Technical White Paper

The Benefits of TMP61 Linear Thermistors in Air Conditioner System

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ABSTRACT

The main function of the air conditioning system is temperature regulation, in which the temperature detection plays a very important role. The temperature sensors convert temperature into an electrical signal. In an air conditioning system, temperature sensors need to be placed in multiple locations to achieve temperature detection and ensure the efficiency.

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1 Application of Temperature Sensors in Air Conditioner

1.1 Working Principle of Air Conditioner

Air conditioning systems can be divided into cooling or heating mode according to the direction of heat flow. Taking refrigeration as an example, its working principle is, the refrigerant in the outdoor unit is compressed into high-pressure gas by the compressor. Then, high-pressure gas is condensed into high-pressure liquid by the condenser. After that, the high-pressure liquid is depressurized by the throttle valve and then passed into the indoor unit. Finally, the evaporator further reduces the pressure of the low-pressure liquid and makes it evaporate into gas. During the whole process, a large amount of heat from the surrounding environment is absorbed to achieve refrigeration. The final gas flows back to the compressor again, completing the cycle. The heating mode is the opposite of Figure 1-1.

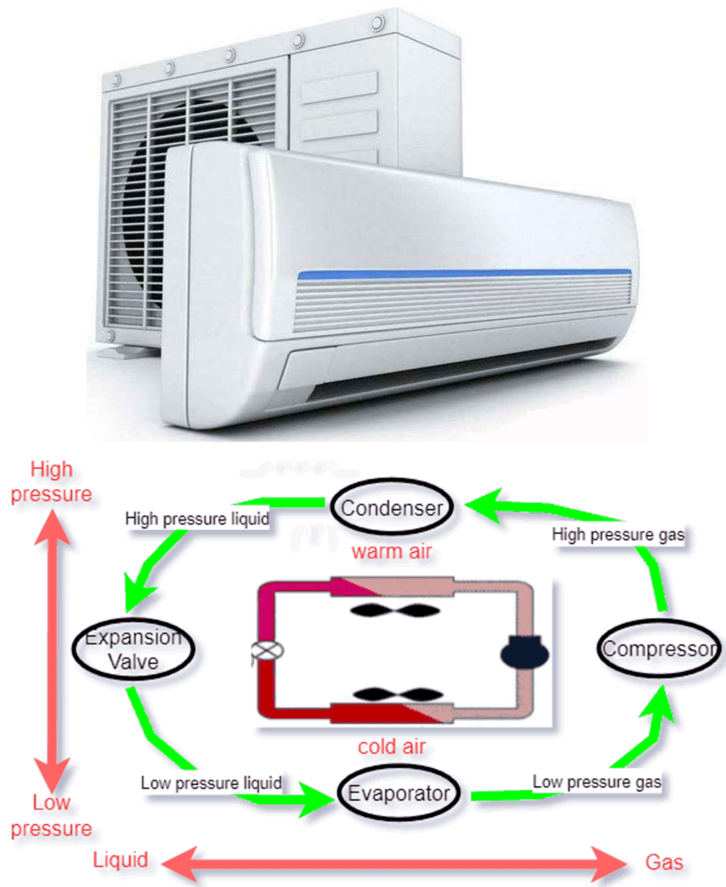

Figure 1-1. Schematic Diagram of the Principle of Air Conditioning and Refrigeration

1.2 Application of Temperature Sensors in Air Conditioner

The typical temperature sensors used in the air conditioner is a thermistor. The temperature is measured by using the characteristic that its resistance changes with the temperature, and the electrical signal is then sent to the microcontroller through the sampling circuit to realize the temperature detection. Thermistors can be divided into Positive Temperature Coefficient (PTC) thermistors and Negative Temperature Coefficient (NTC) thermistors according to their different sensing characteristics. Among them, the resistance of NTC thermistor has a negative temperature coefficient, its resistance decreases with the rising of temperature; while the resistance of the PTC temperature sensors has a positive temperature coefficient, its resistance increases with the rising of temperature.

1.2.1 Temperature Sensors in Indoor Unit of Air Conditioner

In an air conditioner indoor unit, there are usually two temperature sensors, which are an indoor temperature sensor and an evaporator coil temperature sensor. The indoor temperature sensor locates at the air inlet of the indoor unit. Its main function is to measure the indoor ambient temperature during the heating or cooling process. The temperature probe of the evaporator coil temperature sensor is usually attached to the pipeline of the evaporator and fixed on the copper tube by a clip to detect the temperature of the evaporator coil. Figure 1-2 shows the installation position of the evaporator coil temperature sensor.

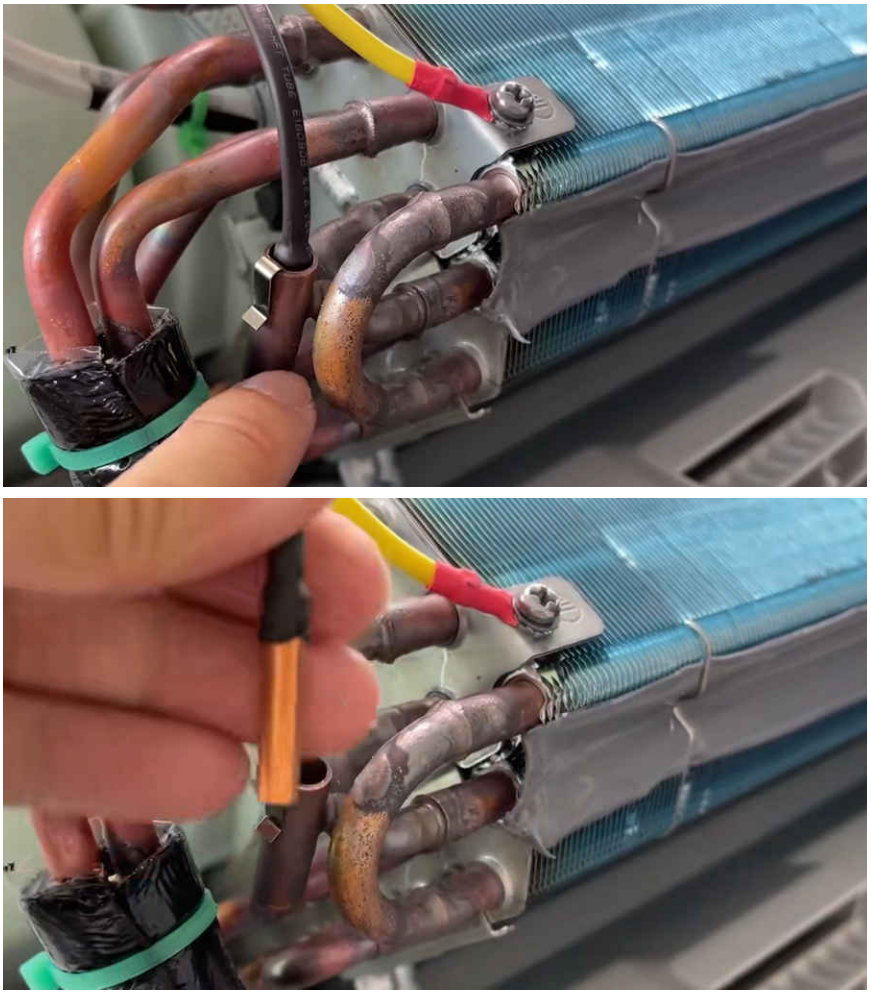

Figure 1-2. Position of the Temperature Sensor for Evaporator Coil

The air conditioner automatically checks the temperature of the indoor evaporator coil after a period of cooling operation. If the temperature does not reach a specified temperature (20°C), it is automatically diagnosed as lack of refrigerant and protected. If the temperature drops below +3°C, it shuts down in order to prevent frost, and the compressor stops working. When the temperature rises to 7°C or the compressor stops for more than 6 minutes, the compressor restarts. During heating, the indoor coil temperature is lower than 32°C, the indoor fan does not blow (anti-cold air), the outdoor fan stops when it is higher than 52°C, and the compressor stops when it is higher than 58°C (overheating). Different manufacturers have different temperature settings, but the basic protection features are similar.

In this process, the evaporator coil temperature sensor has four main functions:

- Overcooling protection during cooling
- Overheating protection during heating
- Controlling the speed of the indoor fan motor
- Assist outdoor defrosting during heating.

Taking a certain brand of air conditioner indoor unit as an example, since the indoor temperature to be detected is different from the evaporator coil temperature, the selected NTC thermistor is also different. The indoor temperature sensor uses a 5K NTC thermistor, and the evaporator coil temperature sensor uses a 10K NTC thermistor. Figure 1-3 shows the schematic diagram.

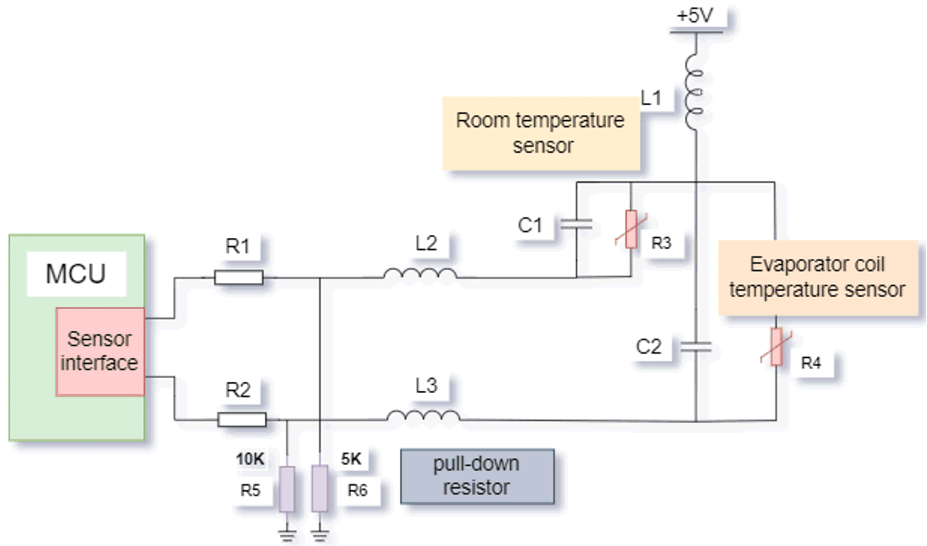

Figure 1-3. Schematic of the Temperature Sensor Circuit of the Indoor Unit

1.2.2 Temperature Sensors in Outdoor Unit of Air Conditioner

The outdoor unit of the air conditioner also has two temperature sensors, one of them is to detect the temperature of the condenser of the outdoor unit. This temperature sensor is usually installed on the surface of the condenser, and the installation method is similar to the indoor evaporator. Another temperature sensor is placed on the air inlet of the condenser to detect the outdoor ambient temperature, which is used to control the speed of the outdoor fan and preheat the compressor in winter. The two temperature sensors are installed as shown in Figure 1-4.

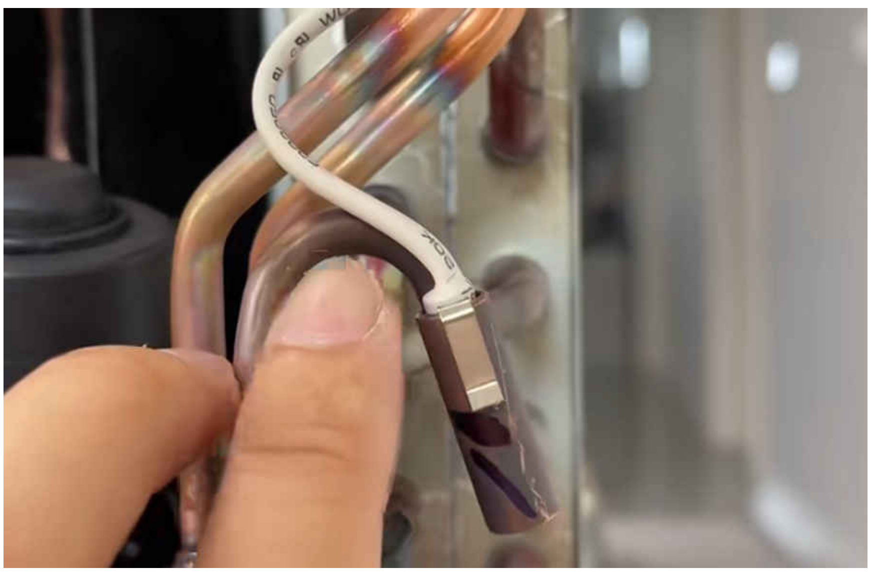

Figure 1-4. Position of Condenser Coil and Outdoor Unit Temperature Sensor

The temperature adjustment of the condenser is mainly divided into two parts: heating defrosting and refrigeration condensation. During heating, the first defrosting of the condenser is a timed defrosting (generally 50 minutes), and the subsequent defrosting is controlled according to the temperature of the outdoor condenser. If the temperature is lower than a specified temperature such as -11 °C, defrosting is required. During cooling, if the detected condenser temperature reaches 68°C, the compressor stops working to prevent the condenser coil from overheating.

In this process, the outdoor condenser coil temperature sensor has three main functions:

- Protection against overheating during cooling
- Protection against freezing during heating
- Temperature control of the condenser during defrosting

The outdoor condenser temperature sensor mainly uses a 20K resistance NTC thermistor (the resistance may be different from different manufacturers), and its circuit schematic diagram is similar to that of the indoor evaporator coil temperature sensor (see Figure 1-3).

1.2.3 Compressor Exhausted Air Temperature Detection

The exhausted air temperature sensor is mainly installed on the exhaust pipe of the compressor. Usually, an NTC thermistor with a resistance of 50K is selected. By detecting the temperature of the exhaust pipe of the compressor, the opening degree of the expansion valve can be controlled. When the temperature of the exhaust pipe is too high, the compressor is turned off for overheat protection.

Figure 1-5. Compressor Discharge Temperature Sensor Installation

2 Problems of NTC Thermistors in Air Conditioners

In air conditioners, temperature sensors are usually made in the form of probes for temperature detection convenience. NTC thermistor is made of metals and their oxides, with low cost and good stability, and is widely used in air conditioning systems, but it also has some problems:

- Non-linearity leads to material management problems

  The relationship between the resistance of the NTC and the temperature is nonlinear, resulting in low resistance resolution in high temperature range. Therefore, NTCs with different resistance are suitable for different temperature ranges. In the air-conditioning system, the temperature ranges are different for evaporator coil, condenser coil and the compressor exhaust, in order to ensure higher temperature resolution for all above locations, their NTC thermistors should be different. Figure 2-1 is a diagram of the R-T relationship of NTCs with different resistance. This also complicates material management as multiple types of NTC thermistors are required.

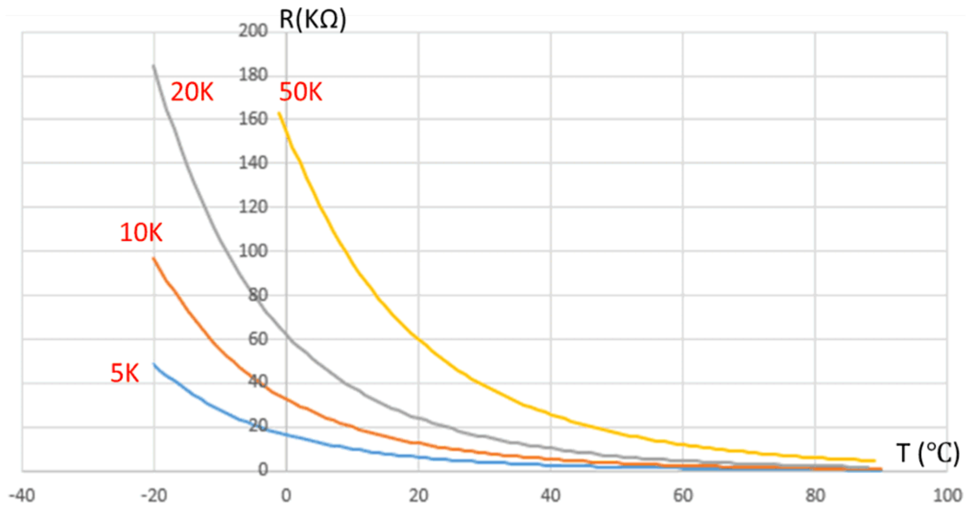

Figure 2-1. Diagram of NTC R-T Relationship With Different Resistance Values

- Slow response time

  NTC thermistor has slow response due to their material, but fast response is very important for good system performance. For example, when the air conditioner is refrigerating, the sensor detects that the temperature of the evaporator coil is 3°C, the actual temperature may already be lower than 3°C. The lag of temperature control increases the working time of the air conditioner compressor, and even causes the evaporator to frost. Therefore, an excessively slow response time increases the energy consumption and reduces the cooling efficiency of the air conditioner.
- Complex software processing

  The traditional NTC thermistor uses R-T look-up table and interpolation fitting to estimate the temperature corresponding to different resistance. The R-T look-up table occupies the ROM space of the MCU. However, each NTCs require a corresponding R-T tables, resulting in the occupation of more MCU ROM resources. To save some ROM resources, the interval of the R-T table for interpolation fitting is usually 1°C, which reduces the temperature detection accuracy.
- NTC resistance tolerance and drift

  The resistance tolerance of conventional NTC thermistors away from 25°C is usually much larger than specified in the device-specific data sheet, and in some cases the resistance tolerance can be increased from ±1% of 25°C to ±4% of – 40 ~150°C. In addition, due to the long life of the air-conditioning system and the large drift of the NTC thermistor, system temperature detection error will further increase for long-term operation.

3 Solutions

TI's TMP61 is a positive temperature coefficient linear thermistor (PTC) provides high linearity and consistent sensitivity over the entire temperature range, realizing a simple and accurate method of temperature conversion. Various packages of the chip are suitable for different application scenarios, as shown in Figure 3-1.

Figure 3-1. TMP61 Packages

- TMP61 silicon-based thermistor good R-T linearity

  The TMP61 linear thermistor is made of silicon, and unlike the metals and their oxides used in NTCs, its resistance versus temperature is linear, so it has many advantages. Its R-T table is shown in Figure 3-2. In the air-conditioning system, a single type of TMP61 silicon-based thermistor can achieve temperature detection at different locations under the premise of high resolution, while simplifying material management.

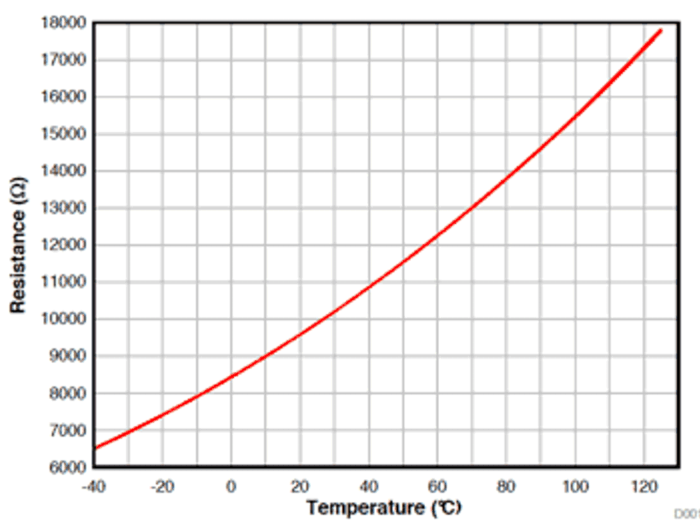

Figure 3-2. TMP61 R-T Relationship Diagram

- TMP61 silicon-based thermistor faster response time

  In the comparison experiment of the response speed of TMP61 silicon-based thermistor and NTC, it is found that the response time of TMP61 can be up to 3 times faster than that of NTC. The experimental results are shown in Figure 3-3. In air conditioning systems, TMP61 silicon-based thermistor is used for outdoor condense coil, which can improve the conditioning performance of condenser temperature control. Taking heating as an example, the rapid response and high accuracy of the defrosting control of the condenser can effectively shorten the working time of the air-conditioning compressor during defrosting and reduce the energy consumption of the system.

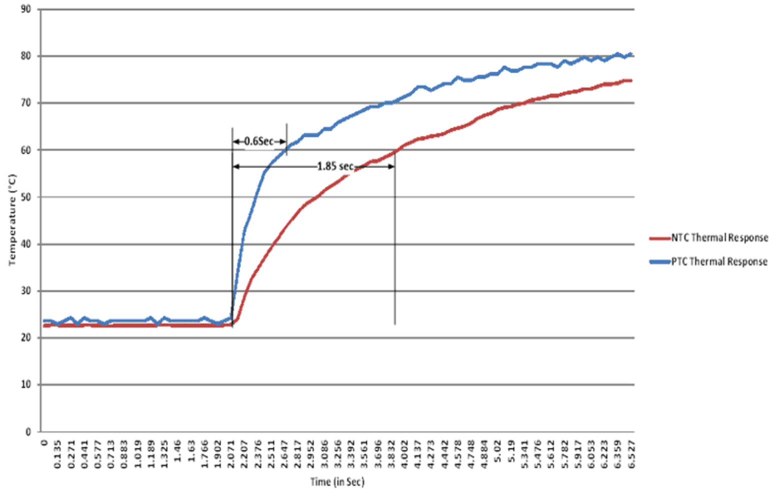

Figure 3-3. Comparison of Response Speed Between TMP61 and NTC

- TMP61 silicon-based thermistor save ROM and simplifies software design

  The R-T table of silicon-based thermistor is almost linear, and the R-T relationship can be directly fitted. At the same time, TI also provides the *Thermistor Design Tool*, which includes R-T fitting relationship, low-pass filtering, oversampling and other functions, and provides the relevant code that can be used directly, as shown in Figure 3-4. Taking the sampling circuit of 20K pull-down resistor as an example, the output relationship between temperature and voltage of TMP61 is obtained as shown in Figure 3-5. The relationship between temperature and voltage is almost linear, and a linear function can be used to fit it.

EXAMPLE OF C CODE **Copy the content of the box below, then paste into your C code**

```
// 4th order polynomial equations to calculate the temperature of the thermistor-----------------------------------------------------------------
// C code examples only  (NOTE: this code example is based on floating point math)

unsigned int RBias =          10000 ;      // set the value of the top resistor
float VBias =                  3.30 ;      // set the VBIAS voltage
unsigned int ADC_BITS =        4096 ;      // set the number of bits based on you ADC (2^# of ADC Bit Value)
float VTEMP = 0;                           // set up the variable for the measured voltage
float THRM_RES = 0;                        // setup the variable for the calculated resistance
float THRM_TEMP = 0;                       // setup the variable for the calculated temperature

float Thermistor(int raw_ADC)              // send the ADC bit value to the calculation function
{
  // THRM calculations - 4th order polynomial regression
  VTEMP = 0;                               // reset these variables to zero in order to recalculate the new factors
  THRM_RES = 0;                            // reset these variables to zero in order to recalculate the new factors
  THRM_ADC = raw_ADC

  float THRM_A0 =      -2.724350E+02 ;
  float THRM_A1 =       5.310830E-02 ;
  float THRM_A2 =      -3.504515E-06 ;
  float THRM_A3 =       1.405146E-10 ;
  float THRM_A4 =      -2.299616E-15 ;

  VTEMP = (VBias/ADC_BITS) * THRM_ADC;     // calculate volts per bit then multiply that times the ADV value
  THRM_RES = VTEMP/((VBias - VTEMP)/RBias);  // calculate the resistance of the thermistor
  THRM_TEMP = (THRM_A4 * powf(THRM_RES,4)) + (THRM_A3 * powf(THRM_RES,3)) + (THRM_A2 * powf(THRM_RES,2)) + (THRM_A1 * THRM_RES) + THRM_A0;  // 4th order regression to get temperature
  return THRM_TEMP;

}
```

Figure 3-4. TMP61 Thermistor Design Tool

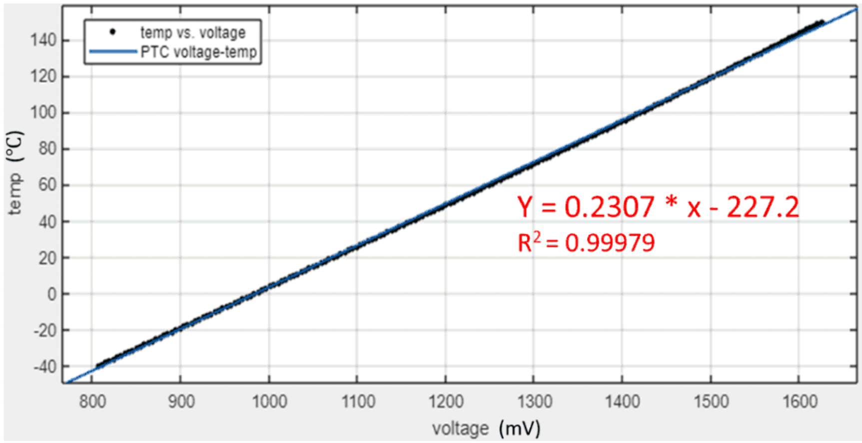

Figure 3-5. The Output Relationship Diagram of Temperature and Voltage of TMP61

In addition to the advantages mentioned above, TMP61 silicon-based thermistor thermistors also have the advantages of small resistance tolerance, easy single point calibration and less drift. For more information, see *Temperature Sensing with Thermistors*.

4 Summary

In the air-conditioning system, the performance of the temperature sensors is very important. Different installation positions are needed to measure different temperature ranges. Due to the nonlinear problem of traditional NTC thermistors, different types of NTCs are required to meet the needs of different temperature ranges, makes material management very complex. TI's TMP61 linear temperature sensor is a silicon-based thermistor, the resistance value and temperature are almost linear, which simplifies the software design, and can complete high-resolution temperature detection at different positions with one type of chip, TMP61. At the same time, the response time of the silicon-based PTC thermistor is faster than that of the NTC thermistor, which is beneficial to improve the working efficiency of the air conditioner. In addition, the smaller resistance tolerance and drift of silicon-based thermistor is beneficial to the reliability of long-term operation of the air-conditioning system.

In addition to the silicon-based thermistor TMP61, TI also provides a digital temperature and humidity sensors, HDC3020 with a temperature accuracy of up to 0.1°C and a humidity detection range of 0% to 100%. This series of temperature and humidity sensors also has a variety of models, such as HDC3021 with a removable tape cover, HDC3022 with permanent IP67 filter. For different scenarios, HDC302x provides users with more choices.

5 References

- Texas Instruments: *Thermistor Design Tool*
- Texas Instruments: *Temperature Sensing with Thermistors*