TEC Controller Evaluation Board TEC24V15AEV2.2

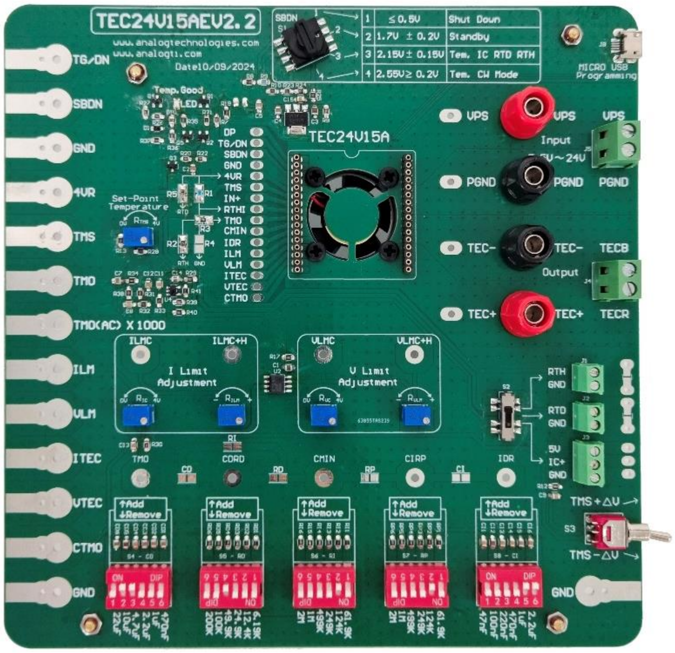

Figure 1. The physical photo of TEC24V15AEV2.2

FEATURES

- Versatile Interface for all necessary measurement nodes
- Easy to use

APPLICATION

Evaluating TEC controller TEC24V15A.

INTRODUCTION

This TEC controller, TEC24V15A, is designed to drive a TEC at high efficiency for regulating the object temperature precisely by controlling the direction and magnitude of the current going through the TEC. It is powered by a DC voltage between 5.5V to 24V and output current can go up to 15A without using a heat sink.

This evaluation board, TEC24V15AEV2.2, is designed for evaluating the controller TEC24V15A conveniently. It is recommended to read this application note with the controller datasheet which provides more detail information about the specifications and application guidance for the controller.

The main purpose of using the evaluation board is to tune the compensation network on the board for matching the characteristics of users' thermal load. The objectives of the tuning are to minimize the response time of the thermal control loop and the dynamic temperature tracking errors, while keeping the control loop stable.

The user will be able to set the maximum output voltage, set the set-point temperature, monitor the output voltage and the actual thermal load temperature, tune the compensation network for matching the thermal load, etc..

BOARD DESCRIPTION

The TEC24V15AEV2.2 Evaluation Board is consisted of a complete application circuit for driving a TEC controller. It can set the output current, the output current limit, has an LED for indicating the working status of the controller, has numerous connection pads and terminal connectors for making connections with external components and instruments. Its physical photo of TEC24V15AEV2.2 is shown in Figure 1.

The silkscreen layer of the evaluation board is shown in Figure 2 with other top layers, including top silkscreen, top copper, top solder mask, and multilayer (vias). Figure 6 only shows the image of top silkscreen layer. There is no component in the bottom side of the board, so that there is no bottom silkscreen layer image.

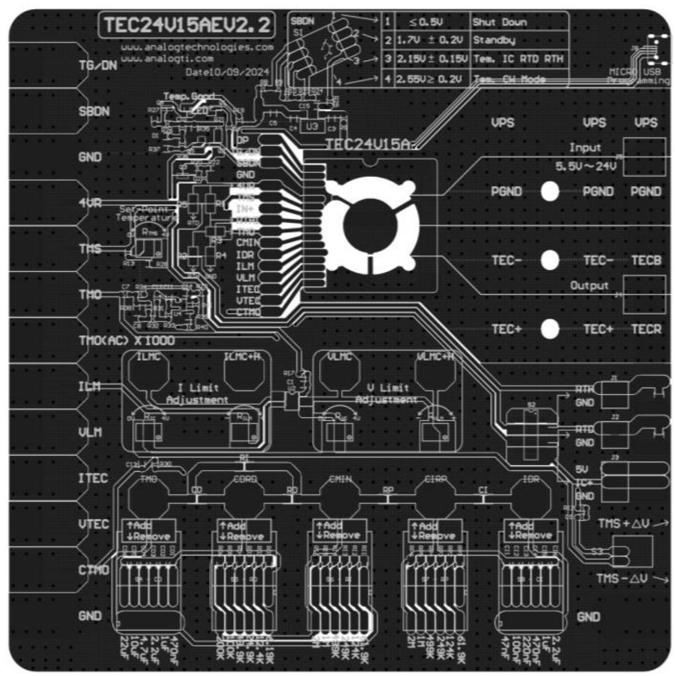

Figure 2. Top Silkscreen Layer with Other Top Layers

There are solder pads on the left edges of the board. These pads can be used for connecting the external instruments or components with and the connections can be made by either soldering wires or clipping by alligator clips.

There are 5 terminal blocks also located on the right side of the board, their connectors are for the same nodes of the solder pads. See the silkscreen image in Figure 6.

When the thermal control loop of the TEC controller works properly, the LED on the upper location will be lit up.

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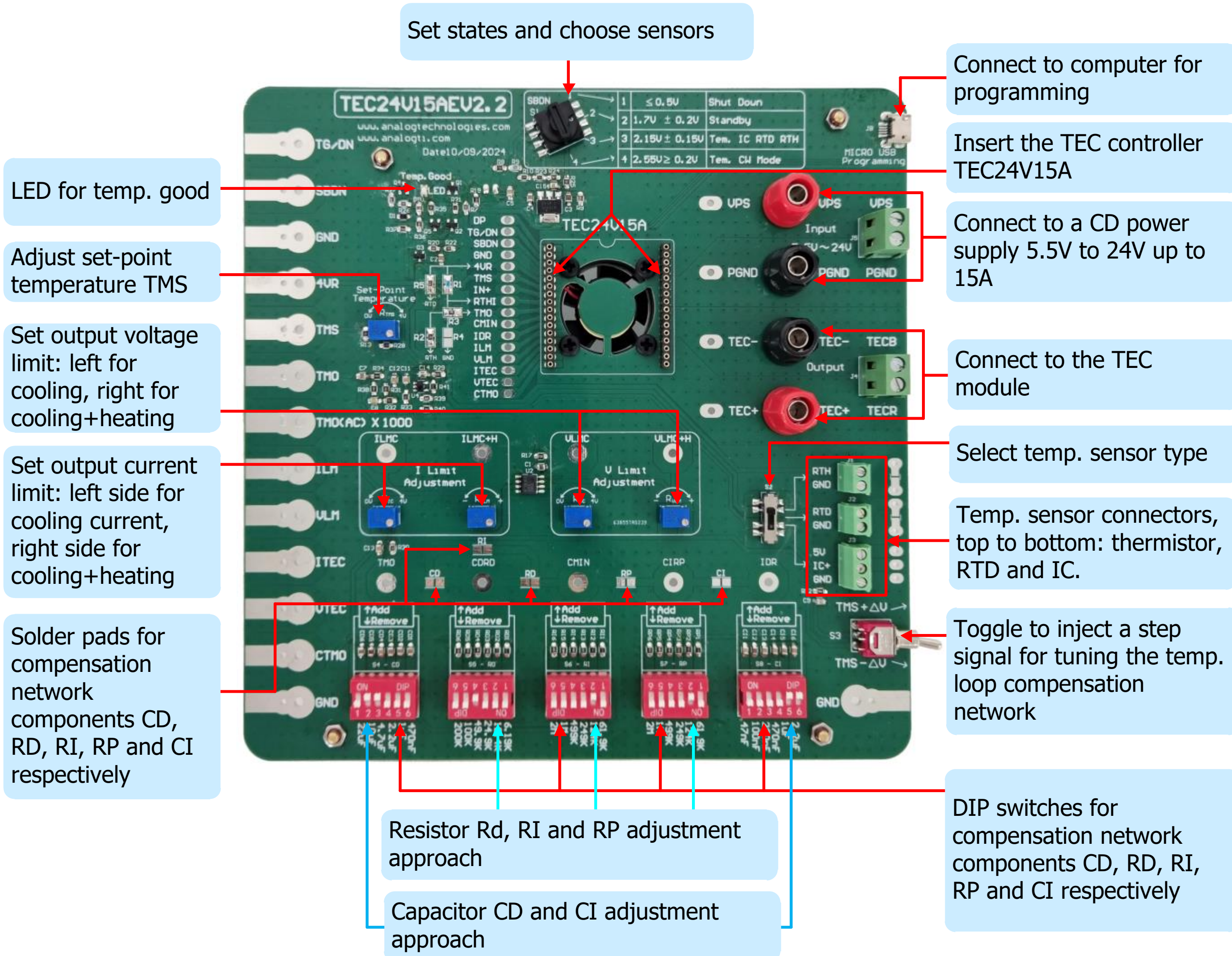

Figure 3. Board Description

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Switch Pisition	SBDN Voltage	Controller State
1	≤0.5V	Shut Down
2	1.7V ± 0.2V	Standby
3	2.15V ± 0.15V	Temp. IC, RTD, RTH
4	2.55V ± 0.2V	Temp. CW Mode

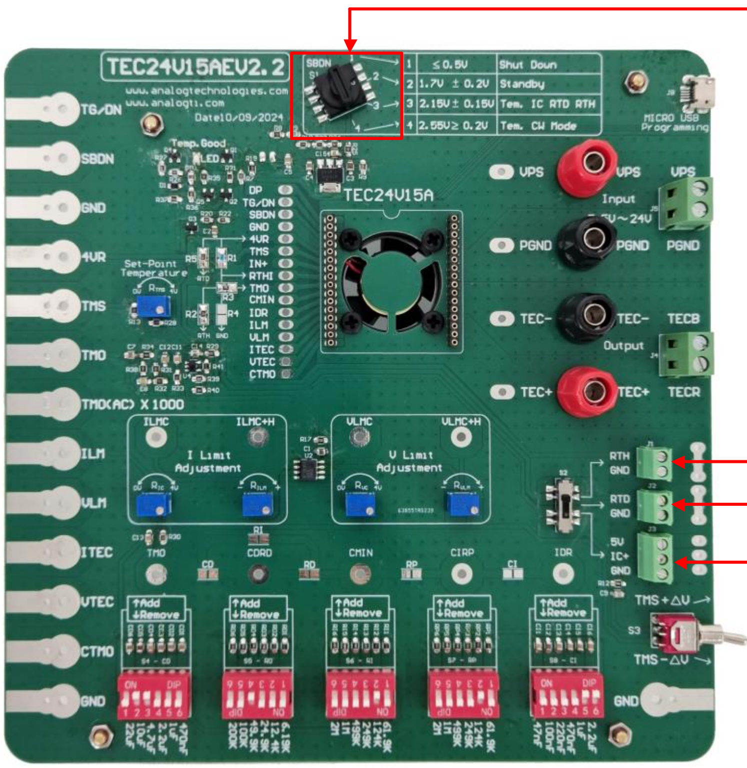

Figure 4. Additional Information for Evaluation Board

Note: RTH (thermistor) sensor has two modes: S/H (sample and hold) mode and CW (continuous wave) mode.
1. Choosing RTH CW mode: set S1 (top center) to position 4 and set S2 (lower middle right) to RTH.
2. Choosing RTH S/H mode: set S1 to position 3 and set S2 (lower middle right) to RTH.

Table 1. Default Component Values for the Compensation Network

Parameter	Value	Note
R_P	124kΩ	
R_I	1MΩ	
R_D	100kΩ	
C_I	22µF	
C_D	14.7µF	

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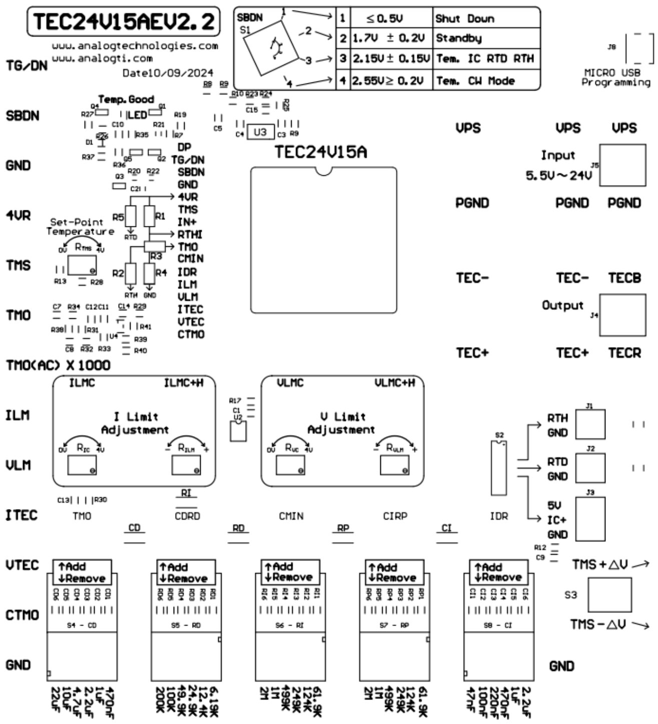

Figure 6. Top Silkscreen

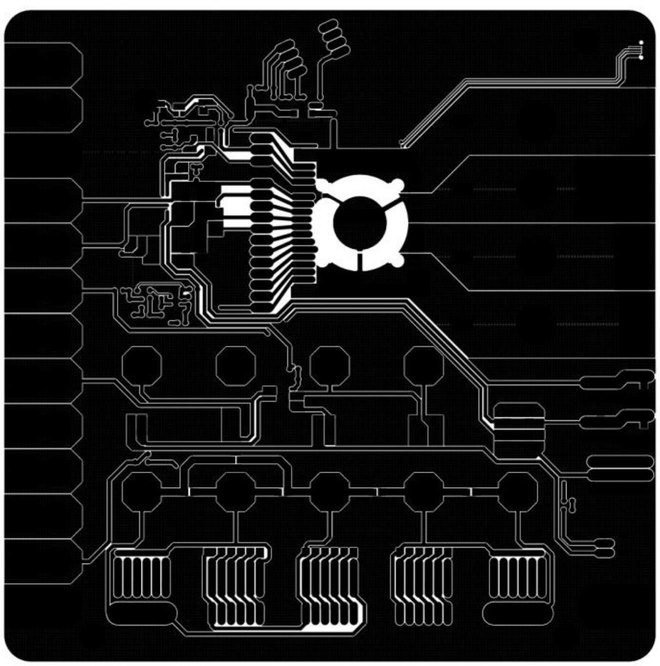

Figure 7. Top Layers without Top Screen Layer

Figure 7 shows the top layers without the silkscreen layer. Figure 8 below shows the bottom layers, including bottom copper, bottom solder mask, and multilayer (vias). Please notice that this is a "see through" image from the top side.

Figures 8 and 9 can be used as a layout reference for designing a system using the TEC24V15A in the system. These are the main points:

1. Connect the power supply return node directly to the PGND pin of the controller before connecting it to any other points. For thermal management purpose, the returned node was not done in this way on the evaluation board.

2. Use as large copper area as possible for the PCB traces of the solder pads of all the pins so that these copper areas become heat-sinks and help dissipating the heat generated by the controller.

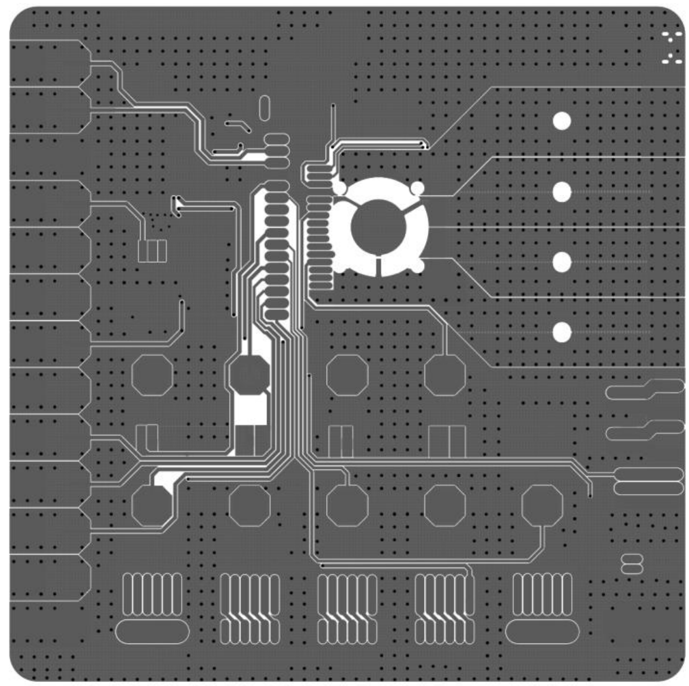

Figure 8. Bottom Layers

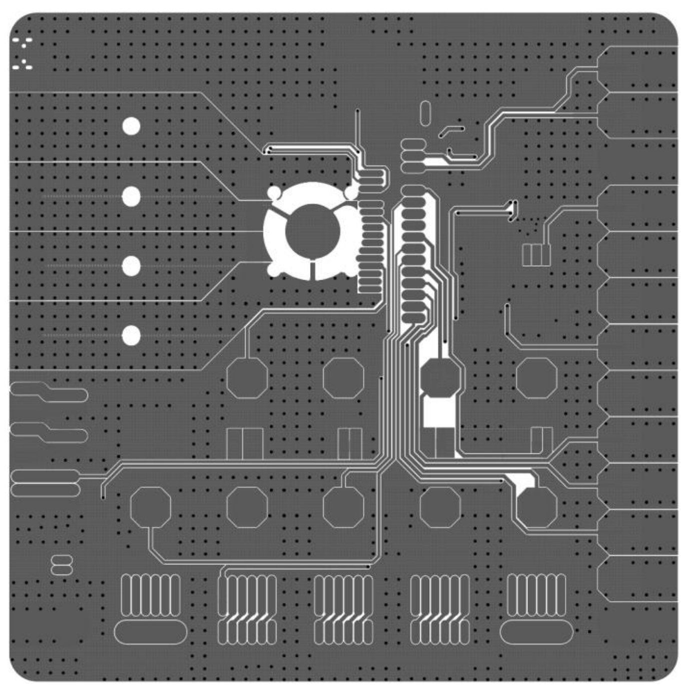

Figure 9. Mirrored Bottom Layers

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Figure 9 shows the mirrored bottom layers which is a directly-seen image from the bottom side.

The controller TEC24V15A is located in the center of the TEC24V15AEV2.2 Evaluation Board. The voltages of all its pins can be measured directly by probing the vias on the left and right side of the module sockets which are connected directly with pins of the electronic module. Some of the pins are also connected to the connectors of the 5 terminal blocks, and/or the soldering pads on the edges of the board. The names of all these nodes are marked on the board.

Table 2 is printed on the actual TEC24V15AEV2.2, which shows the values of V_{SBDN}.

Switch Position	SBDN Voltage	Controller State
1	≤0.5V	Shut Down
2	1.7V ± 0.2V	Stand By
3	2.15V ± 0.15V	Tem. IC, RTD, RTH
4	2.55V ± 0.2V	Tem. CW Mode

The schematic is shown in Figure 10 below.

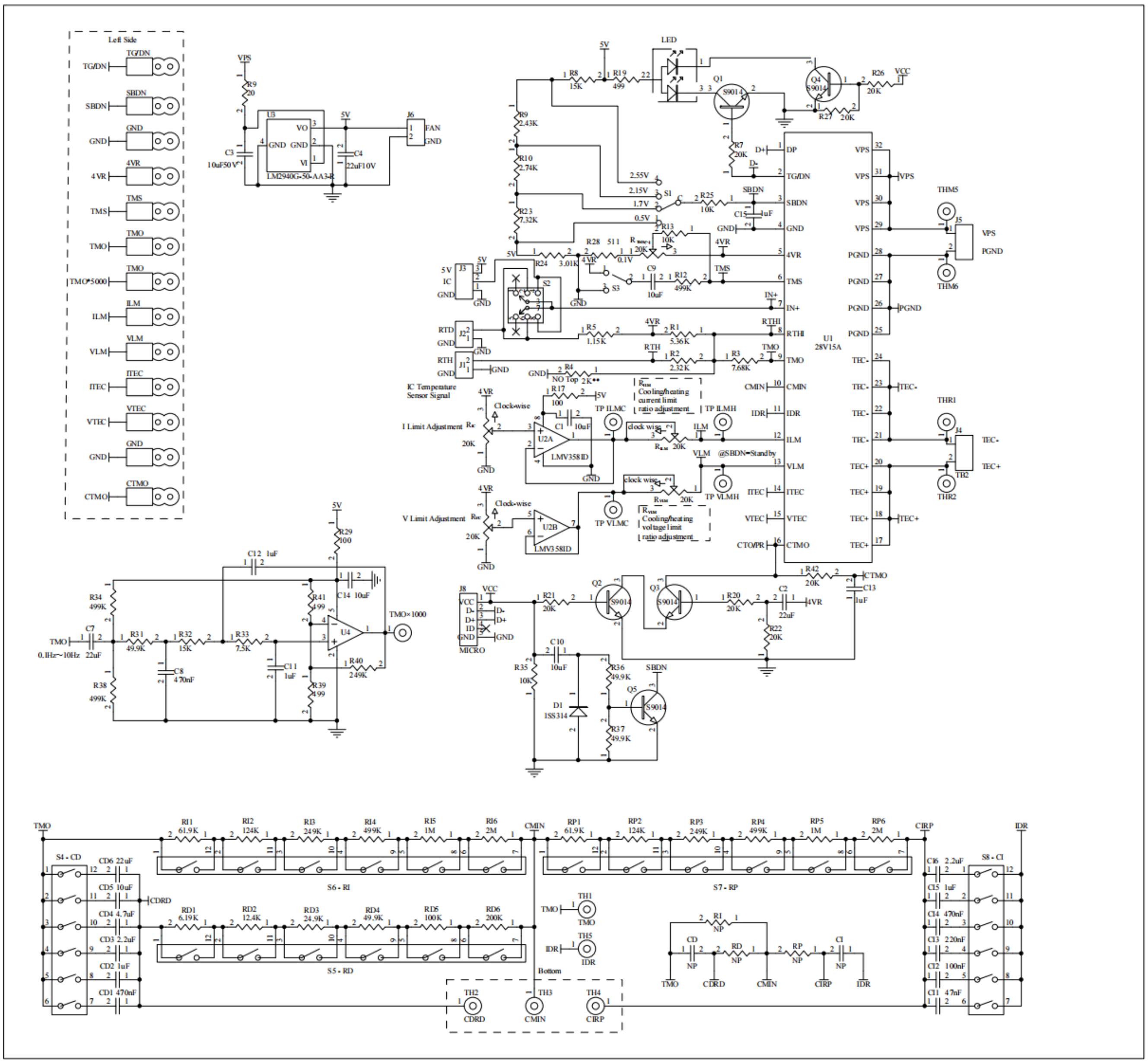

Figure 10. Schematic of TEC24V15AEV2.2

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GETTING STARTED

1. Connect the TEC module and the temp. sensor to the board. Hook up a DC power supply by using banana plug or the terminal block. the voltage will be 1.2 to 2 times higher than the maximum TEC voltage.

2. Set TMS to 2V and tune the compensation network by using S4 to S8 (center bottom). Toggle S3 (lower right) and monitor the waveform at the IDR pin by using an oscilloscope in rolling mode. Tune all the values, CD, RD, RI, RP and CI, to achieve the ideal result in Figures 11 and 12. Make sure, IDR pin's voltage is not saturated to any rails of the power supply. In principle: try to maximize CD, minimize RD, minimize CI, maximize RP, set RI be around 200kΩ to 1MΩ, the lower the better. RD should be about 0.1 × RI, CD about 10 to 100 times CI, RP be about 1 to 5 times RI.

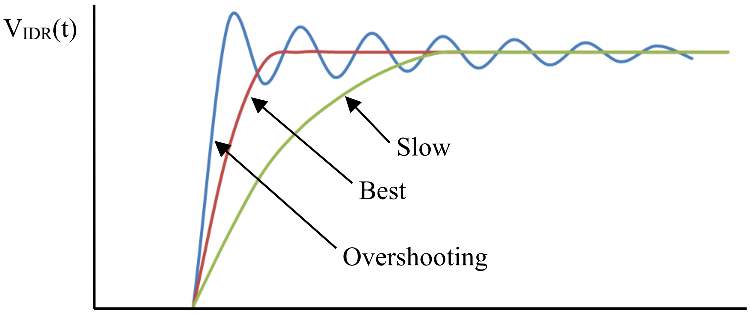

Figure 11. Rise Waveforms of $V_{IDR}(t)$

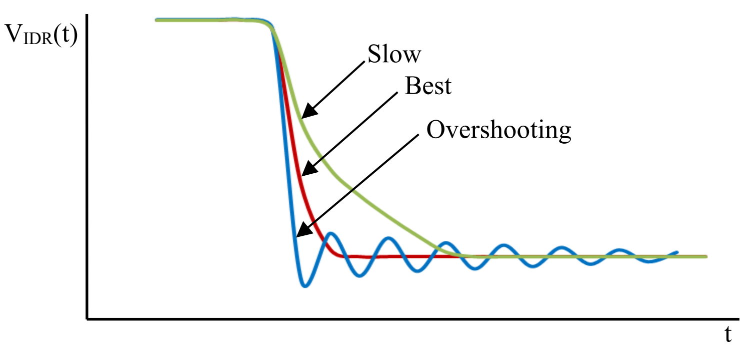

Figure 12. Fall Waveforms of $V_{IDR}(t)$

3. Diagnosis. In case the controller does not work properly:
A. TEC, temp sensor and power supply are properly connected.
B. Check the voltage reference pin 4VR to have 4.096V. Check IDR voltage at least be 0.2V away from GND and VPS.

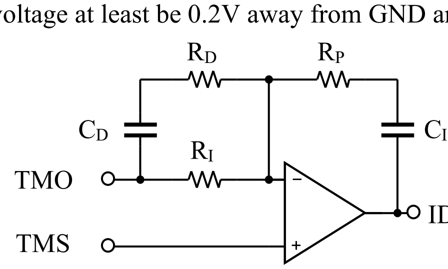

Figure 13. Compensation network

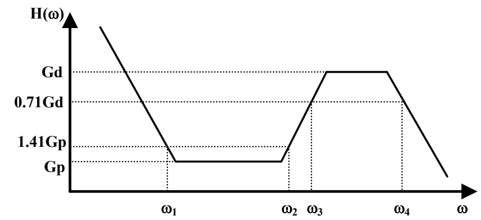

Figure 14. Transfer Function of the Compensation Network

1. **Compensation Network Details**

The transfer function of the compensation network, defined as H(ω)=IDR(ω)/TMO(ω), is shown in Figure 14.

In principle, these are the impacts of the components to the tuning results:

A. R_P/R_I determines the gain for the proportional component of the feedback signal which is from the thermistor, $Gp = R_P/R_I$, in the control loop, the higher the gain, the smaller the short term error in the target temperature (which is of the cold side of the TEC) compared with the set-point temperature, but the higher the tendency of the loop's instability.

B. R_P/R_D determines the gain for the differential component, $Gd = R_P/(R_D//R_I) \approx R_P/R_D$, where symbol "//" stands for two resistors in parallel, since $R_I >> R_D$, $R_D//R_I \approx R_D$. The higher the gain, the shorter the rise time of the response, the more the overshoot and/or the undershoot will be.

C. $C_i \times R_p$ determines the corner frequency, $w_1 = 1/(C_i \times R_p)$, where the integral component starts picking up, as the frequency goes down. It determines the cut-off frequency below which the TEC controller will start having a large open loop gain. The higher the open loop gain, the smaller the tracking error will be.

D. $C_d \times R_i$ determines the corner frequency, $w_2=1/(C_d \times R_i)$, where the differential component starts picking up (see Figure 14), as the frequency goes up.

E. $C_d \times R_d$ determines the corner frequency, $w_3=1/(C_d \times R_d)$, where the differential component starts getting flat. It determines the cut-off frequency above which the TEC controller will give extra weight or gain in response.

F. $1nF \times R_p$ determines the corner frequency, $w_4=1/(1nF \times R_p)$, where the differential component starts rolling down. Since this frequency is way higher than being needed for controlling the TEC, w_4 does not need to be tuned. The capacitor is built into the TEC controller module, not the evaluation board.

Tuning

A. Turn off the differential circuit by setting C_d Open.

B. Set C_i to 1μF, set R_i to 1MΩ, and increase the ratio of R_p/R_i as much as possible, provided the loop is stable, i.e. there are no oscillations seen in $V_{IDR}(t)$. Then, minimize C_i as much as possible, provided the loop is stable.

C. Activate differential circuit. Minimize Rd and maximize C_d while maintaining about 10% overshoot found in $V_{IDR}(t)$. Optimum result can be obtained after diligent and patient tuning. The tuning is fun and important.

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D. To be conservative in stability, use larger C_i and larger R_i; to have quicker response, use smaller Rd and larger C_d.

E. The closer to the TEC the thermistor is mounted, the easier to have the loop stabilized, the shorter the rise time and the settling time of the response will be.

F. After tuning, the values of the components can be read off the corresponding switches S4 to S8.

G. Optimal results are achieved through careful and patient tuning—this process is both critical and rewarding.

Typical Applications

A. When the TEC controller is used to drive a TEC for stabilizing the temperature of a diode laser, there is no need to turn on the laser diode while tuning the TEC controller.

B. For the typical butter fly package laser head, these are the component values: R_i = 499kΩ, R_p = 499kΩ, C_i = 1μF, C_d = 4.7μF, and R_d = 100kΩ. These values may vary, depending on the characteristics of a particular thermal load.

Temperature Stability Measurement

1. After the compensation network is tuned properly, we can measure the temperature stability: use a high precision voltmeter to measure the voltage difference between TMS and TMO. If the set-point temperature range over the 0.1V to 4.096V is 30°C, the temperature error per voltage is approximately: 30°C/4000mV= 0.00075°C/mV .
2. Set output voltage limit. Adjust the potentiometer R_{VC} to set the voltage limit. TP VLIM is the test point for R_{VC}. After the VLM is tuned properly, adjust R_{VLM} to achieve different voltage limit for heating and cooling. As is shown in Figure 15 and Figure 16.
3. Set output current limit. Adjust the potentiometer R_{IC} to set the current limit. TP ILIM is the test point for R_{IC}. After the current limit is tuned properly, adjust R_{ILM} to achieve different ILM for heating and cooling. As is shown in Figure 15 and Figure 16.

The schematic is shown in Figure 17 below.

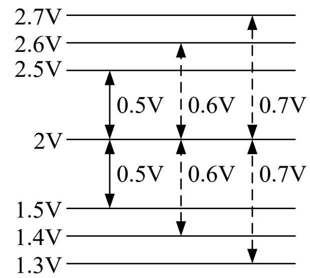

Figure 15. Adjust R_{IC} or R_{VC}

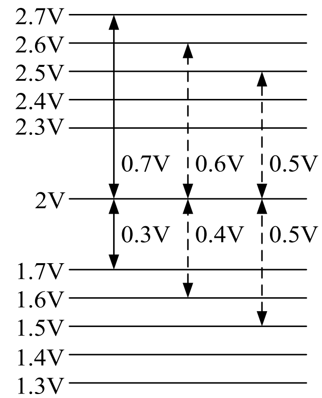

Figure 16. Adjust R_{ILM} or R_{VLM}

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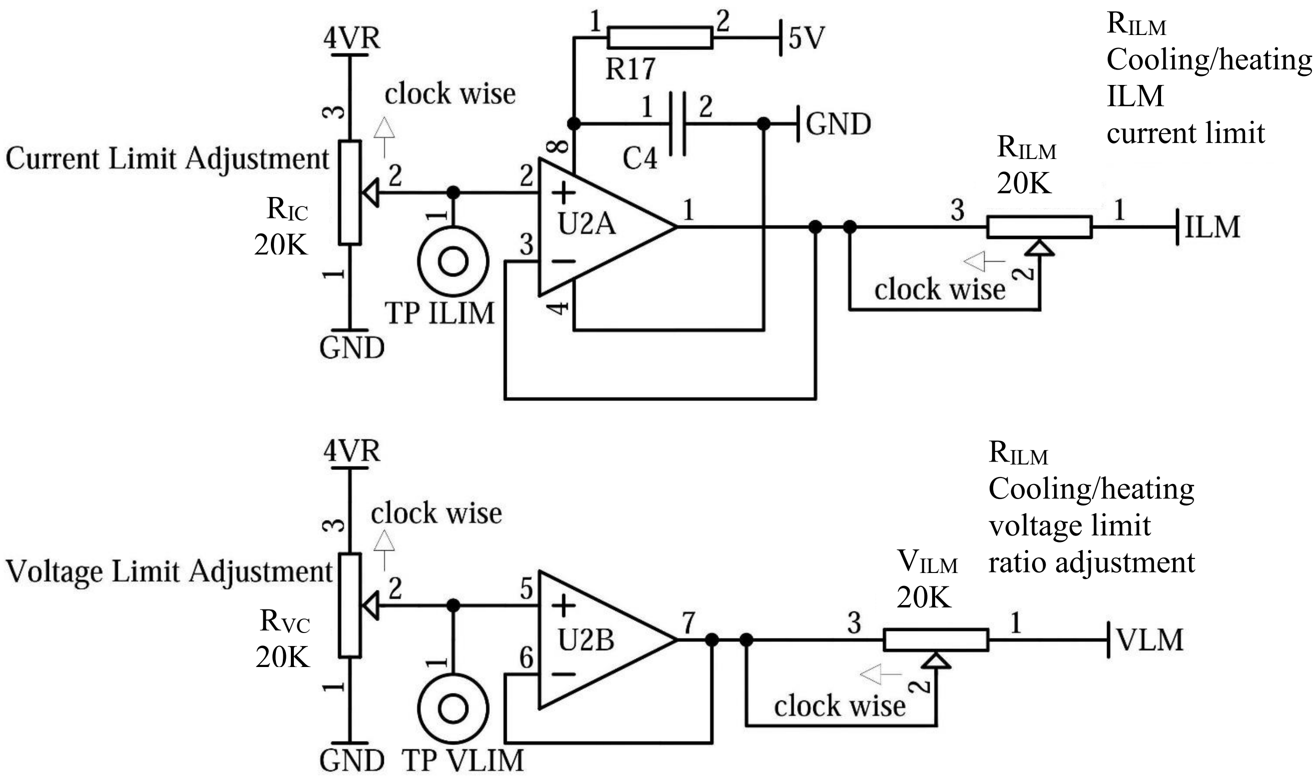

Figure 17. Schematic of Set output voltage or current limit

1. To know more parameters of the TEC controller.

a. To know the actual target temperature, use a voltage meter to measure the voltage between the TMO and the GND pins, the reading result is:
target temperature (°C) = 15°C + V_{TMO} (V) × 5°C for approximation (see the curve in the TEC controller data sheet).

b. To know how hard the TEC is working, measure the voltage VTEC by a voltage meter or an ADC,
V_{TEC} (V) = 15 × V_{VTEC} (V) – 30V.
When the TEC voltage (from the calculation) is positive, it is in cooling mode; when the TEC voltage is negative, it is in heating mode.

c. To try other values of capacitors not provided by the evaluation board for the capacitors in the compensation network, turn down the capacitor switches, to the "OUT" position, connect the component to the corresponding soldering pads as marked on the evaluation board, see Figure 1.

d. To shut down the TEC controller, turn the Shutdown Control S5 to "Off", see Figure 1.

e. To control the set-point temperature directly by using a DAC, set the set-point temperature POT W1 to the middle point (25°C), on which the TMS is about 1.5V, the half value of the reference voltage, connect TMS test point to the output of the DAC and use this formula for approximation when the input voltage is between 0.1V and 3.9V:
set-point temperature (°C) = 25°C + V_{TMO} (V) × 7.89°C. The maximum voltage allowed is V_{VPS} (power supply). See the curve in the TEC controller data sheet.

f. To control the TEC voltage directly by using a DAC, connect VTEC to the output of the DAC and use this formula: V_{TEC} (V) = 15 × V_{VTEC} (V) – 30V.

g. To shut down the TEC controller by using a microprocessor, turn off the Shutdown Control switch, connect SBDN test point (3rd row from the left side, on top side of the board) to one of its digital outputs. When pulling low, the TEC controller is shut off. When pulling high SBDN, the TEC controller is turned on.

h. The evaluation schematic is given in Figure 14.

Using the TEC controller for more applications not described here, and/or having any questions, please feel free to contact us.

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Temperature Sensor Selections

There are usually three temperature sensors, thermistor, RTD (Resistance Temperature Detector), and IC (Integrated Circuit) temperature sensors.

1. Thermistor

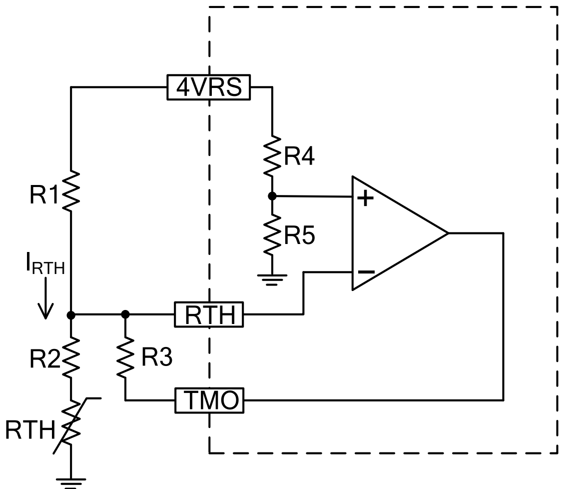
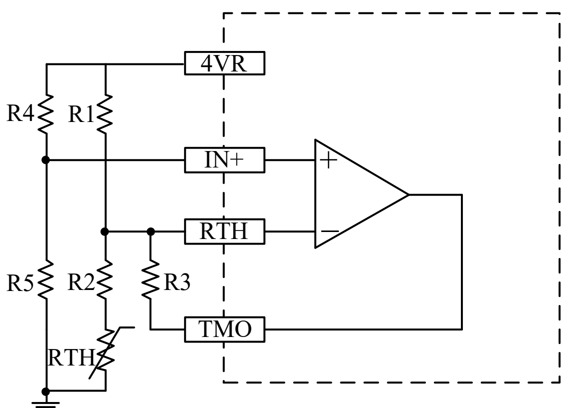


Figure 18. RTH (Pulse Mode)



Note: R4=R5

Figure 19. RTH

To achieve the required V_{TMO} outputs at the three different setting point temperatures in the Temperature Network, use the equation:

$$R1 = R_{MID} + \frac{R_{MID} \times (R_{LOW} + R_{HIGH}) - 2 \times R_{HIGH} \times R_{LOW}}{R_{HIGH} + R_{LOW} - 2 \times R_{MID}} \quad (1)$$

$$R2 = R1 - R_{MID} \quad (2)$$

$$R3 = \frac{R1 \times (R1 + R_{LOW} - R_{MID})}{R_{LOW} - R_{MID}} \quad (3)$$

For example, setting the high set-point temperature at 35°C and the low set-point temperature at 15°C results in a middle set-point temperature (35 + 15)/2 = 25°C. Use the R-T table of a thermistor.

$R_{HIGH} = 6.9k\Omega$

$R_{MID} = 10k\Omega$

$R_{LOW} = 14.8k\Omega$

Note that Equation 1 to Equation 3 result in

$R1 = 17.5k\Omega$

$R2 = 7.5k\Omega$

$R3 = 81.3k\Omega$

To use different temperature measurement ranges, adjust the re sistance of R1, R2 and R3. For example, to make R1=15k, turn S1 to TP W1, adjust the potentiometer W1, and then measure t he resistance of W1 at TP W1 test point with a multimeter. Wh en the resistance changes to 15k, turn S1 to W1.

In order to reduce the injection current to the thermistor to reduce the errors caused by the self-heating effect, the injection current is provided in pulse mode, reducing the current by 10 times as opposed to a continuous current.

It's recommended to connect R1 to 4VRS, and the controller will measure temperature at intervals that will reduce the error caused by the RTH self-heating. At the same time, the SBDN pin should be between 3.1V and 4V. See Table 3.

We can also connect R1 to 4VR, but it may lead to some errors caused by RTH self-heating. At the same time, SBDN pin should be between 2.4V and 2.6V. See Table 3.

2. RTD

RTD is short for resistance temperature detector, which features high accuracy and low drift. It usually generates heat when the current flows through the RTD, which is called self-heating effect. Moreover, RTD has an approximately linear resistance-temperature relationship.

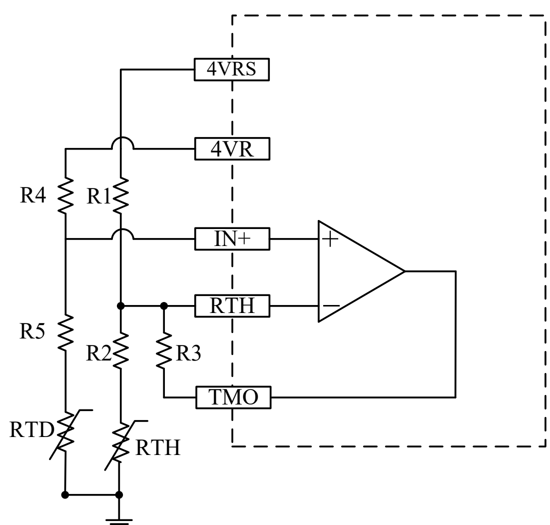


Figure 20. RTD

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To achieve the required V_{TMO} outputs at the three different setting point temperatures in the Temperature Network, use the equation:

$$V_{TMO} = (\frac{R_3 \times (R_1 + R_2 + RTH)}{R_1 \times (R_2 + RTH)} + 1) \times \left| V_I - \frac{V_{4VR}}{2} \right| + \frac{V_{4VR}}{2} \quad (1)$$

$$V_I = \frac{R_5 + RTD}{R_4 + R_5 + RTD} \times V_{4VR} \quad (2)$$

For example, When the ambient temperature is 28°C, the resistance value is as follows:

R_1 = 17.5kΩ R_2 = 7.5kΩ R_3 = 348kΩ R_4 = 17.6kΩ
R_5 = 16.485kΩ RTD = 1.115kΩ RTH = 10kΩ

When the voltage of TMS pin is 1.98V, corresponding to the temperature is 20°C. At this time: $|V_{TMS}-V_{TMO}| < 1mV$. It means that the set temperature is the same as the actual temperature.

3. IC

IC temperature sensor has lower self-heating effect.

We use LM62BIM temperature sensor. The temperature range is from 10°C to 50°C, corresponding to T_L= 0.636V, and T_U = 1.260V. R1=16.4k, C1=4.7uF, R2=100k, R3 = 97.8k, R4 = 19.7k, R5 = 100k. See Figure 21.

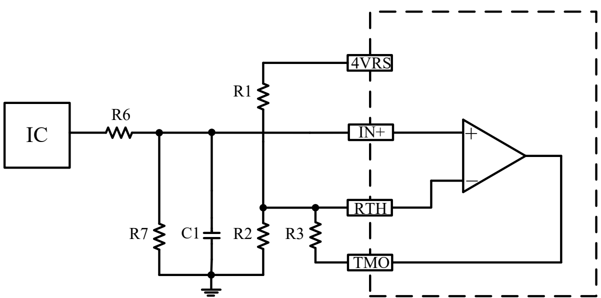

Figure 21. IC temperature sensor

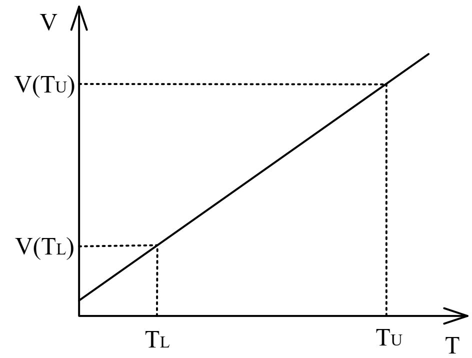

Figure 22. Temperature sensor IC characteristics

$V_{TMO}(T_L)$ = 0.1V, $V_{TMO}(T_U)$ = 3.9V

$$G = \frac{\Delta V_O}{\Delta Vi} = \frac{V_{(TMO)}(T_U) - V_{(TMO)}(T_L)}{V(T_U) - V(T_L)} \quad (1)$$

$$G = \frac{R7}{R6} = \frac{R3}{R1 // R2} \quad (2)$$

$$V_{IM} = \frac{V_{(TU)} + V_{(TL)}}{2}, \; V_{OM} = \frac{3.9V + 0.1V}{2} = 2V \quad (3)$$

$$V_I = V_{IM}, \; V_{OM} = 2V$$

V_I is the output voltage of IC, and V_O is the voltage of TMO pin.

$$V_{IN+} = \frac{R7}{R6 + R7} V_{im}, \; V_{RTH} = V_{IN+} \quad (1)$$

$$\frac{4V - V_{IN+}}{R1} + \frac{V_{om} - V_{IN+}}{R3} = \frac{V_{IN+}}{R2} \quad (2)$$

R3=100k, R6=R1//R2, R3=R7.

$$R2 = \frac{400}{4G - V_{IN+} - V_{IN+}G + 2} \quad (3)$$

$$R1 = \frac{400}{V_{IN+} + V_{IN+}G - 2} \quad (4)$$

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