Second semester PhD report

Brunner Kristof (brunner.kristof@gmail.com)
Particle Physics and Astronomy PhD program
Supervisors: Daniel Barna, Wigner RCP
Sergio Calatroni, CERN

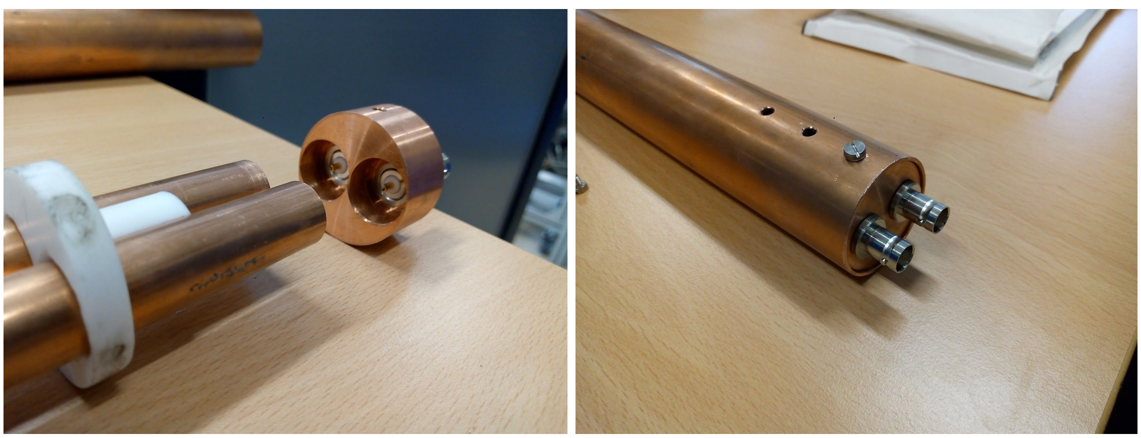
Design and realization of an RF impedance measurement system at cryogenic temperature

Introduction and project description:

The introduction and basics of the project are described in the first-semester report.

Work carried out during the semester:

At the end of the last semester, I started measuring the surface resistivity of a copper tube (as a simplified beam screen) to understand difficulties with the measurement procedure, and to identify the limitations. Since then I did several measurements on the simple cavity made up of 2 inner rods, and an external tube shown in the figure below:



Inner rods and endcap with antenna holder on the left, and assembled setup on the right

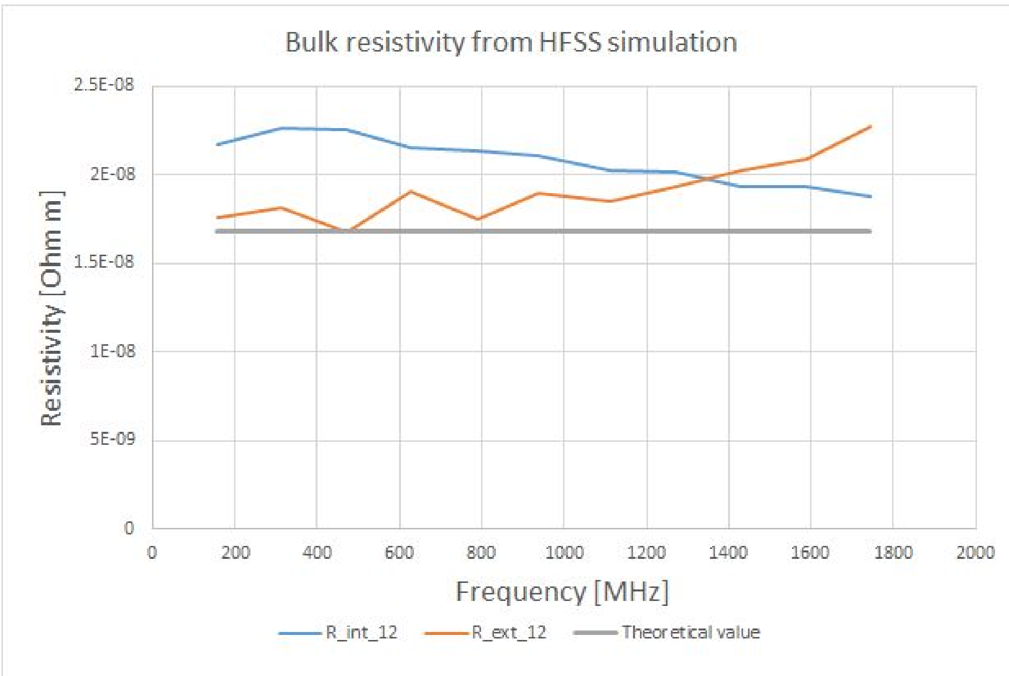
There are 2-2 coaxial cables connected to both ends of the device under test. Through these, I excite and measure the response of the cavity with a vector network analyzer (VNA).

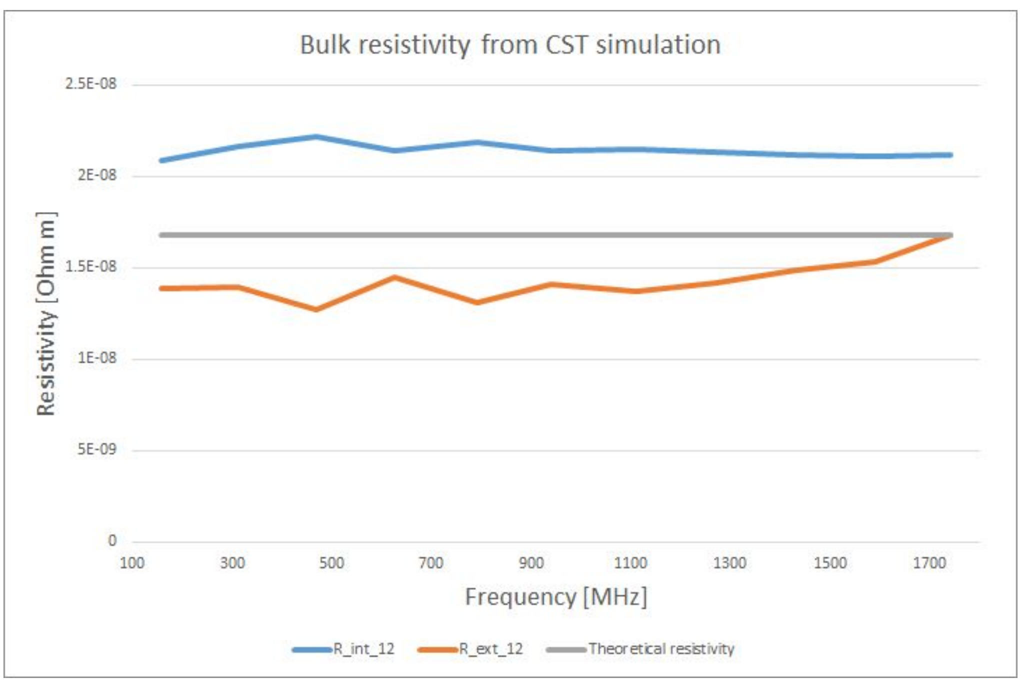
From the quality factor of the resonance peaks (middle frequency of the peak divided by the half width) at different harmonics of the fundamental mode, we can calculate the surface resistivity of the inner rods and the outer tube separately.

This measurement is a long but repetitive process, and after understanding what exactly should I look out for I wrote a python script that scans through the whole spectrum we are interested in, and then measures all the peaks with higher precision one at a time. With this method, the time needed for one measurement cycle went down to ~1h, and no supervision is needed.

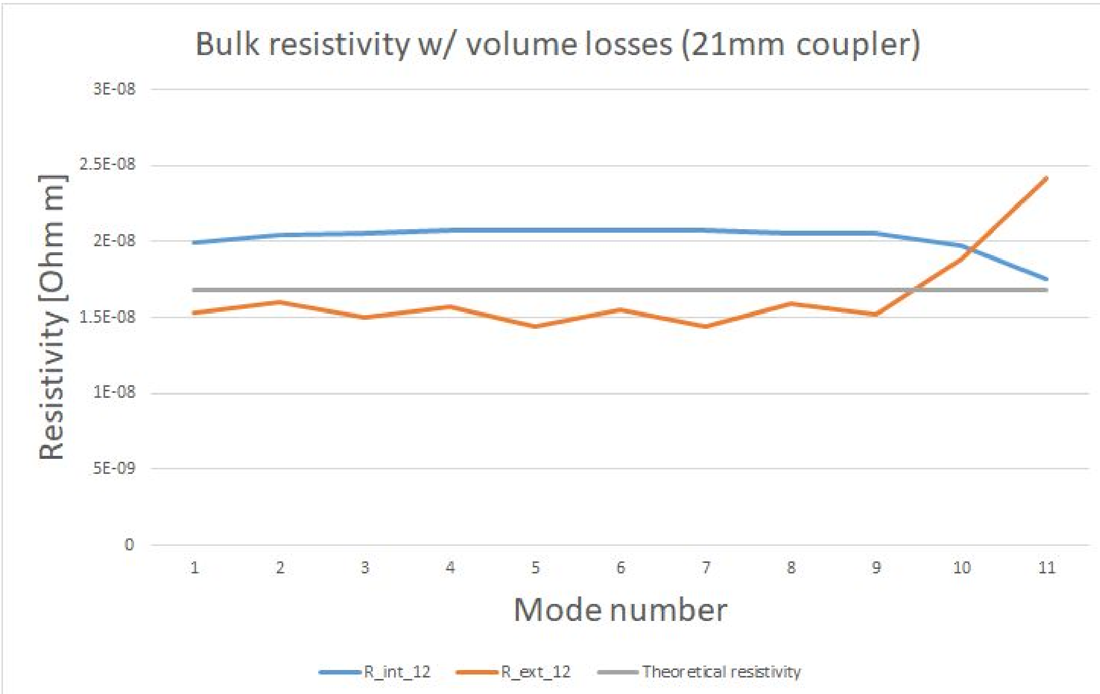
The calculation of the resistivity from the measured data is done afterwards in Excel, but I plan to include it as well in the python script so that what comes out after one hour is only the final results.

I changed the simulation software used to calculate the geometrical factors of the cavity from HFSS to CST since CST seems to provide better results. For comparison, bellowed visible two figures of the same measured data processed using one or the other software's results. The grey line is the theoretical bulk resistivity of copper, while the blue and orange lines are the inner rods' and external tube's resistivity respectively calculated from the measurement.





Since both the inner rods and the tube is made out of copper, from the disagreement of the three lines we can estimate the measurement precision. Early spring the precision of the resistivity was ~30%, but later a few differences between the simulation and reality (e.g. the dielectric constant of Teflon) became clear, and with some changes to the simulation, and also by optimizing the coupling I have increased the precision to around +/-15%. The bulk resistivity result of the improved measurement is visible on the figure below.



Since we are mostly interested in the frequency range 100-1000 MHz, the high-frequency harmonics loss of precision is not a big issue.

The reason for the "oscillation" visible on the external tube's resistivity was also tracked down. In the setup right now there is a Teflon support disc in the middle of the cavity in order to force the inner rods straight. But since Teflon has high volume losses, when the electric field is maximal in the middle of the cavity (fundamental mode, and it's even harmonics) the measured losses are just partially caused by the surface resistivity of the metal parts. This will be corrected in the next iteration of the prototyping process since we will have the setup mounted vertically, we can get rid of the Teflon support in the middle.

Plan for next semester:

As already mentioned before, the next step of the project is to cool down the setup to at least liquid nitrogen temperature and if the thermal contraction makes any difference on the precision of the results, or if maybe some parts of the setup should be changed in order to make it compatible with the cold environment. Since liquid helium is the usual cooling method at CERN (because of all the superconducting material/magnet tests) we will cool down to 4.2 K in one of the Cryolab cryostats, probably from the beginning of September. Until then I will be trying to enhance the measurement precision further, as well as designing new supports (both internal for the rods, and external for the whole cavity inside the cryostat) for the cold measurement.

During the next period of time, I will also start measuring the surface resistivity of the LHC beam screen (seen in the figure below), the most difficult part of which is the simulation of the pumping holes on the top and bottom of the beam screen.

Source: www.finetubes.co.uk

University studies:

I attended two courses this semester. Firstly quantum electrodynamics to establish some basic knowledge before some more advanced courses. And secondly, lattice field theory.

In February I also attended a course organized to PhD students and professionals in the field of high energy physics. It was organized in Archamps (France) and the whole course took 4 weeks. I, however, only attended the course most important for my field of work, namely a 1 week "mixed" course of RF technology and vacuum technology. The course was very interesting, and I gained a huge knowledge of the fields, but most importantly I gathered the tools and sources necessary to understand more advanced phenomena in the field of RF technology. At the end of the course, I also took an examination, the result of which is 19.5/20 points.