Accelerating Structure Alignment

CLIC Workshop 2016

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January 2016

The PACMAN project

PACMAN Particle Accelerator Components? Metrology and Alignment to the Nanometre scale. It's a Marie-Curie Training Network which main aim is to improve the accuracy of alignment for the components to be installed in the next generation of particle accelerators. It is organised in 4 Workpackages:

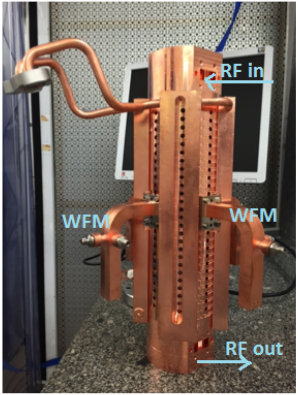
- WP1: Metrology and Alignment.
- WP2: Magnetic Measurements.
- WP3: Precision Mechanics and Nano-Positioning.
- WP4: Microwave Technology.

Objectives

- The objective of my work in WP4 is the development of direct measurement techniques for the in-situ internal alignment of accelerating structures.
- The absolute position of the electrical centre should be found with a precision of 7 μm in a laboratory environment using fiducialisation methods.
- We will use the TD24 Accelerating Structure (AS) for CLIC to reach our goals.

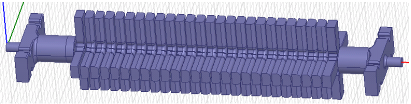
The TD24 Accelerating Structure for CLIC

- Tapered normal-conducting traveling-wave accelerating structure.
- Working frequency: 12 GHz
- Number of cells: 26
- Lenght of the structure: 23 cm
- Iris mean aperture: 5.5 mm
- 4 Wakefield Monitors (WFM)
- 4 radial waveguides in each cell terminated by RF absorbers to minimise the long-range wakefields.

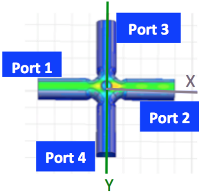


Methodology: Wire as a perturbation of the electromagnetic field

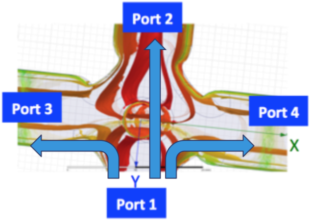
We are going to perform full 4-Scattering (S) Matrix measurement in the middle cell, using a Vector Network Analyser (VNA). The S-parameters relates transmitted and reflected power between ports.



3D model of the AS



Middle cell of the AS



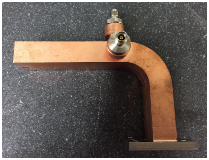
$$\begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix}$$

The S-paremeters are sensitive to the position of a streched-fixed conductor wire moving around the center of the structure when a dipole mode is excited at 18 GHz inside the structure.

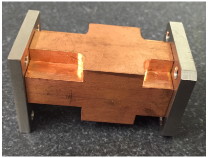
We are interested in:

- $|S_{31} - S_{41}|$ when the wire moves along the X axis.
- S_{21} when the wire moves along the Y axis.
- Amplitude measurements but in the close future we might add phase measurements.

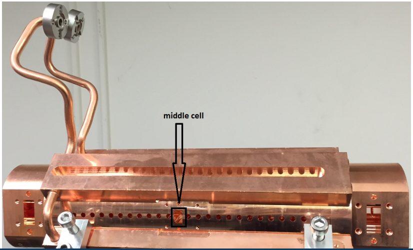
The VNA is connected to the middle cell of the structure by:



Wakefield Monitors. They were initially designed for beam position monitoring.



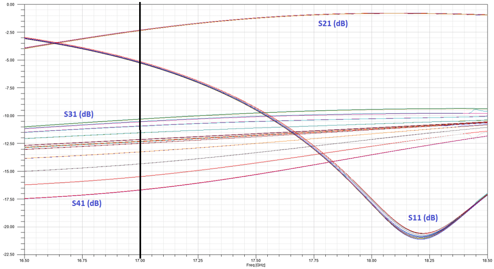
Tapers. We have developed them in order to have a higher level of signal than when using the WFM.



Simulation Results:

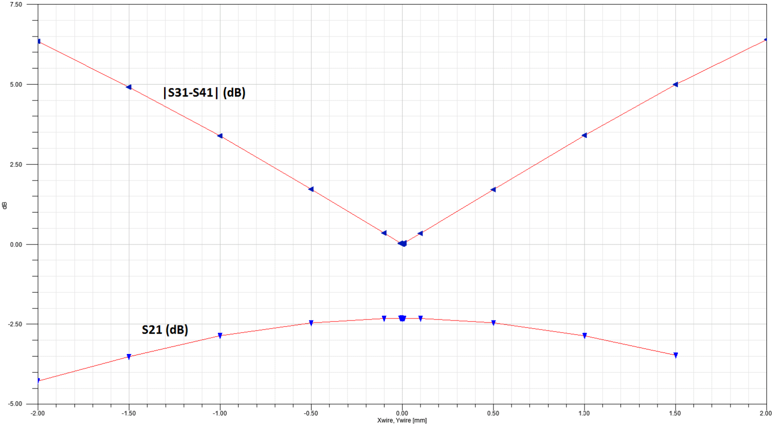
A model of the AS is simulated with ANSYS HFSS, a three-dimension full-wave electromagnetic field solver based on finite element, integral equation and advanced hybrid methods and automatically generates an appropriate, efficient and accurate mesh.

The S-parameters are represented with respect to the frequency when the wire is moving around the center of the AS.

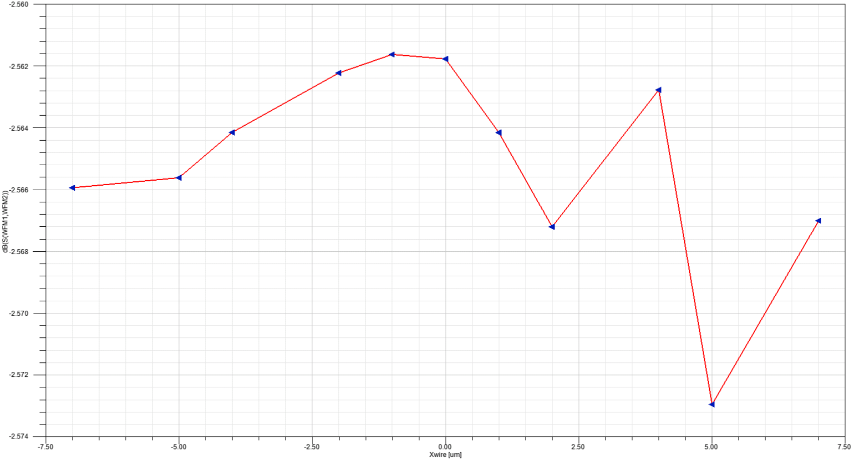


S_{21}: quadratic dependance with respect to the position of the wire. Sensibility=1.125dB/mm.

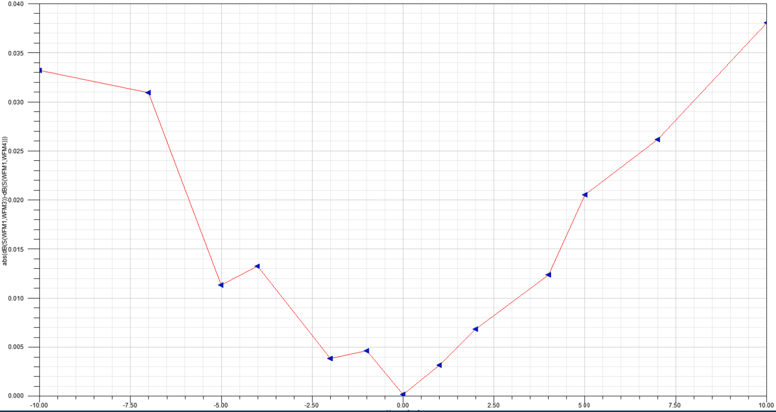
$|S_{31} - S_{41}|$: linear dependance with respect to the position of the wire. Sensibility = 3.2 dB/mm.



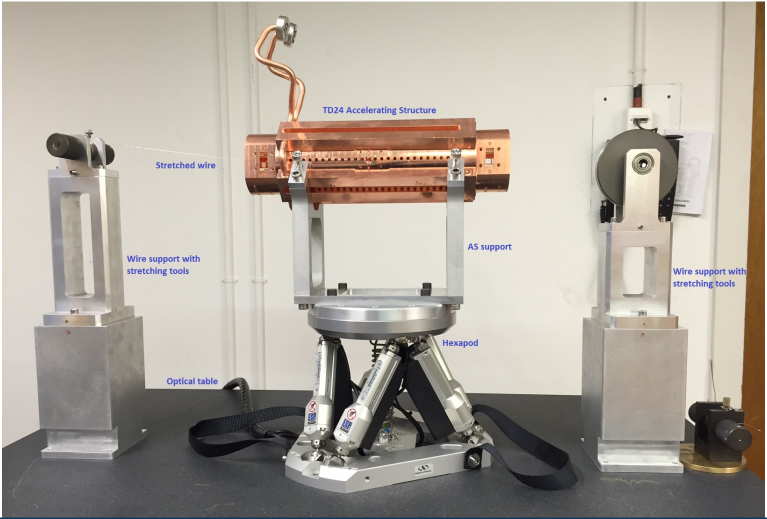
Now, if we zoom the previous plot, we observe that the S_{21} is realistically sensitive to a resolution of 8μm.



$|S_{31} - S_{41}|$ will allow us to find the center with a resolution of 3μm thanks to its linear dependency with the position. Techniques to improve the accuracy of the VNA are going to be applied in our laboratory measurements: IF Bandwidth and Averaging, that reduce the noise floor.



Experimental horizontal set-up



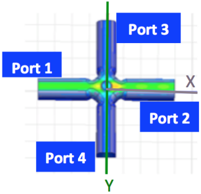
Specifications

- **Active optical table:** for ensuring reduction of transmitted vertical and horizontal vibrations by 85% or more after 5Hz and by more than 95% after 10 Hz, a flatness of 0.1 mm over 600 mm square and a load capacity of 590 kg.
- **Hexapod:** where the AS is placed in order to perform precise movements of $(0.25 \pm 0.25)\mu$m in six degrees of freedom. We have checked the repeatability and precision indicated by the provider using a Coordinate Measuring Machine (CMM).
  - Minimum incremental motion (X,Y,Z)=(0.5; 0.5; 0.25) μm
  - Uni-directional repeatability (X,Y,Z)=(0.5; 0.5; 0.25) μm
  - B-directional repeatability (X,Y,Z)=(4; 4; 2) μm

For further details, see publication: S. Zorzetti et al., "Design of the 15 GHz BPM test bench for the CLIC test facility to perform precise stretched-wire RF measurements", Measurement Science and Technology, Volume 26, Number 9.

Preliminary results

We are now going to present some preliminary results with **10 μm resolution** when we excite the middle cell through the tapers and ports defined as shown in the picture.
We concentrate on the operation $|S_{31} - S_{41}|$

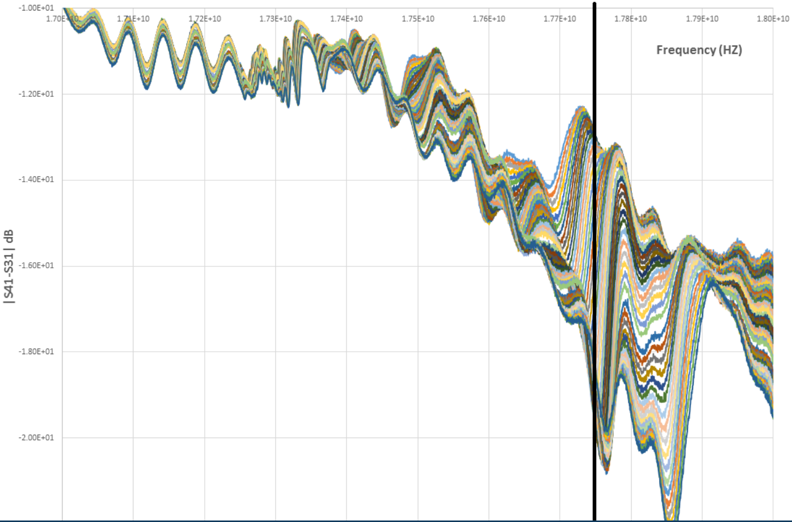


The VNA settings are:

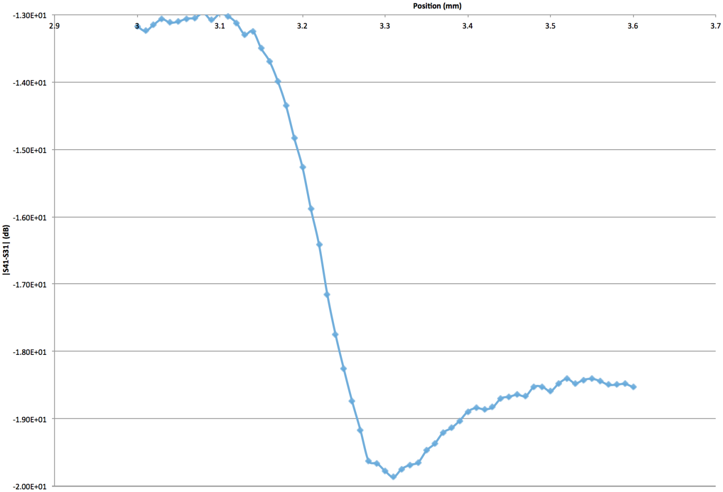
- Frequency sweep: 17 GHz - 18 GHz
- Number of points: 3201
- Input power: 5dBm
- No calibration used.

Temperature: 20±0.3°

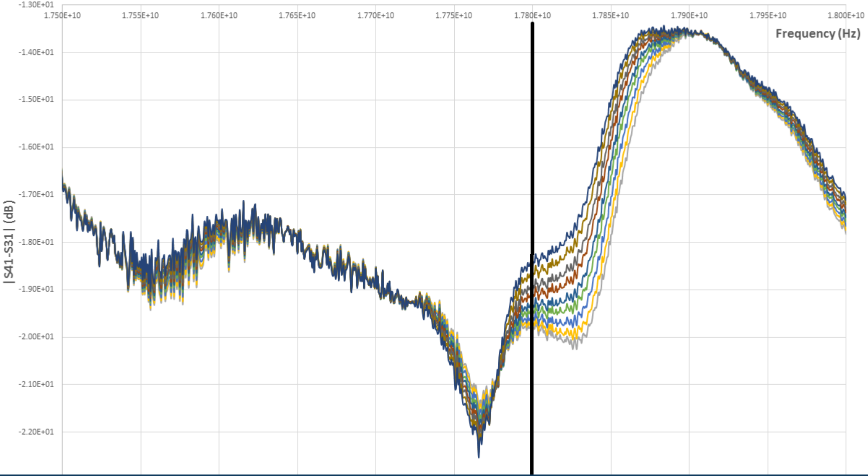
The most sensitive area to the position of the wire is 17.7 GHz - 17.8 GHz.



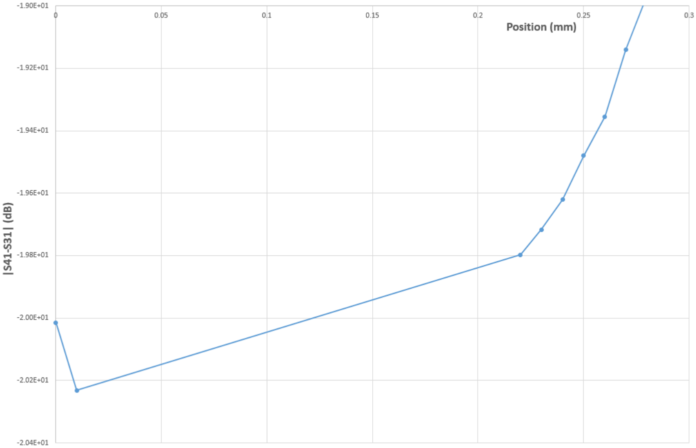
If we focus on one frequency, at 17.75 GHz, we can observe that wire steps of 10 μm around the center are easily detected.



Now, when calibrating the 4-port VNA and trying to find the electromagnetic center of the AS at another range of positions, we find a very similar plot:



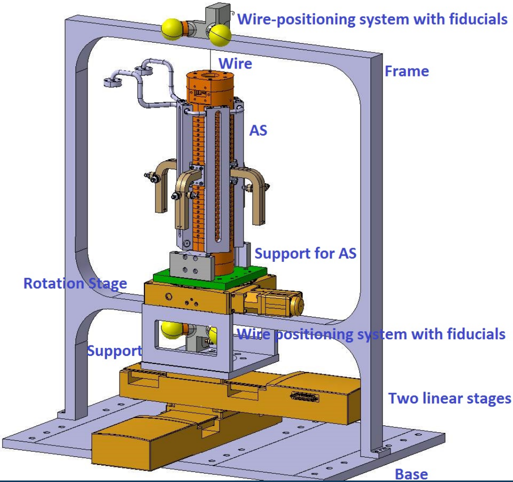
Now, when selecting a frequency at 17.8 GHz, we conclude that a minimum would have been found if we hadn't had a problem in the data acquisition.



Future work using this set-up:

- Reproducibility of the measurements.
- The influence of the calibration on the measurements.
- Repeat the measurements with 1 μm resolution.
- Investigate other frequencies in order to look for optimum sensibility.

Experimental vertical set-up



Current Status

- Base, frame and support for the AS are under drawing process.
- The wire-positioning setup needs to be ordered.
- Linear stages and rotational stage available.
- A perpendicularity between the linear stages of 13 μm over a length of 51 mm has been achieved in metrology.
- The error of the linear stages have been measured in the CMM, which error is $(0.3 \pm (L/1000))$ μm.

Future Plans & Outlook

- Finish the measurements with the horizontal set-up (Feb.16)
- Mount the vertical set-up and start the measurements (Mar.16)
- Measure and correct the verticality of the wire in the metrology laboratory (Apr.16).
- Finish the LabVIEW programming of a user platform to perform automatic measurements (Apr.16).
- Compare experimental results and simulations.
- Make an absolute measurement of the position of the structure with respect to the wire with a fiducialisation method.
- We have experimentally demonstrated the resolution of 10 μm and we keep on working to find a resolution of 1μm.

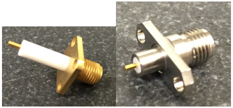
Special thanks to:

Nuria Catalan Lasheras, Angeles Faus Golfe, Anastasiya Solodko, Serge Lebet, Andrej Olyudnin, Wilfrid Farabolini, Pablo Sobrino Mompean, Philippe Guyard, Alexej Grudiev, Walter Wuensch, Manfred Wendt, Didier Glaude, Ahmed Cherif, Cesar Blanch Gutierrez, Juan Jose Garcia Garrigos,...

Measurements to be done:

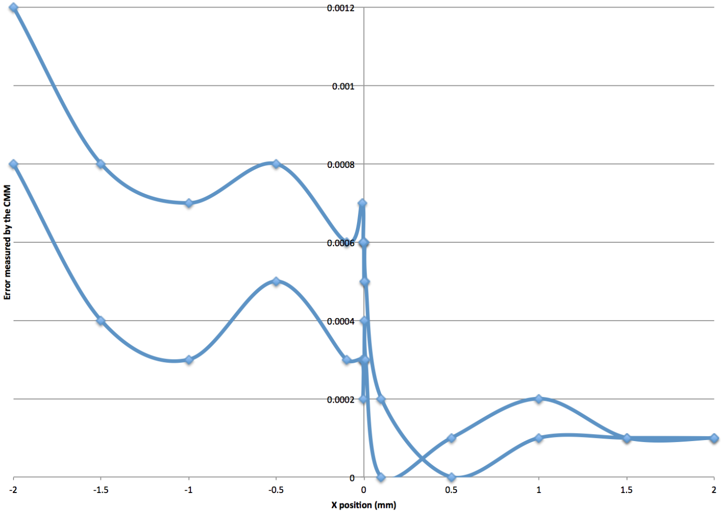
- Repeatibility.
- Reproducibility.
- Error.
- Tilt correction by measuring in the first cell and in the last cell at the same time by special feedthroughs. A switching network that allows a twelve-port extension of the VNA using PCI eXtensions for Instrumentation (PXI) with an insertion loss of -0.3 dB and 26.5 GHz performance.

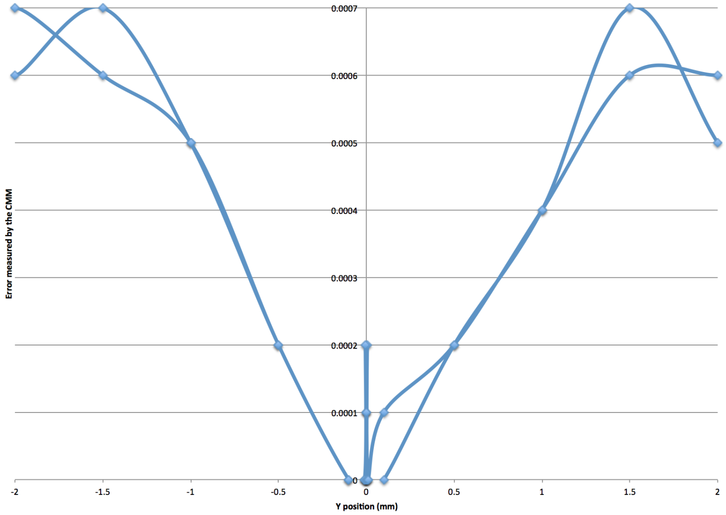
NI-PXI chassis



Transition from cell to standard VNA SMA connector

Hysteresis measured in the linear stages




0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Error measured by the CMM
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Y position (mm)

- We have learnt thanks to the metrology measurements the working areas where the linear stages have a better performance with respect to the home position:
  - The error in the X axis is $\pm$ 0.2 μm from 0 to 2 mm.
  - The error in the Y axis is $\pm$ 0.2 μm from -0.5 mm to 0.5 mm.
- These graphs helps us finding the most optimum algorithm to operate both linear stages and make our measurements with the smallest error possible in the position.
- Our measurements will be done in a clean room, where the temperature is $(20\pm0.3)^{\circ}$ in order to control the deformation of the set-up.