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Ac-Dc Transfer At Cryogenic Temperatures Using A Superconducting Resistive Transition-Edge Temperature Sensor*

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***Abstract* - A prototype, cryogenic thermal transfer device has been constructed and tested using a superconducting transition-edge thermal sensor.**

I. INTRODUCTION

The most accurate RMS measurements of ac voltage and current are made by comparing the heating effect of an unknown ac signal to that of a known dc signal using a thermal converter. The converters are usually composed of one or more thermocouples arranged along a heater structure [1]. The limiting factors for the ac-dc differences of the most accurate converters used at national laboratories are, to a large degree, thermal and thermoelectric effects which are temperature dependent. In order to reduce these effects, a thermal transfer device has been fabricated to operate at temperatures below 10 K, where the thermoelectric effects are expected to be small. Furthermore, the entire converter is mounted on a temperature controlled platform to reduce thermal gradients.

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II. DESIGN

Like a conventional room-temperature converter, the new converter consists of a heater structure and a temperature sensor. The prototype device employs a superconductive resistive transition-edge temperature sensor to monitor the converter heater temperature, a signal heater, and a trim heater [2]. A diagram of the chip layout is shown in Fig. 1. The thermal sensor is a thin-film niobium meander line fabricated on a silicon substrate. During operation, the sensitivity of the sensor is greatly enhanced by thermally biasing the sensor within the superconducting-normal-metal transition. The trim heater is an 800 Ω palladium-gold meander line on the silicon chip adjacent to the sensor. In this experiment, shown in Fig. 2, the signal heater is an external 10 Ω bifilar wire wound onto a copper bobbin mounted in intimate thermal contact with the detector and with niobium-titanium leads to reduce substitution error. The converter is thermally isolated using nylon standoffs from an intermediary thermal platform, whose temperature is servo controlled at a slightly lower temperature by another transition-edge sensor and wire heater. The thermal transfer converter assembly and the platform temperature controller are maintained at their respective temperature set points by the application of a feedback voltage to each of the trim heaters.

III. PERFORMANCE

The whole assembly is mounted in a liquid helium cooled dewar. The resistance of each of the transition-edge sensors is monitored with an ac resistance bridge. The feedback power applied to the trim heater is controlled using room-temperature electronics to maintain a constant converter temperature. Fig. 3 shows the change in the control voltage applied to the trim heater to maintain this constant temperature when a step change in voltage is applied to the signal heater. A three second integration time was applied to the data in Fig. 3. Using the observed change in the trim heater voltage of dV_{trim} as a result of a change in the signal heater voltage of dV_{load}, the responsivity, $\mathcal{R}$, is

$$\mathcal{R} = dV_{trim} / dV_{load} = 43.$$

The noise-limited resolution in the load signal due to the trim heater circuit is

$$dV_{load} / V_{load} = 2 \times 10^{-6}.$$

Performance in the present version is limited by noise in the room temperature servo electronics. The use of lower noise electronics, in conjunction with optimization of the physical design and configuration are expected to significantly improve resolution and permit operation close to the noise limit of the superconducting sensor. Ac and dc signals have been applied to the signal heater, and ac-dc difference comparisons have been made on the prototype device; however, the transmission line carrying the signals through the cryostat walls has not been sufficiently well studied and characterized to permit accurate determination of the ac-dc transfer performance. The dynamic range of the converter can be varied by adjusting the thermal set-point of the intermediary platform. The limitations of the prototype, notwithstanding, the feasibility of a cryogenic converter employing a superconducting, transition-edge sensor has been demonstrated. Successful development of this technology may lead to a new generation of primary reference standards for ac voltage and current.

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