Project updated: 07.06.2021

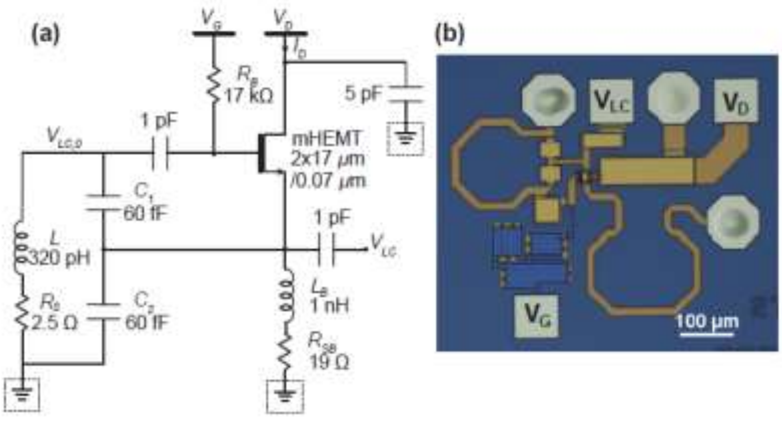
Cryogenic microwave oscillator design for electron spin resonance spectroscopy

Semester project / Master project

(Section: microengineering, electrical and electronic engineering)

Electron spin resonance (ESR) is a powerful and widely applied spectroscopic tool used in physics, chemistry, biology, and materials science to determine the structure and dynamics of compounds with transition metal ions, free radicals, triplet states, and defect centers. Due to the broad range of potential applications, it is important to improve the conventional inductive techniques and develop new detection methods for high sensitivity ESR spectroscopy in the sub-nanoliter range.

In this project, we aim at the realization of inductive electron spin resonance detectors, operating in a broad frequency (10 GHz to 300 GHz) and temperature range (0.3 K to 300 K), capable to achieve significantly better spin sensitivities than those reported to date. Extending the frequency and the temperature range increases both the sensitivity and the possible applications. In particular, we will design microstrip microwave oscillators to: (1) study and improve their limit of detection, (2) perform ESR experiments beyond the sensitivity limitations of inductive systems.



A previously designed single-chip ESR spectrometer [Sahin-Solmaz, 2021]

Work description:

- Microstrip microwave oscillator design using discrete components
- Characterization of the microwave oscillator at cryogenic temperatures
- Electron spin resonance measurements with the designed oscillator
- Project can be adjusted to the student's interests

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Superconducting RF Resonators for Cryogenic Thermometry

Master project

(Section: Microengineering – Physics – Electric Engineering – Materials Science)

The operation of large cryogenic apparatus often relies on distributed temperature measurements. The well-established electric thermometers (4-wire approach) presents a series of inconveniences: feedthrough space requirement, risk of leaks, risk of electric breakdown, heat input (conduction in wires), need for thermalization, etc.. Allocating large number of thermometers or compensating for the absence of distributed thermometry imposes important constraints in the design of the apparatus.

At the LMIS1, we are currently investigating new possibilities of providing a temperature measurement system in cryogenic environment (T<10 K) by means of an RF resonator network [1]. Such a goal would be achieved by exploiting the superconductor's kinetic inductance and London penetration depth temperature dependencies inducing a frequency response of the resonator to temperature (figures 1 and 2).

This student project will contribute to developing temperature sensitive resonators, either by exploiting new materials (e.g. nitride-based LTS [3] (figure 3), nanostructuration, etc…) or by suggesting innovative RF designs, which will be then fully tested and characterized in cryogenic (T<10 K) environments using liquid He and cryostat apparatuses. The topic is highly multidisciplinary, involving aspects of condensed matter physics, RF electronics design and test, cleanroom microfabrication and materials science: the focus can be adjusted depending on the student's preferential interests, best knowledge, previous experience and motivation.

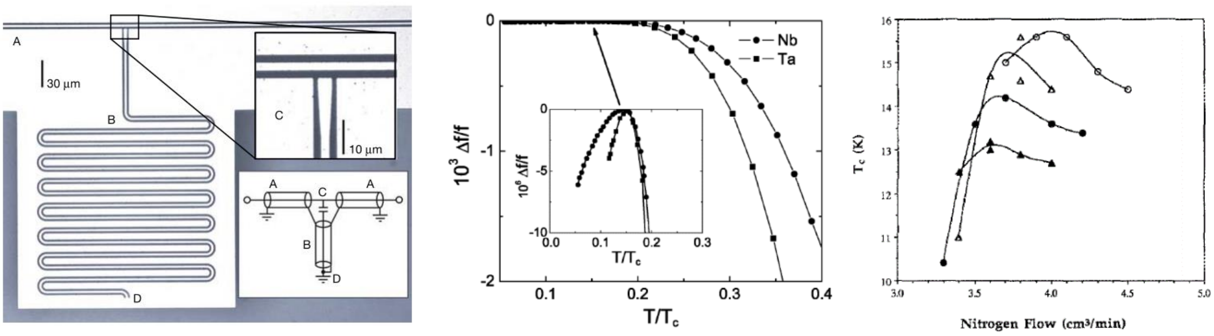

Figure 1 : *Thin film, superconducting coplanar waveguide resonators. Left: pattern example of a CPW resonator kinetic inductance sensor [1]. Center: frequency shift of low temperature superconductor thin film resonators [2]. Right: NbN critical temperature variation with respect to sputtering Nitrogen-flow for different process pressures [3].*

Possible tasks:

- Simulate and analyze superconducting RF coplanar waveguide components and resonators.
- Design, optimize and/or execute process flows at EPFL's state-of-the-art CMi cleanroom:
  - Process flow conception,
  - Drawing individual devices and aggregated chip/wafer lithography layouts,
  - Characterization of the resulting components using SEM, AFM, and other metrology tools.
- Optimize processing and materials for pushing patterning resolution and resonator thermal sensitivity.
- Cryo-RF characterization of finalized devices in a cutting-edge experimental setup.

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[1] PK Day et al. (2003) Nature 425 817.
[2] Barends et al. (2007) IEEE Transactions on Applied Superconductivity 17(2).
[3] Westra et al. (1990) Journal of Vacuum Science & Technology A 8 (3).

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Project updated: 09.06.2021

Superconducting RF Resonators for Cryogenic Thermometry

Semester project

(Section: Microengineering – Physics – Electric Engineering – Materials Science)

The operation of large cryogenic apparatus often relies on distributed temperature measurements. The well-established electric thermometers (4-wire approach) presents a series of inconveniences: feedthrough space requirement, risk of leaks, risk of electric breakdown, heat input (conduction in wires), need for thermalization, etc.. Allocating large number of thermometers or compensating for the absence of distributed thermometry imposes important constraints in the design of the apparatus.

At the LMIS1, we are currently investigating new possibilities of providing a temperature measurement system in cryogenic environment (T<10 K) by means of an RF resonator network [1]. Such a goal would be achieved by exploiting the superconductor's kinetic inductance and London penetration depth temperature dependencies inducing a frequency response of the resonator to temperature (figures 1 and 2).

This semester project will contribute to developing temperature sensitive resonators, either by exploiting new materials (e.g. nitride-based LTS [3] (figure 3), nanostructuration, etc…) or by exploring innovative RF designs, eventually fully tested and characterized in cryogenic environment using liquid He and cryostat apparatuses. The topic is highly multidisciplinary, involving aspects of condensed matter physics, RF electronics design and test, cleanroom microfabrication and materials science: tasks can be adjusted depending on the student's preferential interests, best knowledge, previous experience and motivation.

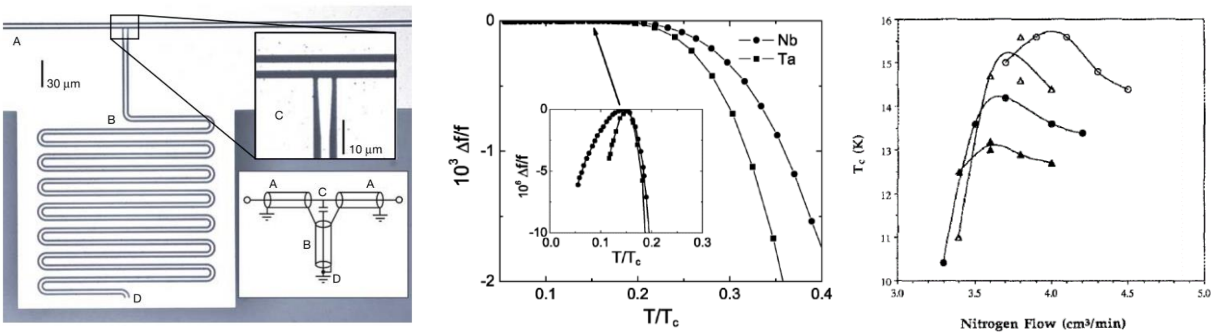

Figure 1 : *Thin film, superconducting coplanar waveguide resonators. Left: pattern example of a CPW resonator kinetic inductance sensor [1]. Center: frequency shift of low temperature superconductor thin film resonators [2]. Right: NbN critical temperature variation with respect to sputtering Nitrogen-flow for different process pressures [3].*

Possible tasks:

- Model and analyze superconducting RF coplanar waveguide components and resonators.
- Characterization of the resulting components using SEM, AFM, and other metrology tools.
- Model and analyze processes and materials for pushing patterning resolution and resonator thermal sensitivity.
- Characterize finalized devices in a cutting-edge Cryo-RF experimental setup.

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[1] PK Day et al. (2003) Nature 425 817.
[2] Barends et al. (2007) IEEE Transactions on Applied Superconductivity 17(2).
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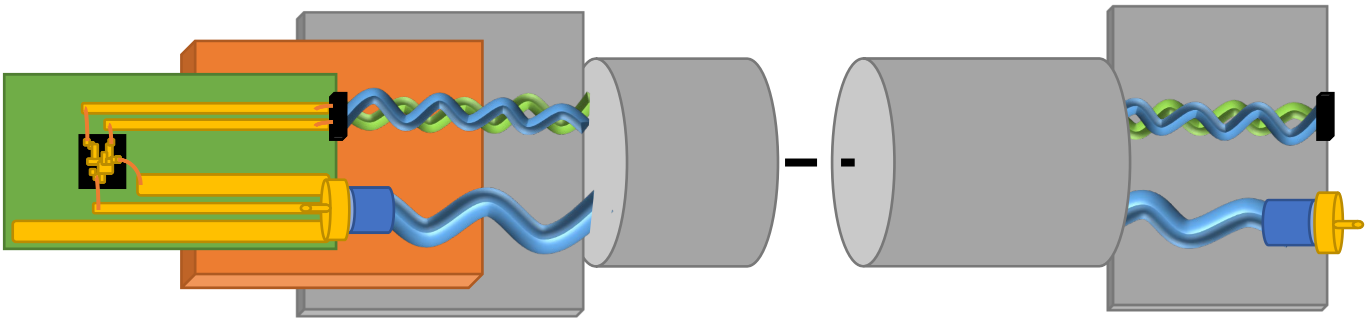
Project updated: 05.06.2021

Design, realization and testing of a cryogenic probe for sensors characterization

Semester project / Master project

(Section: microengineering, mechanical engineering, physics, microelectronics)

The low temperature characterization is of paramount importance in some fields and for some sensors. A proper characterization requires an optimized probe system used to expose the sample to a low temperature environment, allowing at the same time to retrieve in real time the information of interest from the sensor under test. This project aims at designing and testing a low temperature probing system, both for RF and DC signals, to be used with dewars of liquid nitrogen (LN2, 77K) and dewars of liquid helium (LHe, 4K), starting from the requirements forced by the environment and by the sensors to be characterized.



Work description:

- Requirements analysis
- Design of the probe, mechanical end electronics parts (DC and RF)
- Realization of the probe
- Testing of the probe in LN2 / LHe by characterization of one of the sensors it was designed for.

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