Application Note

Closed Loop Constant Power Drive to Simplify Heater Element Control and Extend Battery Life

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ABSTRACT

Many applications require accurate temperature control of a heating element. Closed loop control based on temperature requires measurement of the heater temperature using a thermistor or thermocouple. This can sometimes be mechanically challenging and costly. Additionally, in battery powered applications, traditional PWM drive and associated high current pulses, can reduce battery life and lifetime.

Heater temperature is not linear with voltage or current due to changes in resistance with temperature. However, temperature is close to linear with applied power. By implementing a closed loop constant power drive the temperature can be controlled needing only to measure power and not temperature directly.

This reference design uses a closed loop constant power topology to drive a low impedance heater element. This application note includes the choices and challenges within the hardware and software implementation. The document also shows initial results and discusses advantages of this method of temperature control.

Table of Contents

Trademarks

1 Traditional Heater Control

Traditional heater control uses a temperature sensor to measure the temperature of the heating element as shown in Figure 1-1. This measurement is fed back and used to adjust the drive circuitry to alter the current through the heating element maintaining the temperature at the required set point. This approach has a number of challenges. Firstly, the temperature sensor must be mounted close to or in contact with the heating element, which can be mechanically difficult. Secondly, high temperature measurement usually requires a thermocouple that needs complex interface circuitry.

Temperature responds relatively slowly compared to changes in the electrical signals, so it has been usual to use a simple FET switch PWM to modulate the current through the heating element at a higher electrical frequency and allow the slower thermal response to act as the loop low pass filter. This works perfectly well, but the fast switching edges can result in electrical noise. In addition, in a battery powered system, the large current pulses pulled from the source during the PWM pulses, can reduce battery life between charges and overall battery lifetime.

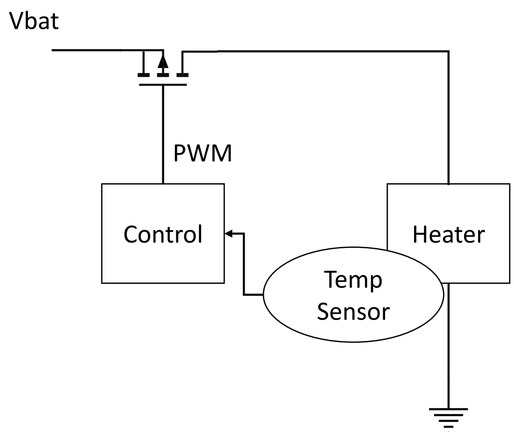

Figure 1-1. Traditional Heating Element Control Loop With Temperature Sensor

2 Constant Power Heater Control

The temperature of a resistive heating element is directly proportional to the power applied. Measuring the electrical power can be mechanically much simpler than measuring the temperature. Driving the element with constant power delivers constant temperature and adjusting the power adjusts the temperature. Unfortunately, the resistance of the heating element can vary significantly between batches and also changes over temperature. This means that both voltage and current need to be measured and the voltage applied needs to be adjusted to maintain constant power as the heater element resistance changes as seen in Figure 2-1. The DC/DC converter controlling the applied voltage draws an average current from the supply which can extend the battery life.

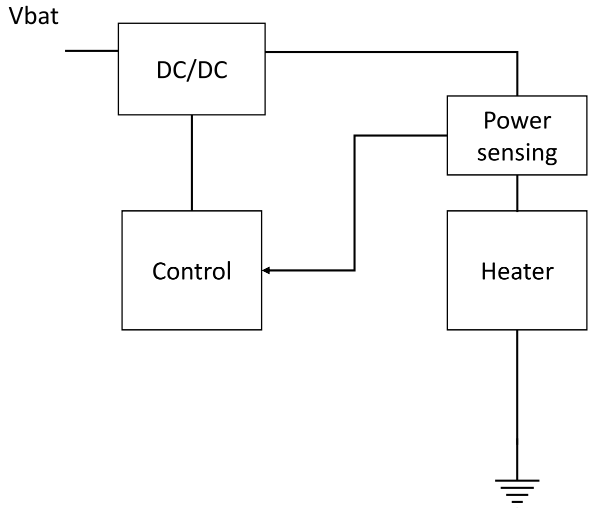

Figure 2-1. Constant Power Heater Control

3 Hardware Implementation

The constant power drive design requires hardware to measure the voltage across the heating element and the current through the heating element to calculate the power. This is achieved using the INA234 which is a 28V, 12bit, I^2C output current/voltage/power monitor. In this design the device measures the voltage directly across the heating element and the current through a high-side 10mΩ, ± 1%, 1W sense resistor. The devices then calculates the power and reports values for voltage, current and power via I^2C.

For this example, we assume a 1Ω heating element that can vary by ± 20% across temperature and batch range. Table 3-1 shows the required voltage and current for different power levels across the resistance range. The input voltage is 3.3V to 5.0V. This means a buck or step-down dc/dc regulator can be used for the whole range required. The applied voltage is controlled using the TPS62868 which is a 2.4V to 5.5V input, synchronous buck converter with 4A output capability. Importantly, this device is I^2C controlled which allows the output voltage to be easily adjusted.

Table 3-1. Voltage and Current for Different Power Levels and Different Resistances

Power (W)	Current (A) at 0.8Ω	Voltage (V) at 0.8Ω	Current (A) at 1.0Ω	Voltage (V) at 1.0Ω	Current (A) at 1.2Ω	Voltage (V) at 1.2Ω
4.0	2.24	1.79	2.00	2.00	1.83	2.19
5.0	2.50	2.00	2.24	2.24	2.04	2.45
6.0	2.74	2.19	2.45	2.45	2.24	2.68
7.0	2.96	2.37	2.65	2.65	2.42	2.90
8.0	3.16	2.53	2.83	2.83	2.58	3.10
9.0	3.35	2.68	3.00	3.00	2.74	3.29

The voltage, current and power is read from the INA234 via I^2C using an MSPM0L1306. This low cost microprocessor is also responsible for adjusting the output voltage of the TPS62868 via I^2C. The simplified and full circuit schematic can be seen respectively in Figure 3-2 and Figure 3-3.

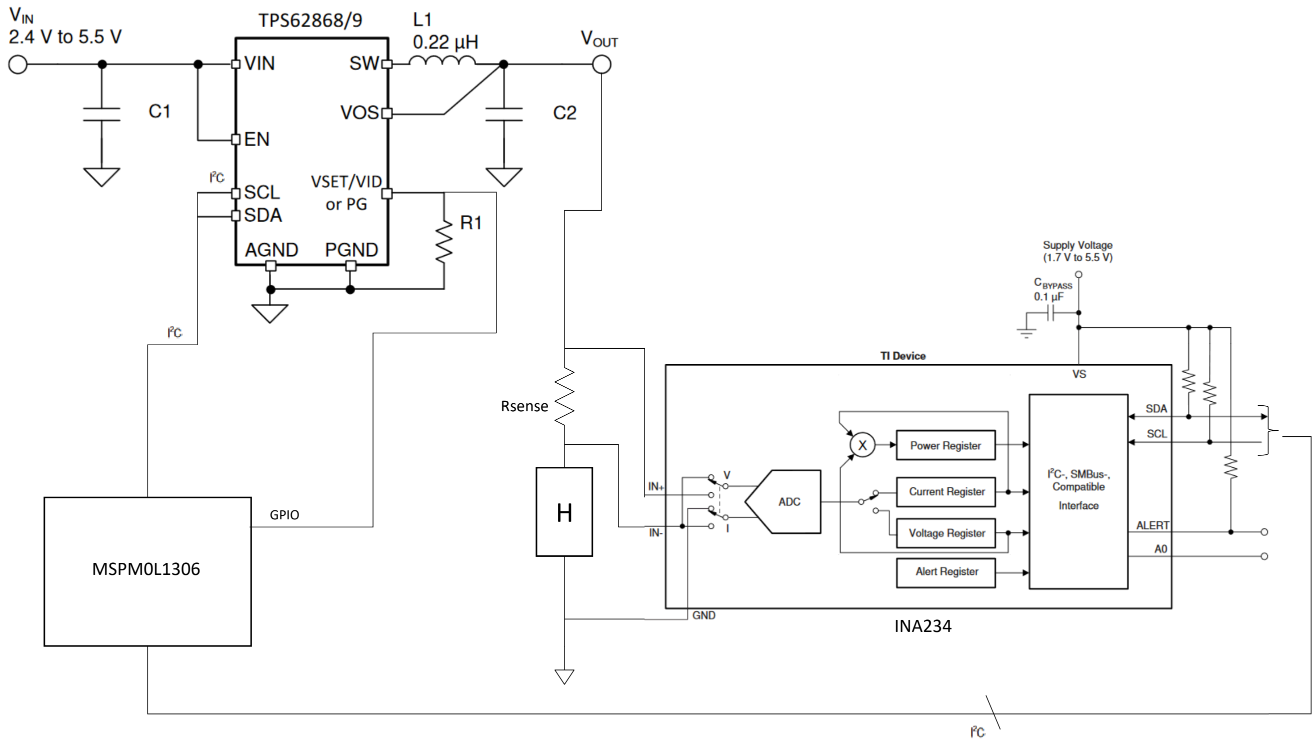

Figure 3-1. Simplified Constant Power Control Schematic

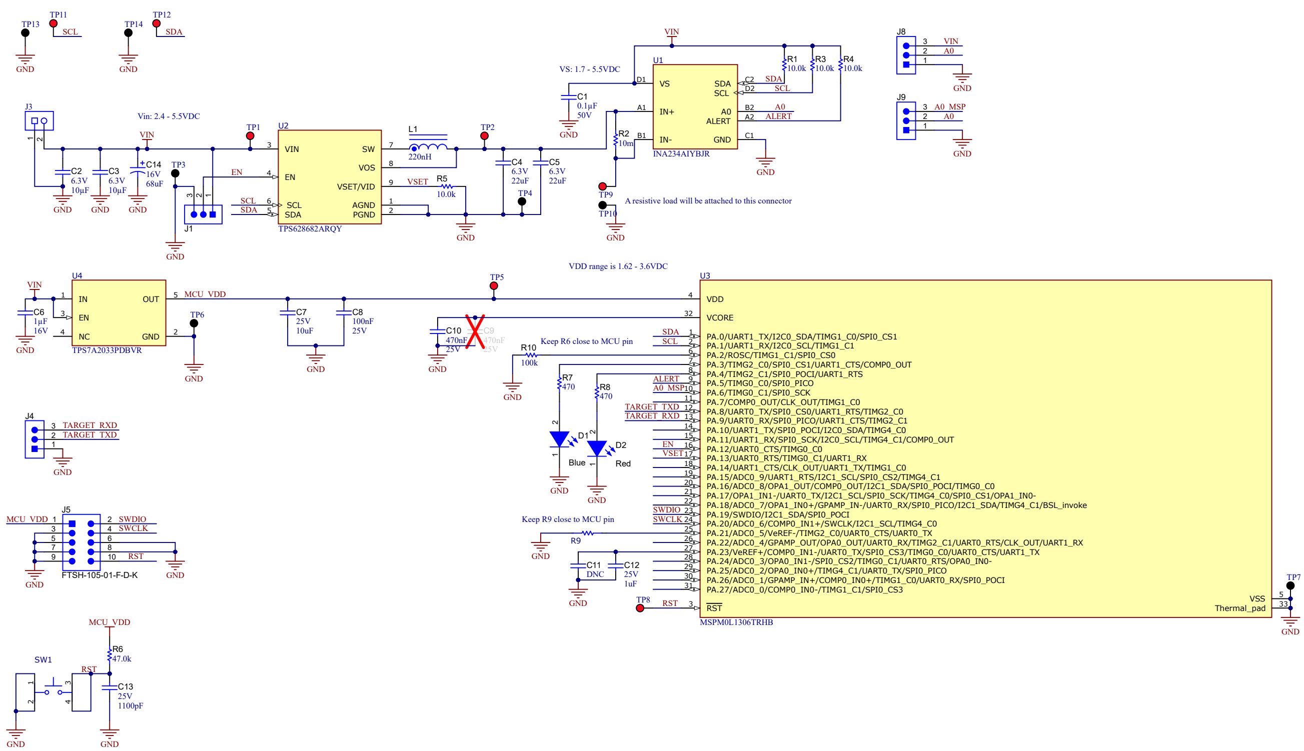

Figure 3-2. Constant Power Control Schematic

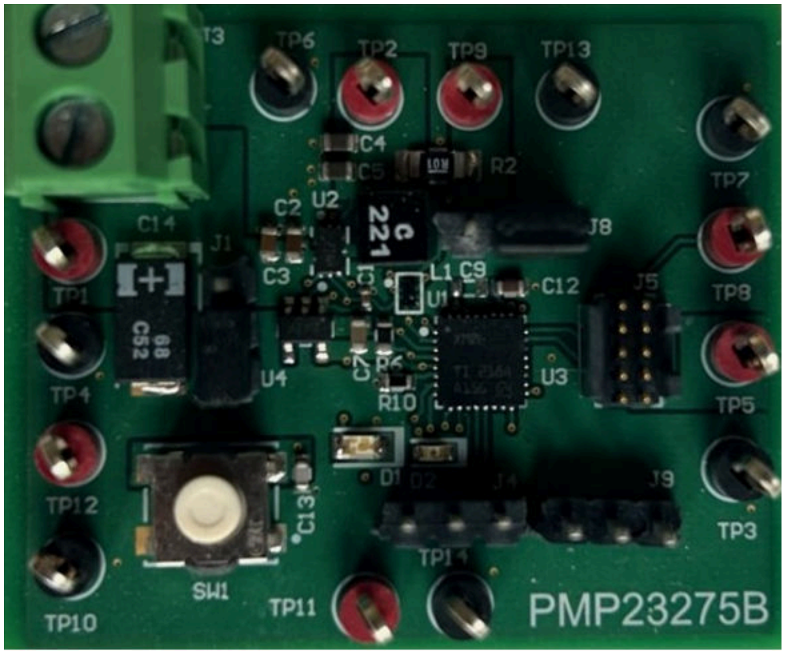

Figure 3-3. Constant Power Control PCBA

4 Software Implementation

At start-up, the software running in the MSP0L1306 begins by initializing the I^{2}C read/write function and then configures the INA234 and TPS62868 via I^{2}C. The MSPM0L1306 is then able to read the voltage, current and power in the load resistor from the INA234 using I^{2}C and control the output voltage of the TPS62868 also via I^{2}C.

The constant power control algorithm is described in the flow chart shown in Figure 5-1. The first step is to read the power INA234_getPOWER_W(INA234) through I^{2}C and store it in the measuredP variable. The measured power is compared with the target power and a power error calculated.

The voltage change needed to correct the power error is calculated as the error scaled by a gain factor of 2. There is a limit applied to prevent excessive voltage changes; it is clamped to a range of ±5.

If the measured power is higher than the target power, the algorithm calculates a new voltage by decreasing the measured output voltage by the calculated voltage step. If the measured power is lower than the target value, the calculated voltage step is added to the measured output voltage. The output voltage of the TPS62868 is then adjusted by writing the new voltage value to the output voltage register via I^{2}C.

5 Software Algorithm Flow Chart

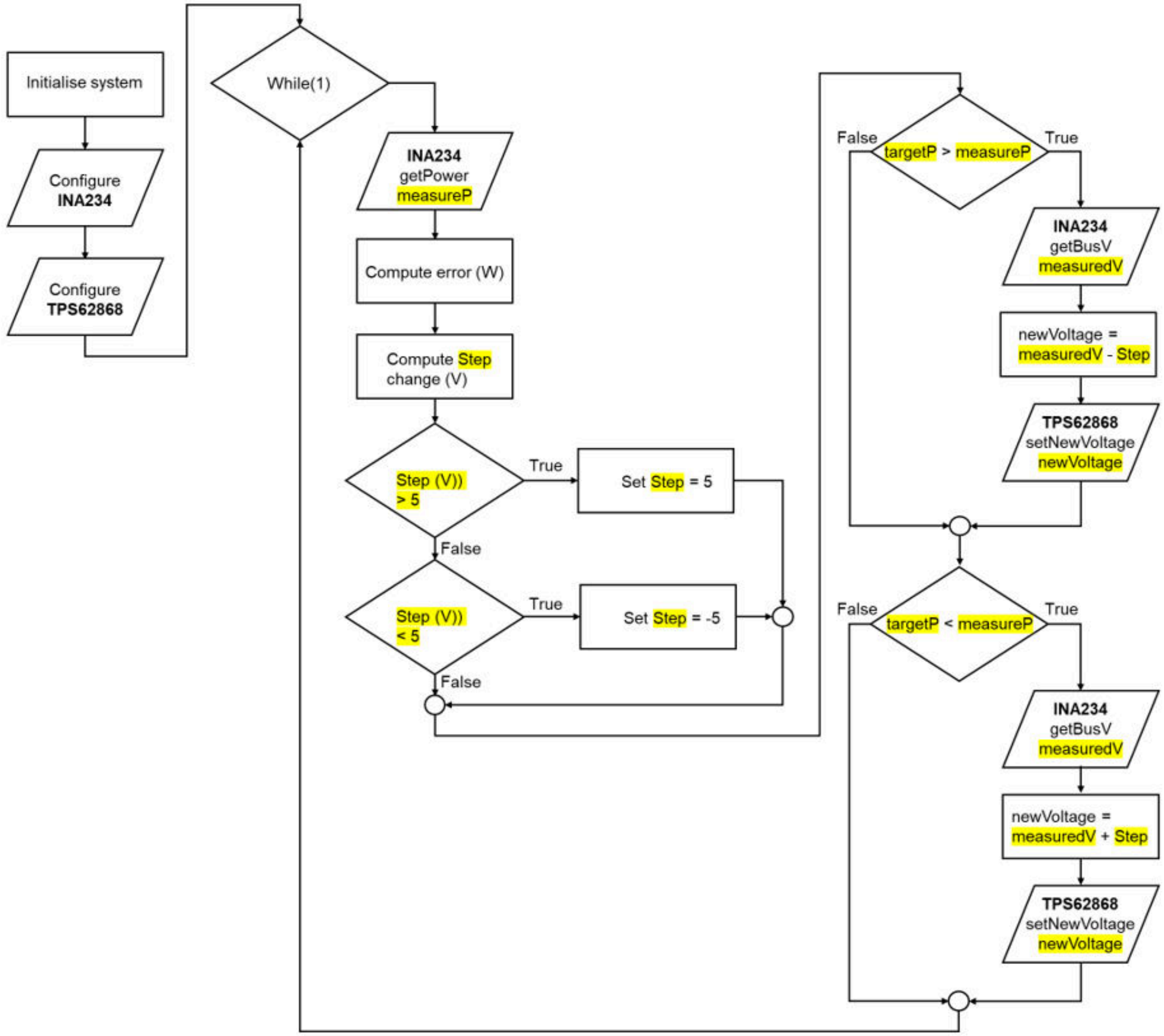

Figure 5-1. Software Algorithm Flow Chart

6 Results

Figure 6-1 shows the measured, steady-state temperature of a 1.5Ω nominal load resistor for different values of applied constant power. The linear response shows that constant power can be used as the control method to set the temperature in the resistive heating element.

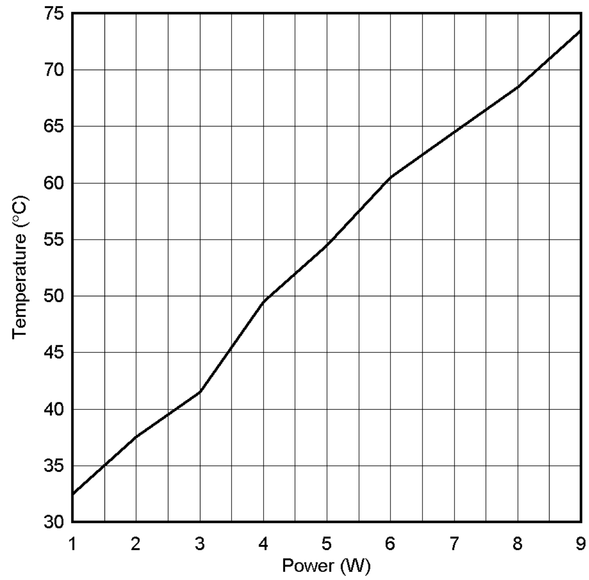

Figure 6-1. Load Resistor Temperature Versus Applied Constant Power

Figure 6-2 shows the measured power for 1W steps from 1W to 9W with a 1.5Ω nominal load resistor. The loop is held running in constant power at each level for 50 seconds and the power measured every 1 second. The absolute variation in measured power increases as the requested power level increases but the percentage variation stays pretty constant as can be seen in Table 6-1 which shows the measured levels and variation for each power level from nominal. The constant power control loop maintains the power applied to the load within ±3.0% of the set level.

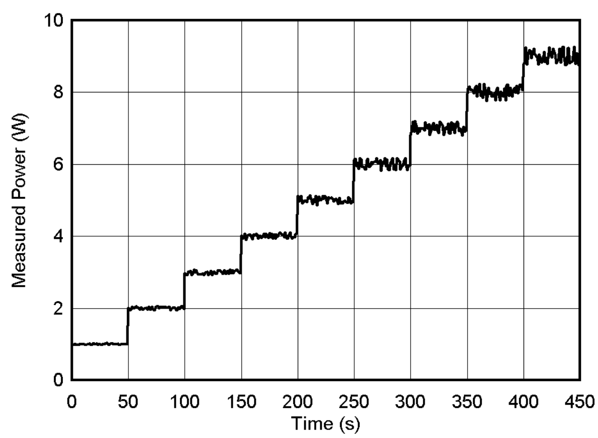

Figure 6-2. Constant Power Control Steps. 1W to 9W in 1W Steps. 50 Seconds at Each Power Level

Table 6-1. Average Measured Power and Minimum or Maximum Variation for Requested Power Steps From 1W to 9W

Requested Power (W)	Average measured power (W)	Minimum measured power (W)	Maximum measured power (W)	Negative variation (%)	Positive variation (%)
1.0	1.0008	0.971	1.029	-2.90	2.90
2.0	2.0073	1.942	2.059	-2.90	2.95
3.0	2.9913	2.911	3.081	-3.00	2.70
4.0	4.0123	3.898	4.116	-2.55	2.90
5.0	5.0108	4.864	5.145	-2.72	2.90
6.0	6.0146	5.840	6.174	-2.67	2.90
7.0	6.9999	6.796	7.204	-2.91	2.91
8.0	8.0209	7.764	8.235	-2.95	2.94
9.0	8.9982	8.752	9.251	-2.76	2.79

Figure 6-3, Figure 6-4, and Figure 6-5 show more detailed plots of the measured power values for 1W, 5W and 9W constant power operation.

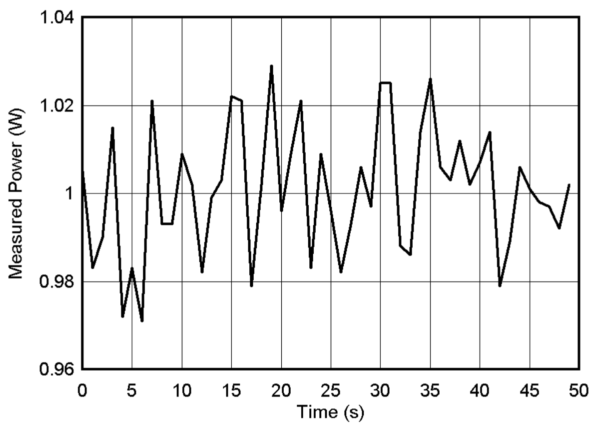

Figure 6-3. Measured Power at 1 Second Intervals for 1W Constant Power Operation

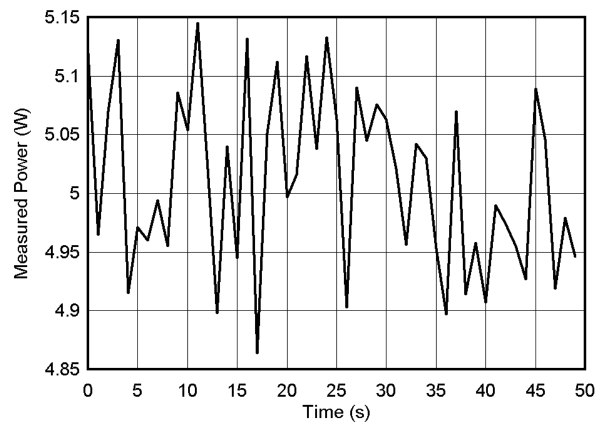

Figure 6-4. Measured Power at 1 Second Intervals for 5W Constant Power Operation

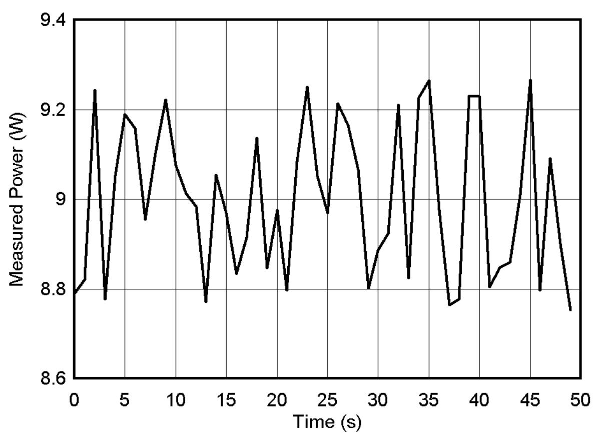

Figure 6-5. Measured Power at 1 Second Intervals for 9W Constant Power Operation

As an additional test of the robustness of the constant power control, the load was driven at constant 4W across a temperature range from around -18°C to +23°C. As the temperature increases the resistance of the nominal 1.5Ω load increases from around 1.33Ω at -18°C to 1.75Ω at +23°C. Figure 6-6 shows the measured current, voltage and power across this temperature range. The constant power control algorithm adjusts the voltage as the resistance changes to successfully keep the power constant across the temperature range. The variation in measured power across this temperature range is +1.5% and -2.1%.

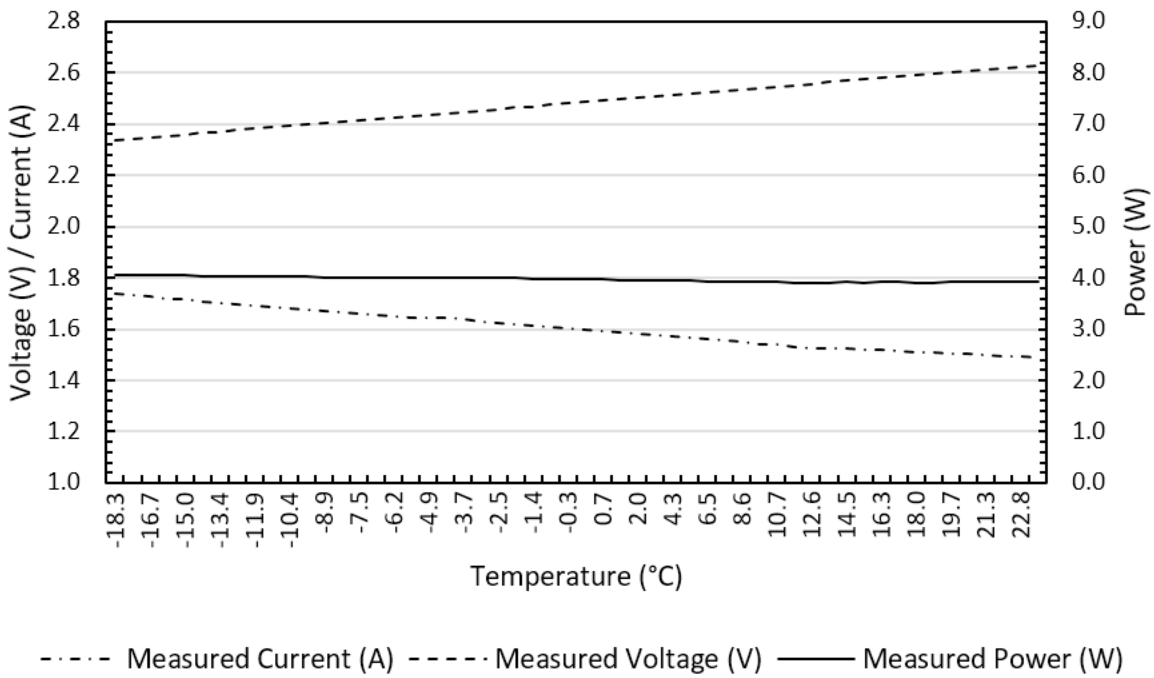

Figure 6-6. Measured Current, Voltage and Power Across -18°C to +23°C Temperature Range

7 Summary and Adaptations

A resistive heating element can be driven with constant power to deliver a fixed temperature, without needing to measure the temperature. The closed loop, constant power example design presented here maintains the measured power in the load to within ±3.0% of the set level across power levels and variations in load resistance due to temperature changes. In this case ±3.0% variation in power corresponds to a temperature tolerance of about ±0.15°C at lower power (1W) and about ±0.75°C at higher power (9W). The temperature tolerance can vary depending on he heating element used. but can be calibrated during product design.

If the input voltage range, the heater resistance or the power required means higher current or a boost or buck-boost topology are required, then other I^2C controlled converter devices can be used. Alternatively, a standard converter can be adjusted by summing a filtered PWM signal into the FB node.

8 References

- Texas Instruments, *INA234 28-V, 12-Bit, Current, Voltage, and Power Monitor With an I2C Interface*, data sheet.
- Texas Instruments, *TPS62868x 2.4-V to 5.5-V Input, 4-A/6-A Synchronous Step-Down Converter with I2C Interface in QFN Package*
- Texas Instruments, *MSPM0 L-Series 32MHz Microcontrollers*, technical reference manual.
- Texas Instruments, *I2C Introduction Lab*
- Texas Instruments, *MSPM0 Ecosystem Training Series*. MSPM0 academy trainings.

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