Replacement of NTC/PTC thermistors with Digital Temperature sensor Pulse Count Interface

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Table of content

Summary:

This technical report explores the replacement of traditional NTC/PTC thermistors with a modern Digital IC Temperature Sensor featuring a Pulse Count Interface. The report delves into the advantages, functionality, and considerations associated with this transition, highlighting the potential benefits in applications.

Situation:

In servo motor has a temperature sensor which is Negative Temperature Coefficient (NTC) thermistor. For NTC thermistor, it requires linear algorithm, and addition analog-to-digital converter (ADCs) in the system to work. However, after doing research about temperature sensor, emerging digital temperature sensors with pulse count interface present alternative approaches that offers enhance reliability, flexibility and greatly simplifies the design

Component Selecting:

Sensor Requirements:

- Temperature of servo motor range from –10^{o}C to 125^{o}C
- Must be easy to mount & implement inside the device
- Low percentage error
- The sensor has a low self-heating effect.
- The sensor was not supposed to have many pins. This reduces the amount of wire running over long distances. (motor runs at high-voltage and speed)

Characteristic	Thermistor	RTD	Thermocouple	IC sensor
Temperature Range	-100 to +500°C	-250 to +750°C	-200 to >+2000°C	-55 to +200°C
Linearity	Worst	Good	Poor	Best
Accuracy	Calibration Dependent	Best	Good	Good
Sensitivity	Best	Less	Worst	Good
Power Consumption	High	High	Low to High	Lowest
External Circuitry	Simple unless high accuracy/low power needed	Complex	Complex	Simplest
Typical Applications	Low precision, moderate temp range – toasters, hair dryers, protection circuits	High precision, extended temperature – gas and fluid flow	Extreme temperature sensing –ovens, kilns, test equipment	Computers, wearables, data logging, automotive

Figure 1: The characteristics of different types of sensor

Sensor Selection:

After doing temperature research, the most suitable IC temperature sensor for this design is LMT01(datasheet) digital temperature sensor. This is a chip silicon-based sensor (IC sensor). This sensor has very low power consumption. This provides a feature temperature-to-digital signal (without worrying about linearization algorithm, addition ADCs, comparator and so on). LMT01 also offers superior noise immunity. Additionally, the reliability of this product has been verified and applied in the industry.

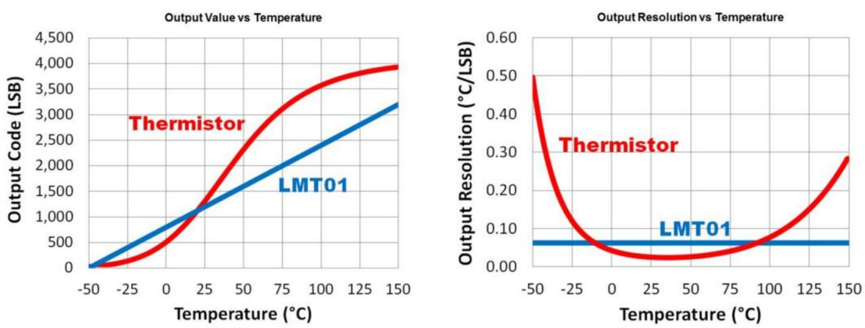


Figure 2: The linear comparison of traditional NTC thermistor and digital IC Temp Sensor

- NTC thermistor requires linear converter system, and ADC converter is the system
- From figure 2, it showcases that LMT01 is almost a linear temperature sensor.
- LMT01's output change in voltage per Celsius
- The output impedance of thermistor NTC is generally higher and varies depending on the temperature. Need to make sure that ADC can handle the impedance of the NTC thermistor
- Due to the LMT01 specification, it requires minimum components; quick example LMT01 don't need the linear converter (including diff op-amp, resistor, capacitor, and ADC converter)

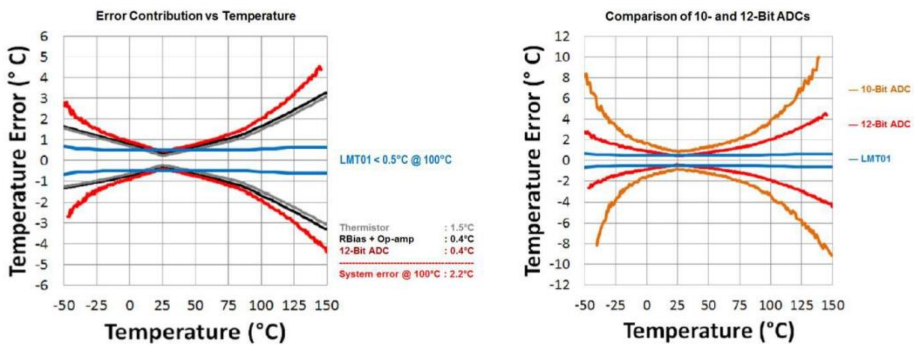


Figure 2: The error comparison of traditional NTC thermistor and digital IC Temp Sensor

- The error of its component must be added to determine the worst-case scenario

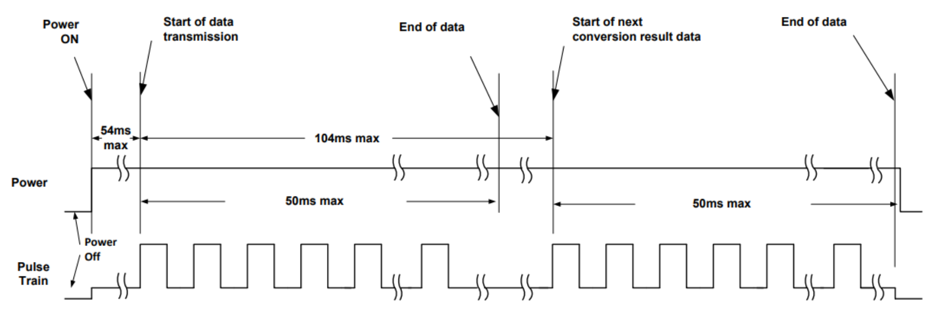
Pulse Count Interface (PCI):

The inclusion of a Pulse Count Interface distinguishes these sensors. This feature allows the sensor to generate pulses based on specific temperature-related events. Applications can range from monitoring rapid temperature changes to counting occurrences of temperature variations.

Advantage with PCI:

- Digital sensors often provide higher precision and accuracy compared to traditional thermistors.
- Seamless integration with microcontrollers and digital systems.
- Pulse count interface facilitates event-based temperature monitoring.
- Supports various digital communication protocols for versatile connectivity.

Sensor Operation and Specification:



- *Figure 3: Digital Pulse Train Timing Cycle*

- The LMT01 temperature output is transmitted over a single wire using a train of current pulses that typically change from 34 µA to 125 µA.

- A simple resistor can then be used to convert the current pulses to a voltage. With a 10-kΩ resistor, the output voltage levels range from 340 mV to 1.25 V, typically.
- A temperature signal can be determined easily by simple algorithms and comparators counting a number of total pulses in a microcontroller or FPGA.
- From figure 3 After power is first applied to the device the current level will remain below 34 µA for at most 54 ms while the LMT01 is determining the temperature.
- When the temperature is determined, the pulse train begins. The individual pulse frequency is typically 88 kHz.
- The LMT01 will continuously convert and transmit data when the power is applied approximately every 104 ms (maximum).
- When the temperature-to-digital conversion is complete, the LMT01 starts to transmit a pulse train that toggles from the low current of 34 µA to a high current level of 125 µA
- The pulse train total time interval is at maximum 50 ms.
- After the pulse count has been transmitted the LMT01 current level will remain low for the remainder of the 50 ms.
- Free-air temperature ranges from –50° to 150°C
- The voltage drops between 2 pins number positive and negative from 2V to 5.5V. This is the perfect for low-voltage application.
- The output of LMT01 can be determined either by Transfer function or LUT.
  - $T = \frac{(PC \cdot 256)}{4096} - 50(oC)$
    - PC: Pulse Count
    - T: temperature sensor output
    - Resolution for each pulse count: $\left[\frac{256}{4096}\right] = 0.0625(oC)$

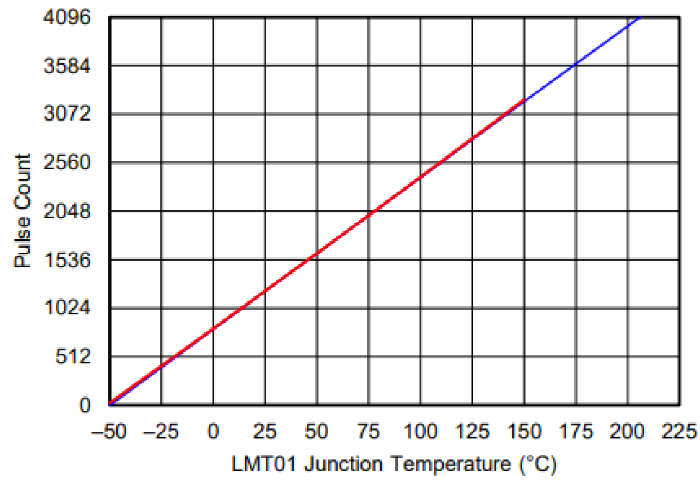


Figure 4: Output Transfer Function

- Due to long wire connection, the simple RC model can be designed to determine the rise and fall time of signal.

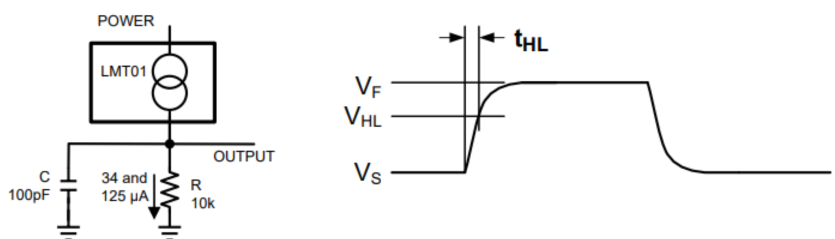


Figure 5: Simple RC model

$$t_{HL} = R \cdot C \cdot \ln\left(\frac{V_F - V_S}{V_F - V_{HL}}\right)$$

Where:

- RC in parallel connection
- V_HL: Target voltage
- V_F: The maximum voltage
- V_S: The minimum voltage

Schematic Design

Due to the environment of high-switching servo motor 420V, it becomes necessary to provide galvanic isolation between the hazardous high voltage side and low voltage controller side. Electrically isolating the sensor provides safety and seamless voltage level shifting and eliminates ground noise, which ultimately enhances performance and reliability while making the system design more complicated because power and data need to be transferred across an isolation barrier.

One would use one transformer for power isolation and another transformer, optocoupler, or digital isolator for isolating the data, which increases complexity, cost, and footprint of the overall temperature measuring solution.

The new tiny 2-pin digital output IC temperature sensor with a single wire pulse count interface enhances reliability and greatly simplifies the design of galvanic isolation architecture for sending both power and unidirectional data through a single low-cost, low-profile transformer

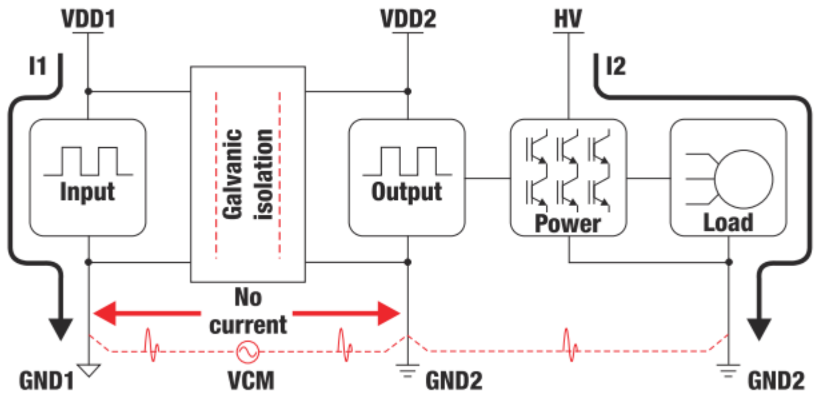


Figure 6: Low-High Voltage block diagram with Galvanic Isolation

Galvanic signal isolation is a technique used to electrically separate two circuits while allowing them to communicate or transfer signals. The primary purpose of galvanic isolation is to prevent the flow of electrical current between the two circuits, thereby protecting sensitive components, avoiding ground loops, and enhancing safety. This is particularly important in applications where different parts of a system operate at different potentials or where there is a risk of electrical noise or interference.

The term "galvanic" refers to the prevention of direct electrical connections. Galvanic isolation is achieved using components that do not conduct electrical current directly between input and output, commonly utilizing isolation transformers, optocouplers (opto-isolators), or magnetic isolators.

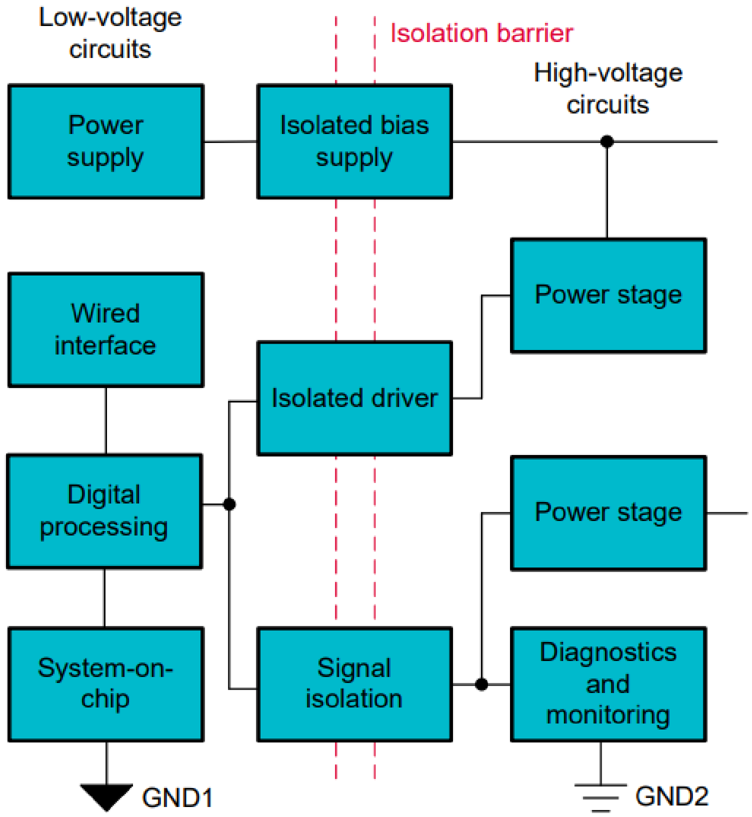


Figure 7: Low-High Voltage block diagram with data flow

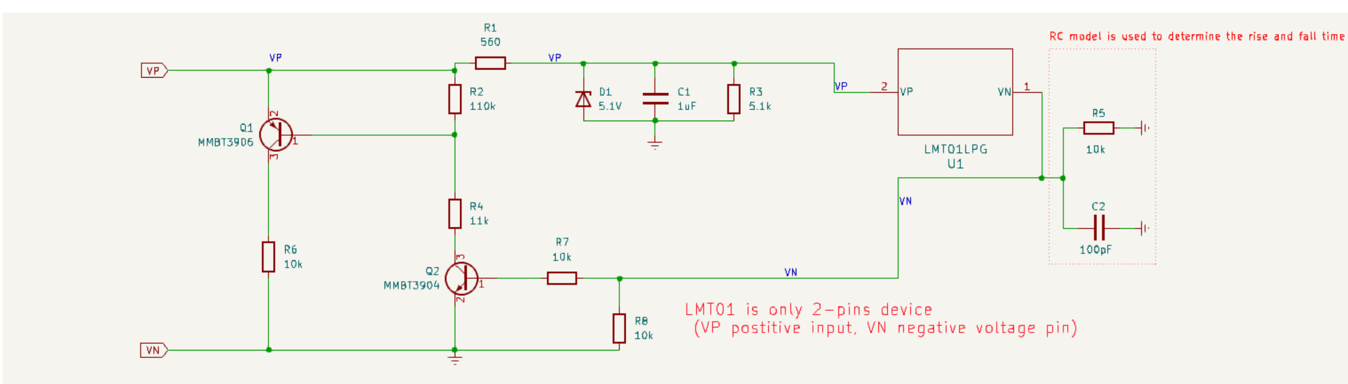


Figure 7: Schematic 1

- This approach allows a single power transformer for power and data isolation while eliminating the extra isolation on the data line.
- Power and data coexist on 2-wire interface. This is applicable for remote temperature sensing across isolation.

- No special power supply requirements; a simple low voltage open loop DC-DC power supply with high switching frequency of 420 kHz.
- Able to detect open circuit and short circuit without any additional hardware

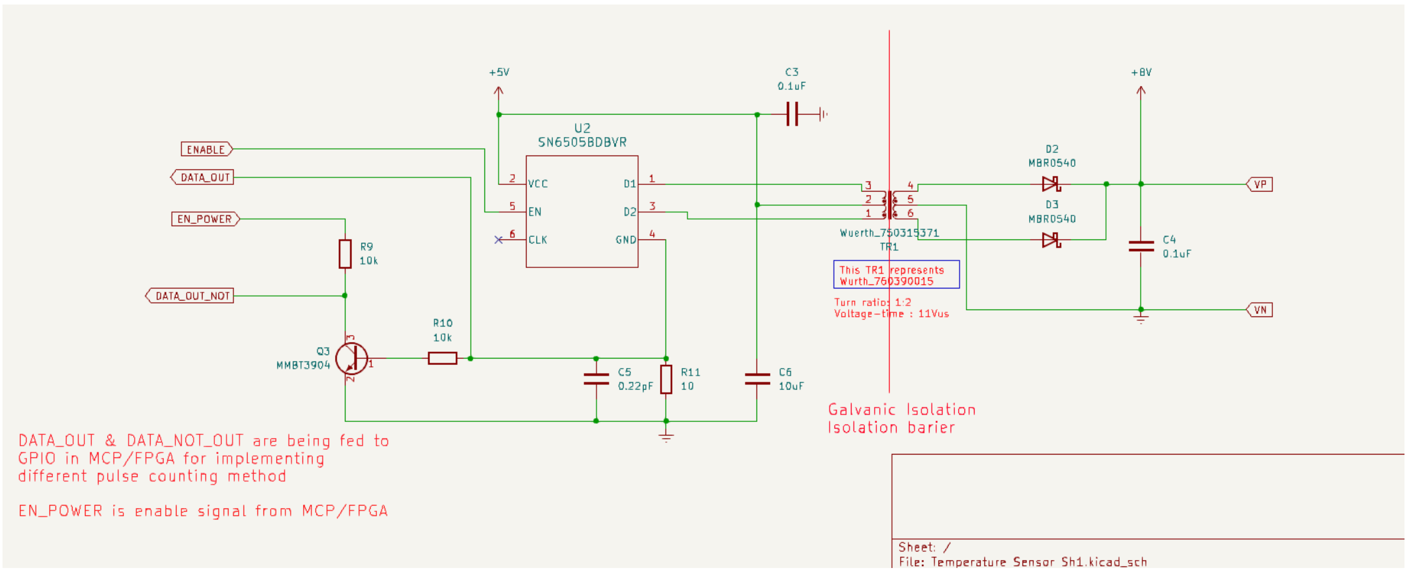


Figure 8: Schematic 2

Item	Qty	Reference(s)	Value	LibPart	Datasheet
1	1	C1	1uF	Device:C	~
2	1	C2	100pF	Device:C	~
3	2	C3, C4	0.1uF	Device:C	~
4	1	C5	0.22pF	Device:C	~
5	1	C6	10uF	Device:C	~
6	1	D1	5.1V	Zener Diode:BZT52Bxx	https://diotec.com/tl_files/diotec/files/pdf/datasheets/bzt52b2v4.pdf
7	2	D2, D3	MBR0540	Schottky Diode:MBR0540	http://www.mccsemi.com/up_pdf/MBR0520~MBR0580(SOD123).pdf
8	1	Q1	MMBT3906	Transistor_BJT:MMBT3906	https://www.onsemi.com/pdf/datasheet/pzt3906-d.pdf
9	2	Q2, Q3	MMBT3904	Transistor_BJT:MMBT3904	https://www.onsemi.com/pdf/datasheet/pzt3904-d.pdf
10	1	R1	560	Device:R	~
11	1	R2	110k	Device:R	~
12	1	R3	5.1k	Device:R	~
13	1	R4	11k	Device:R	~
14	6	R5, R6, R7, R8, R9, R10	10k	Device:R	~
15	1	R11	10	Device:R	~
16	1	TR1	Wuerth_750315371	Transformer:Wuerth_750315371	https://www.we-online.com/catalog/datasheet/750315371.pdf
17	1	U1	LMT01LPG	Project_Library:LMT01LPG	LMT01LPG
18	1	U2	SN6505BDBVR	Project_Library:SN6505BDBVR	SN6505BDBVR

Table 1: BOM Table