A NOVEL APPROACH FOR PRECISE TEMPERATURE MEASUREMENT BY PLANETARY THERMAL PROBES K. Durga Prasad, V. Maniteja and S.V.S. Murty, Physical Research Laboratory (Navarangpura, Ahmedabad-380009, Gujarat,India; durgaprasad@prl.res.in, manitejav@prl.res.in, murty@prl.res.in).

Introduction: Measurement of surface/subsurface thermal profile / heat flow of any planetary body provide us an important insight about its interior heat flux,a necessary input for understanding the geophysics and thermal evolution of the planetary body[1,2]. Therefore, heat flow experiments are indispensable and such probes form an integral part of in situ instrument suite flown or proposed for any planetary mission. Experiments such as Apollo's HFE probes for the Moon, HP^3 on INSIGHT mission for Mars and MUPUS instrument of Philae lander for probing cometary surface are few such examples [3-5]. These thermal probes usually aim to measure temperature variations in subsurface as a function of time and depth to derive heat flow and other thermo-physical parameters. Instrumentation involved in such experiments encounter a number of challenges. Although temperature can be measured by various methods, its precision, accuracy and range of measurement depends primarily on the sensing element, in general, and on the design of its associated electronics, in particular. When developed for planetary exploration, thermal instrumentation demands a meticulous design based on various operational and environmental constraints, at the same time achieving the required optimisation and performance. We have developed a novel scheme for Resistance Temperature Detector (RTD) based precise temperature measurement that can be used in the design of planetary Thermal/heat flow probes. In contrast with conventional approaches, the present design uses a modified and improved signal conditioning technique to achieve a better precision, accuracy and provides a wide range measurement of temperature. A prototype of the system has been designed and evaluated. The design details and evaluation results are presented in this paper.

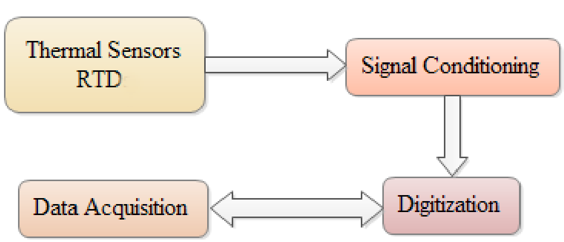

Figure 1: Temperature Measurement System - Block Schematic

Temperature instrumentation: Selection of an appropriate sensing element is the primary requirement of any temperature measurement system. Temperature can be measured in variety of ways. In general, based on the application, range and precision of measurement, either a Thermistor or a Thermocouple or an RTD is used. When developed for probing a planetary surface, these requirements become mission specific and more constrained in terms of dynamic range, accuracy, stability, linearity, operational environment etc. Although thermocouples are traditionally used in most of the earlier missions [6], Platinum RTDs are in general the most promising candidates for the purpose of planetary exploration. Newer sensor techniques are also being developed which are mission specific[2]. Although, selection of a sensing element (RTD) is a key aspect, sensing electronics is integral in achieving the desired performance and demands a careful design. Fig. 1 shows the block schematic of a typical temperature measurement system. As shown in Fig. 1, signal conditioning plays a dominant role based on which the precision and accuracy of measurements are dependent. Bridge circuits are conventionally used for signal conditioning of temperature sensors. However, this technique has several drawbacks viz. low output levels, non-linearity, lead-wire resistance effects etc.[7]. We have devised a novel and optimised scheme for signal conditioning of RTD and evaluated its performance.

Designed scheme for RTD instrumentation: A constant voltage excitation with a bridge approach is conventionally used for RTD signal conditioning. An advanced current loop conditioning scheme is proposed for high accuracy temperature measurements[8]. In contrast, the present scheme utilises an inverted current loop configuration. In order to achieve the required performance, this scheme also exploits the capabilities of the precision devices available today. Some of the target design requirements for the present scheme are :

1. Wide range temperature sensing (~23 K - 523 K)
2. Fair Linearity (Correlation better than 0.99)
3. Accuracy (0.1 K at 273 K)
4. Resolution (better than 0.01 K)
5. Mass and Power Optimisation
6. Space qualification

Circuits for both the schemes - conventional bridge and the present inverted current loop, were designed and tested to comparatively evaluate their performances.

Conventional Bridge Scheme: A voltage excited RTD bridge circuit is shown in Fig. 2. In this configuration, a constant voltage is applied across the junction of bridge with a gain stage and the bridge is made to balance at 0°C (for RTD resistance of 1000 Ω for PT1000 in this case). The final output voltage is then given by

$V_o = A\, I_{tot}(R_a - R_b)$; where $A = R_6/R_7$;

$I_{tot} = V_{Ref}/R_t$;

$R_t = R_1 + R_2 + R_3 + R_5 + R_{rtd}$;

$R_a = ((R_3+R_5)(R_1 + R_{rtd})/R_t$;

$R_b = (R_5 (R_2+R_1+R_{RTD}))/R_t$

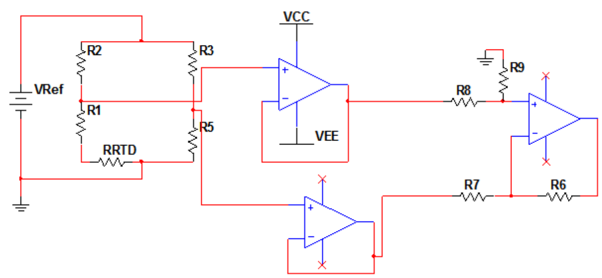

Figure 2: Conventional Bridge Circuit Schematic

The response of this circuit has been measured by varying the resistance of the potentiometer (placed in the fourth arm), simulating an RTD proportional to temperatures in the range 23 K - 523 K.

Present Scheme: The circuit schematic of the present scheme is shown in Fig. 3. In this configuration, an op-amp based constant current drive excites the RTD placed in the feedback loop of an inverting amplifier thus providing a constant potential at its input. Therefore, we termed this scheme as "an inverted current loop configuration". To achieve a wide dynamic range and better resolution, a gain stage has been introduced through a non-inverting amplifier. The final output voltage of this circuit thus becomes

$$V_o = A\,(R_{RTD}/R_1)\,VREF$$

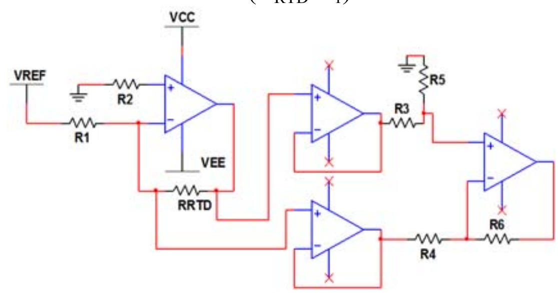

Figure 3: Schematic of the Present scheme developed at PRL

The gain of the second stage is selected as per the range to be achieved. The response of this circuit is also measured in a similar fashion as done in the case of bridge configuration discussed earlier. One of the

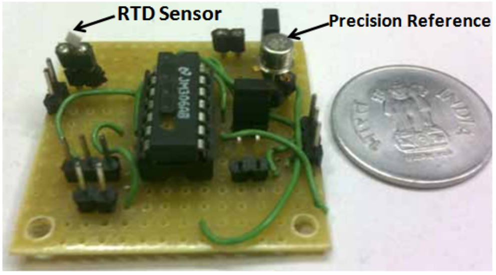

Figure 4: Present scheme - Breadboard Model

key aspects of this scheme is the selection of appropriate components. A four wire Platinum RTD (PT1000) is used as a sensing element. A precision voltage reference is used to provide reference for the first stage and ADC. A low noise, rail-to rail precision quad op-amp is utilised for constructing the various stages of the circuit. Fig. 4 shows the breadboard model of implementation of the present scheme.

Comparative Evaluation: The stage-wise response characteristics for both the circuits have been monitored. In the case of bridge approach, the resolution achieved by the first stage is very poor and demands a high gain amplifier in the subsequent stage to achieve the desired dynamic range. This arrangement will also amplify the noise along with the actual signal which is not desirable. On the other hand, high resolution achieved by the first stage demands a very low gain for the second stage thus making the circuit more noise immune. Comparative assessment of parameters

Parameter	Bridge Circuit	Present Approach
No. of Op-amps required for amplifying	3	4
Gain provided in amplifying stage	~10	2.5
Power Consumption	~12mW	~10 mW
Resolution	1mV/10°C	~10mV/°C)

Table 1: Comparative assessment of bridge and present schemes

for both the configurations is shown in table 1. Experimental and simulation (using NI-Multisim) results for both the schemes are shown in Fig. 5. It is clearly seen that the conventional bridge scheme exhibits a non-linearity, particularly at high temperature and therefore the scheme is not suitable for wide range applications. On the other hand, the present scheme exhibits a linear response making it perfectly suitable for wide range measurement applications.

Issues and Experimental Results: The principal aspect of the current design is to tackle all the issues mentioned in the previous sections and at the same time to achieve linear response with optimum resolution. As shown in Fig. 3, a constant current (in the first stage) less than 1 mA should be provided for the RTD to avoid self-heating. The second stage is designed in such a fashion that it should provide a linear response

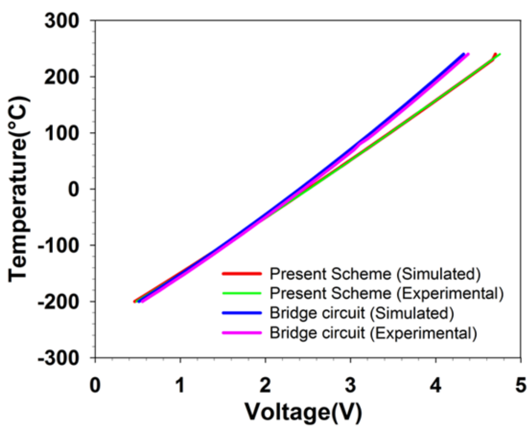

Figure 5: Experimental and simulated output response for the bridge and present schemes

within a wide dynamic range (-250 °C to +250 °C) with a resolution of ~10mV/°C. Various studies were carried out on the designed circuit to evaluate its performance. Various critical issues were addressed by implementing judicious methodologies to meet the requirements which are briefly mentioned below:

Self-heating: Since an RTD measures temperature by passing a current through a resistor (the RTD), self-heating occurs depending on the amount of current passed through it, which may lead to errors in measurement. The magnitude of this error primarily depends upon various factors viz. the sensor's mass, its internal construction, the measurement current and to a

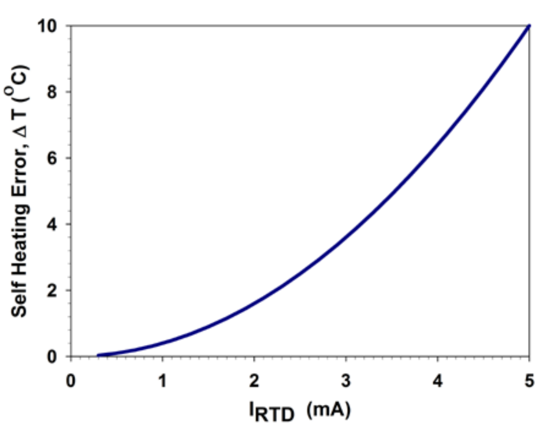

Figure 6: Calculated Self-heating error of RTD with respect to excitation current

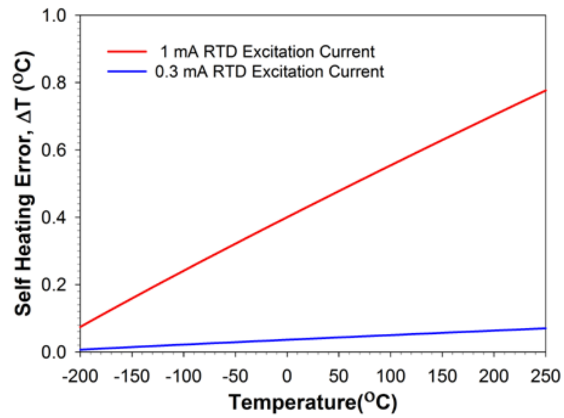

Figure 7: Experimental verification showing the effect of RTD excitation current on self-heating

large degree on environmental conditions. The expected self-heating error in temperature for a typical PT1000 RTD as a function excitation currents is plotted in Fig. 6. Therefore, normally a very small current (~300 µA for PT1000), is preferred to be used in the excitation circuit to minimize this joule heating of the sensor.

RTD Excitation: A constant current excitation mode is used because of its characteristics like high noise immunity, better stability and accuracy. An op-amp based constant current source providing ~ 300 µA is used for exciting the RTD. The measured self-heating error as a function of temperature is shown in Fig. 7. RTD current is monitored continuously under various conditions and was found to have no variations.

Temperature measurement with prototype and Results: A prototype of a single channel temperature measurements has been designed adopting the mentioned scheme. Commercial equivalents of space qualified components have been used for the prototype design. Analog voltage output from the signal conditioning stage is digitised using a 12-bit serial ADC. A data acquisition system was also built using an 8-bit microcontroller. The designed prototype system is shown in

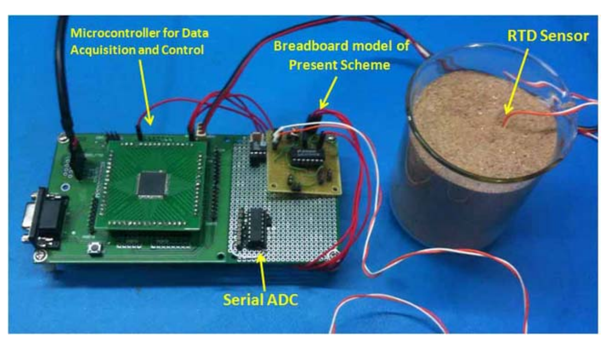

Figure 8. Complete prototype system used for soil temperature measurement under ambient conditions

Fig. 8. The functional and performance test of the prototype has been carried out under ambient and vacuum conditions. Fig. 9 shows a one of these test results where temperature variation of a soil sample is monitored under ambient conditions. As shown in Fig.9, a measurement accuracy of ~0.3 ^{o}C is achieved although it was targeted as 0.1 ^{o}C. This is probably limited due to RTD accuracy, electronics and ADC noise. We are working on improving it to reach the desired performance.

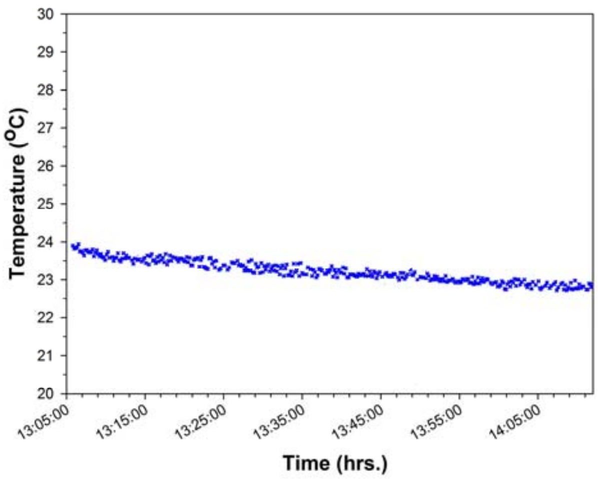

Figure 9: Measurement of soil temperature - Stability test

Summary and Future Work: A novel and precise temperature measurement scheme for planetary thermal probes has been designed and tested. Using this scheme the overall payload can be highly optimised without compromising on its performance. Although the present design provides a single temperature measurement, the same can be parallelised to provide simultaneous measurements at multiple points. We plan to further devise a highly optimised electronics with space qualified components and ruggedise it for planetary exploration tasks.

References: [1] Hagermann A., (2005) Phil. Trans. Royal Soc., 1664 [2] Spohn T. et al., (2007) Space Sci. Rev. 128, 339-362 [3] Siegler M. A., (2010) 41st LPSC, 2650.pdf [4] Spohn T. et al., (2012) 43rd LPSC, 1445.pdf [5]Knollenberg J. (2014) EGU Gen. Assembly, Vol. 16 [6] Langseth M.G. et al., (1972) The Moon 4(3-4), 390-410 [7] Durga Prasad K. et al., (2014) NSSS-14 [8] Hill G.M., (1997) NASA Technical Memorandum 107416