

## Application Brief

# Efficient Cold Chain Management With Scalable High-Accuracy Temperature Sensors



From producers to consumers, it is important that perishable items, especially food and medicines, reach the end consumer in fresh and viable condition, so as to maintain their nutrients and efficacy. To ensure quality and product safety, manufacturers specify the temperatures at which the items must be transported and stored.

Before reaching the consumer at their local grocery, perishable produces like fruits, vegetables or frozen meals, spend a significant time in transportation and on the shelves of large refrigeration units as shown in [Figure 1](#). The same is true of pharmaceuticals such as vaccines. Thus it becomes crucial that these items be maintained at the correct temperature.

Cold chain management and Good Distribution Practices (GDP) ensure that the right conditions are met during every phase of the life cycle of packaged and perishable items. At the same time it ensures that anytime a possible excursion outside the storage temperature is about to occur, an appropriate action can be taken by the operator either during transportation or during storage to ensure that there is as little wastage as possible.



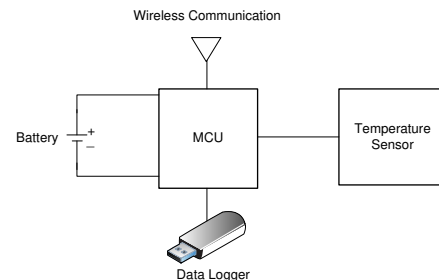
**Figure 1. Typical Grocery Aisle**

### Cold Chain Topology

Use of temperature sensors with gauges and simple analog sensors, have been quite common for a long time. However, with advances in semiconductor technology and the fact that most cold chain management is done in the temperature range of  $-40^{\circ}\text{C}$  to  $+10^{\circ}\text{C}$ , integrated temperature sensors are the best option for cold chain management in these

temperature ranges. Based on the application, there are different topologies that may be deployed. In the point to point topology like that represented in [Figure 2](#), a single microcontroller (MCU) is connected to a temperature sensor that may be an analog output or a digital output sensor. This is useful when managing a pallet of goods or a temperature controlled container during shipping.

The TMP116 temperature sensor operates from  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  with  $0.2^{\circ}\text{C}$  accuracy from  $-10^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ . It contains I<sup>2</sup>C and SMBus-interface communication, as well as an integrated EEPROM memory. There is no calibration required for the TMP116, and minimal current is consumed which minimizes self-heating. The TMP116 is typically found in applications with a heavy focus on high accuracy.



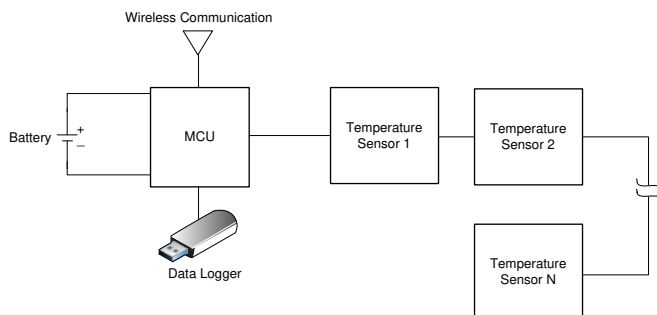
**Figure 2. Point-to-Point Topology**

When sensing multiple locations like display in refrigerators or in reefer containers, the cost of a single MCU is too high to be implemented multiple times in the entire system. In such cases, the most common topologies that are used are the star, daisy chain ([Figure 3](#)) or shared bus, with one MCU being the host controller for multiple sensors. A star topology allows easy fault isolation if one branch fails and may use both analog and digital output temperature sensors, but has a higher cost of implementation as the controller peripheral count is higher because of which the system cannot scale very well and the cost of assembly and cable itself.

On the other hand, with shared bus, the scalability can easily be addressed with digital temperature sensor that share the line and may be individually addresses using in band addressing like the case of

I<sup>2</sup>C bus or out of band signaling using chip select which is the case with SPI. However, reliable power delivery and signal integrity over a long chain may be a concern.

The daisy chain does not require out of band signaling and rather uses in band addressing scheme. As each stage of the chain acts as a buffer for the next chain, signal integrity may be maintained over longer distances.



**Figure 3. Daisy Chain of Temperature Sensors**

Irrespective of which stage of cold chain management is being monitored, electronic systems provide a unique advantage of not only logging the temperature of the pallet or refrigeration unit, but also providing thresholds that generate alert above a certain threshold. Such events can be visually communicated through audio or visual alerts like a buzzer or flashing LED, but also can be integrated into cloud services using either wired or wireless MCUs, allowing round the clock monitoring and data logging.

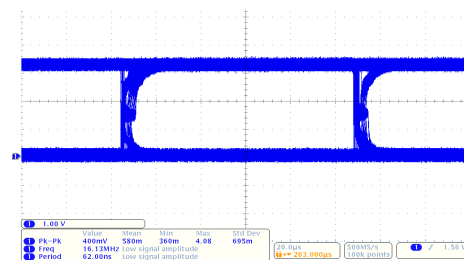
### Daisy chain topology in cold chain management

The TMP107 is a digital output temperature sensor that supports a total of 32 daisy-chained devices and is ideal for replacing NTC thermistors in cold chain management, because of its high accuracy and ease of system wide scalability without the need to add additional MCUs. The TMP107 has a maximum accuracy specification of  $\pm 0.4^{\circ}\text{C}$  in the range of  $-20^{\circ}\text{C}$  to  $+70^{\circ}\text{C}$  and  $\pm 0.55^{\circ}\text{C}$  in the range of  $-40^{\circ}\text{C}$  to  $+100^{\circ}\text{C}$  with a temperature resolution of  $0.015625^{\circ}\text{C}$ .

With an automated address assignment, the TMP107 allows system developers to write software without the need to assign the address at each sensor node as the system is scaled by adding additional sensor node. At the same time, with the use of a push-pull communication IO, the system is made more resilient against the noise affecting the temperature value over long cables. This allows for data transfers over span lengths of 1000 feet between adjacent devices in the chain.

Figure 4 shows the signal integrity of the communication interface at 9600 bps. The

communication interface of SMAART Wire™ uses UART bus which is a standard peripheral on almost all MCU, making it easier develop software, than using bit-banged approach. At the same time, with a daisy chain implementation, it makes it easier to identify the location of a cable break, which enables easy maintenance and overall system reliability.



**Figure 4. Eye Diagram for TMP107**

The current consumption of the TMP107 when performing temperature conversions with an active bus communication is typically  $300\ \mu\text{A}$ . It has a shutdown current of  $3.8\ \mu\text{A}$  in low power mode. With a wide operating voltage of 1.7 to 5.5 V, the low current consumption makes it ideal for battery operated systems during transport phase of cold chain management. At the same time the baud rate can be increased for more real time update as may be the case when storing frozen food items.

Additionally, TMP107 allows the configuration and temperature limits to be stored to its internal non-volatile memory. This enables the device to be automatically configured on power up, eliminating the need for individual device configuration to be performed making the system operational faster. It also has 8 EEPROM locations providing up to 128 bits of EEPROM to store user information or calibration information.

In conclusion, different types of temperature measurement solutions can be used to efficiently track temperature in cold chain applications. The TMP116 could be ideal for monitoring a single location and has accuracy suitable for both produce and pharmaceuticals, while the TMP107 has the right combination of accuracy, power consumption and features to support a battery-based cold chain management system where multi-point monitoring is needed.

**Table 1. Device Recommendations**

Device	Optimized Parameters	Performance Trade-Off
TMP107	0.4°C accuracy and 32 devices in daisy chain	0.4°C accuracy may not be enough for pharmaceuticals
TMP144	Small form factor	16 devices in daisy chain and 1°C accuracy
TMP116	0.2°C accuracy across temperature	No daisy chain capability

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