In situ 1-Port Cryogenic Vacuum Device Calibration

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***Abstract*— We present a method for a 1-port vacuum cryogenic in-situ calibration of a Vector Network Analyzer (VNA) using Commercial Off The Shelf (COTS) RF latching electro-mechanical switches. This procedure is being developed for use in a closed-cycle cryogenic test bench to measure the reflection coefficient of a single port connectorized Device Under Test (DUT) which is loaded onto a cold plate alongside calibration standards. The RF switch allows for the calibration and device measurement to be carried out in a single thermal cycle as opposed to a minimum of 4 cycles, which is required for industry standard Open-Short-Load (OSL) device calibration. This test procedure has been carried out on an arbitrary DUT at ~ 3K temperature, over a 6 GHz bandwidth. However, the goal is to develop a setup and procedure for measuring the frequency and temperature dependent complex impedance of superconducting devices such as Hot Electron Bolometer (HEB) mixers, which are used for down converting the signal in the IF chain of astronomy instruments. Characterization of superconducting devices while they are at their operating temperature is challenging using traditional calibration methods. This COTS alternative is less expensive and more efficient in terms of thermal cycles and set up.**

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I. Introduction

THz astronomy often makes use of superconducting non-linear devices as mixing elements in receivers to down-convert incident sky signal to an intermediate frequency (IF) by convolving it with a local oscillator (LO) signal. Examples of common astronomy instrumentation mixers include superconductor-insulator-superconductor (SIS) mixers (Zmuidzinas et al. 2004), and hot electron bolometers (HEBs) (Gousev et al. 1994). Because these devices are superconducting they must be operated at cryogenic temperatures, achievable only inside vacuum cryostats. Their complex impedance is dependent on frequency, LO power, and temperature. The impedance is an important factor to characterize because if there is impedance mismatch between mixer output and the amplifiers in the IF system, standing waves will be present, complicating data collection. Vector network analyzers (VNAs) are typically used to characterize devices by measuring their scattering, or s-parameters. The accuracy of the s-parameter measurements are dependent on VNA calibration. Calibration requires a series of measurements using already well characterized objects known as calibration standards. A one-port calibration can be carried out using a short circuit, open, and matched 50 ohm load as reference standards, this is known as an OSL calibration. VNA calibration is difficult when the device under test (DUT) is physically isolated inside a vacuum system. Calibration inside the cryostat may be done manually by measuring the individual standards separately at the operating cryogenic temperature, but this would require a minimum of four cool-down, warm-up cycles to obtain one measurement (Rodriguez-Morales, et al. 2010).

In this work we present a method to calibrate a VNA and measure the DUT all in the same cycle. This setup makes use of commercial-off-the-shelf calibration standards, and cryogenic latching switches. A one port in-situ calibration was used to characterize an RLC circuit in a single cycle, and that result was compared to a manual method with four cryogenic cycles.

II. Set-up

The cryogenic test bench is shown in Fig. 1. The closed cycle system can reach ~ 4 K temperatures, which was below the operating point for most superconducting materials. The VNA was a Rhode & Schwarz ZVA 24. The calibration standards were COTS 85033D DC - 6 GHz, 3.5 mm SMA calibration kit. Each of the calibration standards were heat-sunk to the 4 K test stage using copper clamps so that each component was measured at the same temperature. A temperature sensor was fastened to the DUT heat bracket at the highest point. This calibration scheme was made possible by a single pole six-through (SP6T) cryogenic electromechanical latching DC – 18 GHz Radiall R583423251 switch. Port one of the VNA was connected to the switch through the cryostat. Four channels on the switch were connected to the calibration standards, and DUT via short Mini-Circuits hand formable coaxial UT-047 cables. A supplied 28V DC bias actuated the different switch channels. Outside of the cryogenic system was a hermetic DC bias box that could be manually operated to change the switch channels.

Fig. 1. Cryogenic test bed setup. The calibration standards and DUT were heat-sunk to the test bed using copper clamps and brackets, and are numbered 1-4. The Radiall SP6T switch is in the center with DC power supplied through cryo-wire.

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At room temperature the SP6T DC bias of 28 V resulted in an actuating current of 61 mA. At ~ 10 K temperature, the switch was actuating with a 2 V bias. By attaching the reference standards, DUT, and VNA to the same switch, one could measure each component in a single cycle. A one port RLC made with COTS surface mount components was the DUT for both a single cycle in-situ measurement and a four cycle manual calibration. For all testing the VNA port power was -20 dBm, the IF bandwidth was 10 Hz, the averaging was x16.

III. Results

The RLC was measured at room temperature using an automated electronic calibration kit, and then using the manual OSL kit. First, this manual calibration was done without the switch. The individual standards were connected one at a time to the first port of the VNA via coax cable. Then the VNA was calibrated with the same standards using the switch. Channel one of the switch was the open, channel two was the short, channel three was the matched load, and channel four was the DUT. These three measurements were in agreement which validated an OSL measurement using the SP6T at 300 K. The S_{11} of the DUT at 300 K can be seen in Fig. 2 as the blue trace. The cryostat was brought to ~ 4 K temperature. The room temperature calibration had drifted due to a change in temperature and conditions inside the cryostat. The switch test was repeated when the system was at 3.3 K. The new result can be seen as the pink trace in Fig. 2. The RLC resonance was recovered by recalibrating at cryogenic temperatures using the SP6T. The result was shifted slightly in frequency. The shift was likely due to objects contracting at cooler temperatures and changing the values of not only the RLC test device, but of some of the calibration standards. The linear coefficient of thermal expansion (CTE) determines how objects will change with temperature for the different materials. The ~ 1.75% shift in frequency indicates a change of ~ 3.50% in the inductance and capacitance LC. The cryogenic calibration was repeated using a manual method where each standard was measured separately at cryo and replaced over multiple cool downs was used to verify that this shift is not coming from the switch. Each cycle changed the measurement environment by changing the thermal load on the test bed, and because the internal coax lines were disturbed by the act of replacing standards and the DUT. The manual method took 2 days, and the results can be seen in Fig. 2 as the brown trace. The two traces are nearly identical with some variation due to the change in environment in the manual method and the lack of temperature control. Without stable temperature control of the test stage the DUT, measurements had a narrow window to be recorded. The final temperature with the bulky SP6T and calibration standards installed together, was 3.3 K. The individual standards and DUT installed alone would reach ~ 2.7 K. This meant averaging had to be started before the objects reached 3.3 K to measure the same conditions.

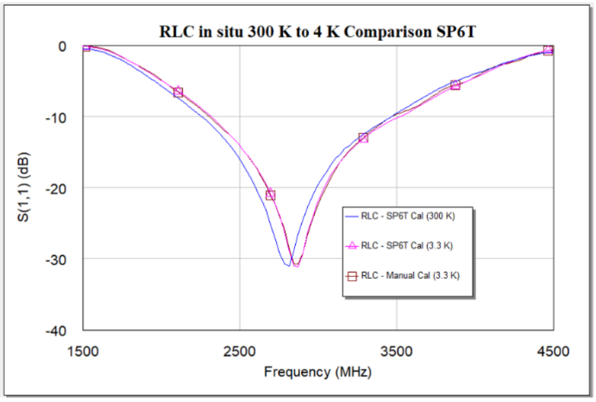

Fig. 2. An RLC DUT test circuit measured at room temperature 300 K (blue), and at 3.3 K using an RF SP6T (pink). The result is compared to a manual method (brown).

IV. Conclusion

The in-situ one-port VNA calibration using an SP6T to switch between reference standards and DUT provides an alternate calibration scheme to a multi-cycle manual error correction. The SP6T method is in good agreement with the manual as shown in Fig. 2. The S_{11} response is nearly identical between both methods. The variations result from the drawbacks of the manual method, namely the inconsistency of environment between measurements, i.e. cable position and exact temperature. The SP6T offers several improvements over the alternatives. The setup is entirely COTS and relatively inexpensive. The technique only requires a single cryogenic cycle to calibrate and test which can save days of measurement time. Due to that fact, the calibration can be restarted in the same cycle if temperature fluctuates before or during measurement with very little time lost. Having characterized a generic RLC DUT, the follow up measurement will be that of an HEB built for THz astronomy instrumentation. With more accurate characterization a matching network may be implemented to improve power transfer from the HEB to the rest of the IF system.

References

[1] Gousev, Y. P., et al., "Broadband ultrafast superconducting NbN detector for electromagnetic radiation", *Journal of Applied Physics*, April. 1994.

[2] Rodriguez-Morales, F K., et al., "Wide-band IF-integrated terahertz HEB Mixers: Modeling and characterization", *IEEE Transactions on Microwave Theory and Techniques*, April. 2010.

[3] Zmuidzinas, J., et al., "Superconducting detectors and mixers for millimeter and submillimeter astrophysics," *Proceedings of the IEEE*, Sept. 2004.