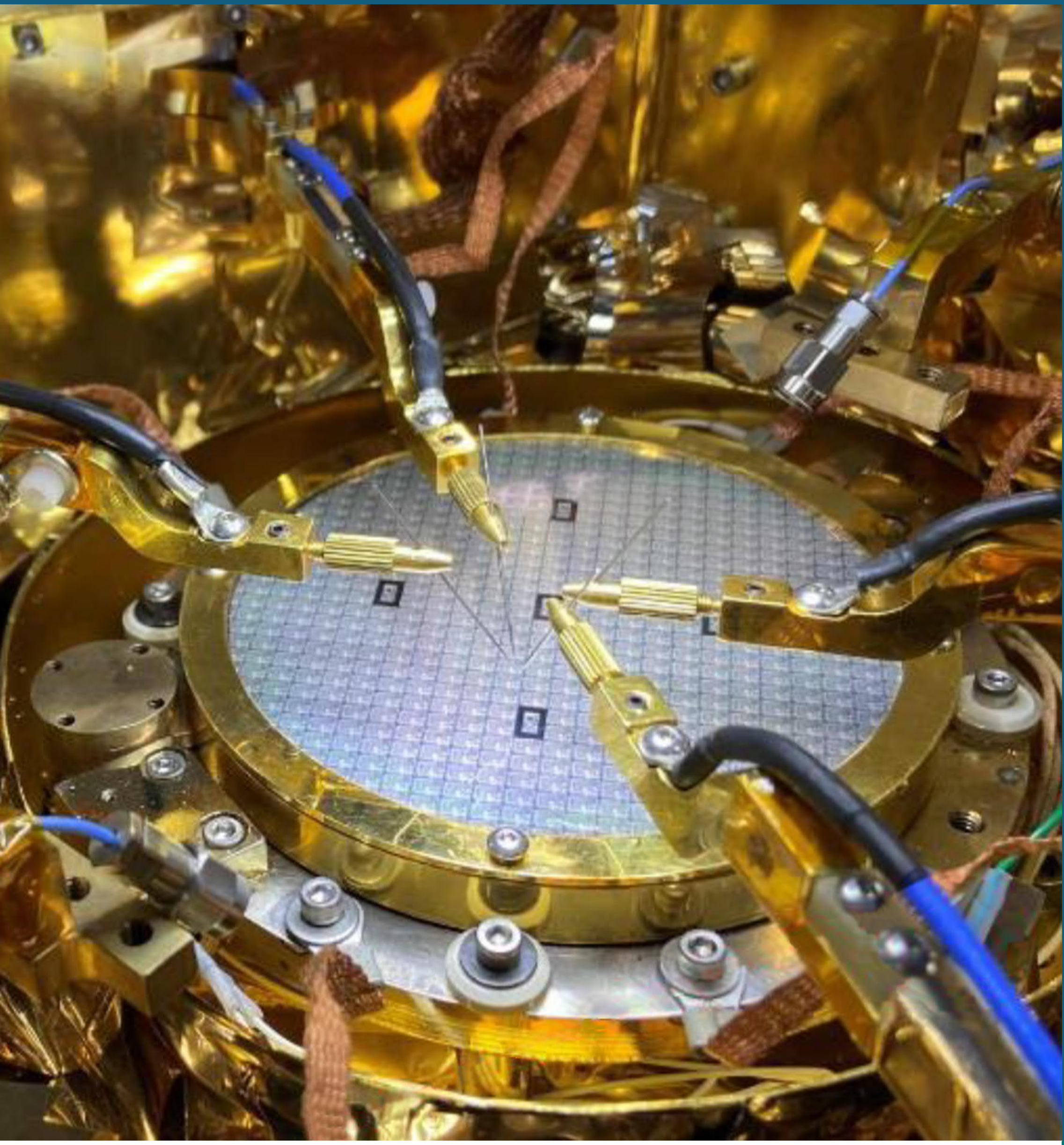
MICROWAVE METROLOGY FOR SUPER-CONDUCTING QUANTUM CIRCUITS



SCIENTIFIC OBJECTIVES

1

Optically integrated Josephson Arbitrary Waveform Synthesizer with unprecedented bandwidth

2

Cryogenic quantum-traceable 1 THz sampling oscilloscope

3

Scattering-parameter measurements in situ at low temperatures

4

New superconducting quantum sensors for microwave power

We are pleased to welcome you to the 2nd newsletter for the “SuperQuant” Joint Research Project that started in September 2021 and will run for 3 years. The project will establish novel metrological and scientific tools for the measurement of microwave signals in circuits in-situ in cryogenic environments down to the millikelvin range using a combination of superconducting, semiconducting, integrated and conventional photonics, and plasmonic techniques. This includes the development of a quantum standard of microwave power, a quantum-traceable cryogenic sampling oscilloscope, and an optically integrated quantized arbitrary waveform generator that will enable energy- and cost-efficient generation of thousands of microwave signals at cryogenic temperatures.

This newsletter presents selected studies from the previous year. More details will be available through further newsletters and on our webpage.

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Project homepage

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

CONSORTIUM:

Optoelectronic generation and detection of ultrafast broadband signals on-chip under cryogenic temperatures

Electric read and write signals to superconducting quantum circuits inside dilution fridges are typically transmitted from room temperature to the millikelvin environment using electrical cables. This not only causes heat insertion to the cryogenic environment but also leads to signal distortion. These drawbacks might be improved by in-situ optoelectronic generation and electro-optic detection of electrical signals.

To that end, researchers at PTB have developed a measurement platform operating at cryogenic temperatures, where write and read signals are transmitted to the device-under-test (DUT) through optical fiber cables (OFC), see Figure 1. OFC, which are made of dielectrics, provide thermal insulation superior to electrical cables and enable ultra-broadband operations.

To demonstrate the functionality of this measurement platform, optical write signals corresponding to 200 femtosecond short optical pulses, excited an on-chip photodiode (PD). The optoelectronic conversion resulted in fast voltage pulses. The voltage pulses traveled on a coplanar waveguide, on top of which a Lithium Tantalate crystal (LTA) was placed. The refractive indices of the LTA changed under the influence of the voltage pulses due to the electro-optic effect.

The change of refractive indices was probed using 200 femtosecond short optical read-out pulses with a center wavelength of approximately 1550 nm. By changing the temporal delay between the voltage pulses and the optical read-out pulses, the shape of the voltage pulse was obtained in a time-equivalent sampling scheme, see Figure 2 (a) where voltage pulses measured at room (300 K) and cryogenic (4 K) temperatures are plotted. The corresponding spectra are visualized in Figure 2 (b) and show spectral components up to frequencies of approximately 250 GHz.

The measurement platform can now be applied to superconducting quantum circuits, but it might also turn out to be a valuable tool for the characterization of cryogenic photodiodes.

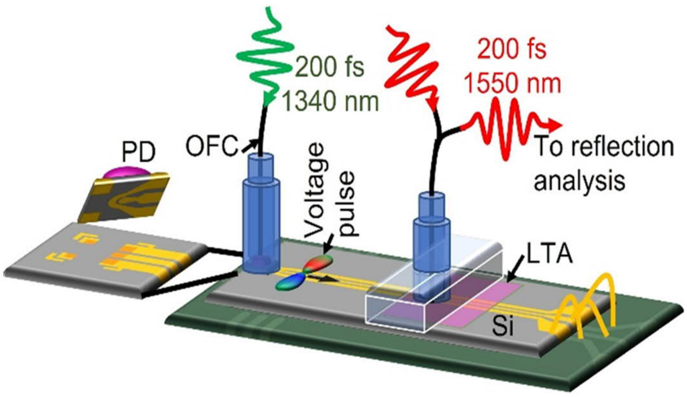

Figure 1. Developed measurement platform operating at cryogenic temperatures. Signals are transmitted to the DUT through optical fibers.

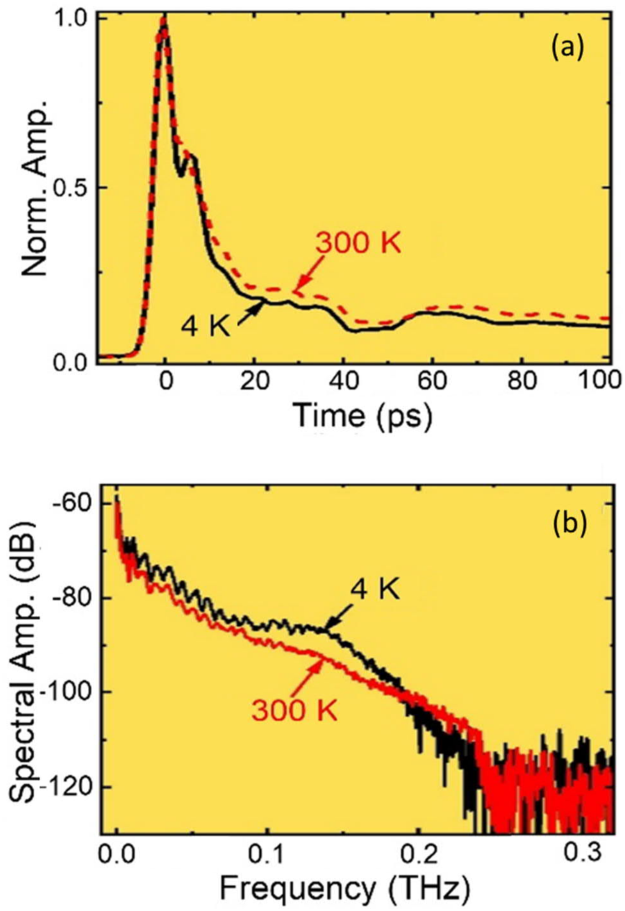

Figure 2. (a) shape of the voltage pulse obtained in a time-equivalent sampling scheme at 300 K and 4 K temperatures; (b) the corresponding spectra showing spectral components up to frequencies of ~250 GHz.

EM based definition of cryogenic on-wafer calibration substrates

TU Delft carried out an extensive simulation and measurement campaign to improve the knowledge of the standard terminations used for on-wafer calibrations. These calibration kits consist of small chiplets realized on alumina or fused quartz substrates. The activity covered the following steps:

- Experimental characterization of the electrical response of the conductive layers versus temperature.
- Definition of the mechanical deformation due to temperature change, and EM model to generate the nominal standard response at cryogenic temperature.

Alumina and fused silica substrates were characterized at 7 K and the usage of the EM based cryogenic models show a substantial improvement in the calibration quality.

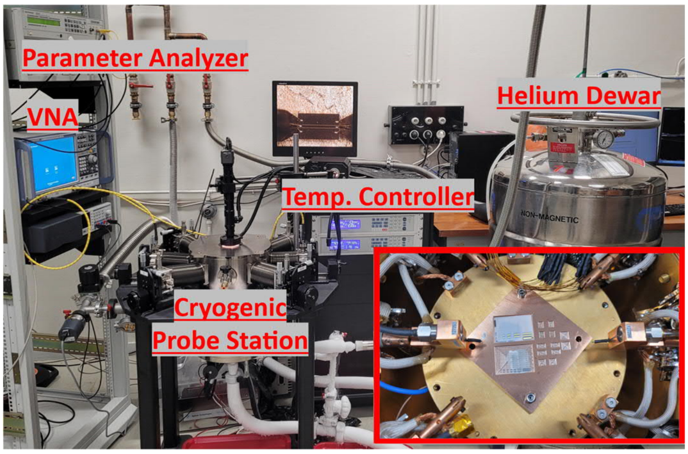

Figure 3. Cryogenic probe station measurement setup used for planar calibration kits (ISS) measurements, (inset) copper plate for alumina based and fused quartz based ISS.

This work will be presented in session We3A at the IMS 2023 to be held in June in San Diego.

Quantum power sensor

RHUL is developing a universal quantum power sensor, which will be used for probing the microwave power delivered from the room temperature to cryogenic.

Two major components of the sensor are:

- Superconducting qubit that provides the quantum scale for measurement of the microwave power
- Compact assembly housing the qubit at cryogenic temperatures. The assembly has superconducting and Cryoperm shielding. (Figure 4)

The power calibration is done with four different methods depending on the amplitude of the driving power. Current development is focused on the optimization of the qubit and housing assembly design, assessment of power calculation algorithm and improving signal to noise ratio. Extensive tests are carried out in the limit of strong and weak driving power to determine the dynamical range of the sensor.

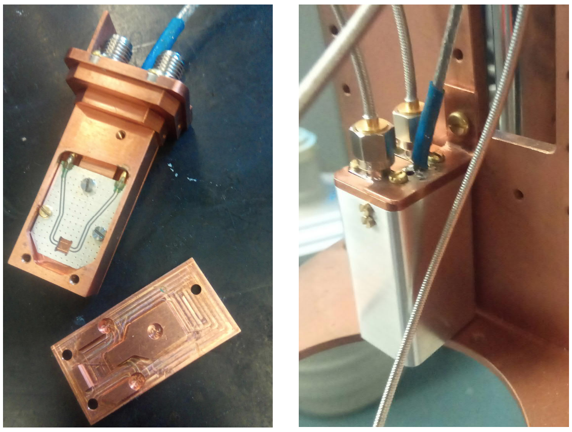

Figure 4. Compact qubit housing of the power sensor. The μW signal is fed through standard SMA components.

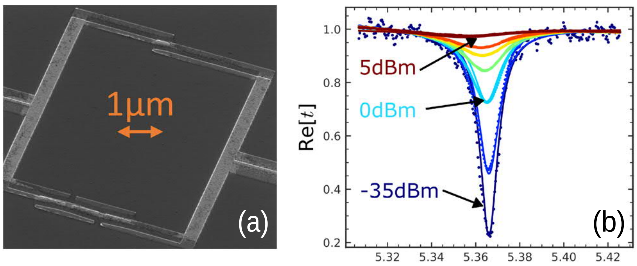

Figure 5. (a) The flux qubit acting as the power sensor; (b) the resonance in transmission signal enabling to perform absolute power calibration.

Realization of a coaxial setup for S-parameter measurements at cryogenic temperatures

INRiM has developed a coaxial setup (Figure 6) for scattering parameter measurements at cryogenic temperatures. The setup involves a couple of equivalent input and output lines that are heavily attenuated to reduce thermal noise at the input port of several devices under test (DUTs) below the single photon level.

The input lines pass through two cryogenic directional couplers. The DUTs can be controlled by bias currents supplied by two coaxial bias-tees. The RF+DC ports of the bias-tees are connected with low attenuation superconducting coaxial cables to the input ports of two electro-mechanical cryogenic RF six-ports switches. The position of the switches is controlled by a custom python-based graphical user interface (GUI) that drives a custom control box hosting an Arduino Mega microcontroller board.

The output lines, which connect the output ports of the directional couplers with the room temperature interface, are realized with the same superconducting coaxial cables up to the 3 K stage, where two high-electron-mobility-transistor amplifiers (HEMTs) constitute the first stage of amplification of the readout line. To protect the DUTs from the backward noise generated by the HEMTs, a couple of isolators with 60 dB of attenuation are placed along both the readout lines at the level of the base temperature plate. The latters set the limit of the measurable frequency range to 4–12 GHz.

The experiment yields reliable results, and we are able to preliminarily measure the scattering parameters of some devices under test. Although a proper cryogenic calibration kit is still under development, we are able to exploit uncalibrated Thru and −20 dB cryogenic components as a reference.

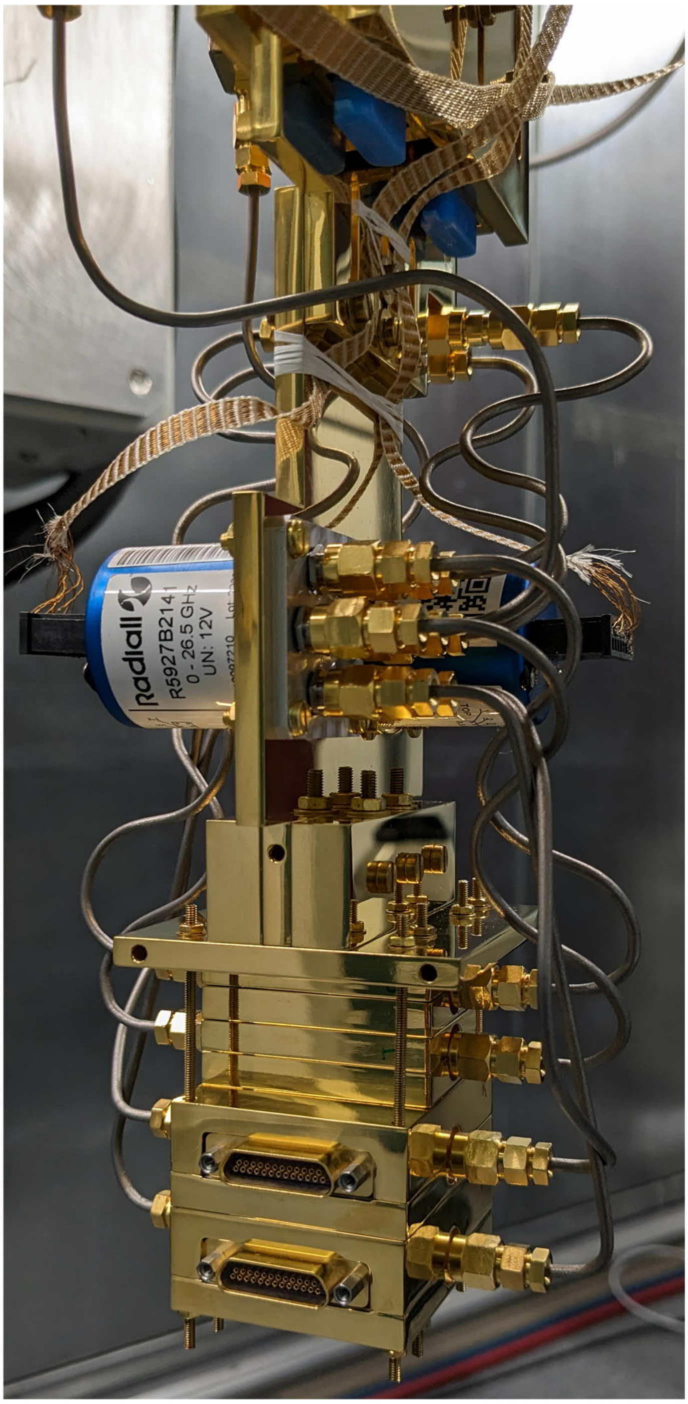

Figure 6. Coaxial setup for S-Parameter measurements at cryogenic temperatures.