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Configurable IC Simplifies Conversion Of Temperature To Frequency

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Temperature sensors are one of the most important types of physical sensors because many different processes are regulated by temperature. For example, temperature measurement in a power semiconductor device is necessary to rapidly identify damage to power components. Knowledge of semiconductor device temperatures in a power electronics system can also be used to predict mechanical failure, to influence the temperature profile of devices to prevent overheating and to implement smart cooling control.

Besides, the temperature measurement allows indirect determination of other physical parameters, such as matter flow rate, fluid level, etc. Typically, sensors convert a measured physical value into an analog signal, and temperature sensors are no exception here. For processing by a CPU or computer, the analog temperature signal must be converted into digital form and expensive analog-to-digital converters (ADCs) are commonly used for this conversion.

The purpose of this article 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 a GreenPAK configurable mixed-signal IC. 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 because it eliminates the need for the use of expensive analog-to-digital converters. Also, digital signal transmission is more reliable than analog. In addition to explaining the design and operation of this temperature-to-frequency converter circuit, this article offers links to the GreenPAK design files which are needed to configure the desired circuit.

Design And Circuit Analysis

Different types of temperature sensors and their signal processing circuits can be used depending on specific requirements, primarily those relating to temperature range and accuracy. The most widely used are NTC thermistors, which reduce the value of their electrical resistance with increasing temperature (see Fig. 1). NTC thermistors have a significantly higher temperature coefficient of resistance than metal resistive sensors (RTDs) and they cost much less.

The main disadvantage of thermistors is the nonlinear dependence of their 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.

Fig 1. shows the graphical dependence of thermistor resistance vs temperature (the data points were taken from manufacturer datasheets). For our design, we used two similar NTC thermistors with a typical resistance of 10 kΩ at 25°C. These models are listed in the Fig. 1 caption.

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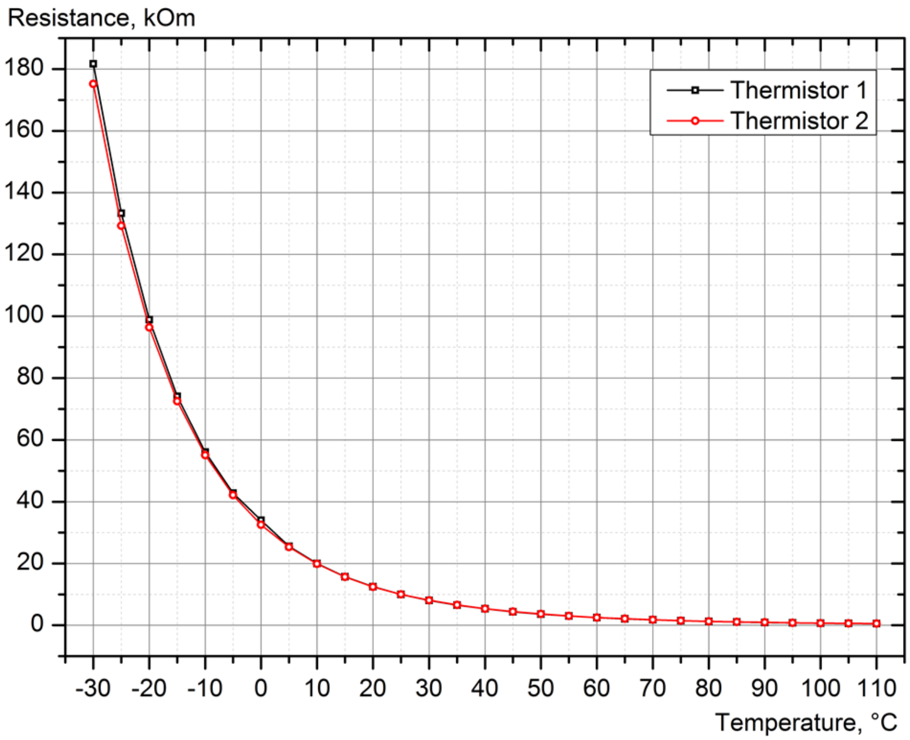

Fig. 1. Thermistor resistance vs temperature plot. Thermistor 1 is an NTC MF52E 103F3950 10k and Thermistor 2 is an NTC LE100E3103 640-10k.

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 (Fig. 2). 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:

$$F \approx \frac{1}{2.3 R_1 C_1}$$

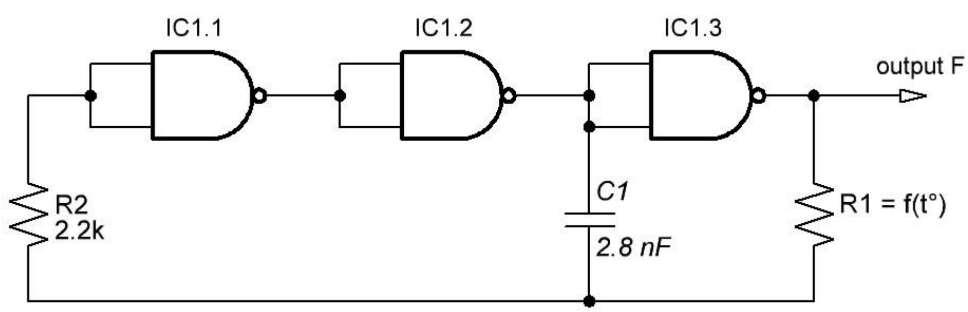

Fig.2. Schematic of the active sensor.

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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 value of the frequency generated.

Using the SLG46108V GreenPAK IC, two variants of the temperature-to-frequency converter were constructed. Fig. 3 shows both of these active temperature sensors with a one-cent coin included to indicate scale. The application circuit for these sensors is presented in Fig. 4.

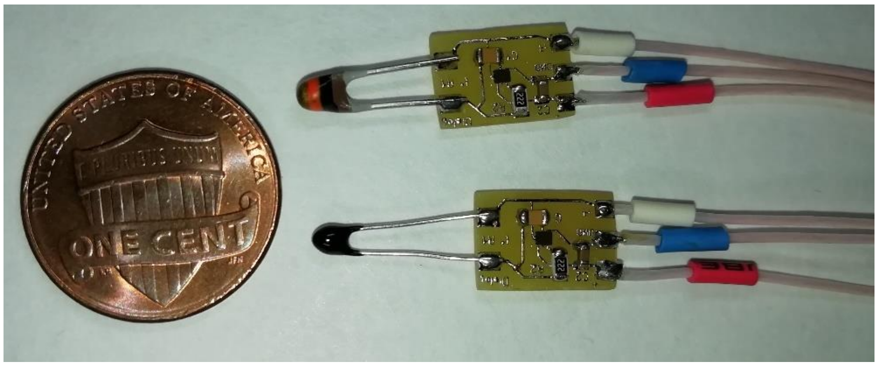

Fig. 3. Photo of active temperature sensors.

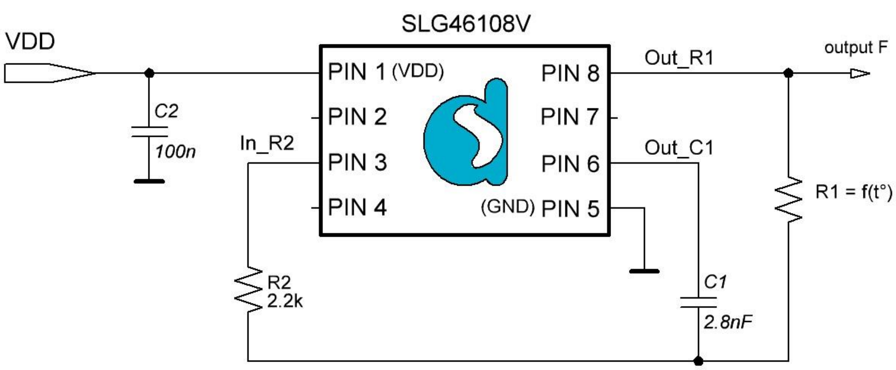

Fig. 4. Electrical circuit of active sensors for the SLG46108V GreenPAK.

The design, as we have already said, is quite simple. It is a chain of three NAND elements that form a ring oscillator (see Figs. 5 and 2) with one digital input (PIN#3), and two digital outputs (PIN#6 and PIN#8) for connection to external circuitry.

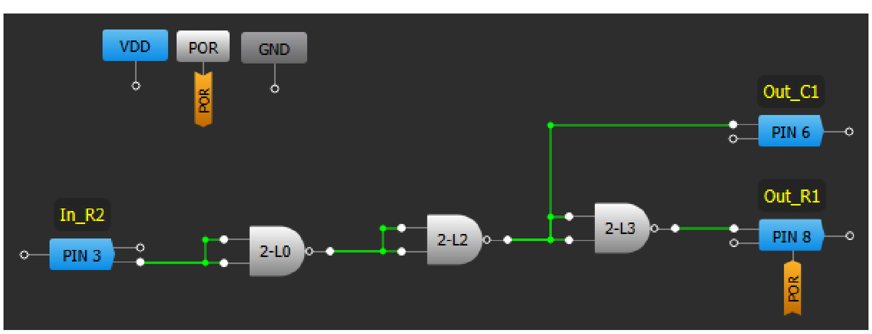

Fig. 5. GreenPAK designer schematic.

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Measurements were taken to evaluate the correct function of these active temperature sensors (see Fig. 3 again). Our temperature sensor was placed in a controlled chamber, the temperature inside of which could be changed to within an accuracy of 0.5°C. The frequency of the output digital signal was recorded and the results are presented in Fig. 6.

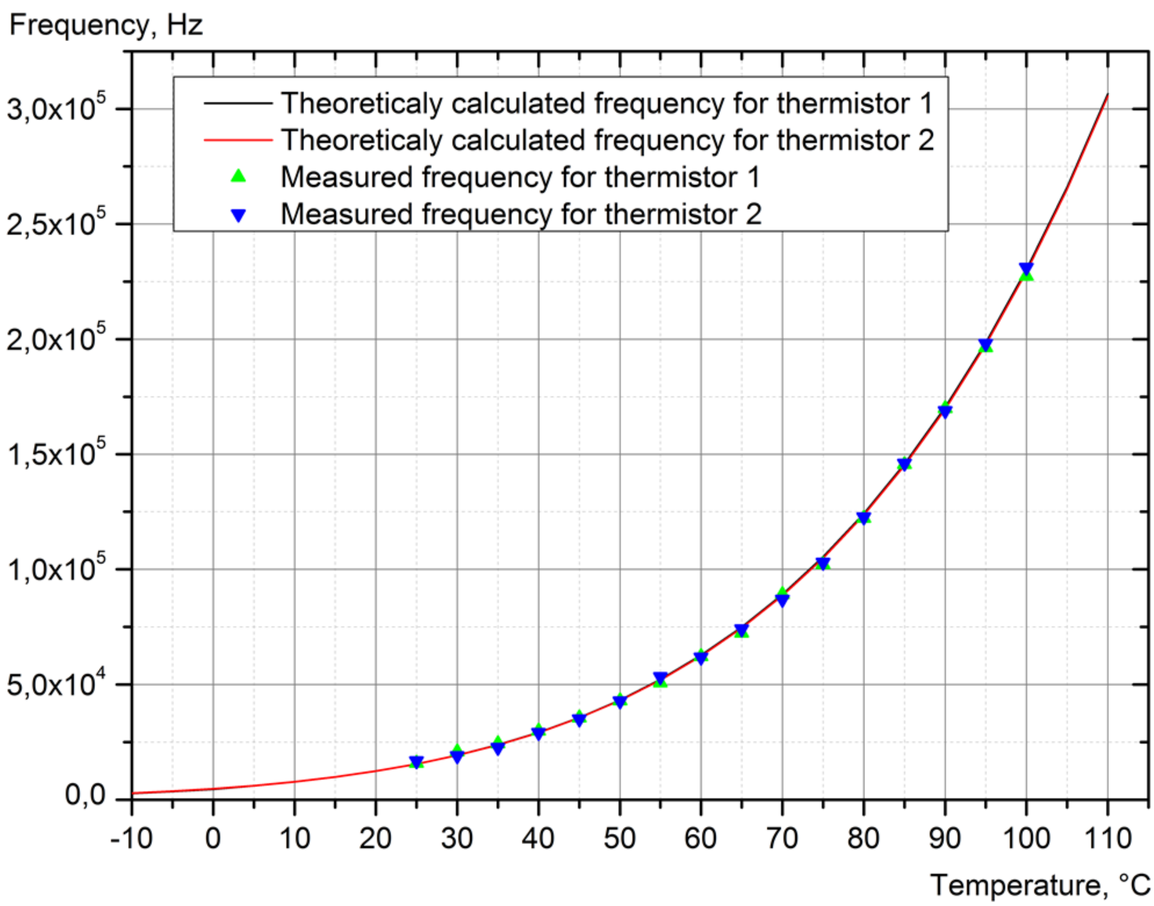

Fig. 6. Comparison of calculated vs. measured frequency.

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.

In addition to the two circuits described above, a third active temperature sensor was built (Fig. 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 Fig. 8), 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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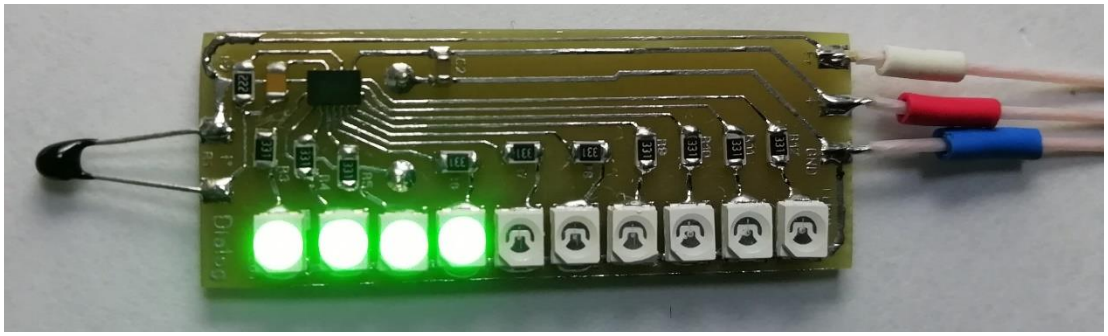

Fig. 7. A GreenPAK-based active temperature sensor with LED indicators forming a simple thermometer.

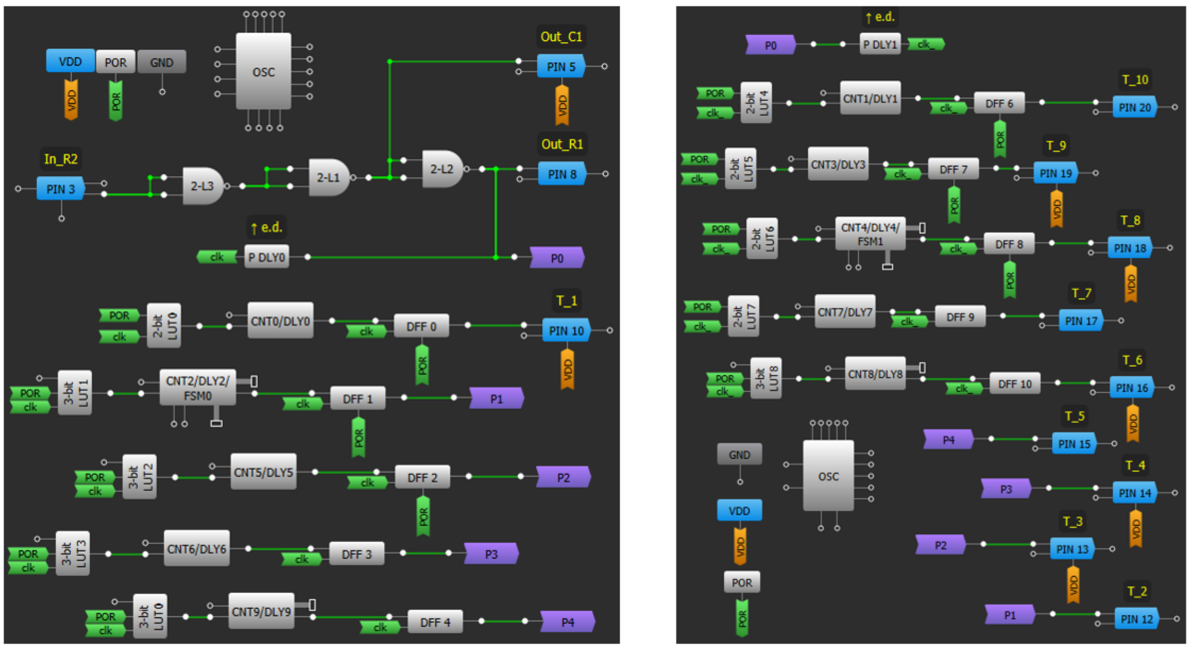

Fig. 8. GreenPAK Designer schematic view of the SLG46620V.

Fig. 9 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 the temperature value without separately analyzing the generated digital signal.

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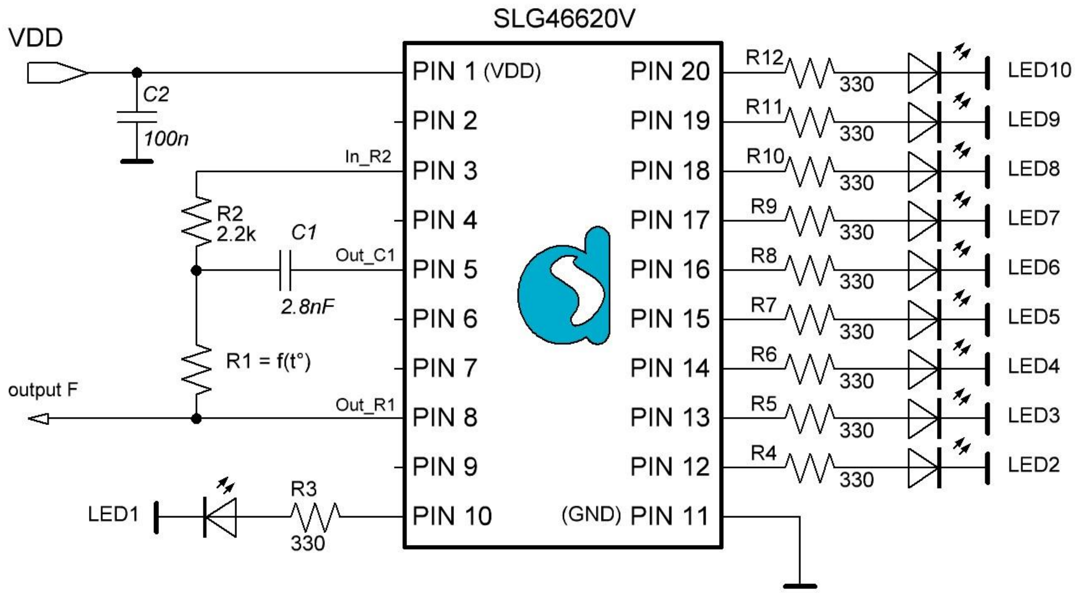

Fig. 9. Electrical circuit for the active temperature sensor based on the GreenPAK LG46620V.

Conclusion

In this article, we proposed a method for converting a temperature sensor's analog signal into a frequency modulated digital signal using GreenPAK products from Dialog. The use of thermistors in conjunction with a GreenPAK configurable mixed-signal IC allows predictable measurements without the use of expensive analog-to-digital converters, and avoiding the requirement to measure analog signals such as voltage and current.

A GreenPAK device is well suited 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 added bonuses for choosing GreenPAK as the main controller for many circuit designs.

For related documents and software, please visit Dialog Semiconductor's website.[1] To download the free GreenPAK Designer software, see reference 2. To open the .gp files and view the proposed circuit design, see reference 3. Use the GreenPAK development tools in reference 4 to freeze the design into your own customized IC in a matter of minutes. In addition, Dialog Semiconductor provides a complete library of application notes[5] featuring design examples as well as explanations of features and blocks within the Dialog IC.

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About The Author

Oleksiy Kravchenko has over 10 years of experience in electronics including repair, debug, and modification work. His interests include microcontrollers, system automation and analog and digital electronics. Among his current activities, Oleksiy writes application notes for Dialog Semiconductor. Oleksiy graduated from Ivan Franko Lviv National University in the Ukraine where he studied in the Department of Medical and Biomedical Electronics.

For more information on temperature sensing in power design, see How2Power's Design Guide, and do a keyword search on "thermistor."

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