Application Note

Designing Air-Heater With ISOTMP35-Q1 for EV Cockpit

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ABSTRACT

In EV (Electric Vehicle) system, to have a better working circumstance for electronic equipment in EV cockpit at extreme low temperature condition, such as -40℃, there can be a need for a air-heater unit to meet this target, this document provides PWM heating design for this requirement. This can make heater running automatically according to ambient temperature change without MCU control. Besides ISOTMP35-Q1, such as PWM controller UCC28C43-Q1, operation amplifier OPA333-Q1 are used as well to form closed temperature control loop in this design

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Trademarks

1 Introduction

The ISOTMP35-Q1 is the industry's first isolated temperature sensor IC, combining an integrated isolation barrier, up to 3000VRMS withstand voltage, with an analog temperature sensor featuring a 10mV/°C slope from –40°C to 150°C. This integration enables the sensor to be co-located with high voltage heat sources (for example: HV FETs, IGBTs, or HV contactors) without requiring expensive isolation circuitry. The direct contact with the high-voltage heat source also provides greater accuracy and faster thermal response compared with approaches where the sensor is placed further away to meet isolation requirements. Operating from a non-isolated 2.3V to 5.5V supply, the ISOTMP35-Q1 allows easy integration into applications where sub-regulated power is not available on the high-voltage plane. The integrated isolation barrier satisfies UL1577 requirements. The surface mount package (7-pin SOIC) provides excellent heat flow from the heat source to the embedded thermal sensor, minimizing thermal mass and providing more accurate heat-source measurement. This reduces the need for time-consuming thermal modeling and improves system design margin by reducing mechanical variations due to manufacturing and assembly. The ISOTMP35-Q1 class-AB output driver provides a strong 500μA maximum output to drive capacitive loads up to 1000pF and is designed to directly interface with analog-to-digital converter (ADC) sample and hold inputs

2 ISOTMP35-Q1 Key Information for Design

2.1 Simplified Design Schematic to Sense Temperature

Figure 2-1 shows the very simple design schematic, this means design engineers can use ISOTMP35-Q1 easily and quickly, the TSENSE pin can connected to target heat source directly without complicated assemble procedure. VDD is in the range of 2.3V to 5.5V, in normal, LDO is a good power supply for ISOTMP35-Q1.

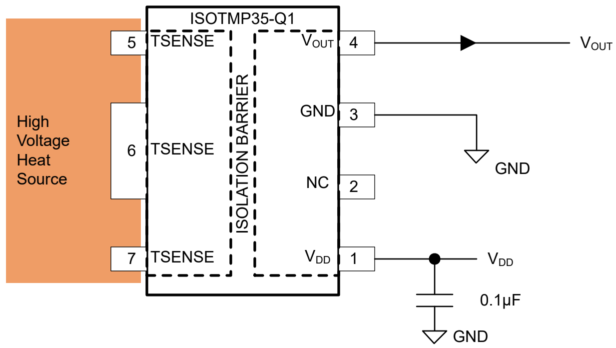

Figure 2-1. ISOTMP35-Q1 Typical Schematic

Figure 2-2 shows RC filter design consideration when designer gets started real design, to remove noise from ADC unit or other noise source, normally this needs RC filter network on the front of analog output port in ISOTMP35-Q1, please note, the total capacitance (C17+C20) on the analog output of ISOTMP35-Q1 *must not* be more than 1000pF, R15 MUST be in the range of 10K to 100K

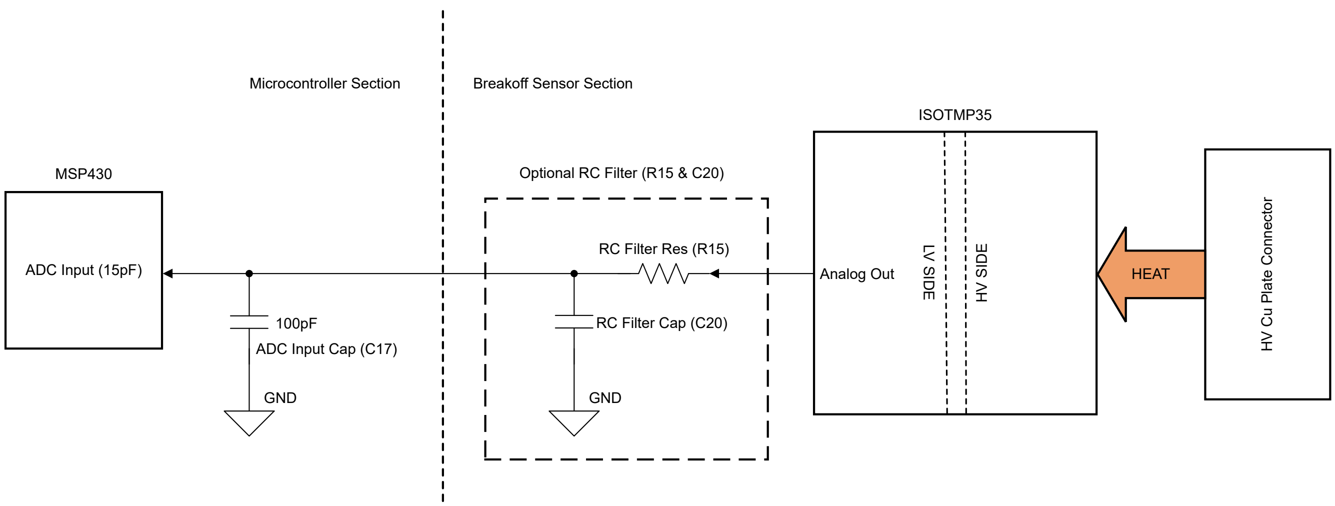

Figure 2-2. ISOTMP35 Front RC Filter Design Consideration

2.2 Temperature Transfer Table

Table 2-1 shows excellent linearity of ISOTMP35-Q1 between sensed temperature and analog output, this can be read by ADC unit in MCU or be used as analog feedback signal for PWM controller such as UCC28C43-Q1 to form closed loop of temperature control.

Table 2-1. ISOTMP35-Q1 Temperature Transfer Table

TEMPERATURE (°C)	V_{OUT} (mV) CALCULATED LINEAR VALUES	V_{OUT} (mV) PIECEWISE LINEAR VALUES
–40	100	100
–35	150	150
–30	200	200
–25	250	250
–20	300	300
–15	350	350
–10	400	400
–5	450	450
0	500	500
5	550	550
10	600	600
15	650	650
20	700	700
25	750	750
30	800	800
35	850	850
40	900	900
45	950	950
50	1000	1000
55	1050	1050
60	1100	1100
65	1150	1150
70	1200	1200
75	1250	1250
80	1300	1300
85	1350	1350
90	1400	1400
95	1450	1450
100	1500	1500
105	1550	1550.5
110	1600	1601
115	1650	1651.5
120	1700	1702
125	1750	1752.5
130	1800	1805/5
135	1850	1858/5
140	1900	1911.5
145	1950	1964.5
150	2000	2017.5

3 PWM Controller UCC28C43-Q1 Key Information for Design

3.1 UCC28C43-Q1 Internal Block Diagram

Figure 3-1 shows there are PWM, error amplifier, current sense units, if provides analog signal to FB, UCC28C43-Q1 can generate a square waveform on output, and duty cycle can change when FB analog signal change accordingly.

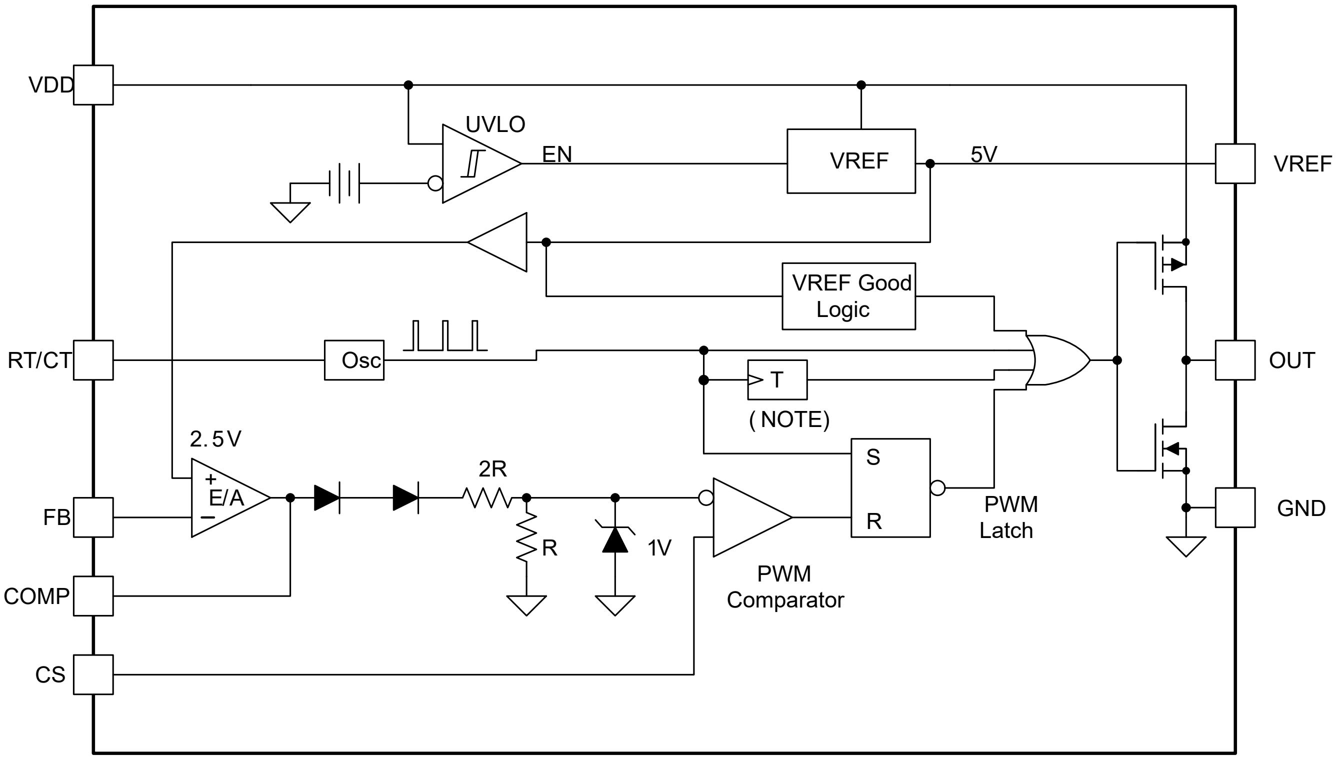

Figure 3-1. Internal Block Diagram

3.2 UCC28C43-Q1 Voltage Mode Setting

Figure 3-2 shows a way to set voltage mode, in heater application, voltage mode can be used since there is no current loop in circuitry, T1, R6, R2 combination forms voltage mode control. T1 2N2222 is NPN transistor, this acts as voltage follower, so there can be a same shape of saw waveform on CS pin as RT/CT pin, R6 and R2 is used to adjust the amplitude of saw waveform on CS pin, in simple words, CS pin can act as just like saw or triangle waveform input port, the error signal from error amplifier on UCC28C43-Q1 is sent to the inverse input of comparator so as to realize PWM feature.

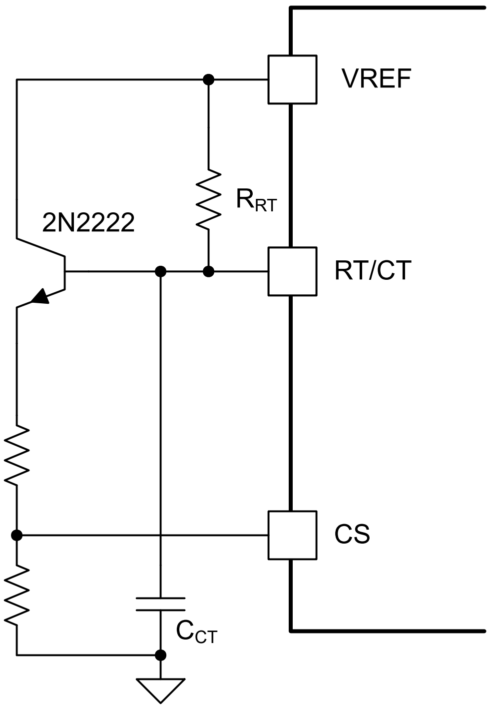

Figure 3-2. Voltage Mode Setting

3.3 UCC28C43-Q1 Heating Frequency Setting

By using RT and CT component, designer can set heating frequency quickly.

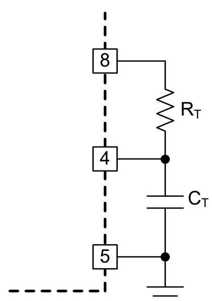

Figure 3-3. Heating Frequency Setting

4 OPA333-Q1 Key Information

- AEC-Q100 qualified for automotive applications
- Temperature grade 1: -40°C to +125°C, T_A
- Low offset voltage: 10µV (Maximum)
- 0.01Hz to 10Hz noise: 1.1µVPP
- Quiescent current: 17µA
- Single-supply operation
- Supply voltage: 1.8V to 5.5V
- Rail-to-rail input and output

Figure 4-1 shows the typical connection for a non-inverting amplifier. The non-inverting amplifier is used to amplify the voltage signal from the ISOTMP35-Q1 analog output port to use the weak temperature signal as feedback for the UCC28C43-Q1 device. The designer can use Equation 1 to calculate the output voltage of OPA333-Q1, or VFB_UCC28C43-Q1 quickly.

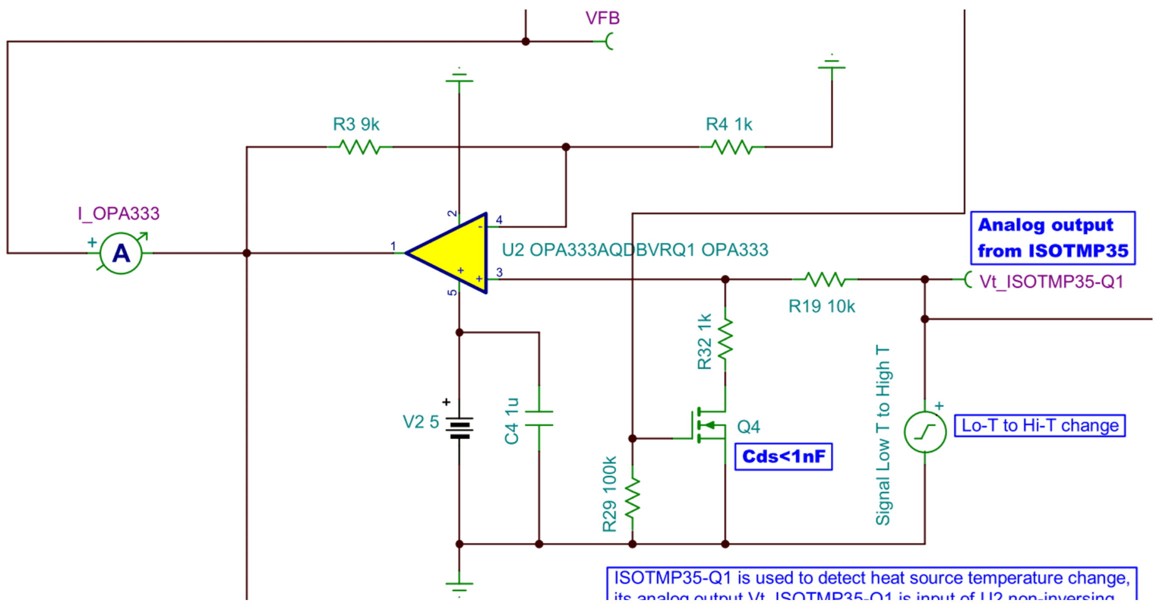

Figure 4-1. OPA333-Q1 Typical Non-Inverting Amplifier Circuitry

$$V_{FB\_UC2843L} = \left(1 + \frac{R3}{R4}\right) \times V_{O\_ISOTMP35} \tag{1}$$

5 Air Heater Circuitry Design Sample

5.1 Working Mechanism Explanation

- ISOTMP35BEDFQRQ1 is used to collect temperature information from a heat source.
- OPA333AQDBVRQ1 is used to amplify the voltage from the ISOTMP35-Q1 analog output.
- UCC28C43QDRQ1 is used to drive the external PTC heater and form a closed temperature control loop.

5.2 Air Heater Schematic Design

5.2.1 Working Condition

- Input range: 12V-30V
- Heating threshold: < -15°C
- Stop heating threshold: > -10°C
- PWM heating mode: Duty cycle can be adjusted according to temperature change. Duty cycle is inverse proportional to temperature. This means that a higher temperature results in a lower duty cycle.
- Heating frequency: 1KHz
- Heater: PTC

5.2.2 Design Procedure

1. Set heating frequency with UCC28C43-Q1: R1>5K, arbitrarily obtain R1=20K if frequency is 1KHz. Then C1 = 0.1µF.

$$F_{HEATING} \approx \frac{1.72}{R1 \times C1} \quad (2)$$

2. Configure EA of UCC28C43-Q1. According to internal EA structure in UCC28C43-Q1, this is standard inverse amplifier with 2.5V biased, we can configure UCC28C43-Q1 EA as simplest 1x inverse amplifier (R9 and R8), since there is 2.5V biased reference voltage on the non-inverting input port, so the final calculation equation can be changed to:

$$V_{COMP\_UC2843L} = V_{REF} \times \left(1 + \frac{R8}{R9}\right) - V_{FB\_UC2843L} \times \frac{R8}{R9} \quad (3)$$

3. Arbitrarily get R8=R9=10K

$$V_{COMP\_UC2843L} = 2 \times V_{REF} - V_{FB\_UC2843L} \quad (4)$$

4. Estimate duty cycle for heating.

$$Duty_{Heating} = \frac{V_{COMP}}{V_{CS}} = \frac{(V_{COMP\_UC2843L} - 1.4)/3}{V_{SAW} \times R2/(R6 + R2)} = \frac{(2 \times V_{REF} - V_{FB} - 1.4)/3}{V_{SAW} \times R2/(R6 + R2)} \quad (5)$$

   Here:
   - V_{SAW}=1.72V
   - V_{REF} means the voltage reference in UCC28C43-Q1, this is 2.5V
   - 1.4V means the forward voltage of 2 diodes that in UCC28C43-Q1 EA unit
   - 1/3 is coefficient for resistor divider R/(2R+R) in UCC28C43-Q1 EA unit

   From Equation 5when VFB_UC2843L increases, duty cycle decreases accordingly, or when temperature increases, duty cycle decreases accordingly.
5. Set heating and stop heating threshold with ISOTMP35-Q1
   - Heating threshold: < -30℃, output voltage from ISOTMP35-Q1=200mV
   - Stop heating threshold: > -15℃, analog output voltage from ISOTMP35-Q1=350mV
6. Set amplify coefficient of OPA333-Q1, or R3, R4 setting according to the duty cycle equation.

$$Duty_{Heating} = \frac{V_{COMP}}{V_{CS}} = \frac{(V_{COMP\_UC2843L} - 1.4)/3}{V_{SAW} \times R2/(R6 + R2)} = \frac{(2 \times V_{REF} - V_{FB} - 1.4)/3}{V_{SAW} \times R2/(R6 + R2)} \quad (6)$$

Here:

- V_{SAW} = 1.72V

- Arbitrarily get R6=R2=1K
- V_{REF} means the voltage reference in UCC28C43-Q1, this is 2.5V
- 1.4V means the forward voltage of 2 diodes that in UCC28C43-Q1 EA unit
- 1/3 is coefficient for resistor divider R/(2R+R) in UCC28C43-Q1 EA unit

$$Duty_{Heating} = \frac{V_{COMP\_UC2843L}}{V_{CS}} = \frac{\left(V_{COMP\_UC2843L} - 1.4\right)/3}{1.72 \times 0.5} = \frac{\left(2 \times V_{REF} - V_{FB} - 1.4\right)}{2.58} = \frac{\left(3.6 - V_{FB}\right)}{2.58} \tag{7}$$

When Duty cycle is 1, 0, then $V_{FB\_UC2843L}$ is 1.02V and 3.6V respectively

- For stop heating, the threshold is -15°C or 350mV, the amplified ratio for OPA333-Q1 is: Stop heating means duty cycle is 0, so VFB at least needs to be more than 3.6V, according to Equation 2, or 3.6V/0.35V= 10.3, this means if ratio is more than 10, this can trigger stop heating threshold.
- For start heating, the threshold is -30°C or 200mV, the amplified ratio for OPA333-Q1 is: Start heating means duty cycle is more than 0, VFB needs to be less than 3.6V, according to Equation 2, 3.6V/0.2V=18, this means if ratio is less than 18, this can trigger start heating threshold.

Consider both stop and start amplified ratio data, 10 is an option for this design, but stop threshold can be slightly higher than expected, according to Equation 2, arbitrarily get R3=9K, so R4=1K.

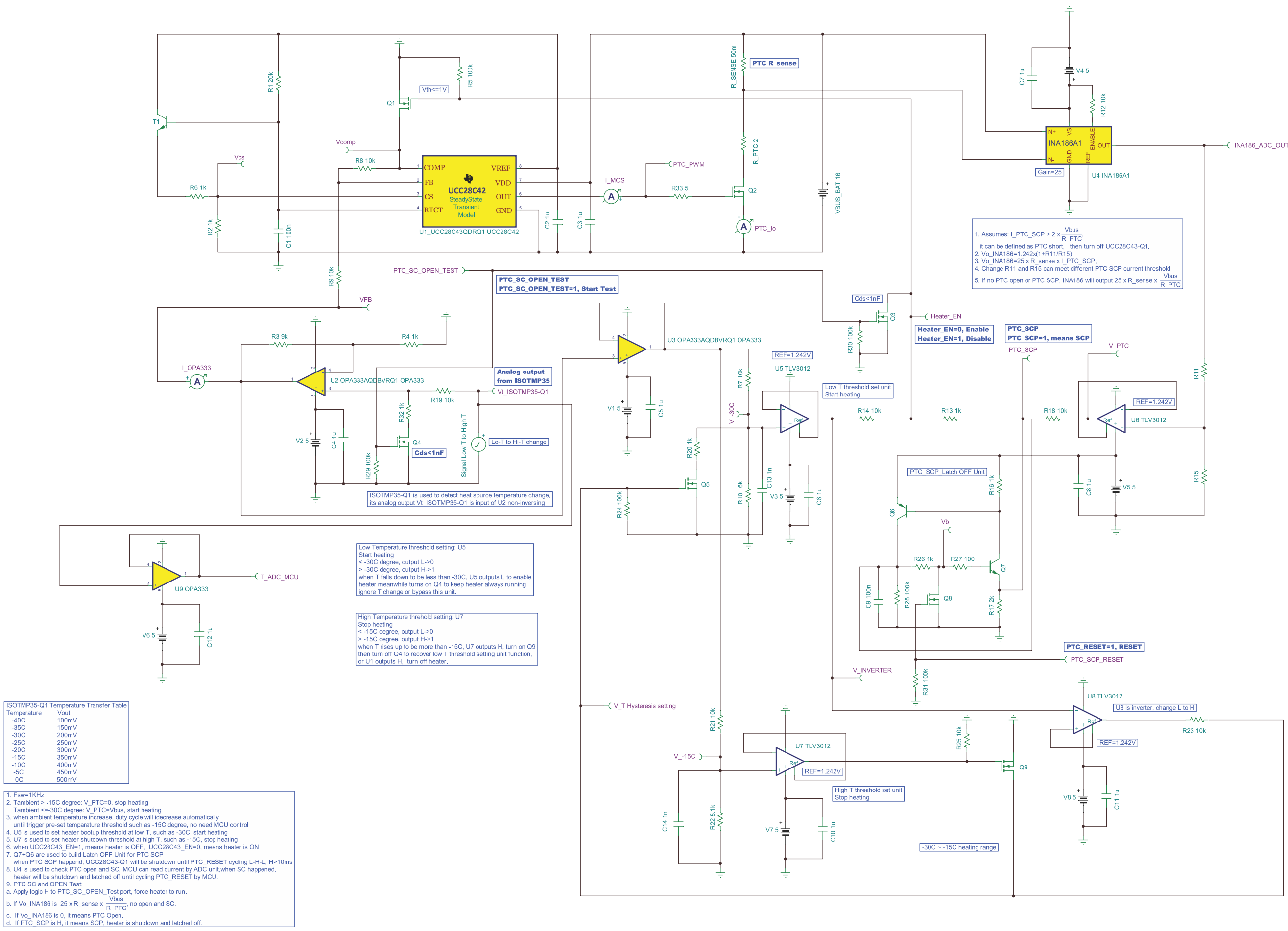

Figure 5-1. Typical Heater Schematic

Here:

1. Signal Lo-T to Hi-T source is used to simulate the analog output of ISOTMP35-Q1.
2. $IO_{\_PTC}$ means the current that flows into PTC, or heating current.
3. PTC_PWM means PWM driving signal to PTC_MOSFET, or Q2.

Notes:

1. For R and C component in this design, the component needs to meet AEQ grade for automotive field.
2. For 48V EV system, please use buck LMR38010FSQDDARQ1, maximum input voltage is high up to 80V, provide fixed 12V power rail to UCC28C43-Q1, LDO TPS71550QDCKRM3Q1 for fixed 5V power rail (from 12V power rail of buck) for OPA333-Q1 and ISOTMP45-Q1
3. For 12V EV system, since the input range can be 9V to 16V, this needs buck-boost to generate 12V, TPS55160QPWPRQ1 can meet target application, LDO TPS71550QDCKRM3Q1 for fixed 5V from 12V bus directly.
4. If designers need more features, such as power on or power off, temperature hysteresis, PTC SCP or open detection, please refer to the note description in simulation schematic.

Simulation Waveform: -35℃ - -20℃, or 150mV - 300mV, start heating to continue heating

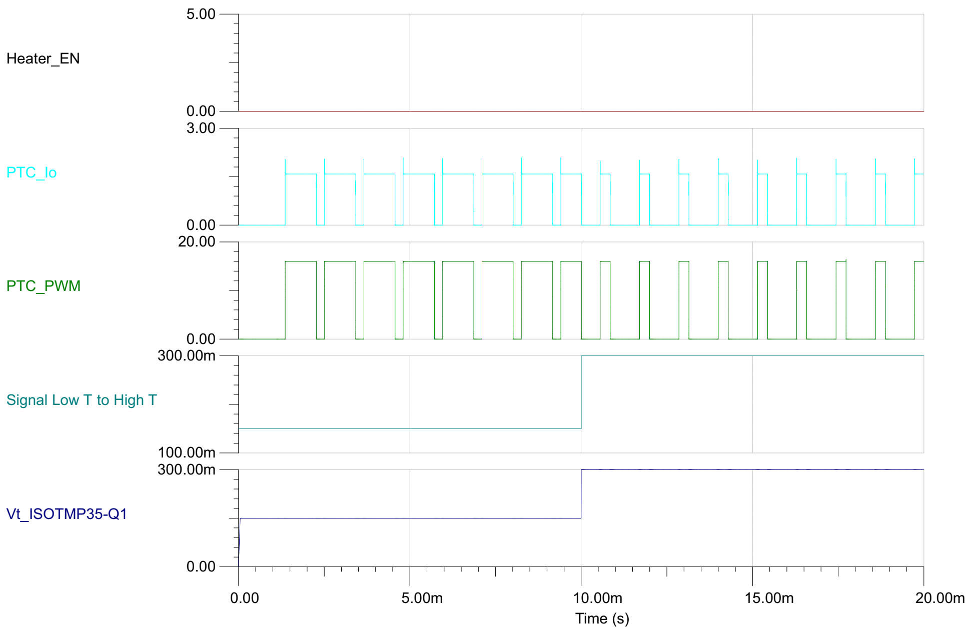

Figure 5-2. Heating: -35°C to -20°C

Simulation Waveform: -35℃ - -12℃, or 150mV - 380mV, continue heating to stop heating

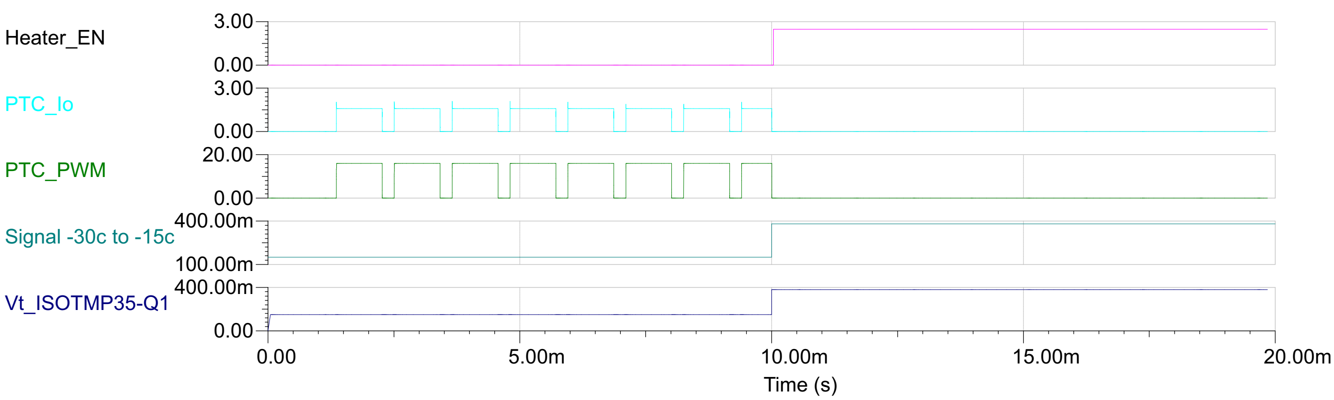

Figure 5-3. Stop Heating: -12°C

Simulation Waveform: -35℃ - -12℃, or 150mV - 300mV, heating to PTC SCP

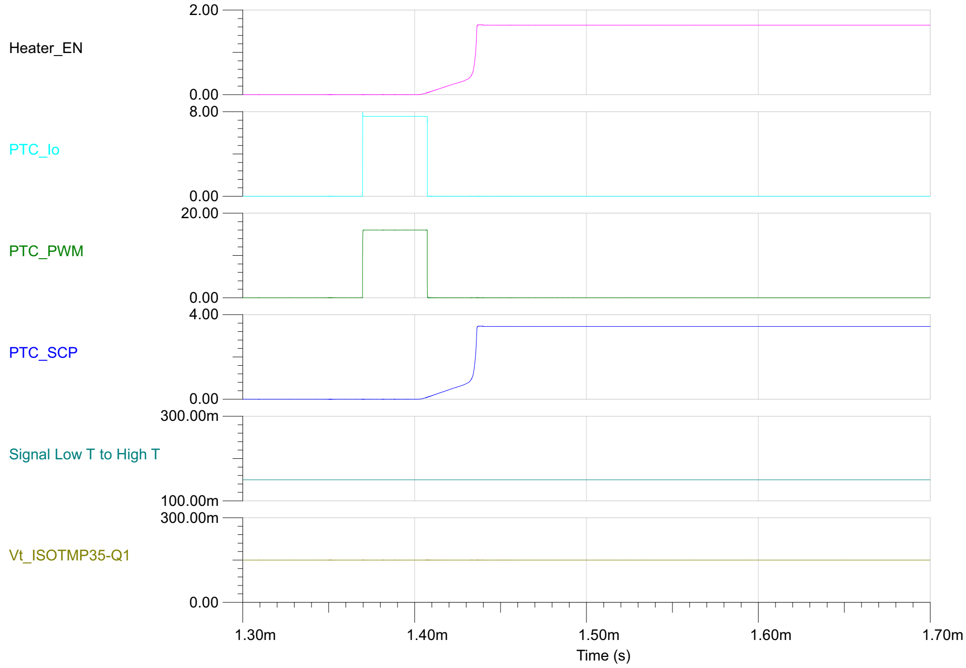

Figure 5-4. PTC Short Protection 2A to 8A

6 Typical Heater Schematic

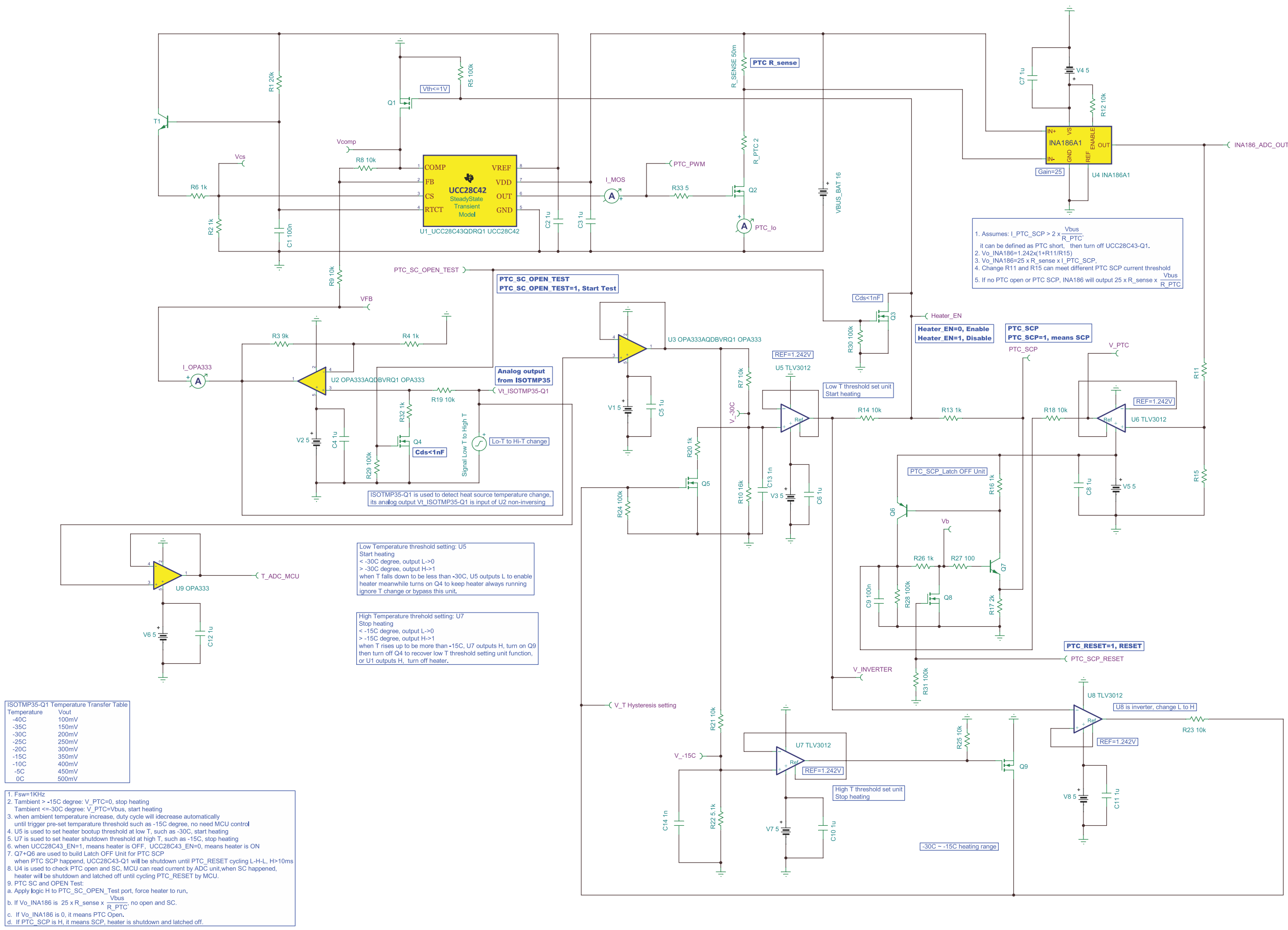

Figure 6-1. Typical Heater Schematic

7 References

- Texas Instruments, *ISOTMP35-Q1 Automotive ±1.5°C, 3-kVRMS Isolated Temperature Sensor With Analog Output With < 2 Seconds Response Time and 500VRMS Working Voltage*, data sheet.
- Texas Instruments, *ISOTMP35B Evaluation Module*, EVM user's guide.
- Texas Instruments, *OPA333-Q1 Automotive, 1.8V, Micropower, CMOS, Zero-Drift Operational Amplifier*, data sheet.
- Texas Instruments, *UCC28C4x-Q1 BICMOS Low-Power Current-Mode PWM Controller*, data sheet.

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