

# Using Kinetis K53 Amplifiers for Connecting Thermocouple and Thermistor Devices

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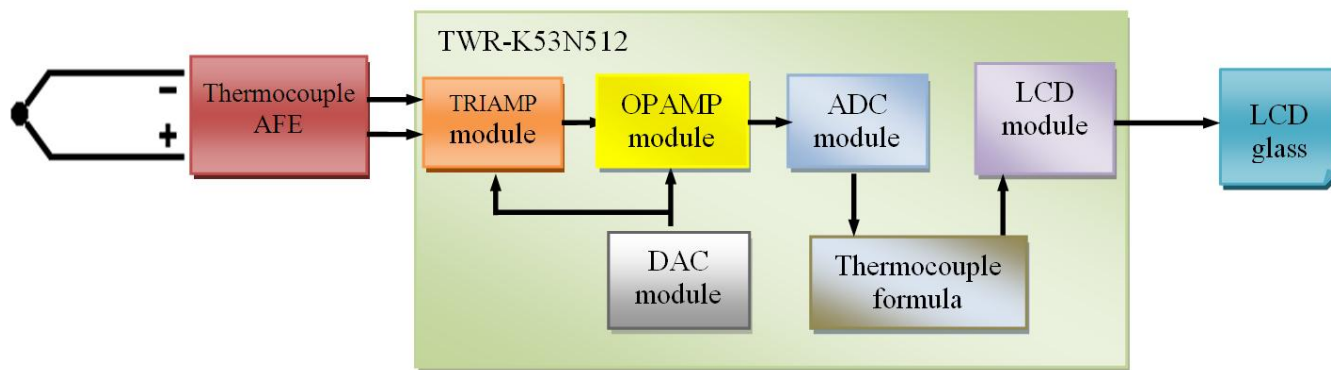
## 1 Introduction

This application note provides guidelines on Kinetis K53 family for using the internal Operational Amplifiers (OPAMP), Transimpedance Amplifiers (TRIAMP), and the Analog-to-Digital Converter (ADC) modules to measure the temperature through a thermocouple and a thermistor and the result is shown on a LCD display using the LCD Controller (LCD) module. All these modules are available on the K53 MCU.

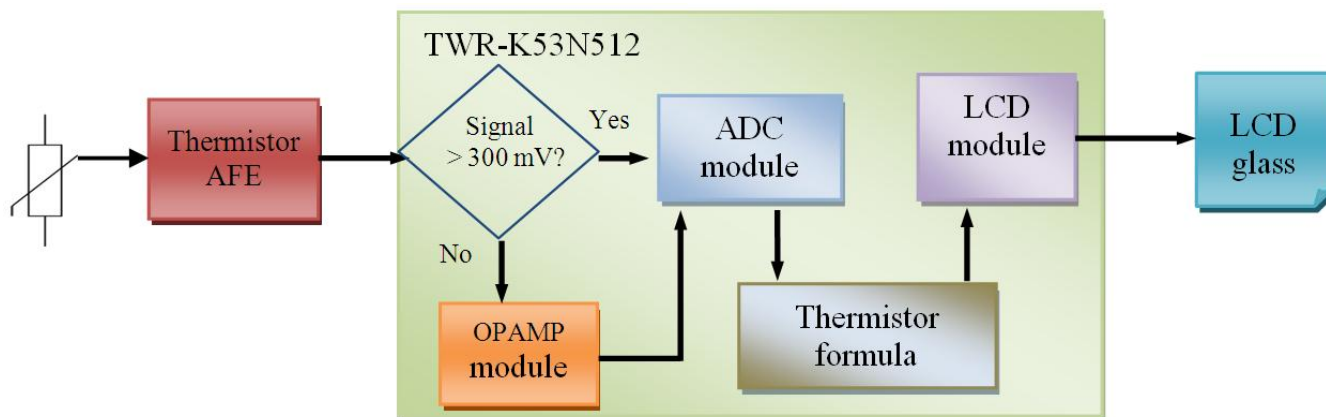
The application uses different OPAMP configurations, such as internal gain and external gain using external resistor. TWR-K53N512 board was used as base hardware for performing this application.

Figure 1 shows the thermocouple's application block diagram, while Figure 2 shows thermistor's application block diagram.

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**Figure 1. General block diagram of thermocouple**



**Figure 2. General block diagram of thermistor**

This document is intended to be used by engineers, industrial control development engineers, or any person related with temperature monitoring. However, it is necessary to know the fundamentals of electronic analog and digital circuits.

This application note includes a video that demonstrates Kinetis K53 MCUs for instrumenting thermistor and thermocouple devices, watch the video by clicking on the link <http://www.youtube.com/watch?v=5vNuPG0crO8>.

## 2 Background

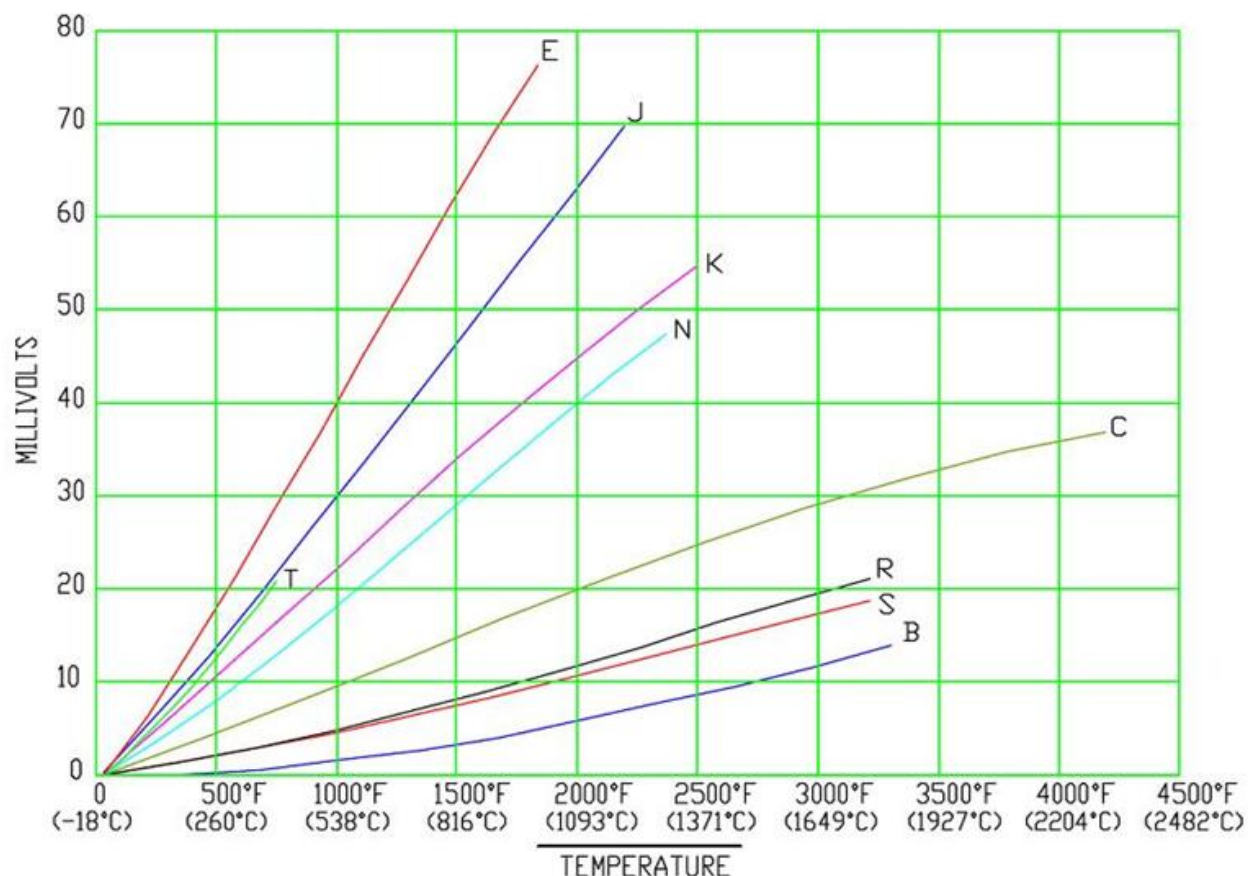
This section provides some fundamentals about thermocouple and thermistor devices, which will help to understand how the application has been developed.

### 2.1 Thermocouple

A thermocouple consists of two different conductors that produce a small voltage which is proportional to a temperature difference between either ends of the conductor pair. Thermocouples are a widely used type of temperature sensor for measurement and control and can also be used to convert a heat gradient into electricity. Thermocouples are self-powered and do not require external form of excitation. The main limitation is accuracy and system errors of less than one degree Celsius (C) can be difficult to achieve.

Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Practical instruments use electronic methods of cold-junction compensation to adjust for varying temperature at the instrument terminals. Electronic instruments can also compensate for the varying characteristics of the thermocouple, and so improve the precision and accuracy of measurements.

Certain combinations of alloys have different cost, availability, convenience, melting point, chemical properties, stability, and output. Different types are best suited for different applications. They are usually selected considering the temperature range and sensitivity needed. Thermocouples with low sensitivities (B, R, and S types) have correspondingly lower resolutions. Figure 3 shows a chart of the temperature/millivolts for the different types of thermocouples.



**Figure 3. Typical values for different types of thermocouples<sup>1</sup>**

## 2.2 Thermistor

A thermistor is a type of resistor whose resistance varies significantly with temperature, more so than in standard resistors. They are widely used as inrush current limiters, temperature sensors, self-resetting over-current protectors, and self-regulating heating elements.

There are two types of thermistor:

- If the resistance increases with increasing temperature then the device is called a positive temperature coefficient (PTC) thermistor or posistor.
- If the resistance decreases with increasing temperature then the device is called a negative temperature coefficient (NTC) thermistor.

1. <http://deltacnt.com/index.htm>

Figure 4 shows Resistance –Temperature Characteristics (Typical) of different types of thermistor.

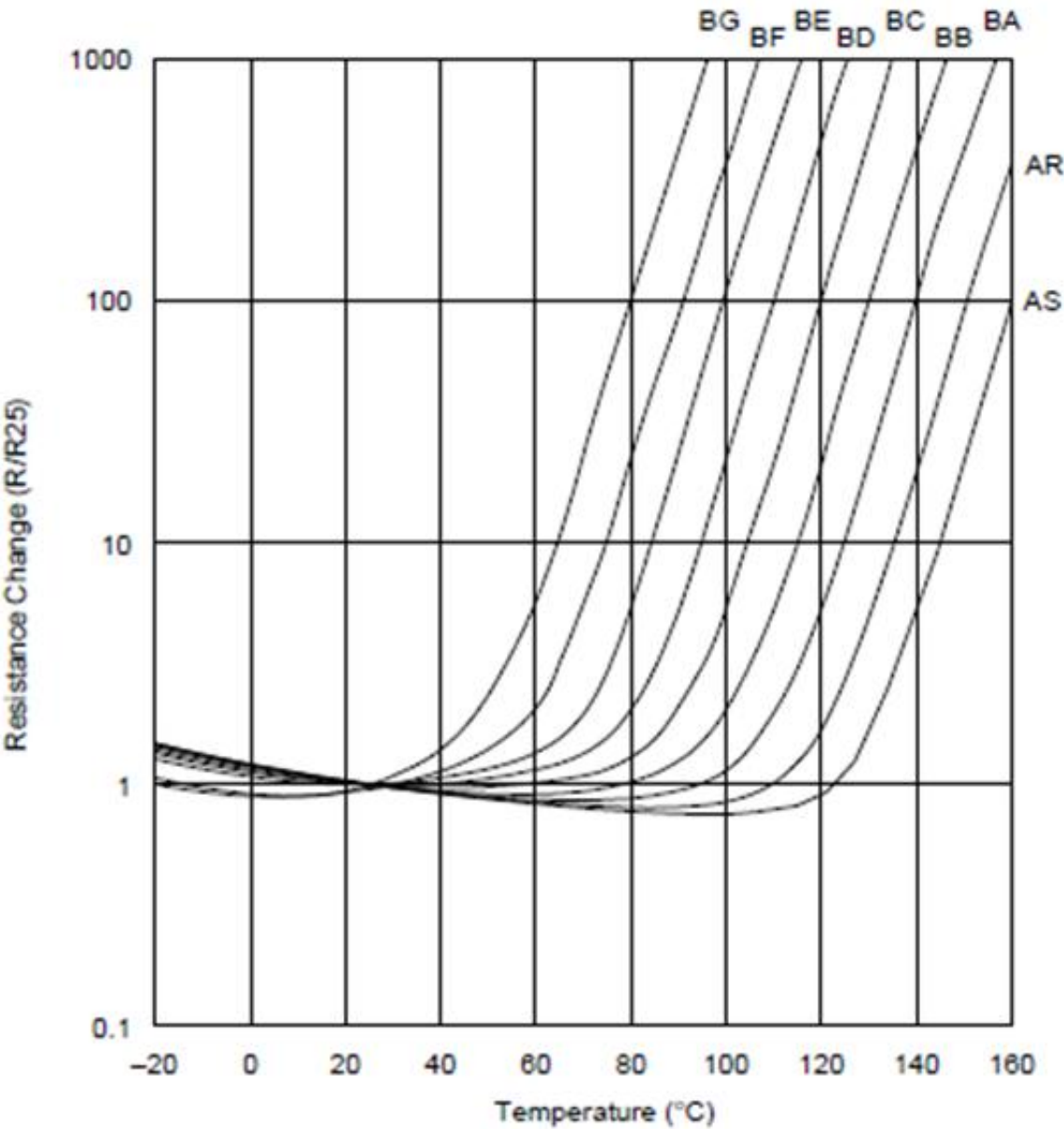


Figure 4. Thermistor typical charts2

### 3 OPAMP module configuration

This section explains different pin configurations that can support the K53 MCU for the OPAMP module.

2. Murata PTC Thermistors "POSISTOR®" Data sheet. [www.murata.com](http://www.murata.com)

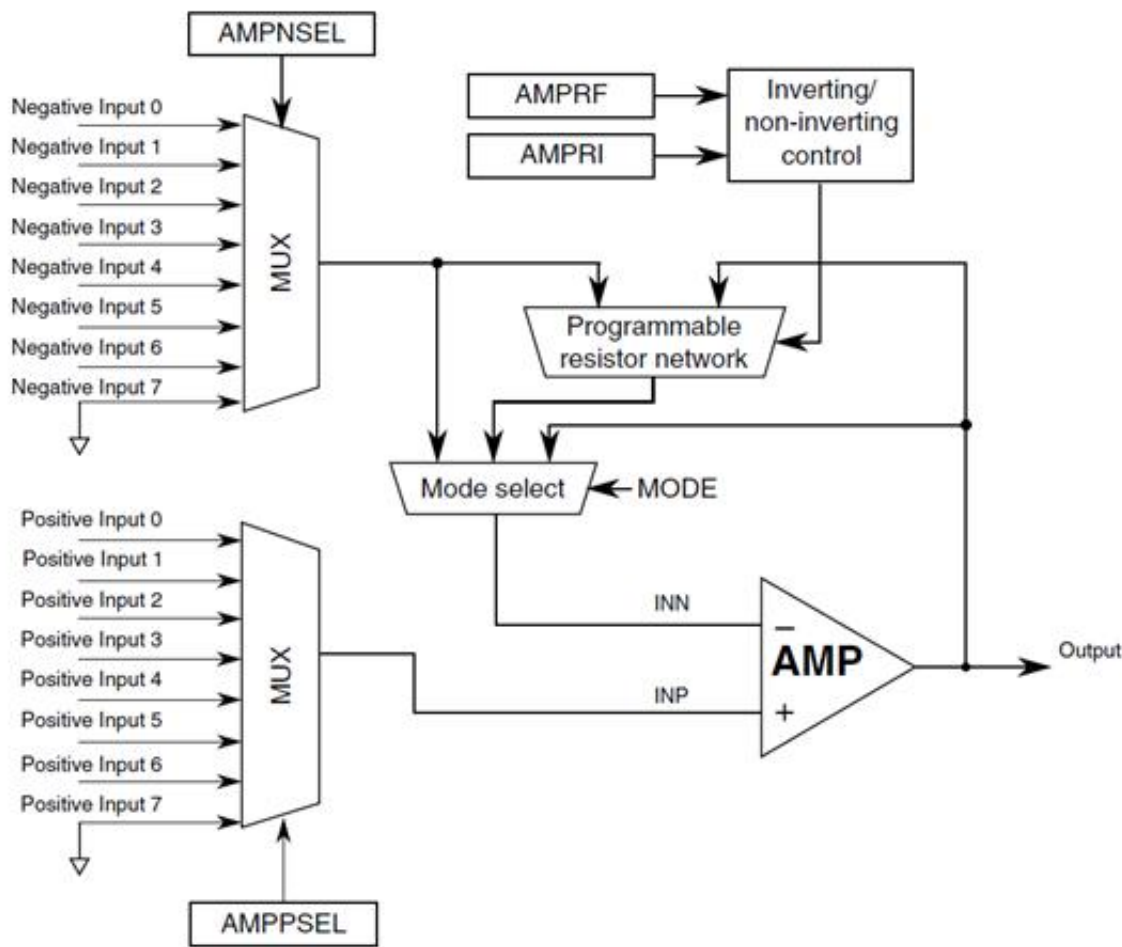


Figure 5. OPAMP configurations

### 3.1 OPAMP description

This device contains two OPAMP modules: OPAMP 0 and OPAMP 1.

### 3.2 OPAMP 0 input mux connections

The OPAMP 0 module contains multiplexers for selecting positive and negative inputs. The inputs to these muxes are defined on [Table 1](#) and [Table 2](#) :

Table 1. OPAMP0 minus input mux

| OPAMP 0 minus input number | Signal connection              |
|----------------------------|--------------------------------|
| 0                          | OP0_DM0 input signal (default) |
| 1                          | Reserved                       |

Table continues on the next page...

**Table 1. OPAMP0 minus input mux (continued)**

| OPAMP 0 minus input number | Signal connection         |
|----------------------------|---------------------------|
| 2                          | OPAMP 1 output            |
| 3                          | CMP0 6-bit DAC output     |
| 4                          | <b>12-bit DAC0 output</b> |
| 5                          | 12-bit DAC1 output        |
| 6                          | VDD                       |
| 7                          | Ground                    |

**Table 2. OPAMP0 plus input mux**

| OPAMP 0 plus input number | Signal connection           |
|---------------------------|-----------------------------|
| 0                         | <i>OP0_DP0 input signal</i> |
| 1                         | OPAMP 0 output              |
| 2                         | OPAMP 1 output              |
| 3                         | CMP0 6-bit DAC output       |
| 4                         | 12-bit DAC0 output          |
| 5                         | 12-bit DAC1 output          |
| 6                         | VDD                         |
| 7                         | Ground                      |

### 3.3 OPAMP 1 input mux connections

The OPAMP 1 module contains multiplexers for selecting the positive and negative inputs. The inputs to these muxes are defined on [Table 3](#) and [Table 4](#).

**Table 3. OPAMP1 minus input mux**

| OPAMP 1 minus input number | Signal connection             |
|----------------------------|-------------------------------|
| 0                          | OP1_DM0 input signal          |
| 1                          | OPAMP 0 output                |
| 2                          | OP1_DM1 input signal          |
| 3                          | CMP0 6-bit DAC output         |
| 4                          | 12-bit DAC0 output            |
| 5                          | TRI0_OUT/OP1_DM2 input signal |
| 6                          | VDD                           |
| 7                          | Ground                        |

**Table 4. OPAMP1 plus input mux**

| OPAMP 1 plus input number | Signal connection     |
|---------------------------|-----------------------|
| 0                         | OP1_DP0 input signal  |
| 1                         | OPAMP 0 output        |
| 2                         | OPAMP 1 output        |
| 3                         | CMP0 6-bit DAC output |
| 4                         | 12-bit DAC0 output    |
| 5                         | 12-bit DAC1 output    |
| 6                         | VDD                   |
| 7                         | Ground                |

### 3.4 OPAMP output connections

The outputs of OPAMP modules are optionally available as is specified on [Table 5](#) :

**Table 5. OPAMP0 and OPAMP1 output availability**

| OPAMP number | OPAMP output signal connection |
|--------------|--------------------------------|
| 0            | CMP1 input                     |
| 0            | ADC0 channel                   |
| 0            | OP0_OUT output signal          |
| 1            | CMP2 input                     |
| 1            | ADC0 channel                   |
| 1            | OP1_OUT output signal          |

### 3.5 OPAMP registers

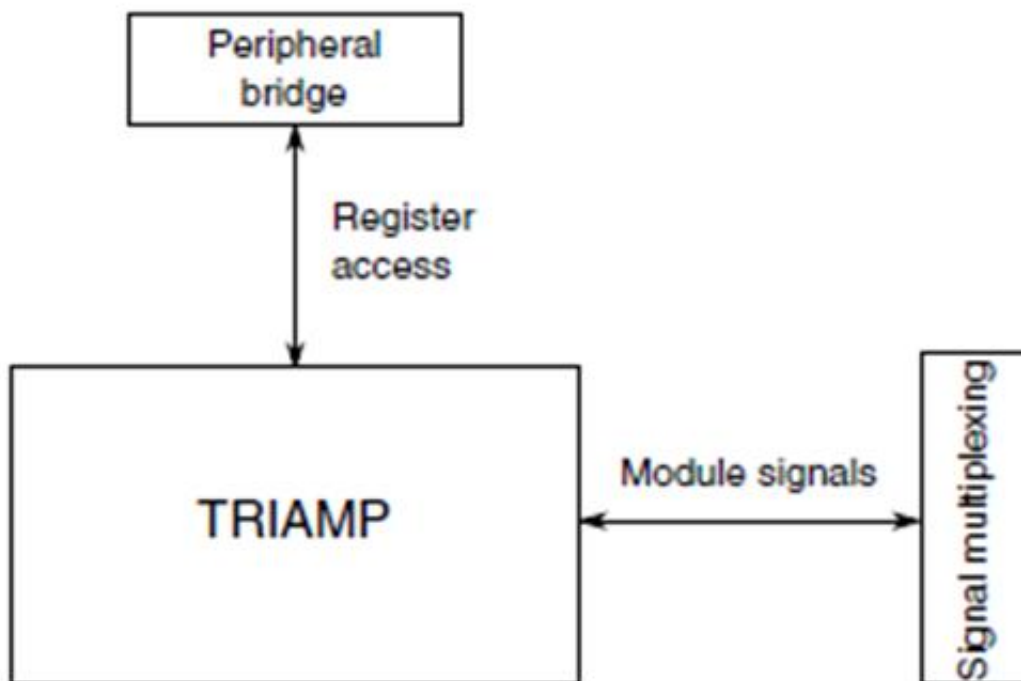
The OPAMP registers on the K53 are Control Register 0 (OPAMPx\_C0), Control Register 1 (OPAMPx\_C1), and Control Register 2 (OPAMPx\_C2).

- The Control Register 0 (OPAMPx\_C0) is used for enabling the amplifier and configuring its operating mode, and setting high-speed or low-power modes.
- The Control Register 1 (OPAMPx\_C1) is used to set the gain of the OPAMP.
- The Control Register 2 (OPAMPx\_C2) is used to set positive and negative input terminals.

This configuration is shown on the Amplifiers.c file of this application.

## 4 TRIAMP module configuration

This section explains the different pin configurations that TRIAMP modules of K53 support.



**Figure 6. OPAMP configurations**

## 4.1 TRIAMP signals

Details regarding the TRIAMP signals used on this device are as follows:

- The TRIAMP inputs, `TRIx_DM` and `TRIx_DP`, are dedicated low-leakage input pads.
- The TRIAMP0 output is driven to external pin, `TRIO_OUT`, and is shared with the `OP1_DM2` analog input.
- The TRIAMP1 output is driven to external pin, `TRI1_OUT`, and is shared with the ADC1's `AD22` and CMP2's `IN5` inputs.

## 4.2 TRIAMP register

TRIAMP modules have just one related register. The Control Register 0 (`TRIAMPx_C0`) is used to enable the TRIAMP module and set it on high-speed mode or low-power mode.

# 5 Developing the application

This section describes the hardware and software configuration to handle the signal from the thermocouple and the thermistor to get an appropriate signal to be processed by the MCU using the TWR-K53N512's medical connector.



# 5.1 Medical connector signal description

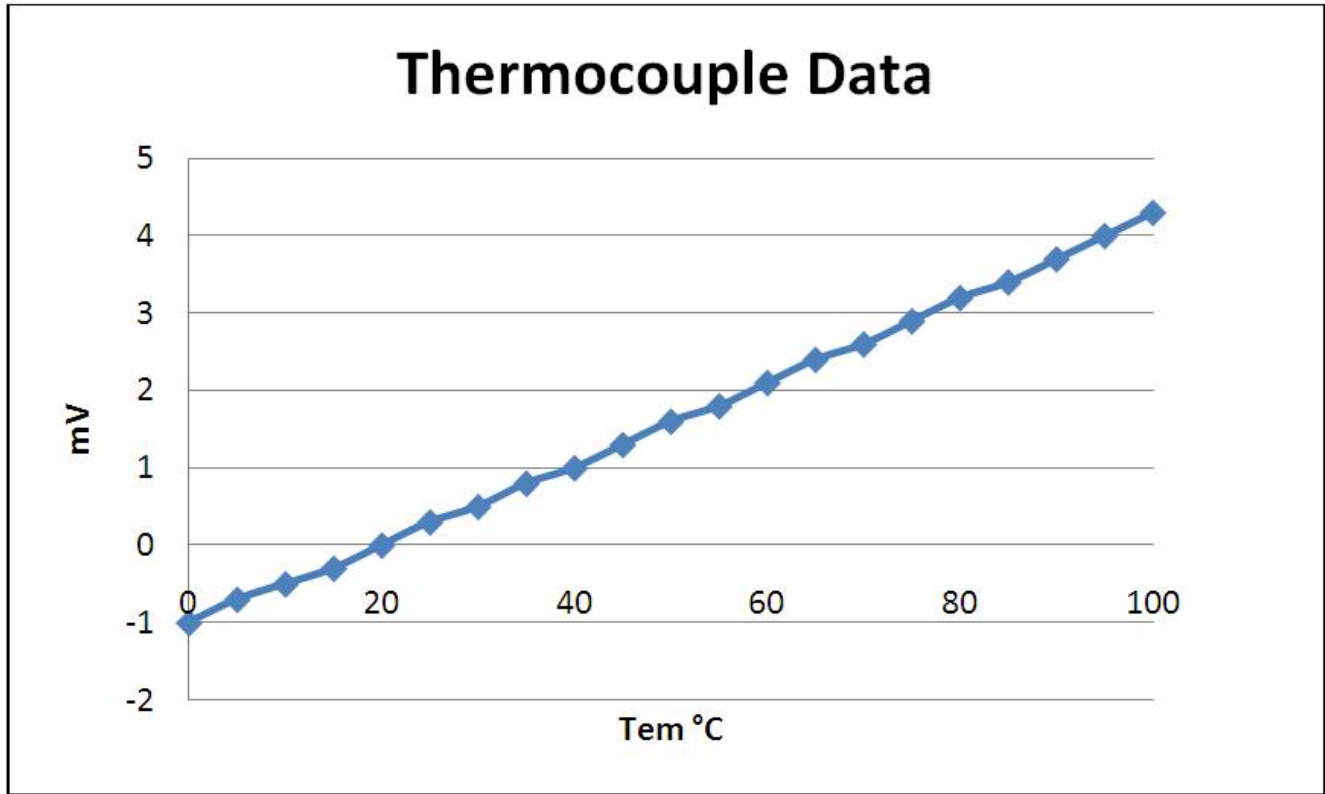
Header J19 (2x10 pins) of TWR-K53N512 is the medical connector. It allows the use of internal OPAMPs, TRIAMPs, ADC, and DAC. [Table 6](#) shows the signals present in each pin of medical connector.

**Table 6. Medical connector signals**

| Medical connector signal | Pin |    | Medical connector signal |
|--------------------------|-----|----|--------------------------|
| VDD(3.3V)                | 1   | 2  | GND                      |
| IIC1_SDA                 | 3   | 4  | IIC_SCL                  |
| ADC0_DPO                 | 5   | 6  | ADC0_DM0                 |
| ADC1_DPO                 | 7   | 8  | DAC0_OUT                 |
| OP0_OUT                  | 9   | 10 | OP1_OUT                  |
| OP0_DM0                  | 11  | 12 | OP1_DM0                  |
| OP0_DP0                  | 13  | 14 | OP1_DP0                  |
| TRI0_DP                  | 15  | 16 | TRI1_DP                  |
| TRI0_DM                  | 17  | 18 | TRI1_DM                  |
| TRI0_OUT                 | 19  | 20 | TRI1_OUT                 |

# 5.2 Thermocouple signal configuration

For this application note, thermocouple J has been used. Data in millivolts (mV) on different known temperatures are found, which are shown in [Figure 7](#).



**Figure 7. Thermocouple chart**

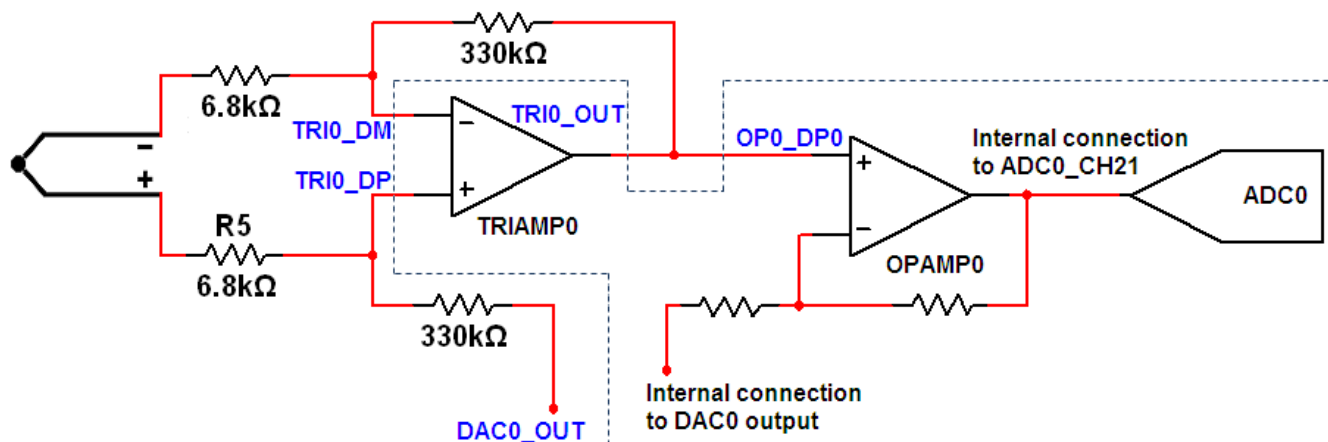
The thermocouple has a linear function. In order to amplify this signal and condition it for being handled by the application, the TRIAMP0 is used as differential amplifier using external resistors, and then, the signal goes through a no-invert amplifier using the OPAMP0 with internal gain. Besides, a 1.0 V offset signal is used as reference in order to handle negative inputs.

**NOTE**

Measurements may vary according to the thermocouple and the connection used.

### 5.2.1 Thermocouple circuit

Figure 8 shows the circuit used for the application. The 6.8 K $\Omega$  and the 330 K $\Omega$  resistors are external. Names in blue indicate connections to medical connector pins. Components inside dashed line indicate internal modules/connections of K53 device.



**Figure 8. Thermocouple connection schematics**

The reference voltage used on the TRIAMP0 is connected from DAC0\_OUT (pin 8) of the medical connector through 330 KΩ resistor to TRI0\_DM (pin 17). With this configuration there is a gain of about 48.53.

The TRI0\_OUT (pin19) is connected to OP0\_DP0. The OP0 is set with an internal gain of 10, and the DAC0\_OUT as offset, internally connected to OP0\_DM0. Please see [OPAMP 1 input mux connections](#) for further details.

The OP0\_OUT is set to be internally connected to ADC0 channel 21. Please see [OPAMP output connections](#) for further details.

Using linear regression with the data from [Thermocouple signal configuration](#) the thermocouple formula is obtained. Applying this formula, the temperature value is obtained, which is shown on the TWRPI-SLCD expansion board.

## 5.2.2 Thermocouple initialization code

As is shown on [Figure 8](#), thermocouple application requires using one transimpedance amplifier and one operational amplifier with internal gain. The function which performs the initialization of amplifiers is the following:

```
void vfnThermocouple_init(void)
{
    TRIAMP0_HighMode();
    opamp0_noninverting_mode(Gain10);
}
```

The operational amplifier is configured for applying internal gain; however, as the non-inverting input is provided from the transimpedance amplifier output, the signal should be feed from the external pin (AMPPSEL=0). In addition, in order to connect the DAC output to the inverting input, AMPNSEL should equal to four. These configurations are mentioned on [Table 1](#) and [Table 2](#) of this document. The function that performs it is shown below (included in file “Amplifiers.c”):

```
void opamp0_noninverting_mode(unsigned char gain)
{
    ENABLE_OPAMPS;
    OPAMP0_C1 = gain; //Set Gain
    OPAMP0_C2 = (OPAMP_C2_AMPPSEL(0) | OPAMP_C2_AMPNSEL(4));
    // Positive input INP0+ ; Negative Input DAC0 output
    OPAMP0_C0 = (OPAMP_C0_EN_MASK | OPAMP_C0_MODE(3));
    //Non-Inverting PGA; OPAMP Enabled
}
```

### 5.3 Thermistor signal configuration

For this application note, a thermistor Murata PTGL18BD series is used and data in Ohms ( $\Omega$ ) in different known temperatures are obtained which are shown in [Figure 9](#).

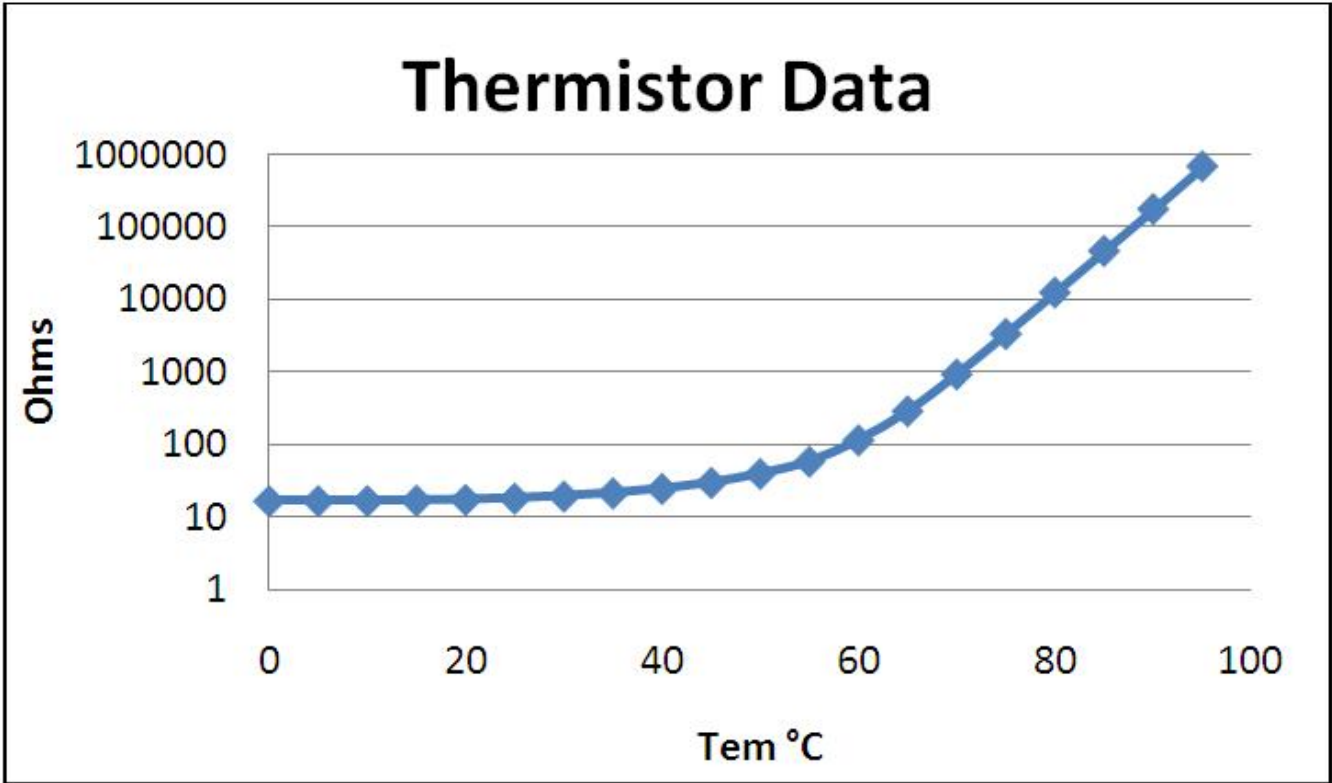
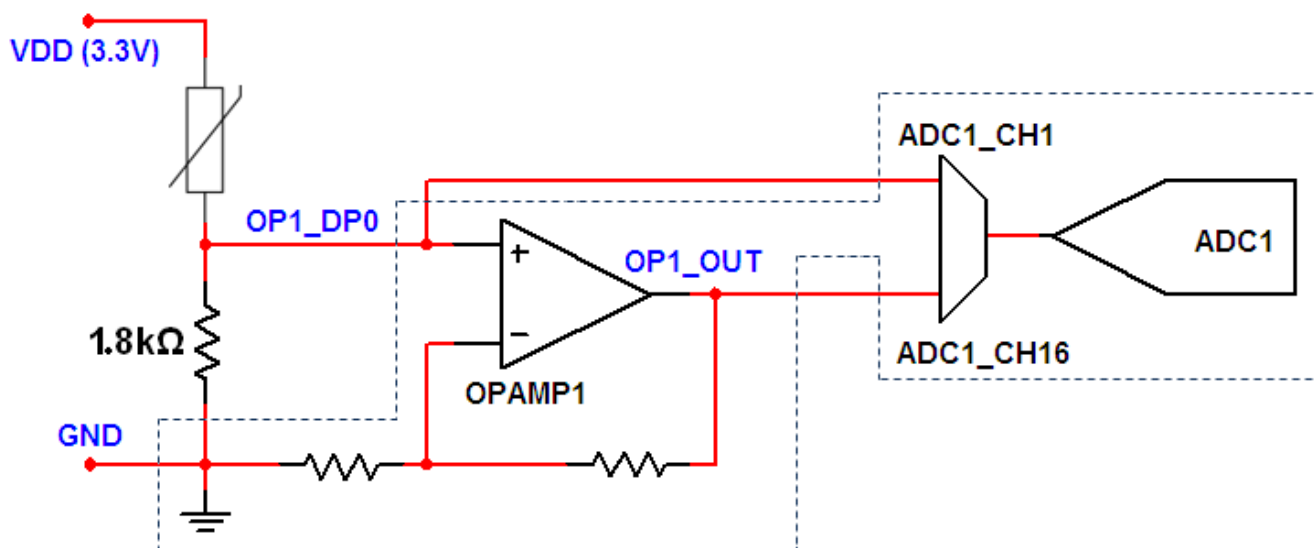


Figure 9. Thermistor chart

#### 5.3.1 Thermistor circuit

[Figure 10](#) shows the circuit used for the application. Names in blue indicate connections to medical connector pins. Components inside dashed line indicate internal modules/connections of K53 device.

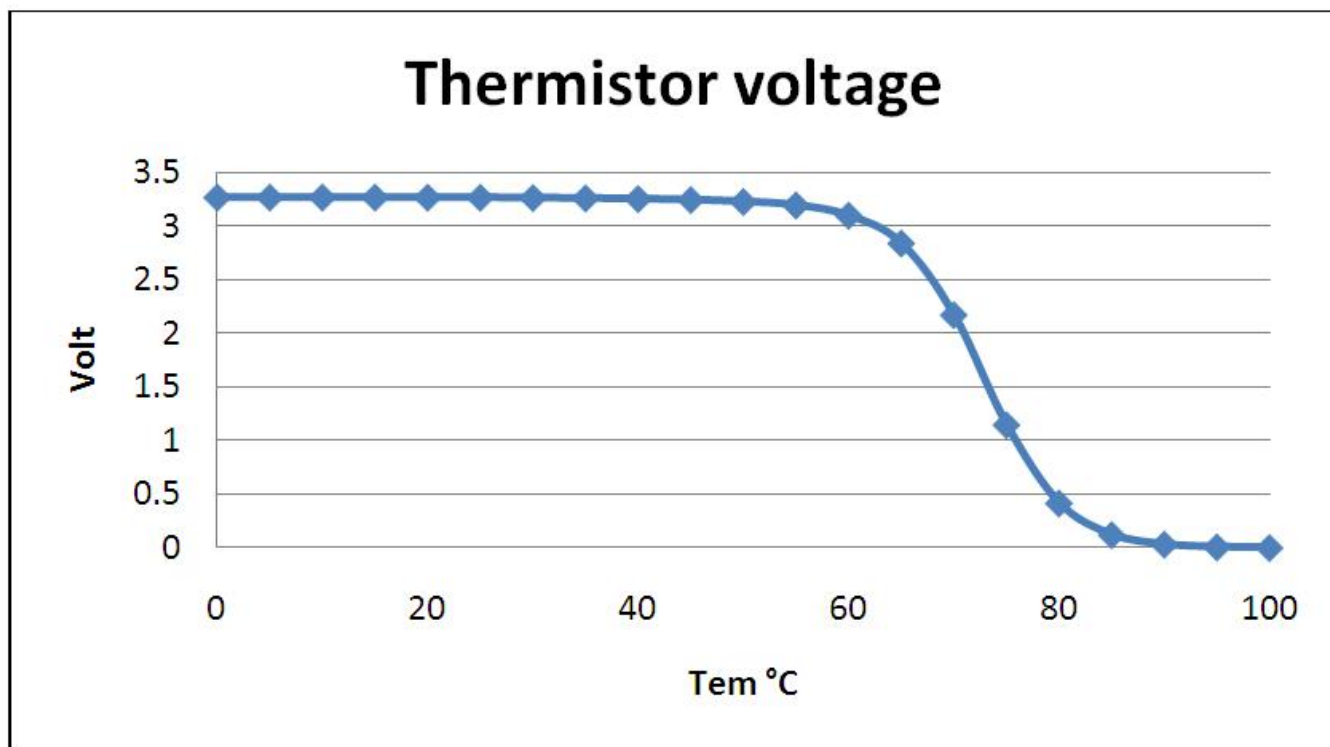


**Figure 10. Thermistor connection schematics**

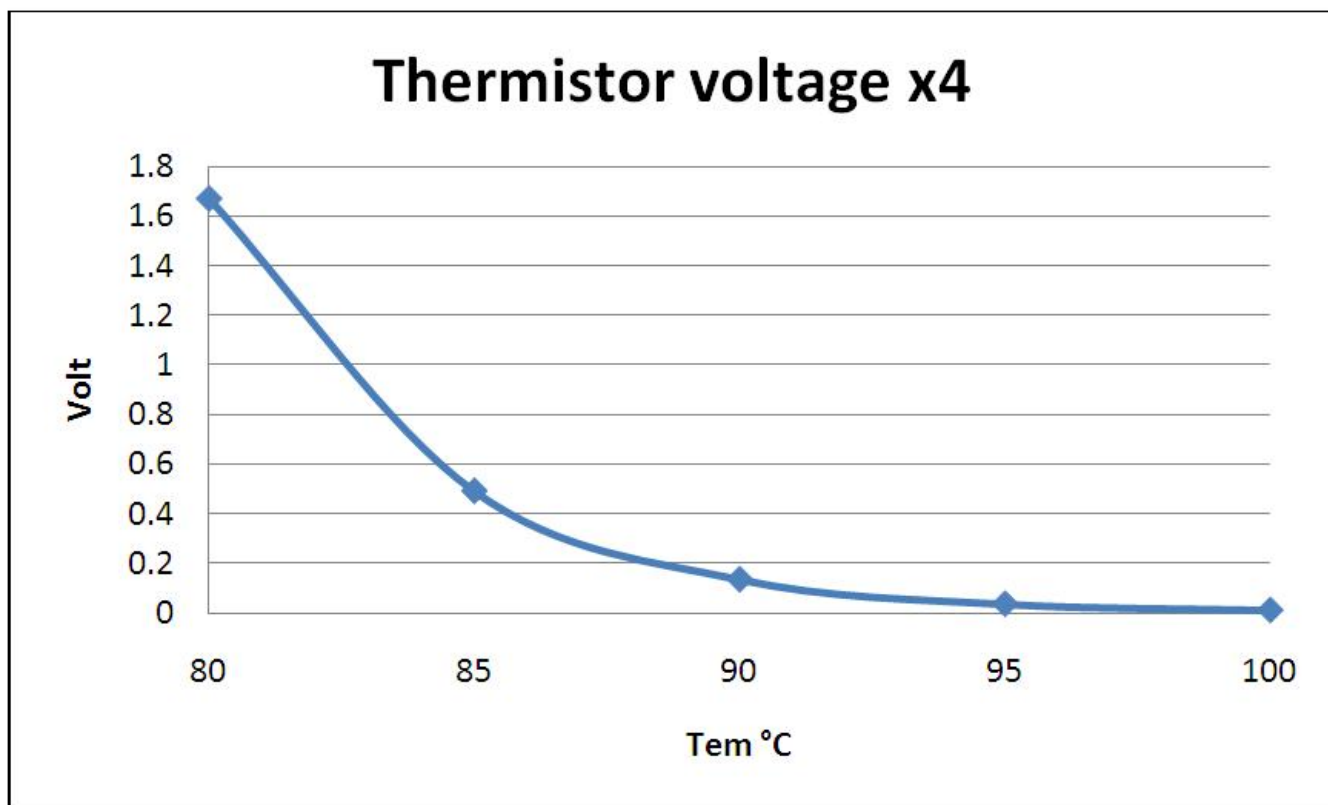
A thermistor's pin is connected to pin 1 of medical connector. In order for the pin 1 to be VDD, it is necessary to put the PTC14 as GPIO output low enable. The other pin is connected to OP1\_DP0 (pin 14).

Voltage on OP1\_DP0 (pin 14) changes when voltage in the thermistor vary. When the value of the thermistor is too high (MΩ) and the voltage on OP1\_DP0 is less than 300 mV, the voltage goes through the OP1 to be amplified using the internal resistor. If the thermistor value is low, that is greater than KΩ, and the voltage on OP1\_DP0 is more than 300 mV, it is not necessary to amplify the signal and is sent directly to the ADC1.

Figure 11 shows the voltage on OP1\_DP0 without any amplification and Figure 12 shows the voltage with a gain of 4. This gain is applied only if the voltage is less than 300 mV.



**Figure 11. Voltage without gain**



**Figure 12. Voltage with gain**

Those voltages with and without gain go to ADC1 on channels 1 and 16. As the thermistor is not a linear function, so to process the result of the ADC1 conversion it is necessary to split the data in a 10° range to generate the appropriate thermistor formula.

Because the values of the thermistor below 30 °C are too small (18 Ω) and to simplify the program, if the temperature is less than 30 °C the LCD will show 30°. On the range of 30 °C to 85 °C different thermistor formulas have to be used to get the temperature value.

### 5.3.2 Thermistor initialization code

As the thermistor varies its resistance depending on the temperature, a series circuit is required, allowing a variable voltage drop on the thermistor. In addition, thermistor has exponential transfer function; the voltage may drop slowly or rapidly. This is the reason why the thermistor's AFE includes a direct connection or an amplification, as shown in [Figure 10](#).

The function that performs the initialization of amplifier and enables the voltage on Medical Connector, which is required for series circuit, is the following:

```
void vfnThermistor_init(void)
{
    SIM_SCGC5 |= SIM_SCGC5_PORTC_MASK;    // Enable PORT C clock
    PORTC_PCR14 = 0;
    PORTC_PCR14 |= PORT_PCR_MUX(1);        //PTC14 as GPIO
    GPIOC_PDDR |= (1<<14);                //PTC14 as output
    //PTC14 as OUTPUT to enable voltage on medical connector
    GPIOC_PCOR |= (1<<14);                //Active Low enable
    opamp1_noninverting_mode(Gain4);
}
```

The operational amplifier is configured for applying internal gain; the noninverting input signal should be fed from the external pin (AMPPSEL=0), and inverting input should be connected to ground (AMPNSEL=7). These configurations are mentioned on [Table 3](#) and [Table 4](#). The function that performs this is shown below, which is included on file “Amplifiers.c”:

```
void opamp1_noninverting_mode(unsigned char gain)
{
    ENABLE_OPAMPS;
    OPAMP1_C1 = gain;           //Set Gain
    OPAMP1_C2 = (OPAMP_C2_AMPPSEL(0) | OPAMP_C2_AMPNSEL(7));
    // Positive input INP1+ ; Negative Input GND
    OPAMP1_C0 = (OPAMP_C0_EN_MASK | OPAMP_C0_MODE(3));
    // Non-Inverting PGA; OPAMP Enabled
}
```

## 6 Running the application

This section includes the required material, jumper settings, hardware assembly, code download, and application execution.

### 6.1 Required material

For this application, the following material is required:

- TWR-K53N512 MCU board.
- TWRPI-SLCD board.
- One USB cable A-miniB.
- PC or Laptop with CodeWarrior v10.2.
- One custom board that includes external resistors and connections required by thermistor and thermocouple in order to connect them to Medical Connector.
- One thermistor and one thermocouple.

### 6.2 Jumper settings

For correct functionality of the application, the following jumper settings must be applied, taking as reference the default jumpers settings of TWR-K53N512 board:

|     |                             |
|-----|-----------------------------|
| J1  | open                        |
| J32 | changed to position 2 and 3 |
| J33 | changed to position 2 and 3 |

### 6.3 Hardware assembly

The following steps should be followed to assemble the hardware after making sure that the jumper configuration was properly applied:

- Connect the TWRPI-SLCD board on connector J8 of TWR-K53N512 board.
- Connect the custom board to Medical Connector of TWR-K53N512 board (J19), ensuring the correct orientation.
- Connect the USB cable to TWR-K53N512 board, which is the Open Source JTAG, and to a USB port of the computer.

An example of the hardware already assembled is shown in [Figure 13](#).



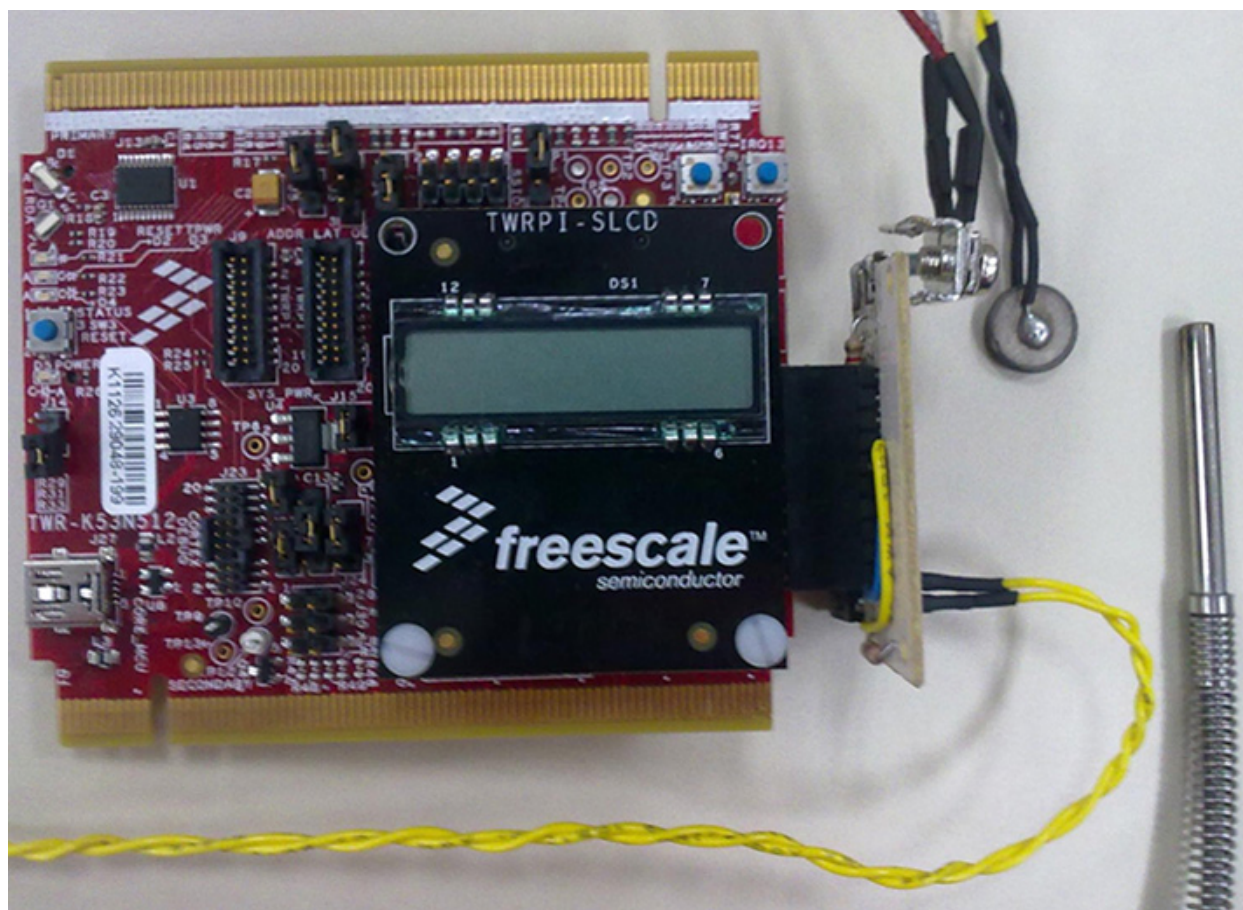


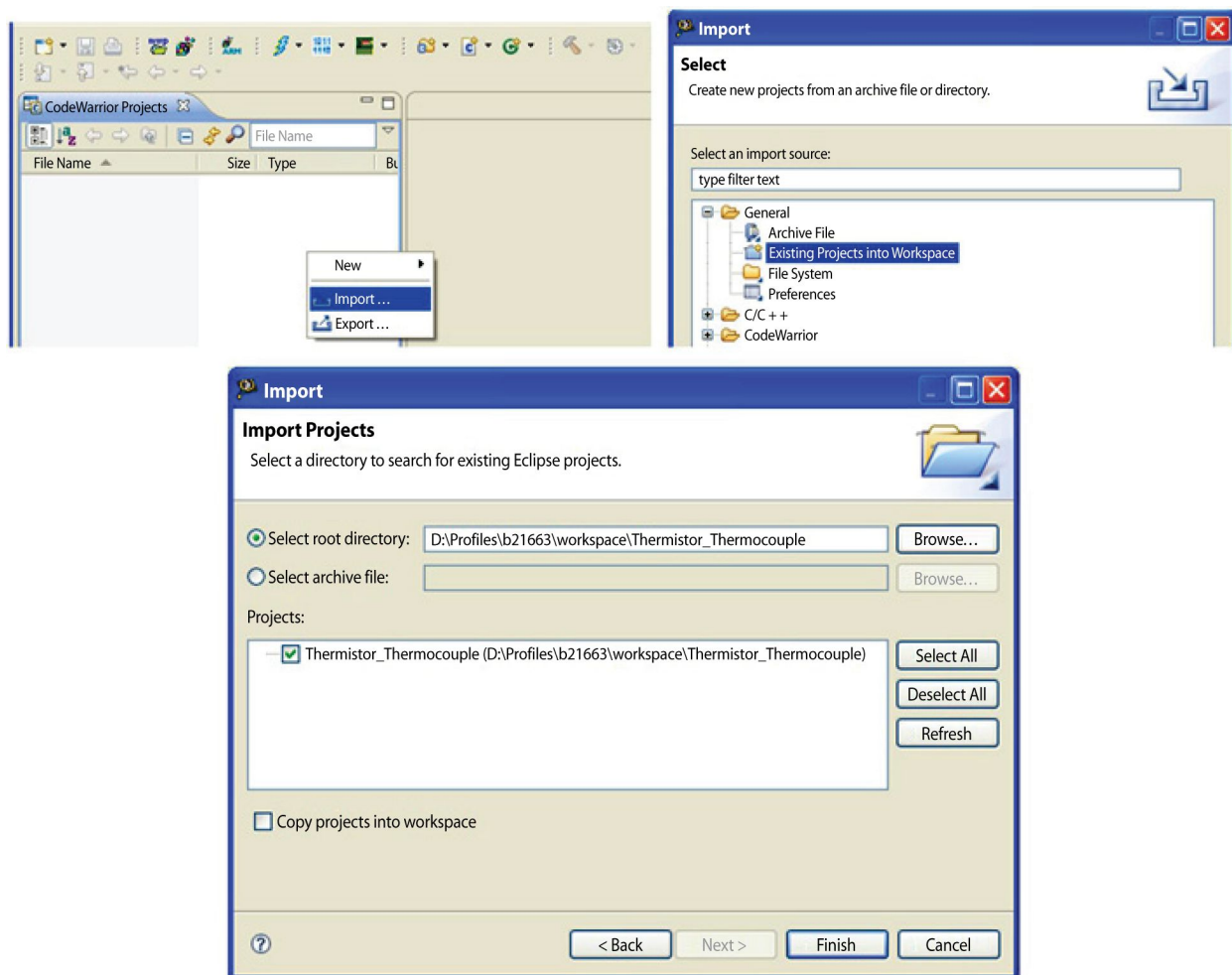
Figure 13. Assembled hardware

## 6.4 Code download

To download the code to devices, follow the steps given below:

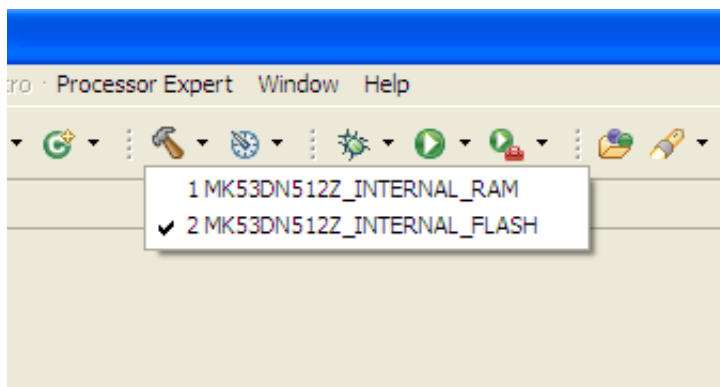
- Open CodeWarrior for Microcontrollers v10.2.
- Import the project “Thermistor\_Thermocouple”.





**Figure 14. CodeWarrior project importer**

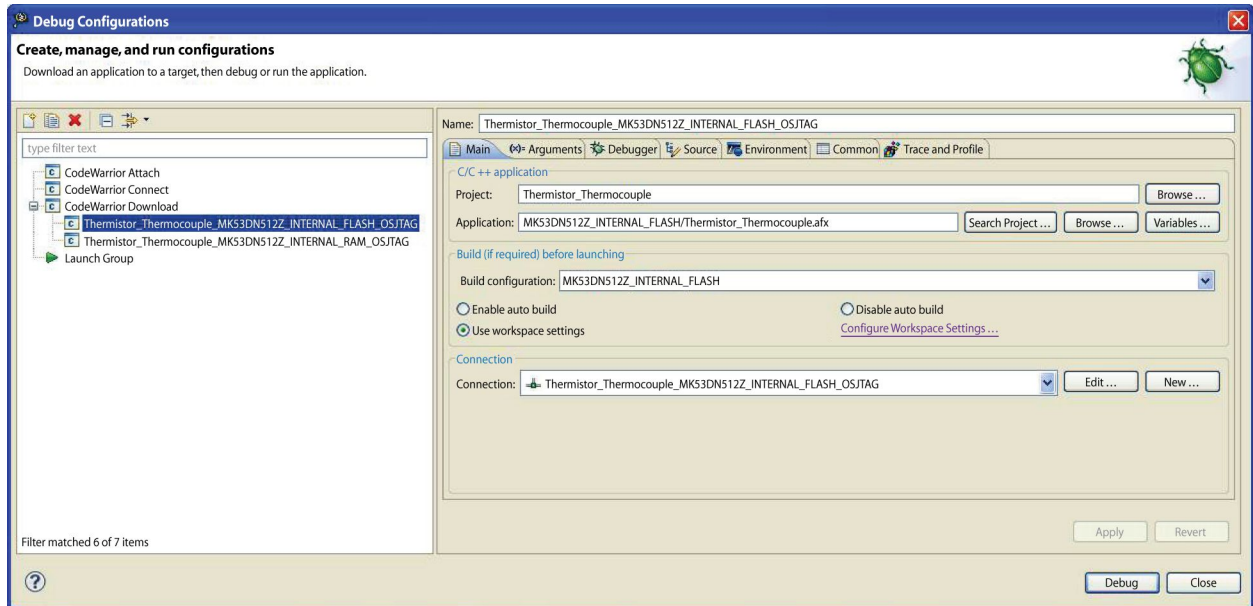
- Once the project has been opened, you can select compiling the application for RAM or Flash targets, by clicking on the small triangle next to hammer icon.



**Figure 15. Project's target selection**

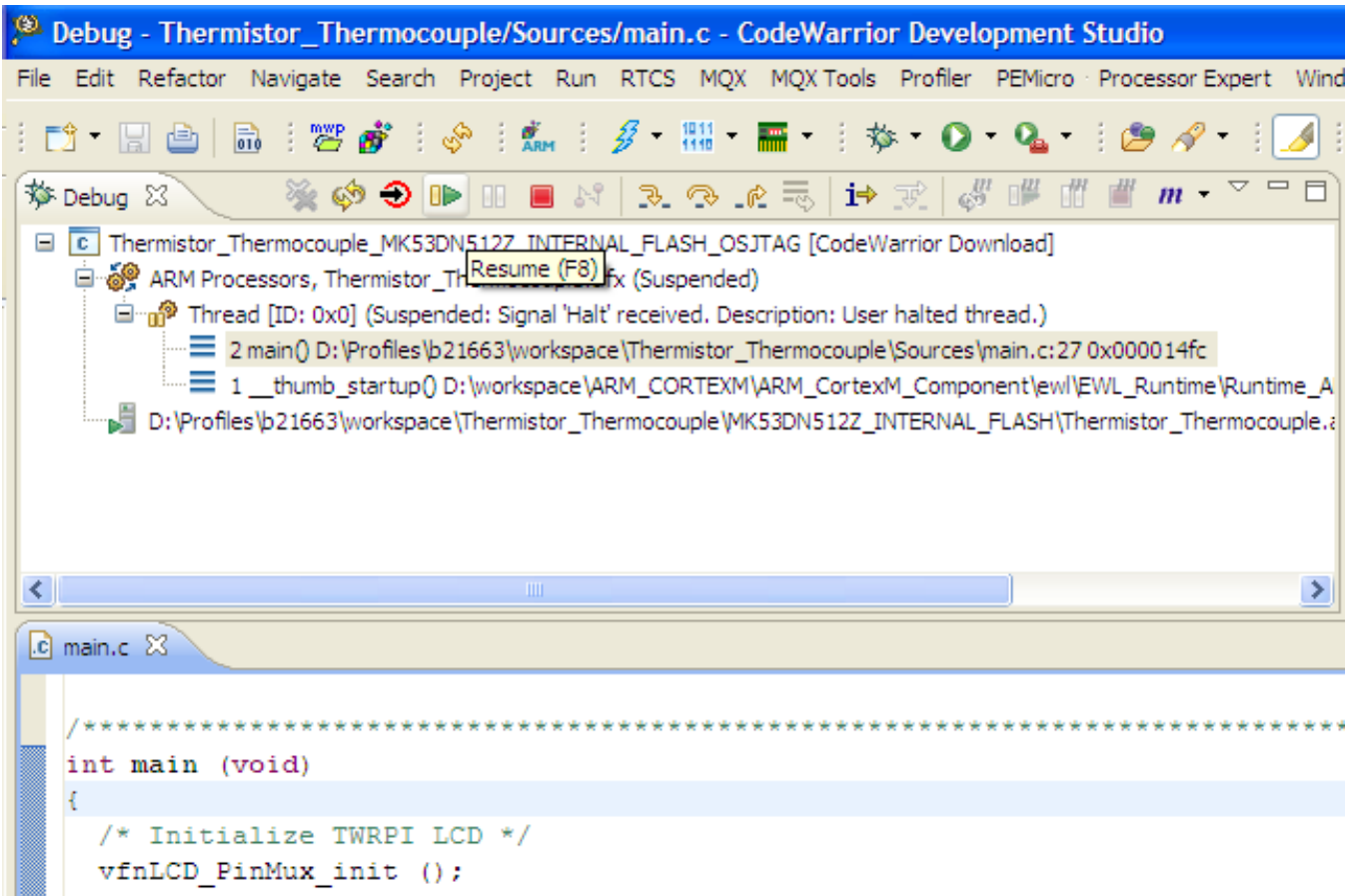
- The same procedure applies for “Debug Configurations” by clicking on the small triangle next to the bug icon. The debug configuration may be selected on the window as shown in [Figure 16](#).

## Running the application



**Figure 16. Debug configurations**

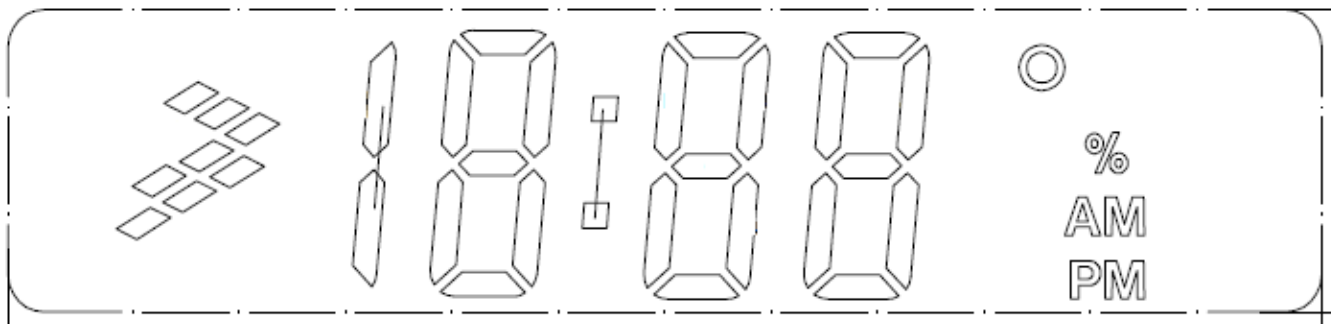
- When the device has been programmed, click on “Resume” button.



**Figure 17. CodeWarrior debug perspective**

## 6.5 Application execution

The TWRPI-SLCD is the main interface of the application. Figure 18 shows the available segments of this LCD crystal.



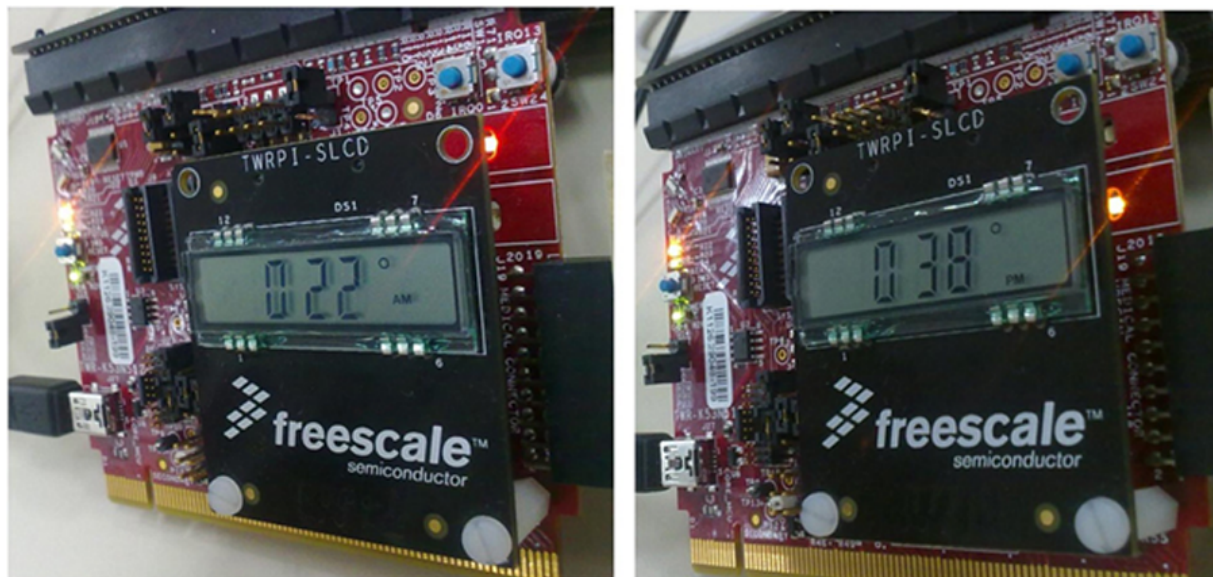
**Figure 18. TWRPI-SLCD segments**

Once the application is running, the TWRPI-SLCD will show the temperature value using the numeric segments and degrees segment. In addition, the other segments are used as indicators as follows:

- Freescale logo segment indicates that the selected thermal device is measuring the lowest possible value.
- Percentage segment indicates that the selected thermal device is measuring the higher possible value.
- AM segment indicates that the current thermal device selected is the Thermocouple.
- PM segment indicates that the current thermal device selected is the Thermistor.

Besides, LEDs D6 and D7 also indicate which thermal device is being measured. D6 will turn on when Thermocouple is being measured, while D7 will turn on when Thermistor is being measured.

Switch SW2 is used to change which thermal device is being measured. The default thermal device that will be shown on the TWRPI-SLCD will be the Thermocouple. Figure 19 shows, at the left side, the application measuring the Thermocouple, while on the right, it is measuring the Thermistor.



**Figure 19. Application execution measuring both thermal devices**

The provided code includes a macro for configuring the amount of samples that the ADC will take to perform on an average. It is included at the beginning of “Thermodevices.h” file, as is shown below:

## Conclusions and references

```
/*  
*****  
#define AVERAGE_QUANTITY 32
```

# 7 Conclusions and references

This application note showed the capabilities of K53's integrated amplifiers for instrumenting thermal devices. Besides, it provides drivers for several Kinetis modules such as ADCs, DACs, OPAMPs, TRIAMPs, LCD, and IRQ.

Software for this application note, AN4508SW, was developed on CodeWarrior v10.2 and can be found in <http://www.freescale.com>.

If you want to learn more about Kinetis K50 family devices, please visit Freescale Web site at <http://www.freescale.com>.

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