

Application Note

Temperature to Frequency Conversion Using GreenPAK

AN-CM-274

Abstract

This application note describes a simplified technique for directly converting a temperature sensor analog signal to digital frequency using GreenPAK.

This application note comes complete with design files which can be found in the References section.

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1 Terms and Definitions

ADC	Analog-to-digital converters
CPU	Central processing unit
RTDs	Resistance temperature detectors

2 References

For related documents and software, please visit:

[GreenPAK™ Programmable Mixed-Signal Products | Renesas](#)

Download our free [GreenPAK™ Designer](#) software [1] to open the .gp files [2] and view the proposed circuit design. Use the [GreenPAK](#) development tools [3] to freeze the design into your own customized IC in a matter of minutes. Find out more in complete library of application notes [4] featuring design examples as well as explanations of features and blocks within the GreenPAK IC.

- [1] [GreenPAK Designer Software](#), Software Download and User Guide
- [2] [AN-CM-274 Temperature to frequency conversion using GreenPAK.gp](#), [GreenPAK Design File](#)
- [3] [GreenPAK Development Tools](#), [GreenPAK Development Tools Webpage](#)
- [4] [GreenPAK Application Notes](#), [GreenPAK Application Notes Webpage](#)

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3 Introduction

Temperature sensors are one of the most important kinds of physical sensors, because many different processes (in everyday life as well) are regulated by temperature. Besides, the temperature measurement allows indirect determination of other physical parameters, such as matter flow rate, fluid level, etc. Typically, sensors convert the measured physical value into an analog signal, and temperature sensors are no exception here. For processing by the CPU or computer, the analog temperature signal must be converted into a digital form. For such a conversion expensive analog-to-digital converters (ADCs) are commonly used.

The purpose of this application note is to develop and present a simplified technique for direct conversion of the analog signal from a temperature sensor into a digital signal with proportional frequency using GreenPAK. Subsequently, the frequency of a digital signal that varies depending on temperature can then be more easily measured with a fairly high accuracy and then converted to the required units of measurement. Such direct transformation is interesting in the first place by the fact that there is no need for the use of expensive analog-to-digital converters. Also, digital signal transmission is more reliable than analog.

4 Design and Circuit Analysis

Different types of temperature sensors and their signal processing circuits can be used depending on specific requirements, primarily in temperature range, and accuracy. The most widely used are NTC thermistors, which reduce the value of their electrical resistance with increasing temperature (see Figure 1). They have a significantly higher temperature coefficient of resistance compared to metal resistive sensors (RTDs) and they cost much less. The main disadvantage of thermistors is their nonlinear dependence of the characteristic "resistance vs. temperature". In our case, this does not play a significant role since during conversion, there is an exact correspondence of the frequency to thermistor resistance, and therefore, the temperature.

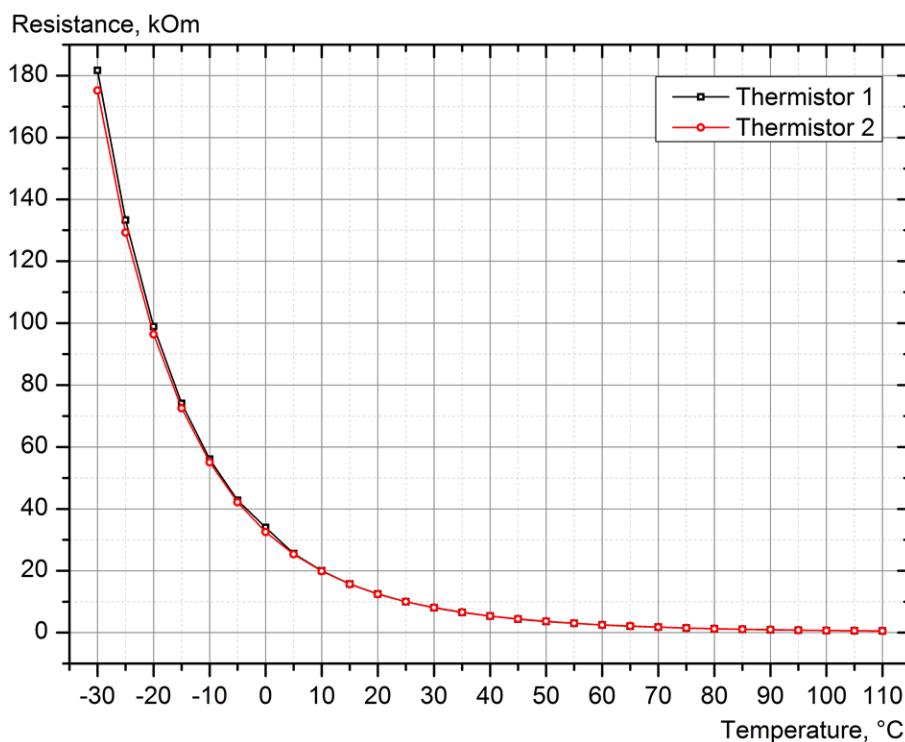


Figure 1: Thermistor Resistance vs Temperature plot

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Figure 1 shows the graphical dependence of thermistor resistance vs temperature (which were taken from manufacturer datasheets). For our design, we used two similar NTC thermistors with a typical resistance of 10 kOhm at 25 °C.

Table 1: Type of Used Thermistors

Symbol on the charts	Thermistor Type
Thermistor 1	NTC MF52E 103F3950 10k
Thermistor 2	NTC LE100E3103 640-10k

The basic idea of the direct transformation of the temperature signal into the output digital signal of a proportional frequency is the use of the thermistor R1 together with the capacitor C1 in the frequency-setting R1C1-circuit of the generator, as part of a classical ring oscillator using three “NAND” logic elements. The time constant of R1C1 depends on the temperature, because when the temperature changes, the thermistor's resistance will change accordingly.

The frequency of the output digital signal can be calculated using the following formula:

$$F \approx \frac{1}{2.3R_1C_1} \quad (1)$$

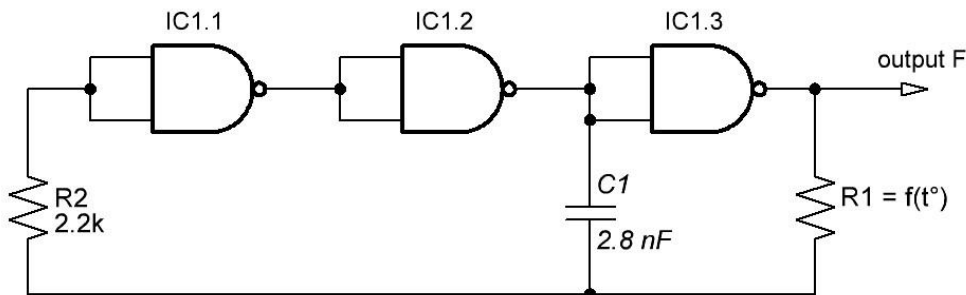


Figure 2: Schematic of Active Sensor

This type of oscillator typically adds a resistor R2 to limit the current through the input diodes and reduce the load on the input elements of the circuit. If the resistance value of R2 is much smaller than the resistance of R1, then it does not actually affect the generation frequency.

Consequently, based on the GreenPAK SLG46108V, two variants of the temperature to frequency converter were constructed (see Figure 5). The application circuit of these sensors is presented in Figure 3.

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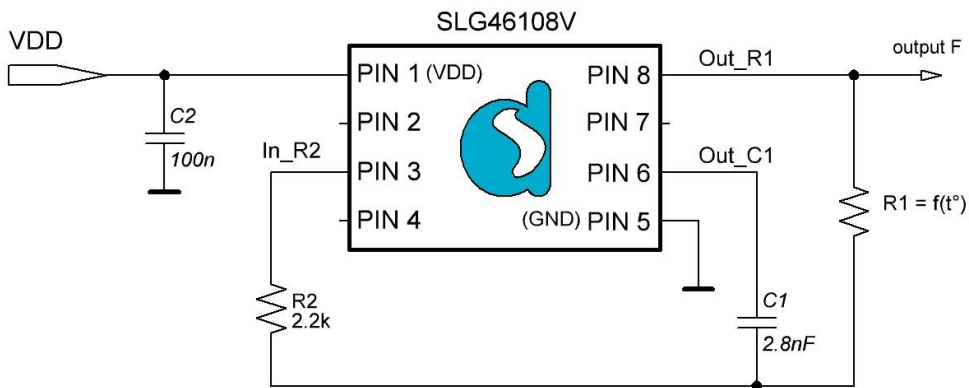


Figure 3: Electrical Circuit of Active Sensors (for GreenPAK SLG46108V)

The design, as we have already said, is quite simple, it is a chain of three NAND elements that form a ring oscillator (see Figure 4 and Figure 2) with one digital input (PIN#3), and two digital outputs (PIN#6 and PIN#8) for connection to external circuitry.

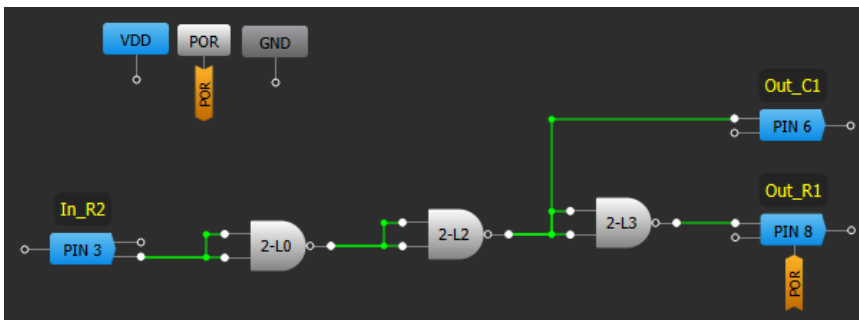


Figure 4: GreenPAK Designer Schematic

Figure 5 Photo shows the active temperature sensors (a one cent coin is for scale).

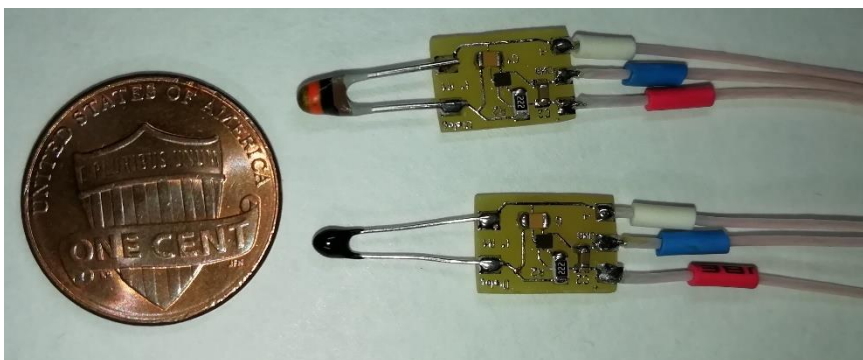


Figure 5: Photo of Active Temperature Sensors

Measurements were made to evaluate the correct function of these active temperature sensors. Our temperature sensor was placed in a controlled chamber, the temperature inside of which could be changed to an accuracy of 0.5 °C. The frequency of the output digital signal was recorded and the results are presented in Figure 6.

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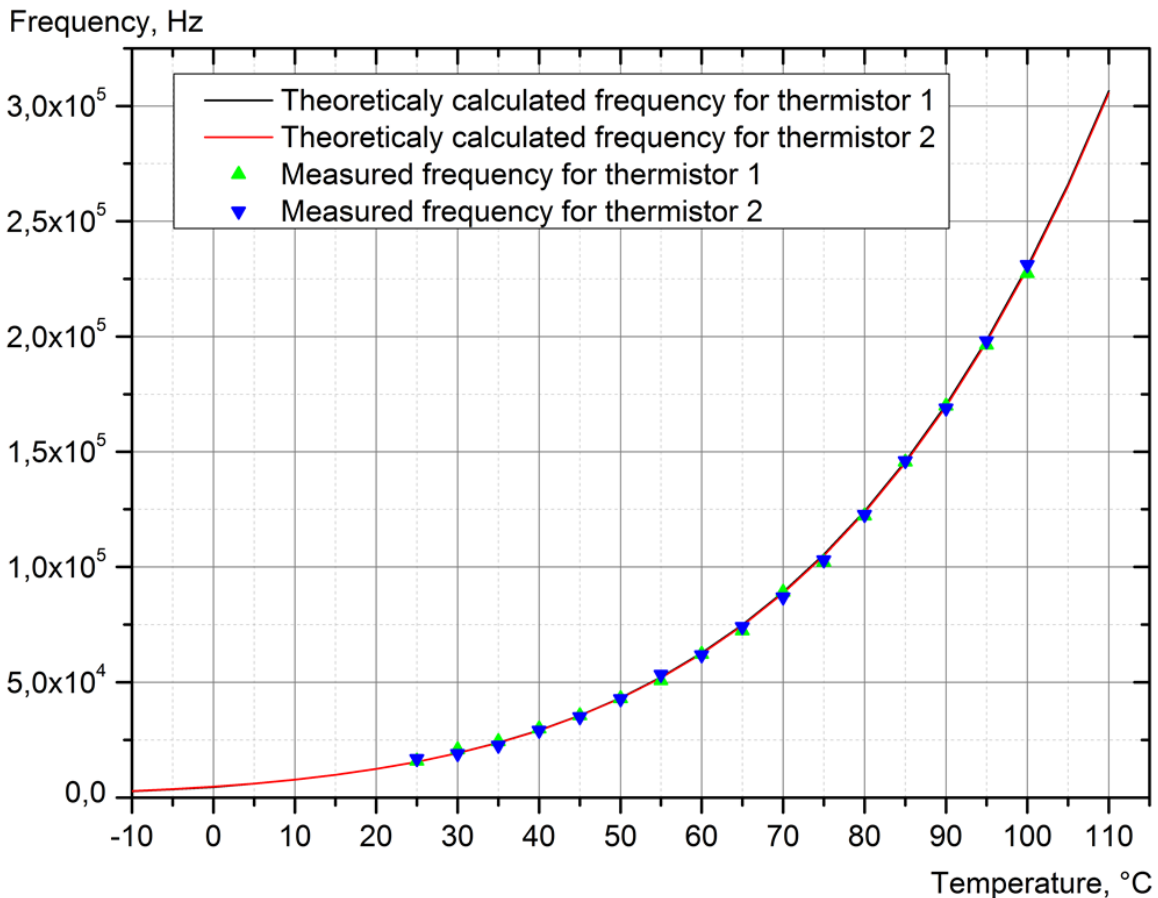
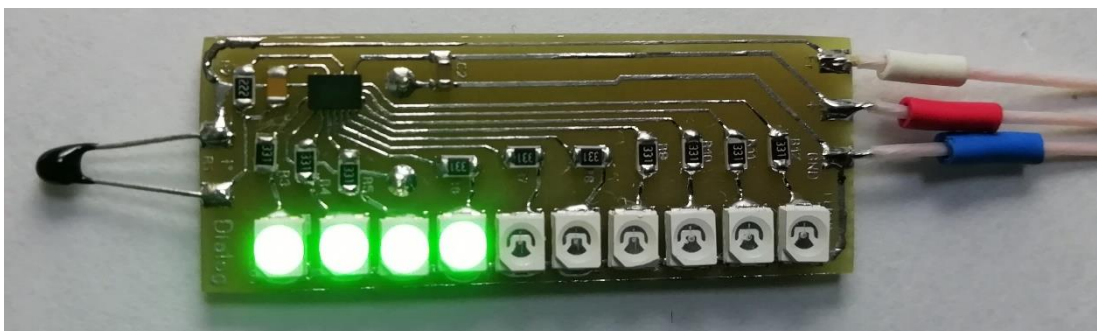


Figure 6: Comparison of Calculated vs. Measured Frequency

As can be seen from the plot shown, the frequency measurements (green and blue triangles) almost completely coincide with the theoretical values (black and red lines) according to formula (1) given above. Consequently, this method of converting temperature to frequency is working correctly.

Also, a third active temperature sensor was built (see Figure 7) to demonstrate the possibility of simple processing with visible temperature indication. Using the GreenPAK SLG46620V, which contains 10 delay elements, we have built ten frequency detectors (see Figure 9), each of which is configured to detect a signal of one particular frequency. In this way, we constructed a simple thermometer with ten customizable points of indication.



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Figure 7: Photo of Active Temperature Sensor with LED Indicators

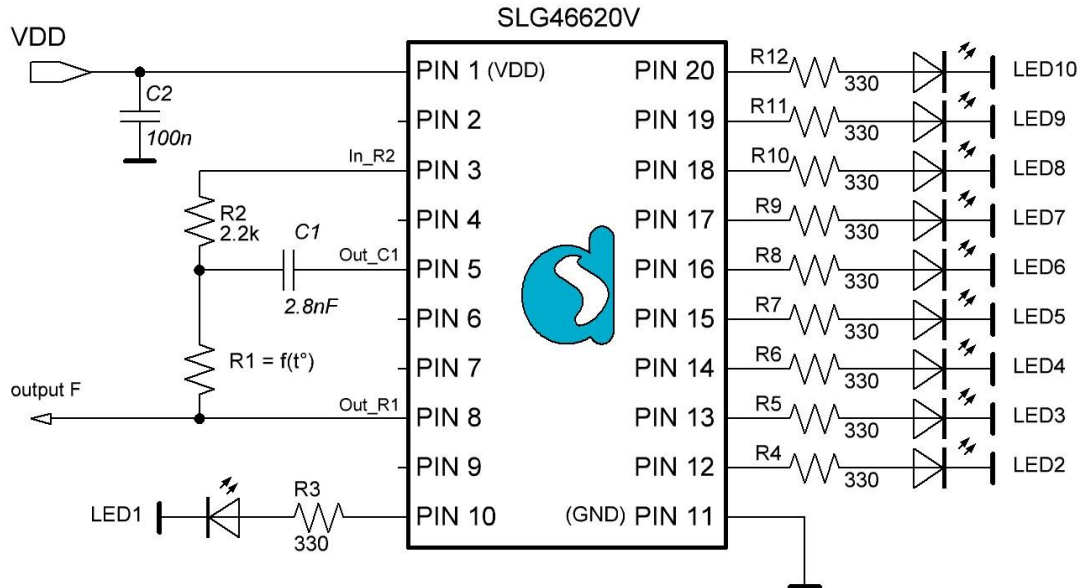


Figure 8: Electrical Circuit of Active Sensor (for GreenPAK SLG46620V)

Figure 8 shows the top level schematic of the active sensor with display indicators for ten temperature points. This additional function is convenient because it is possible to visually estimate temperature value without separately analyzing the generated digital signal.

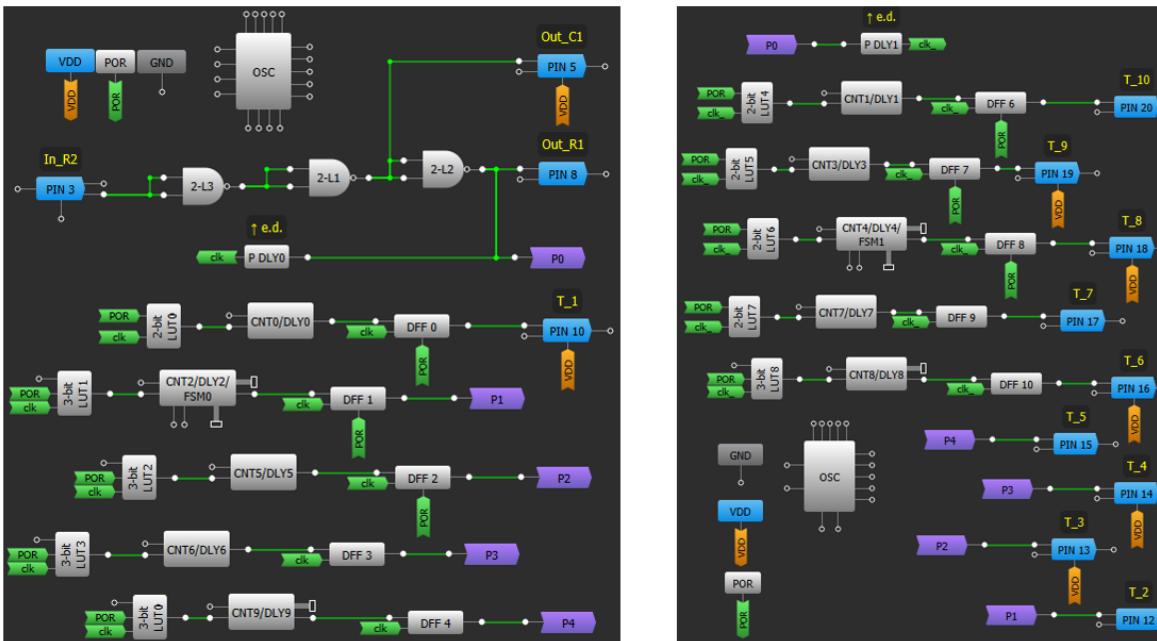


Figure 9: GreenPAK Designer Schematic View of SLG46620V

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5 Conclusions

In this application note, we proposed a method for converting a temperature sensor analog signal into a frequency modulated digital signal using GreenPAK products. The use of thermistors in conjunction with GreenPAK allows predictable measurements without the use of expensive analog-to-digital converters, and avoiding the requirement to measure the analog signals. GreenPAK is the ideal solution for the development of this type of customizable sensor, as shown in the prototype examples constructed and tested. GreenPAK contains a large number of functional elements and circuit blocks necessary for the implementation of various circuit solutions, and this greatly reduces the number of external components of the final application circuit. Low power consumption, small chip size and low cost are an added bonus for choosing GreenPAK as the main controller for many circuit designs.

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Revision History

Revision	Date	Description
1.0	09-Nov-2018	Initial Version

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