Electronic Basics #15: Temperature Measurement (Part 1) || NTC, PT100, Wheatstone Bridge

Introduction

Temperature measurement is a crucial aspect of various industrial, medical, and scientific applications. Different sensors, such as **NTC thermistors** and **RTDs (Resistance Temperature Detectors)**, are used for accurate temperature sensing. This note explains how to build a **digital thermometer** using **an RTD (PT100), thermistors, voltage dividers, Wheatstone bridge, and amplifiers**. The final temperature reading is processed and displayed using a **microcontroller**.

NTC Thermistors for Temperature Sensing

What is an NTC Thermistor?

A **Negative Temperature Coefficient (NTC) thermistor** is a **temperature-sensitive resistor** that decreases in resistance as temperature increases. These thermistors are widely used for precise temperature measurements due to their **high sensitivity and rapid response**.

Resistance-Temperature Relationship

The resistance of an NTC thermistor is governed by the **Steinhart-Hart equation**:

T=1A+BlnR+C(lnR)3T

where:

- TT = temperature in Kelvin
- RR = thermistor resistance in ohms
- A,B,CA, B, C = thermistor-specific constants

Since the **resistance vs. temperature graph is nonlinear**, complex calibration or software compensation is needed for accurate temperature readings.

Fig15.1: NTC Thermistor

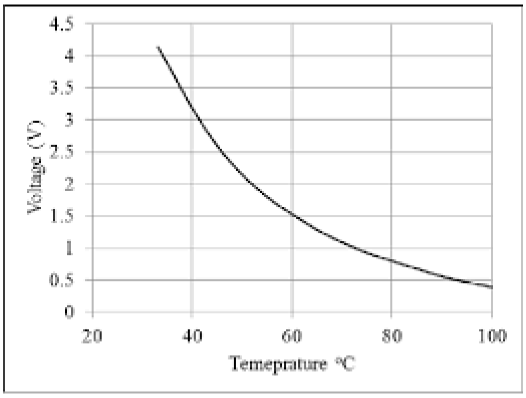

Fig15.2: NTC Characteristic Curve

PT100 and RTD for High-Accuracy Measurement

What is an RTD?

A **Resistance Temperature Detector (RTD)** is a high-precision temperature sensor that **increases resistance as temperature rises**. The **PT100** is a common RTD type with a resistance of **100Ω at 0°C**.

Resistance-Temperature Relationship of PT100

The resistance of a PT100 sensor changes approximately **0.385Ω per °C**, following the equation:

RT=R0(1+αT)R_T

where:

- RTR_T = resistance at temperature TT
- R0=100ΩR_0 = 100\Omega at **0°C**
- α=0.00385Ω/Ω/°C\alpha = 0.00385 \Omega/\Omega/°C (temperature coefficient)

This relationship is **linear over a limited range**, making PT100 more precise than NTC thermistors for industrial use.

PT100 Characteristic Graph

The **resistance vs. temperature curve of PT100 is nearly linear** over a wide range. However, for extreme temperatures, **nonlinearities occur**, which can be corrected using mathematical compensation in software.

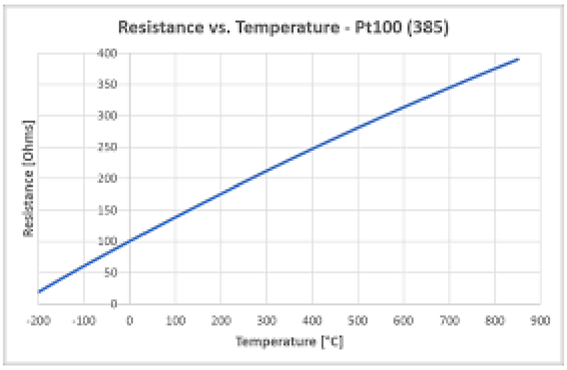

Fig15.3: PT100 Characteristic Curve

Overcoming Measurement Errors

Adding a Low-Constant Current Using LM317

To measure resistance variations accurately, the PT100 must be excited with a **low, constant current source**. The **LM317 adjustable voltage regulator** can be configured as a **constant current source**, ensuring that the PT100's resistance changes only due to temperature variations and not due to fluctuating current.

Offset Voltage at 0°C and Using a Voltage Divider to Solve the Problem

One challenge with PT100 sensors is the **offset voltage** at **0°C** due to the resistance of connecting wires and circuitry. This offset can be reduced using a **voltage divider**, ensuring the reference voltage remains stable for accurate measurement.

Using a Wheatstone Bridge for Accurate Resistance Measurement

A **Wheatstone bridge** circuit is used to precisely measure the **small resistance changes** of the PT100. The bridge consists of:

- Two **fixed resistors**
- One **variable resistor** (for calibration)
- The **PT100 sensor**

The output voltage of the bridge provides an accurate measurement of the **temperature-dependent resistance change**.

Vout=Vin×R2R1+R2−Vin×RTR3+RTV

where RTR_T is the PT100 resistance. When the bridge is balanced, **any deviation in PT100 resistance due to temperature causes a measurable voltage change**.

Signal Conditioning with an Amplifier

The small voltage output from the Wheatstone bridge needs to be **amplified** for processing by a **microcontroller**. An **operational amplifier (op-amp)** is used to boost the signal. A **precision instrumentation amplifier (such as INA333 or LM358)** provides high gain with minimal noise.

Microcontroller-Based Digital Display

Processing the Data with a Microcontroller

A **microcontroller (such as Arduino, ESP32, or PIC)** reads the amplified signal using its **ADC (Analog-to-Digital Converter)**. The ADC converts the analog voltage into a digital value, which is then processed to calculate the temperature.

Code for Temperature Measurement (Arduino Example)

```
const int sensorPin = A0;  // Analog input for PT100

float Vref = 5.0;          // Reference voltage

float R0 = 100.0;          // PT100 resistance at 0°C

float alpha = 0.00385;     // Temperature coefficient

int adcValue;


void setup() {

  Serial.begin(9600);

}


void loop() {

  adcValue = analogRead(sensorPin);

  float Vout = (adcValue / 1023.0) * Vref;

  float Rt = (Vout / (Vref - Vout)) * R0;

  float temperature = (Rt - R0) / (R0 * alpha);


  Serial.print("Temperature: ");

  Serial.print(temperature);

  Serial.println(" °C");


  delay(1000);

}
```

This code:

- Reads the **analog voltage** from PT100
- Converts it to **resistance**
- Calculates **temperature using the PT100 formula**

- Displays the temperature on a **serial monitor**

Applications of Digital Thermometers

- **Industrial Temperature Monitoring** – Used in **boilers, manufacturing, and HVAC systems**.
- **Medical Applications** – Accurate measurement in **body thermometers and incubators**.
- **Food Industry** – Ensures **temperature control in storage and processing**.
- **Weather Monitoring** – Used in **meteorological stations**.
- **Automotive Sensors** – Monitors engine temperature for efficient operation.

A **digital thermometer** can be built using **RTDs (PT100), NTC thermistors, Wheatstone bridge circuits, amplifiers, and microcontrollers**. The **PT100 provides high accuracy**, while **signal conditioning ensures precise readings**. With proper calibration and microcontroller programming, an **accurate and reliable digital thermometer** can be designed for industrial, medical, and general-purpose applications.