11. Thermodynamic Temperature Measurements

***D. C. Ripple**, W. L. Tew, G. F. Strouse, W. C. Ausherman, M. Moldover, S. Benz (814), J. Martinis (814), and S. W. Nam (814)*

Objective: To improve the accuracy of thermodynamic temperature measurements and to develop new metrology capabilities in the fields of acoustic thermometry and in Johnson Noise Thermometry (JNT).

Problem: There remain unresolved inconsistencies in previous measurements of thermodynamic temperatures in the temperature range 80 K to 220 K, and at 500 K and above. These inconsistencies have led to uncertainties in the thermodynamic values of the ITS-90 that are much larger than the reproducibility of platinum resistance thermometers calibrated on the ITS-90.

The unique characteristics of JNT address a separate problem: commonly used high-accuracy thermometers are subject to drift as a result of contamination or mishandling. In JNT, a thermometer calibration can be corrected for probe drift by making an in situ measurement of the probe resistance. However, the state-of-the-art techniques now being used are limited by amplifier non-ideality, resulting in relative uncertainties of temperature of $1{\times}10^{-4}$. The use of JNT beyond this limit requires a new approach.

Approach: For the Acoustic Thermometry Project, we utilize the simple relation between the speed of sound of a monatomic gas to the thermodynamic temperature. Utilizing this relationship and acoustic resonance techniques, we will determine thermodynamic temperatures between 300 K and 800 K from measurements of the speed of sound of argon in a spherical cavity. Acoustic thermometry up to 800 K requires development of novel transducers, control of gas impurities, and novel flow-control techniques. With a thermometer incorporating these improvements, we expect reductions in the uncertainty of the thermodynamic temperature above 500 K by factors of 3 to 8.

For JNT, the recent advances in intrinsically accurate, ac waveform synthesis via the Josephson ac voltage standard now permit the construction of a calculable, synthetic noise source. This type of noise source can be tailored to serve as a matched noise voltage reference to a JNT system. With the advent of higher speed, higher accuracy, analog-to-digital converters (ADCs), it is now feasible to construct a digital cross-correlation Johnson noise system over larger bandwidths than ever before possible. The integration of these techniques will allow a comparison of the JNT power spectrum with a synthetic spectrum of Fourier components known in terms of $h/2e$. Consequently, the goal of realizing thermodynamic temperature via a JNT over a wide range of temperatures, coherently linked to voltage and frequency standards, is now possible.

Results and Future Plans: During FY00, in the area of acoustic thermometry, we tested the performance of the acoustic thermometer under conditions of flowing gas and active thermal control, at temperatures up to 470 K. These experiments demonstrated that: a) the flow and temperature control schemes enabled accurate acoustic measurements for both flowing and non-flowing conditions, b) temperature control was highly satisfactory, and c) outgassing rates from the resonator and related plumbing will contribute only a small component to the overall uncertainty. Further work was limited by the transfer of a key staff person to the Group Leader position. A staffing arrangement to meet the needs of the Acoustic Thermometry Project has been formulated and implemented. In FY01, training of the new staff will continue, the furnace will be completed, and the metrological properties of the resonator will be tested. Following completion of these tasks, measurements of thermodynamic temperature will commence.

In FY00 in the field of JNT, the project's logistical and resource planning was finalized. Activities in Div. 836 focused on collaboration with D. R. White of the New Zealand MSL/IRL on theoretical modeling; renovation of laboratory space; design of JNT probes for measurement and testing; and specification for and testing of a gallium triple point system for use by the Div. 814 staff. During FY01, the Division 836 staff will: continue to build, test, and refine JNT probes for use both by both divisions; develop impedance measurement capabilities in the 100 kHz band; and design a mid-range capsule/long stem SPRT comparator system with ultra-low noise performance.

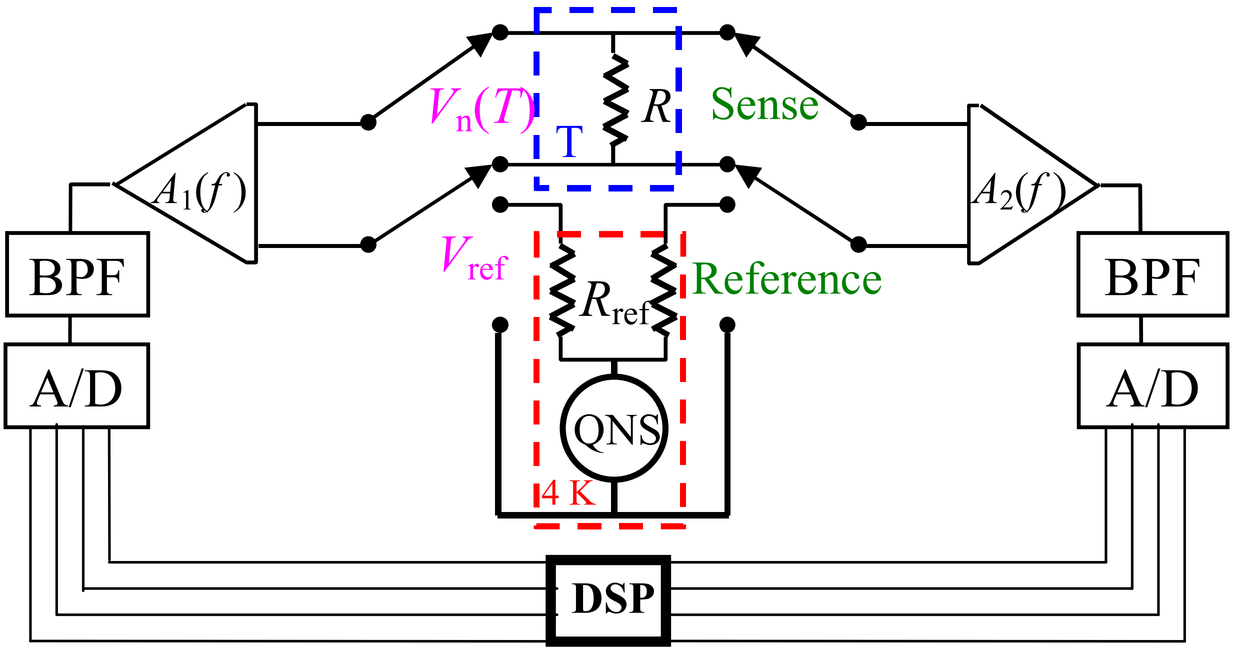

Figure 3. A system level block diagram of the Josephson noise synthesis and Johnson noise comparison measurement.