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FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2014/41
SMR/ICHMI/ORNL/TR-2014/02

Report of the Final Configuration of the Johnson Noise Thermometry System

February 2014

Prepared by

Charles L. Britton Jr.
N. Dianne Bull Ezell
Michael Roberts

UT-BATTELLE

ORNL-27 (4-00)

ORNL/TM-2014/41
SMR/ICHMI/ORNL/TR-2014/02

REPORT OF THE FINAL CONFIGURATION OF THE JOHNSON NOISE THERMOMETRY SYSTEM

Author(s)
Charles L. Britton Jr
N. Dianne Bull Ezell
Michael Roberts

Date Published: February 2014

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ABSTRACT

This report summarizes the final hardware and software configuration of the Johnson Noise Thermometry System being developed at ORNL. Much of this information has been reported previously but is included for completeness. In addition to providing design and testing details, we will describe some of the issues encountered during development.

1. SYSTEM DESCRIPTION

As presented in the previous reports [1-4], the JNT system consists of several parts as shown in Fig. 1. This report describes the final configuration of the JNT system and includes a brief description of each major system component. The amplifier/filter block diagram is shown in Fig. 2, the digitizer block diagram is shown in Fig. 3, the filter/interface board is shown in Fig. 5, and a photo of the integrated front-end electronics is shown in Fig. 7. Each of these blocks will be discussed in the following sections.

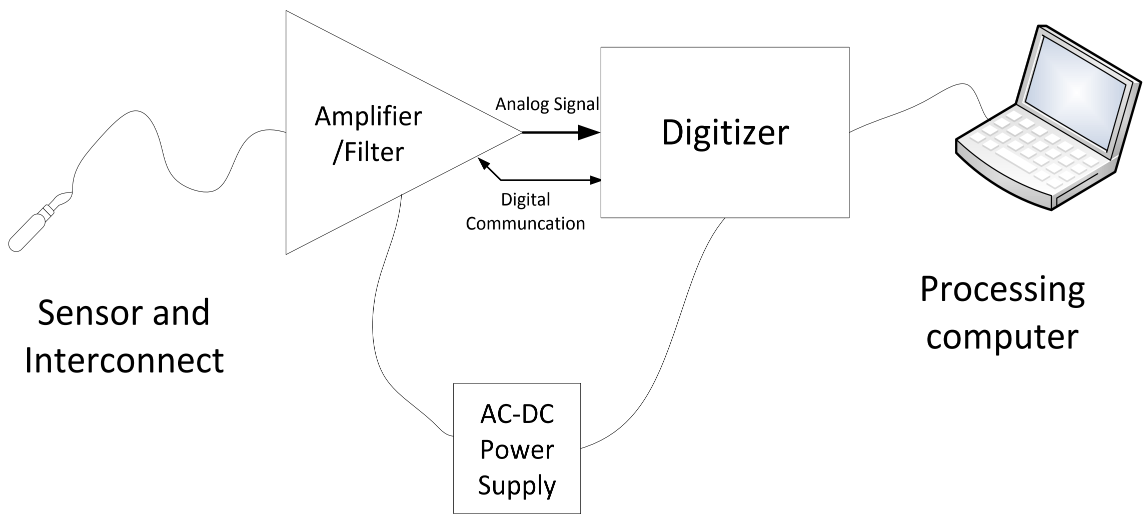

Fig. 1. JNT System Block Diagram.

Amplifier/Filter

1. Preamplifier. The noise signal from the RTD sensor is extremely small and needs to be sensed with an appropriate preamplifier having very low inherent noise and relatively high gain. The low noise is required so that the preamplifier injects the least possible amount of its own noise into the signal which would result in an incorrect reading. The gain is required so that the very small noise signal amplitude can be increased to a point where the electronic noise of successive stages will not be a significant source of error.

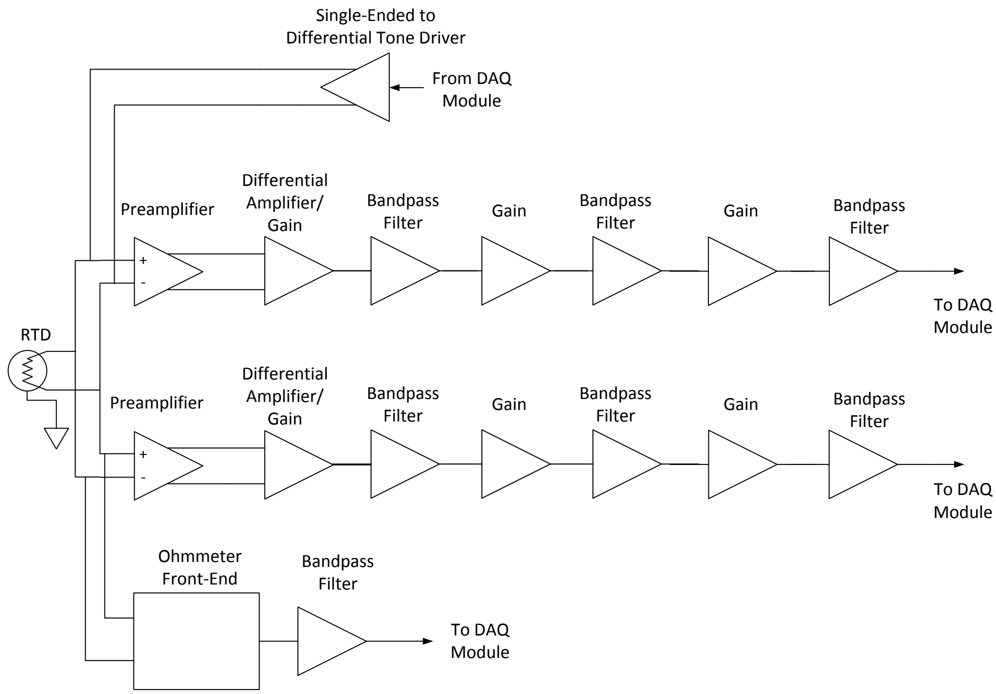

Fig. 2. JNT Amplifier/Filter Block Diagram.

The RTD noise is sensed differentially by two independent channels which are treated as separate but equal amplifier chains. The signal at each of the two channel outputs contains primarily the sensor noise plus a small amount of noise from the filters and the other amplifiers associated with the channel. The final software processing of the signals includes routines to autocorrelate the noise between the two channels. The only signal of interest that is in both channels is the desired sensor noise (correlated) so that the autocorrelation of the two channels removes other electronic noise from the amplifiers and filters.

2. Differential Amplifier/Gain. The output of the differential preamplifier consists not only of the desired noise of the resistor but also the common-mode noise of extraneous pickup in the sensor lines. In order to remove the undesired pickup noise we process the differential preamplifier output with a differential amplifier which passes the resistor signal of interest and cancels most of the pickup noise.

3. Bandpass Filter/Gain. The bandpass filter design utilizes the Sallen-key filter topology to implement the high-pass and low-pass functions. The Sallen-Key (SK) filter was chosen for this application for two reasons. First, this filter topology utilizes a finite-gain operational amplifier configuration which maintains a stable transfer function over variations in operational amplifier performance thus simplifying the choice of amplifiers in the design. Second, the filter design is relatively simple since each second-order filter block is entirely independent of the other filter blocks. The filter and gain stages were discussed in more detail in previous reports.

4. Ohmmeter Front-End/Bandpass Filter. For the DC resistance measurement (ohmmeter), a 100-μA current is supplied to the RTD through a low-noise configuration that

has a minimal impact on the measured noise. Two amplifiers, one for each side of the RTD, measure the voltage drop across the RTD due to the known 100-µA current being injected. The two amplifiers are input to a differencing amplifier (thus forming a differential amplifier) with gain and then filtered with a low-pass filter to remove high-frequency noise. This configuration removes common-mode offset and noise to enable an accurate DC measurement. Since this is a 4-wire measurement, the current is supplied through one set of wires to the RTD and the voltage is measured across the remaining set of wires.

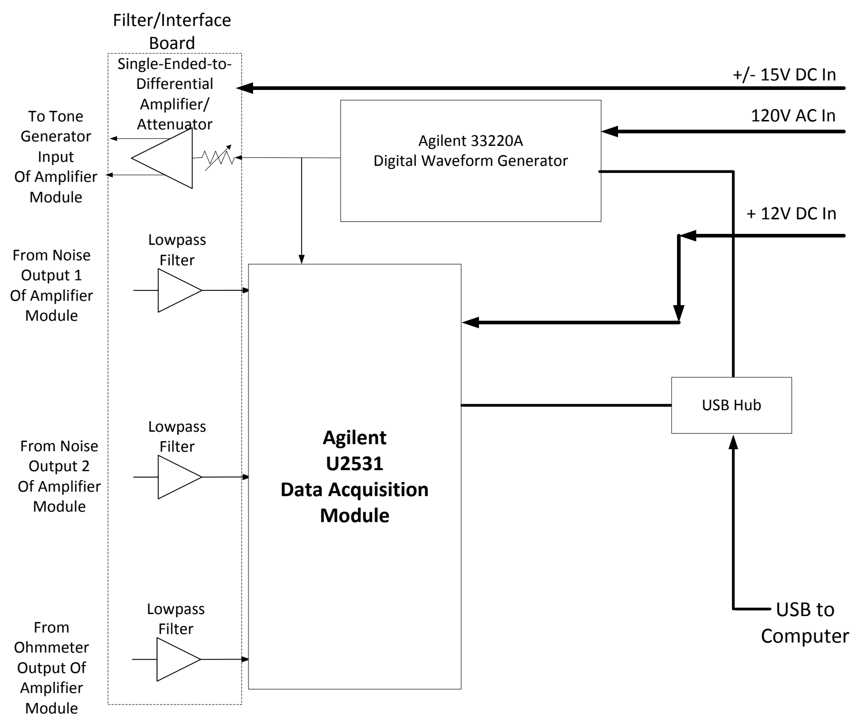

Fig 3. Digitizer Block Diagram.

Digitizer

The digitizer, shown in Fig. 3, receives the processed analog inputs from the amplifier/filter module and translates them into digital information, which is then sent to the signal processing program residing on the processing computer. The waveform synthesizer is used to generate the pilot tone to the processing electronics. The external computer acts as the system controller, which programs and operates the both the digitizer and the digital waveform synthesizer.

Because there are numerous commercial options for the ADCs and because of the limited time and budget associated with this project, a mostly commercial, off-the-shelf system was chosen for implementation. The individual modules are described below.

1. Data Acquisition System (DAQ) – (Agilent U2531A). The U2531A is the heart of the data-acquisition system. The device contains four 14-bit, 2-Msamples/s analog-to-digital converters (ADCs). In addition, it contains TTL-programmable digital outputs, digital counter channels, and 2 analog output channels. The only functionality used in this

application is the set of four ADCs. Two of the ADCs are used for signals from the noise channels, one is used for the DC ohmmeter signal, and the fourth handles the pilot-tone digitization. The device is programmed and controlled from a standard USB interface, which is connected through a USB hub to the control computer. To minimize internally-generated electromagnetic interference, the U2531A is wrapped in copper mesh and single-point grounded to the main chassis.

2. <u>Pilot-Tone Generator – (Agilent 33220A Digital Waveform Generator).</u> The pilot tone is a frequency-modulated sine wave that is swept from 1 kHz to 100 kHz with very stable amplitude of approximately 0.75 V peak-peak. The Agilent 33220A is used for this function, as it is capable of 14-bit, 50 2-Msamples/s output. The device is also programmed and controlled from the USB interface, which is connected through a USB hub to the control computer. Again, to minimize internally-generated electromagnetic interference, the 33220A is also wrapped in copper mesh and single-point-grounded to the chassis.

3. <u>Filter/Interface Board.</u> The Filter/Interface Board (FIB), shown in Fig. 4, provides connections between the Amplifier Module and the rest of the system. The FIB's functions are as follows:

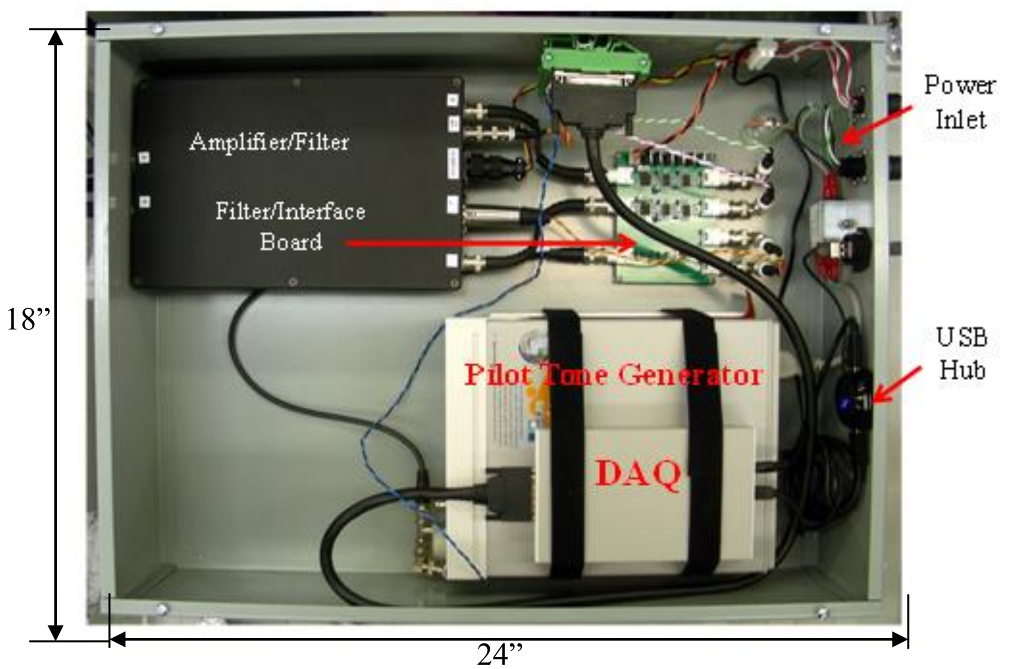

Fig 4. Photograph of the Completed System inside the Steel Box.

A. The two noise-channel outputs are fed from the Amplifier Module into two of the input channels of the Agilent U2531 through the FIB. The FIB(see Fig. 5) provides an adjustable voltage gain of 2-20 and additional low-pass filtering, with cutoff frequencies of approximately 40 kHz. The DC voltage supply is taken from the input ± 15 V source and locally regulated to ± 12 V.

B. The board also contains the circuitry to convert the single-ended output of the Agilent 33220A into an attenuated (~70 dB) differential drive suitable for the Amplifier Module.

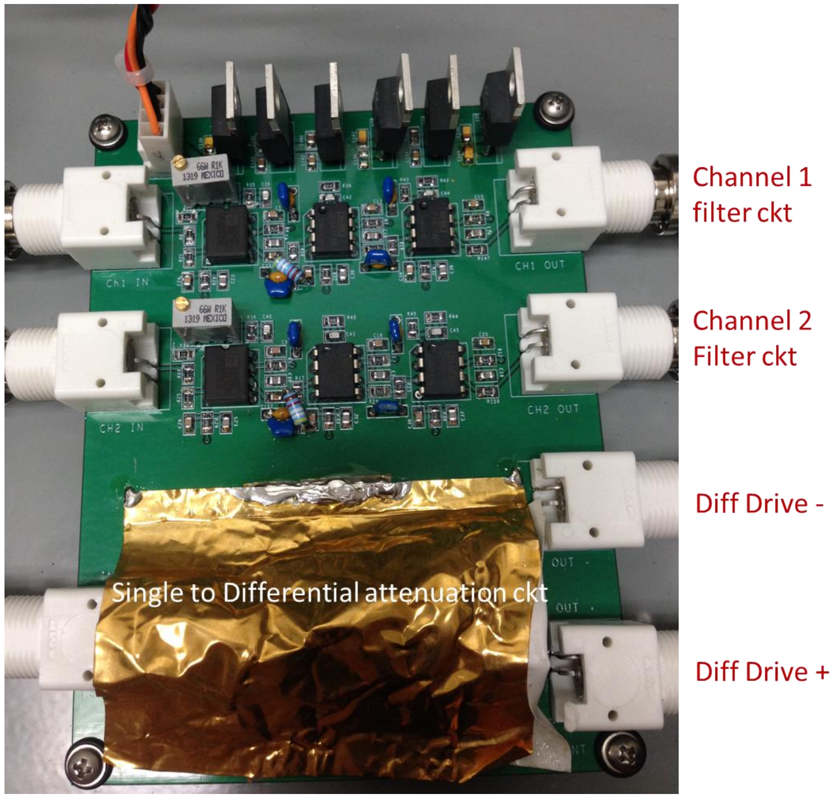

Fig 5. Filter/Interface Board.

4. Computer Interface. The computer interface was chosen to be Universal Serial Bus (USB) for two reasons. First, consultation with local and industry colleagues indicated that for this prototype, the type of connectivity was not critical for the demonstration. Second, the most common interface for benchtop electronic equipment is USB due to its simplicity and ease of use. Consequently, we decided to use USB for the entire system. A USB hub was also installed in the box to enable convenient communication with the two Agilent modules, both of which use USB interfaces.

A photograph of the completely fabricated system is shown in Fig. 4. It is enclosed in a 24x18x6" steel box through which power is supplied and signals are run. There is copper mesh surrounding the Pilot-Tone Generator and DAQ which provides shielding from noise. This is omitted for clarity in the picture. The Filter/Interface board, attached to the steel chassis directly, is not enclosed in a box since the signals are already large and relatively immune to noise.

AC/DC Power Supplies

The power supplied to the digitizer system consists of clean DC voltage driver from two linear DC power supplies and 120V AC, all controlled by a single switch on the power-supply box (see Fig. 6). The Agilent U2531 is supplied from the factory with an external 12-V, 2-A switching supply which was, in earlier tests, found to inject noise into the Amplifier/Filter Module. To mitigate this for all possible configurations, we replaced the supply with a linear, non-switching DC supply and enclosed it in a 12x10x4" box with the system +/15-V supply.

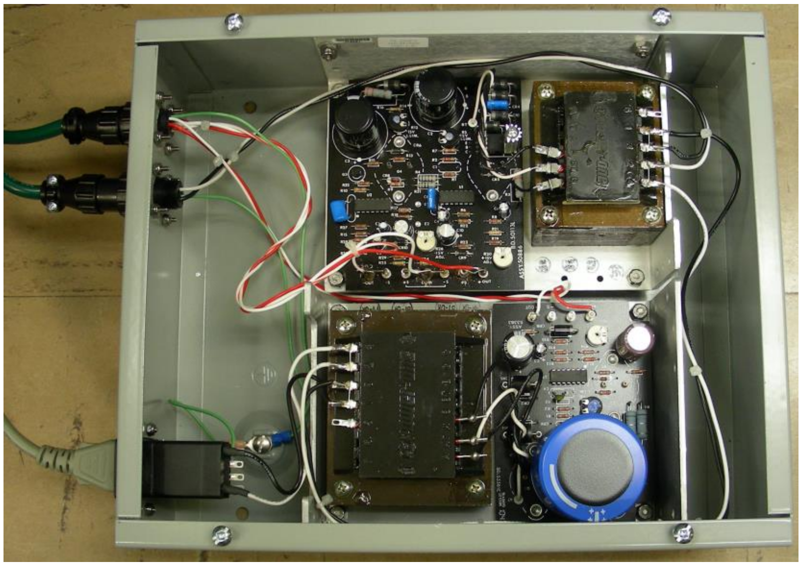

Fig. 6. Low-Voltage Power Supply Box.

Processing Computer/ Interface Description

The computer used for this system is a standard device running Windows™ 7. We are currently running the instrument system on a Dell desktop using LabView™ as the programming software for the JNT calculations and control; we plan to remain with that platform combination through our present development/demonstration cycle. The machine is in a mini-tower configuration, which should be adequate for transporting to various sites for testing. The entire system is shown in Fig. 7 sitting on a portable cart. The steel box is on top, with the power-supply module on the bottom.

2. CONSTRUCTION

The system shown in Fig. 7 was constructed to have a minimal impact on present facilities utilizing the JNT system. To implement this, all of the electronics were integrated into a single front-end electronics steel box and all power supplies were integrated into a single power module. If an existing RTD in a facility was replaced with this system, the only added requirements would be a small amount of space for the boxes, a 120Vac power, and a USB cable to network with a computer. Previous reports describe fabrication and construction of individual components.

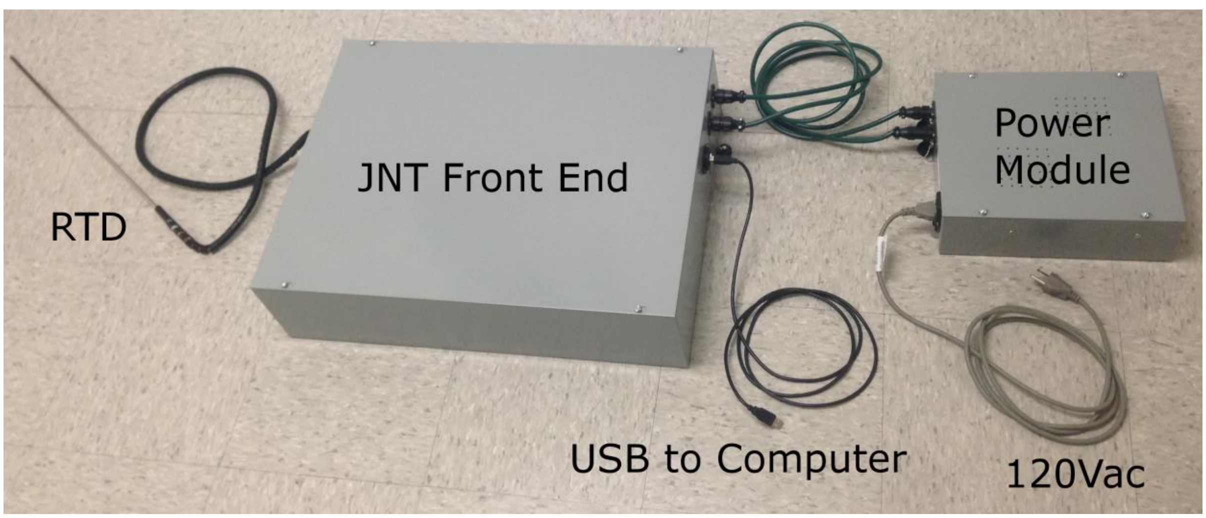

Fig. 7. Finished System Photographs.

Future Work and Testing

In the laboratory environment there was a demonstrated difference between the various measurements using different cable lengths. We are therefore testing the new system in various internal rooms with varying cable lengths. The internal rooms had various sources of noise similar or worse than the realistic environment of a reactor. After this, we will be placing the system into a realistic environment such as the High-Flux isotope Reactor at ORNL.

3. CONCLUSION

The entire integrated system was successfully designed, constructed, and tested at ORNL. The system contains the input amplifiers, data acquisition, pilot-tone generation, power filtering and USB interface in a single box. The integrated system was designed to have minimal impact on the facilities utilizing the system. Testing has shown that the device is working as designed, and the system is presently being tested under various environmental conditions to determine the effects of EMI on the measurement.

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