Frequency and Temperature Dependence of High-Temperature Superconductor Coated Conductors Surface Resistance

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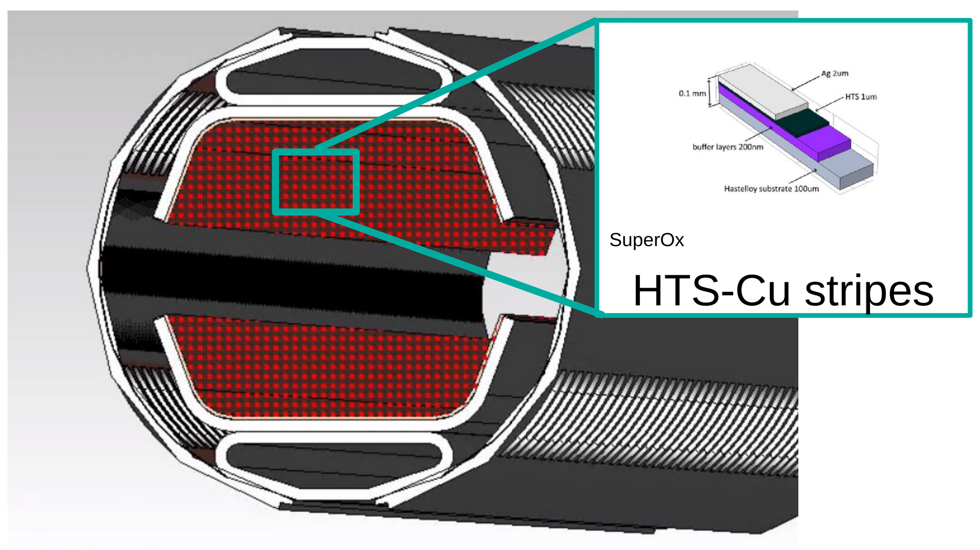
ABSTRACT

High temperature superconductors-coated conductors (HTS-CC) with their significantly low surface impedance at low temperature (below superconducting critical temperature T_C) are being considered a good alternative to Cu as coatings for the beam screen of the hadron-hadron future circular collider (FCC-hh). In particular, rare-earth barium cuprates (REBCO-CC) are excellent candidates considering their commercial availability in km lengths and appropriate widths. Several studies have been performed to study their surface impedance as a function of temperature, AC magnetic field that mimics the image current, as well as under the influence of an external DC magnetic field. Its frequency dependence at frequencies of interest for the FCC-hh, however, has yet to be studied. We present an illustrative example of experimental determination of REBCO-CC surface resistance between 8 and 30 GHz, as a function of temperature. The microwave technique allows the determination of the depinning frequency, flux creep factor, and an estimate of the beam impedance as a function of frequency.

Introduction



- The Future Circular Collider (FCC-hh) requires very low resistive wall impedance to ensure stable beam operation.
- The current Cu coating is close to the limit of what is acceptable.
- High-temperature superconductors are proposed to use as beam-screen coating with surface impedance significantly lower than copper.
- Feasibility of using REBCO coated conductors shows very promising surface impedance even at high fields. However, the frequency dependence of their surface impedance is yet to be studied.

Objective : To present frequency dependent measurements of REBCO coated conductors.

Measurement Set-up and Principle

Three Dielectric Resonators have been used:

1. Multimode Resonator (8 GHz – 11 GHz)

- Dielectric resonator for simultaneous frequency dependent measurements
- Uses dielectric rutile

2. Loss tangent Resonator (6 GHz – 11 GHz)

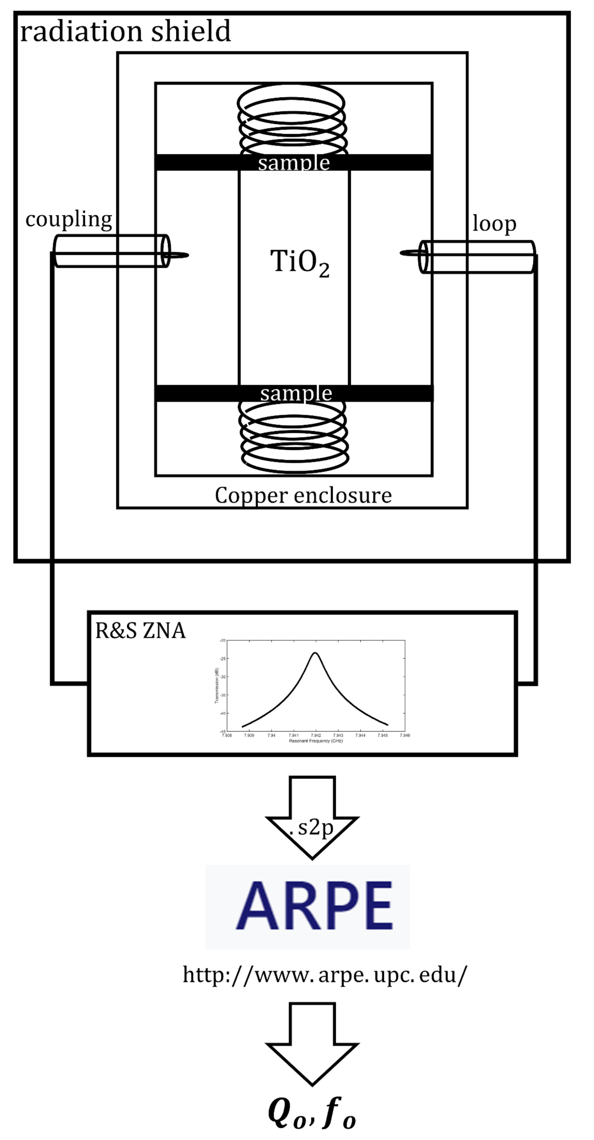
- Dielectric loss from rutile is not negligible
- Used to individually characterize rutile's dielectric loss in use

3. Single mode Resonator (8 GHz , 27 GHz)

- Already working and used in [a] with the use of dielectric rutile and sapphire.
- To verify the applicability of multimode resonator

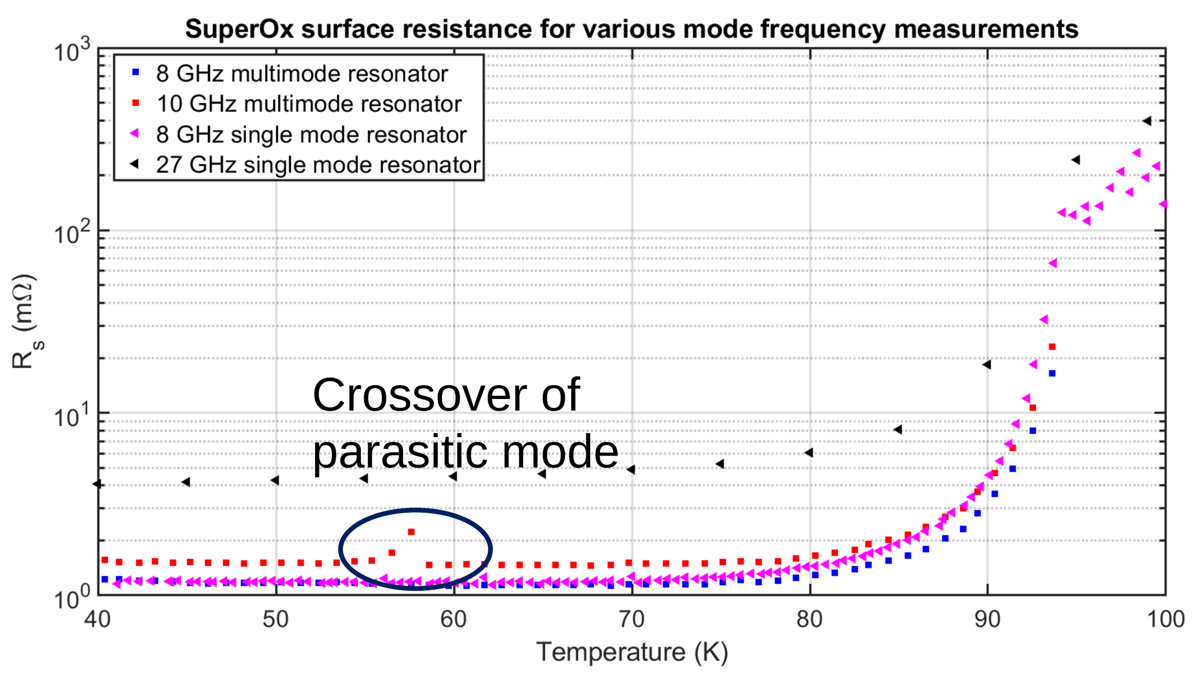
- ➢ Commonly used measurement technique for surface impedance characterization in high-temperature superconductors
- ➢ All of the resonators uses transverse-electric modes
- ➢ With high quality factor and insensitive to electrical contacts

[a] **P. Krkotic *et al.*,** "Small Footprint Evaluation of Metal Coatings for Additive Manufacturing," Proc. 48th European Microwave Conference (EuMC) (2018).

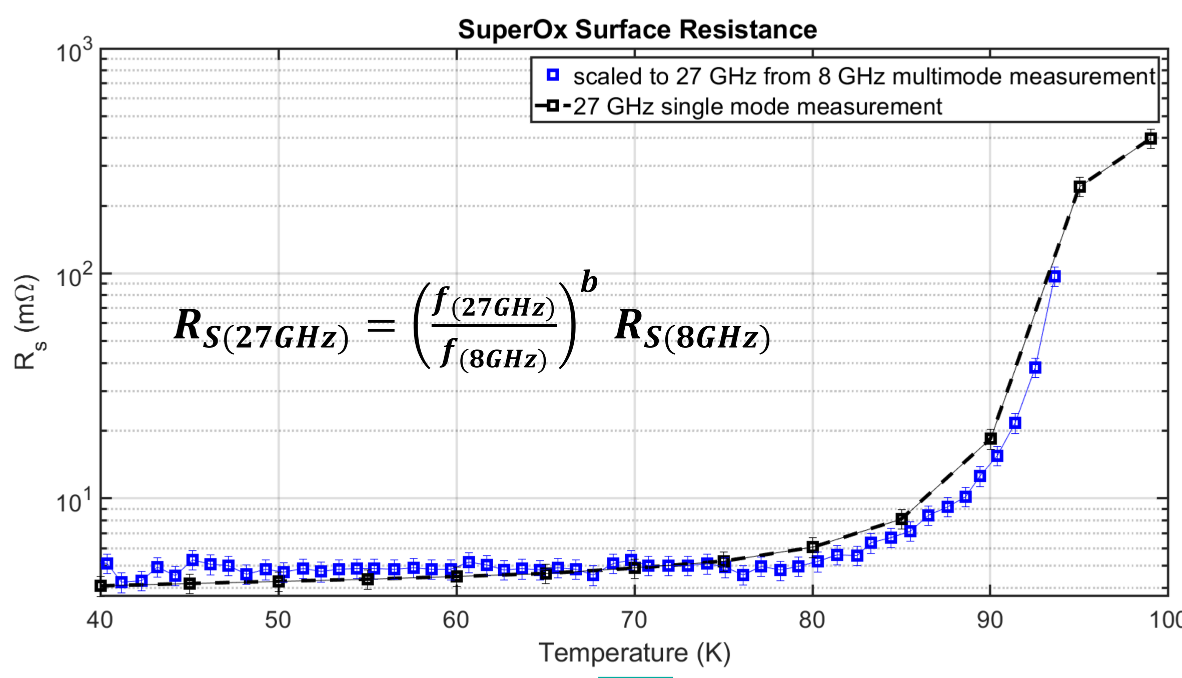


$$R_S = \frac{G_S}{2}\left(\frac{1}{Q_o} - p\tan\delta\right)$$

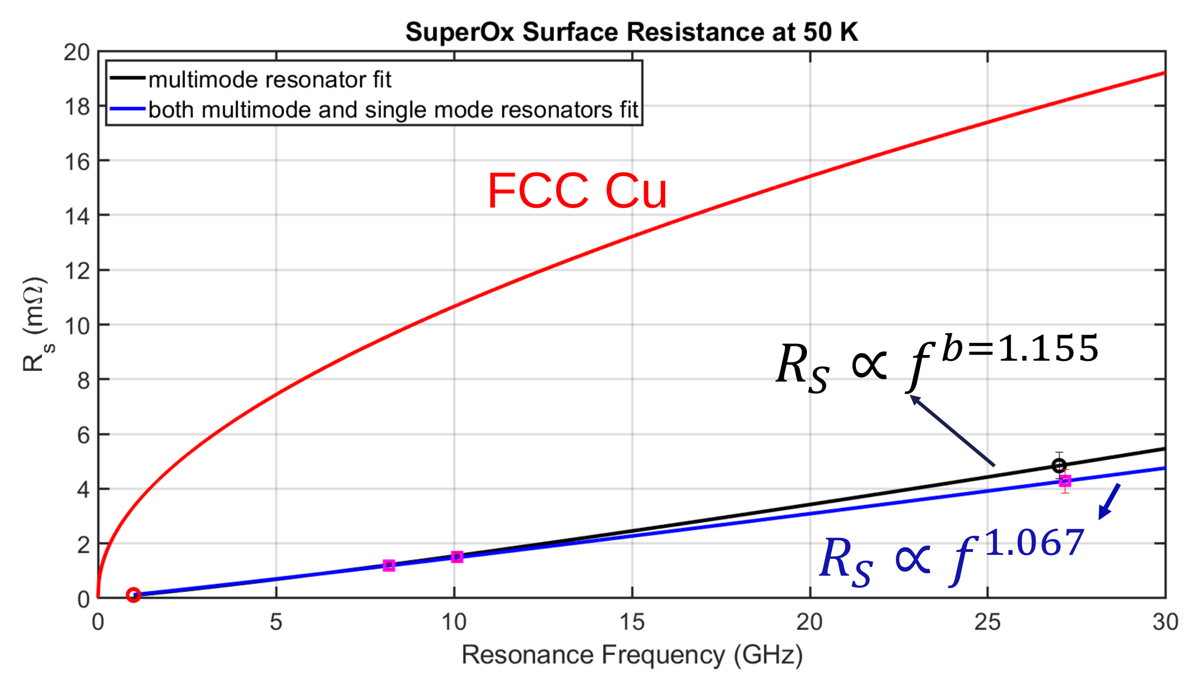
Results and Discussions



- Surface resistances for one REBCO coated conductor provider measured with both the multimode and the single mode resonators at 0T applied external field.
- At around 57 K, a parasitic mode gets so close to the mode of interest that it distorts the measurement. At lower and higher temperatures ARPE can identify the correct mode.



- The frequency scaling using multimode resonator is estimated over the temperature range from 40 to 100 K. The error bar assumes 10% error in the calculated b.
- **The scaled R_S of multimode resonator coincides within 10% with the 27 GHz measurement of single mode resonator which implies applicability of the measurement technique.**
- The good fitting also confirms applicability of the loss tangent resonator for accurate surface resistance measurements.



- Surface resistance as a function of frequency.
- The black line is the R_S scaling at 50 K using the two frequency points from multimode resonator. The black point at 27 GHz is extrapolated from fitting to give emphasis to its comparison with the magenta point at the same frequency measured from single mode resonator. **The two points at 27 GHz coincide within 10%, indicating that the data can be well extrapolated up to 27 GHz.**
- The blue fitting is the least square fitting of the three measured surface resistances in magenta. Consequently, at 50 K, the $R_S \propto f^{1.067 \text{ to } 1.155}$ unlike with most HTS whose R_S scales with the square of frequency. The reasons for this deviation are under study but might be related to the small thickness of this sample (0.9 μm) that renders the thick film approximation not valid.
- The surface resistance of FCC Cu is calculated from anomalous skin effect. **R_S (HTS) < R_S (Cu) in all frequency range including at 1 GHz emphasized by the red point.**
- It is worth noting that the frequency dependence at 16 T might be different and has to be measured. This capability will be implemented in the system being commissioned at ICMAB.
- The frequency dependence measurement technique allows the determination of depinning frequency and flux creep factor of HTS high field applications.
- In addition, the frequency dependent surface impedance obtained from this measurement could provide knowledge for the resistive wall impedance as seen by the beam as a function of frequency.

CONCLUSION AND PERSPECTIVES

- We have developed a multimode resonator for the measurement of frequency dependent microwave properties of REBCO coated conductors.
- Prior to surface resistance measurements, dielectric loss has to be measured using loss tangent resonator.
- The scaling of multimode resonator provides good estimation of the frequency dependence of surface resistance in REBCO coated conductors.

Acknowledgement

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