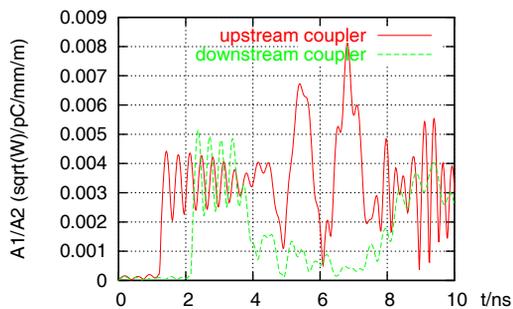


Figure 5: Signal envelope from up- and downstream monitors vs. time.

positioned by the beam in this synchronous cell needs time to get distributed in the structure – the distance between the synchronous cell and the wake field monitor leads to a time delay, before the signal shows up in the monitor signal. Signals from different part of the structure have a different delay. In the output signal (Fig. 5), this results in an initial rectangular pulse (with some beating on top) of 2-3 nanoseconds length.

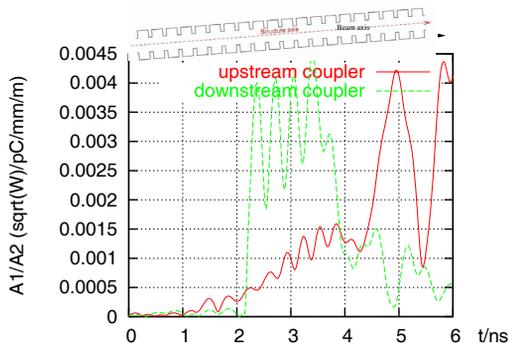


Figure 6: Signal envelope up- and downstream monitors vs. time assuming structure axis tilted to beam axis.

The beam offset in individual parts of the structure is correlated to different synchronous frequencies and this in turn with different delays in the time domain signal. So it is a valid question, whether we can identify also tilts with respect to the beam. A tilted structure is aligned with the beam in the middle, whereas the extremities are offset generating a transverse signal. The resultant wake monitor signals are shown in Fig. 6. The upstream monitor is the more significant one in this case, it sees the total front half of the structure. Where a constant offset gives a more or less rectangular pulse like in fig. 5, we now have a ramp starting at zero (no offset in the middle) and growing linearly to the peak (high offset at beginning). The downstream signal is similar but not as pronounced, since it sees only part of the structure. In the case of bends, dispersion effects smearing out the signal are too strong to see a clear pattern.

What is the effect of mechanical tolerances on the resolution of the monitors? The beam passes through the structure, sees random non correlated offsets of individual cells and will, independent of the global offset, excite wake fields and wake signals showing up as noise in the measure-

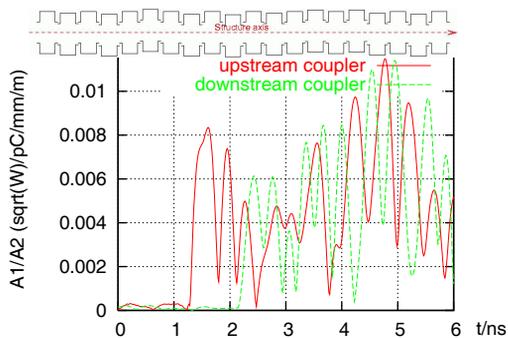


Figure 7: Signal envelope up- and downstream monitors vs. time assuming random, uncorrelated misalignment of individual cells in the structure.

ment. We implemented a model for that into the equivalent circuit model and simulated it [5]. Figure 7 shows an example for the output. The peak random offset signal in the first four nanoseconds is roughly a factor two larger than the equivalent signal for a constant offset (Fig. 5). Said otherwise, a structure with a random cell offset of 1  $\mu\text{m}$  rms creates a signal proportional to a systematic offset of 2  $\mu\text{m}$  – we would have a resolution limit of 2  $\mu\text{m}$ . Resolutions below 10  $\mu\text{m}$ , corresponding to a mechanical cell to cell alignment of better than 5  $\mu\text{m}$ , seem entirely realistic.

## CONCLUSION AND OUTLOOK

An X band structure for the new CLIC reference frequency has been designed, used for high gradient testing at CLIC and as a prototype structure for the PSI-XFEL/FERMI projects. It offers an efficient fundamental mode performance with a wide aperture minimizing transverse wake field effects. Two wake monitors in the structure giving information about offsets and tilts of the structure allow a high quality alignment to the beam. The RF design and mechanical construction is nearly finished, we are currently in the transition into fabrication. Structures for high power testing are expected to be ready toward the end of 2009.

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