**Fourth semester PhD report**
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# 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.

**Disclaimer:**

Because of the COVID-19 pandemic, CERN went into “safe mode” in the middle of April, and is now in the phase of restarting work on site. Because of this for the last 3 months, most of the work was halted, and all that could be done was to study, simulate, and plan ahead for the future.

**Work carried out during the semester:**

At the beginning of the semester, I had a fruitful collaboration with another PhD student doing his PhD in Barcelona at the Polytechnic University of Catalonia. The main topic of his PhD is the high-frequency measurement of surface resistivity of HTS (high-temperature superconductor) coated samples. We already did 1 week of collaborating work last summer, and we continued it in March 2020. The goal of this collaboration is to develop a small resonator (dielectric resonator) that is able to measure flat sample surface resistivity at high frequency. To achieve this, we were simulating and measuring a cylindrical resonator with copper walls and bottom piece, with two different alumina pieces (and a Teflon piece) in the center. By changing geometric parameters of the setup we could identify a good geometry, that we will be able to use for high precision measurement once we receive the ordered single-crystal Sapphire.

The dielectric inside the cavity achieves two separate goals:

1. It reduces the resonant frequency of the cavity (we would like to measure around 1 GHz)
2. It concentrates the electric field in the center of the cavity, in hand reduces the contribution of the contact resistivity at the edges of the cavity.

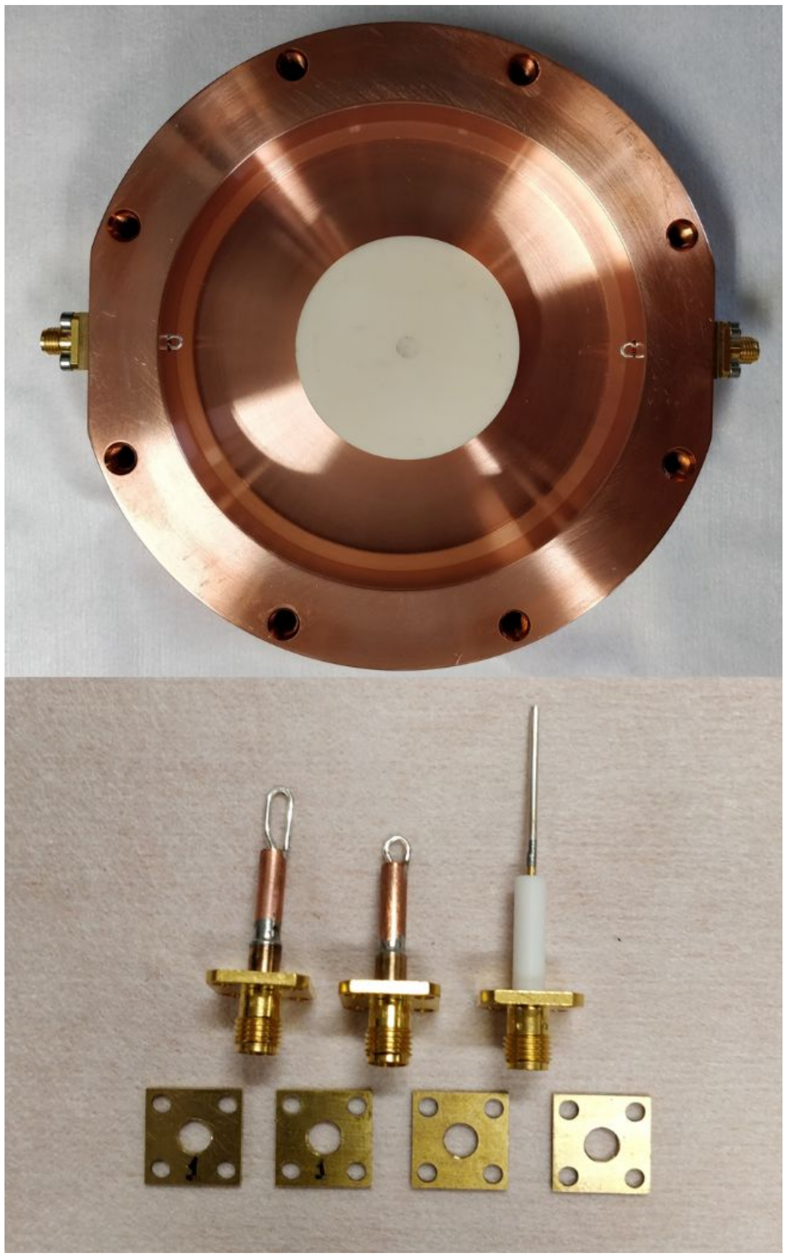
A sufficiently precise measurement requires single-crystal Sapphire as the dielectric because the dielectric constant of it is high, well known (and only depends on the crystal orientation), and the dielectric losses inside it are relatively low.

During this collaboration we spent a few days simulating the setup, trying to find a good set of geometric and dielectric parameters. We want to measure 2 modes of the cavity at the same time:

- The TM010 the frequency of which only depends on the radius of the cavity, and the dielectric constant of the "load"
- The TE011 the frequency of which only depends on the height of the cavity and slightly on the dielectric constant

For example, the results of altering the dielectric constant are only a slight shift in resonant frequency but by fitting the frequency of the simulation to the measurement we can estimate the real dielectric constant of our "unknown" alumina block.

**Dielectric cavity with different coupler antennas**



**Results of the permittivity sweep in CST simulation**

| Permittivity | $f_{TM010}$ | $f_{TE011}$ |
|---|---|---|
| 9.4 | 1.33593 | 3.21413 |
| 9.5 | 1.33373 | 3.19746 |
| 9.6 | 1.33157 | 3.18105 |
| 9.7 | 1.32945 | 3.16489 |
| 9.8 | 1.32736 | 3.14897 |

From these sweeps, we were able to determine that the permittivity of our alumina was around 9.6, while the electrical loss tangent was tan(delta) = 0.0009.

After the simulations, we did several measurements trying different configurations, different dielectric samples, and even slightly altering the height of the cavity by putting different thickness spacers on top of it. Since in the TE010 mode the electric field is tangential, so in the wall only horizontal currents flow, and also the current lines dont cross the corners of the cavity. We were able to measure the resonance with an insulator inserted between the top plate and the walls. This insulator kills all TM mode, so it can be used to identify the TE010 mode of interest.

Work with my main project was significantly set back by the closure of CERN. I did not have the possibility to conduct new cryogenic tests on my setup. I have identified a large source of noise in the cryogenic RF feedthroughs and ordered a new one, that arrived in the middle of March on the week when CERN went into safe mode.

The next stage of the device will be inserted into a cryogenic dipole magnet (FRESCA) to measure surface resistivity of beam screen demonstrators at cryogenic temperature and in large (7 T) dipole magnetic field. The design and manufacturing of this insert will take at least 9 months all together, so my CERN supervisor and I have started weekly discussions with the design group at CERN. We identified the most feasible way of cooling, I calculated heat loads in the cryogenic setup (this included a few days of learning Introduction to cryogenics), and in June some tests have been started to measure cooling power of the chosen way of cooling.

The difficulty in cooling is that we would like the setup to be cooled to 4.2 K (using liquid helium) but also to have some stable temperature points between 4 - 50 K. This is possible in several ways ("cryo-fan", cold helium gas being cooled with liquid helium, and then circulated through the insert, capillary liquid helium cooling, and some way of heating the setup with resistive heaters). In the end, after several hours of discussion with professionals in the field of cryogenic magnets, and cryogenic system designers, we decided on a combination of liquid and gaseous helium coming from a phase separator (helium boils away, we can take 4.2 K liquid helium from the bottom, or ~5 K helium gas from the top). And use local heaters to set the temperature of the helium to the desired 10, 20, 30, 40 K then circulate it through the insert.

**Plan for next semester:**

From July I can go back to work and will try to catch up with testing the second prototype. The discussions of the magnet insert will continue and hopefully, by the end of summer, the designing of the setup can be started. We estimate the insert to be ready sometime during 2021 Q2 which does not leave too much time for me testing the setup and measuring possible beam screen candidates. I try to design everything in a way that the operation of the measurement can be passed down to someone else continuing the project without significant setbacks.

It was planned that in July I will go to Barcelona to continue working on the dielectric resonator together with the other PhD student, but because of the recent events, all planned travels were deleted. Probably sometime in the next semester I will go, and work on it since we are planning to write a paper about the measurement method in the near future.

**University studies:**

This semester I attended the course “Standard model” taught by Zoltan Trocsanyi.