Application Report
SBOA138A–September 2015–Revised October 2015

Easy-to-use Cabling Interface for Measuring Temperature with the TMP107

Mihail Gurevitch
HPA Sensing Group

ABSTRACT

This application note provides recommendations on how to design a robust temperature measuring cabling system based on the TMP107 temperature sensor. Design considerations and helpful hints are provided for this UART-based system as well as initialization procedures and debugging suggestions. By following the recommendations provided, the user can design a long-distance temperature measuring chain while achieving the performance as stated in the data sheet specifications.

Contents

List of Figures

Microsoft, Windows are registered trademarks of Microsoft Corporation.

1 Introduction

The TMP107 can measure ambient temperatures from –55°C to 125°C with a typical precision of ±0.4°C. Temperature measurements in the range of –70°C to –55°C are also possible; but without assured precision. Up to 32 parts can be connected serially using just 3 wires between two sensors. It is possible to extend a chain of TMP107 devices for several hundred meters. It is assumed in the following text that the user has already read the TMP107 data sheet (SBOS716A) from the TI website and is familiar with the part commands, parameters, and SMAART bus protocol. The SMAART bus protocol is a UART compatible, bidirectional one-wire interface that can be used with an off-the-shelf UART transceiver and a tri-state buffer with a pullup resistor on the output..

2 Overview

To correctly design a TMP107 temperature measuring chain, determine the following chain parameters:

- TMP107 mode of operation
- Distance to the object and number of measuring points
- Measurement sampling rate
- Desired measurement precision
- SMAART bus communication speed
- Chain supply voltage
- The type of chain controller

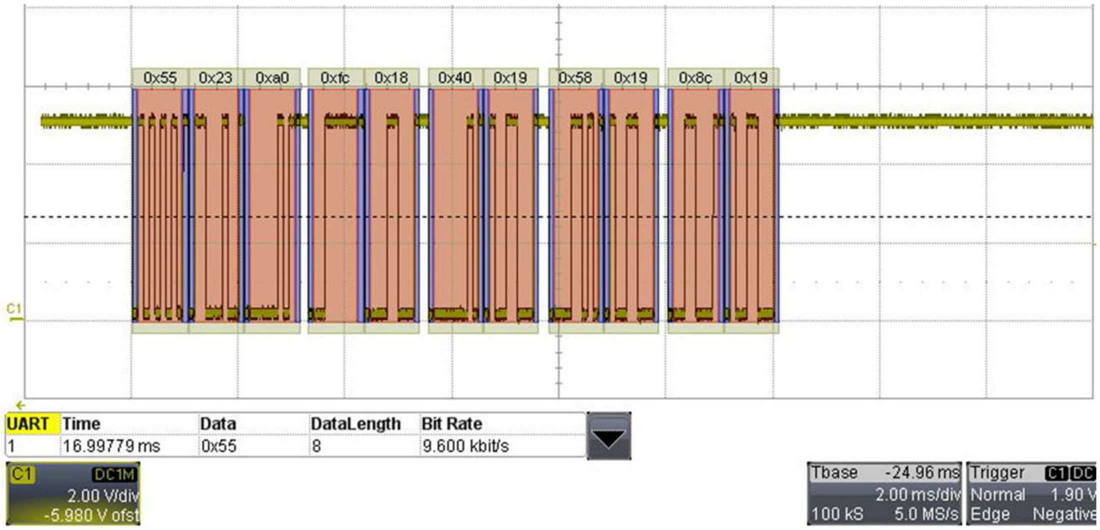
Consider these parameters and how they can affect the design.

2.1 TMP107 Mode of Operation

There are three main methods to operate the TMP107 chain:

(A) All devices are in continuous conversion modes with a sampling rate configured by the host controller. By using the *Global Read* command, the host periodically reads the data from the chain. Because there is no synchronization between the parts, the sampling moment in each part is not precisely coincident with the other devices in the chain. Data transmission in this mode can overlap the ADC conversion and can occasionally return offset values up to 1 C. For highest precision in this mode, TI recommends using the minimal supply voltage and highest communication speed, which will reduce communication time. The continuous conversion mode is primarily intended to be used with temperature thresholds and active alerts.

Figure 1 shows a data transmission for a 4 part chain in this mode. The first byte is a synchronization byte, the next two are the *Global Read* command from the host. The following 2 bytes are the content of register zero of the 4th part. Next comes temperature data from parts 3, 2, and 1. In this example, all parts in the chain are already configured into continuous conversion mode.

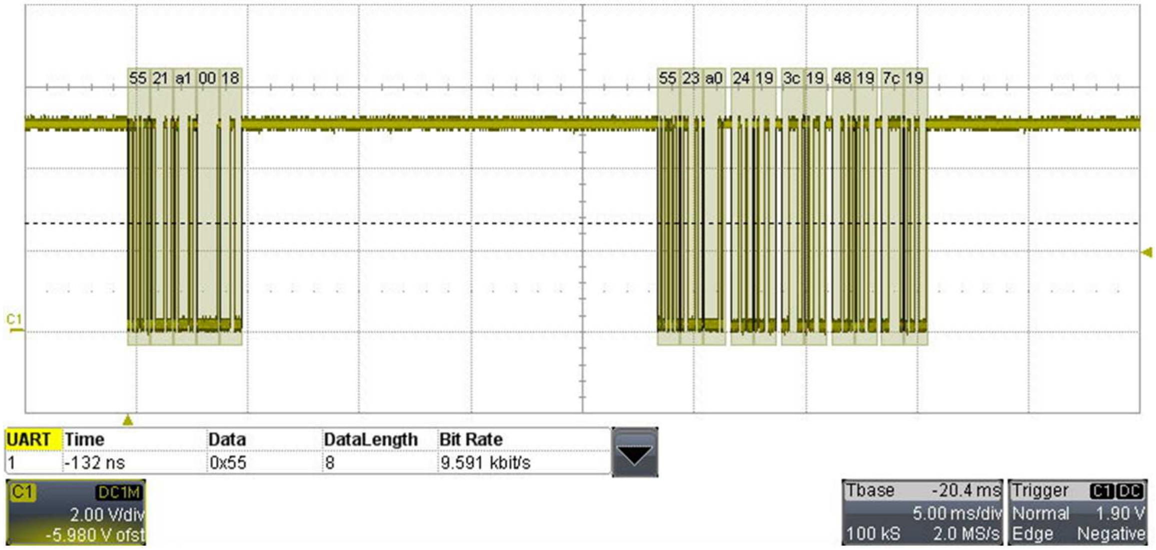


Bus speed = 9.6 kBd

Figure 1. Oscilloscope of *Global Read* Command in Continuous Conversion Mode

(B) All parts in the chain are in shutdown mode. When necessary, the host sends a *Global Write* command triggering a one-shot conversion and after at least 15 ms, reads the data from the chain. After data transmission, the parts return into shutdown mode and wait for the next host command. The advantage of this mode is that ADC conversion never overlaps with communication. Additionally, all parts are sampled simultaneously and power consumption and self-heating is minimized. Compared with the continuous-conversion mode, two commands are required; one to start the conversion followed by at least 15 ms of waiting and then a *Global Read* command to capture the temperature conversion data stored in each device.

Figure 2 shows a data transmission capture for 4 parts in a chain in one shot mode. The first 5 bytes are the *Global Write* command from the host to each device's configuration register to trigger a one shot conversion. Next comes a pause for ADC conversion, followed by *Global Read* command. All parts in this chain were already set into shut-down mode.



Bus speed = 9.6 kBd

Figure 2. Oscilloscope of Temperature Data Collection in One Shot Mode for 4 Parts Chain

(C) All parts in chain are in shutdown mode. When it is needed, the host activates one or more devices in the chain. The host uses the individual read command to get data from a specific part. This approach reduces the current consumed by the chain and therefore reduces the voltage drop over the wire's resistance, creates a mostly noiseless situation for active parts, and allows for long cable usage. This method is good for slowly changing temperatures where the simultaneous sampling is not needed. Potentially, this method provides the best precision.

2.2 Distance to the Object, Number of Measuring Points

The length of the chain and number of measuring devices are key factors in determining the cost of the measuring chain. Cost-sensitive applications favor small diameter, 3-conductor cabling. Limitations of this approach include high line resistance and reduced cable endurance. Cable length, conductor resistance, and total current consumption by devices determines the supply voltage drop along the chain and affects the minimal supply voltage acceptable at the host and driver side of the cable. Over long distances, the cable length between neighboring TMP107 can cause a reduction in the maximum bus speed. For chains in excess of 100 m, it is recommended to increase the part’s bypass capacitor to 1 µF or put an additional high capacity electrolytic capacitor (100 µF to 6000 µF) at the last device.

Another approach to improve the reliability of long-line communication without lowering the bus speed is to insert additional TMP107 devices as intermediate line drivers and buffers to reach the final, intended device for remote measurement. For example, if a temperature measurement is needed 600 m from the host, insert at least 3 additional devices in the chain. The distance between the parts then reduces to 150 m and makes bus communication in the system less vulnerable. The additional devices can be set in the shut-down mode and will work only as data buffers.

2.3 Desired Measurement Precision

The desired temperature measurement precision defines the TMP107 mode of operation. The data sheet parameters are ensured when the ADC conversion is not overlapped with communication through the device and when self-heating of the device is minimal. To get the best precision, the one-shot mode with no overlapping communication should be used. Conversely, configuring the part in continuous conversion mode with 15-ms sampling interval (no gap between conversions), the maximum power supply voltage and constantly overlapping communications produces the worst case for temperature measurement. In this case, the precision can drop considerably to at least ±1.5°C, especially for negative temperatures. If the lower level of precision is acceptable, it gives the user much more freedom during system design. In case the highest precision is needed and the system cannot operate with minimal power dissipation, system-level device calibration is recommended.

2.4 Sampling Rate

The maximum possible temperature sampling rate is 62 conversions per second (or one conversion every 15 ms). In this mode, the ADC is running continuously and bus communication is unavoidable during the ADC conversion. This leads to measurement noise, higher power consumption and self heating of the device. To achieve the best precision, it is recommended not to use a sampling rate higher than needed. In the case of 15-ms sampling rate, it is recommended to use the minimum acceptable supply voltage.

The TMP107 offers a wide range of conversion times. There are 8 continuous-conversion modes with sampling intervals from 15-ms to 16-sec and with average supply current from 200 µA to 5 µA (V+ = 3.3 V). For example, the manufacturer default conversion rate is 1 s, but that only consumes 200 µA for 15 ms during sampling, and then has 985 ms of just standby current (13.6 µA). Combining all this yields an average current of 16 µA at that conversion rate. It is important to remember that there is no inherent synchronization between devices for ADC conversions. To force a temperature sampling event at a certain time, the host issues a *Global Write* requesting a conversion. This aborts any current conversion in progress and starts a new one.

2.5 SMAART Bus Communication Speed

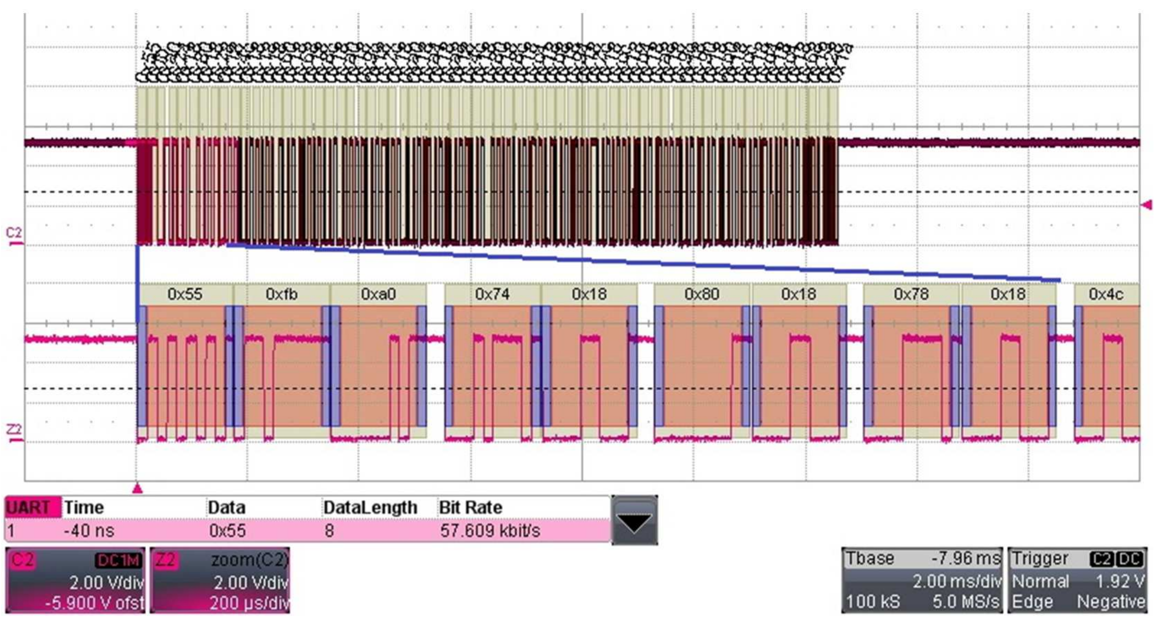
The SMAART bus communication speed can be set to any baud rate between 4.8 kBd and 115.4 kBd. Be sure to use a baud rate high enough to be able to retrieve temperature data from all parts on the chain during one sampling interval. For example, if 32 TMP107 devices in a chain are set to the 15-ms sampling period, the minimum communication speed is 37 kBd, assuming the *Global Read* command from the host is 3 bytes and the temperature data from every part is 2 bytes.

For very long chains, with potentially hundreds of meters between sequential parts, the maximum speed of 115.4 kBd can be too high. Communication at high speeds can create the signal reflection which cannot be filtered by TMP107 input circuitry and communication becomes unstable. In this case a lower speed should be used or additional devices should be added into the chain as buffers. The rule for long lines (above 200 m) is simple: the longer its cable - the slower the communication speed should be. For most cases, the standard UART bus speed of 57.6 kBd works very well.

A common mistake is not allowing enough time between transmission send and receive commands for the data to propagate to all devices in a chain. Only after the last bit of the 5-byte read command is received by the device will the command be executed. For example, to deliver the command *Global Read* to the chain with bus speed of 57.6 kBd, it will take 1.4 ms. In the case of 9.6-kBd bus speed, the time to send this 5-byte command will be 8.33 ms. Propagation time through the devices is in the nanosecond range, and can generally be ignored.

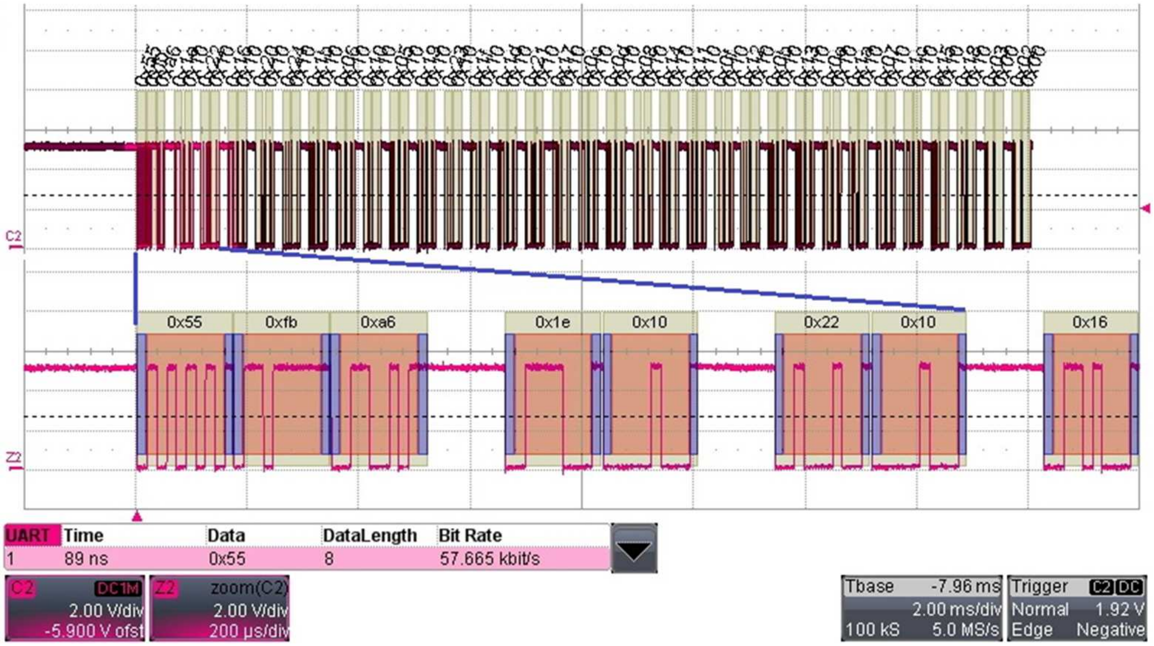
For example, 11 ms is needed to deliver data from 32 parts in the chain with bus speed of 57.6 kBd. This time is counted from the moment when the last bit of *Global Read* command reaches the last part. After that, the host can start to read the data from the UART port read buffer. The additional 2.4 ms reserve time is included inside the 11 ms to compensate the part's delay to respond and compensate for the TMP107 internal clock variations. Figure 3 shows the diagram of a *Global Read* command the temperature registers for this case. Reading the EEPROM location needs 160 µs of additional time for each word which is used for EEPROM activation in the parts. The oscilloscope diagram of EEPROM reading is shown in Figure 4.

If during the communication in any direction for any reason the data flow interrupt appears for more than 35 ms, the SMAART bus interface inside the TMP107 times out and is reset. TMP107 communication block goes back to its default condition - translating data from the I/O1 to the I/O2 pin. This means that to be absolutely safe and avoid direction conflicts on the bus, the host should send the next command 35 ms after finishing sending out the previous read command. This ensures that all parts in a chain are ready to receive the next host command. In typical applications, this precaution is not necessary and adding this 35 ms safeguard between commands is only recommended if communication errors are observed.



SMAART bus speed = 57.6 kBd. The total time for communication is 12.6 ms.

Figure 3. Oscilloscope of 32 Device Chain Global Temperature Data Read Event



SMAART bus speed is 57.6 kBd. The total time for communication is 16 ms.

Figure 4. Oscilloscope of 32 Device Chain Global EEPROM Cell-1 Data Read Event

2.6 Chain Supply Voltage

To minimize power consumption, self-heating effects, and minimize the distortion from the communication during an ADC conversion, the minimum supply voltage of 1.8 V is recommended. For maximum reliability, ability to compensate the voltage drop on supply wires, and to have a voltage reserve in case of unexpected leakage in a chain and maximum immunity to external EMI, the highest supply voltage of 5.5 V is recommended. When the user has the freedom to choose a chain voltage, the chosen one is a compromise between these two alternative extremes.

To calculate the minimum voltage for the long chain, consider the resistance (ground and V+) of the supply wires and maximum current in the chain. If the communication is going to happen during the ADC conversion, then the two currents should be added together. If programming the TMP107 EEPROM cells is planned to be done in all parts simultaneously, then the EEPROM programming current is the maximum expected current. The supply voltage in this case should always be above 1.8 V in all parts. If the part's Alert pins are used, then these pins' currents should also be taken into consideration.

In order to reduce voltage drop along the chain, the user can use the TMP107 in lower power consumption modes, use thicker wires with less resistance, apply the supply voltage on both ends of the measuring chain, use larger bypass capacitors (1 µF and above), and add one large capacitor (1000 µF, for example) at the far end of the chain. But the rule of thumb is simple: the longer the chain - the higher supply voltage is needed.

2.7 Chain Implementation

The measurement chain usually consists of small printed-circuit boards (PCBs) connected with cables. Each PCB has a TMP107, a bypass capacitor, a small connector on one side, and a soldered cable with a connector on the other board side. The cable connector allows to easily add or remove devices along the chain to make the debugging process much easier. This simple schematic can be done on a single-layer board. To reduce TMP107 self heating and decrease the temperature resistance to the environment it is recommended to make large pin soldering pads, use boards with increased copper layer thickness, and avoid boards covered with protection stain, if possible. See example of the TMP107 EVM and its associated temperature sensing boards in Figure 5.

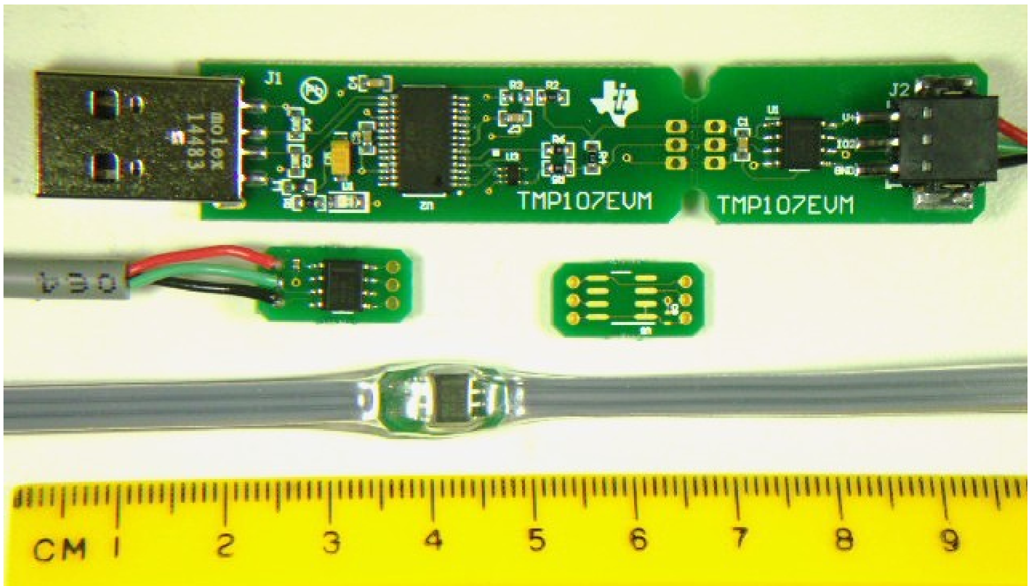


Figure 5. Example of Host Control Board Based on PC USB Port and Coupon Board With TMP107

2.8 Host Control Board

One of the advantages of using the TMP107 is the simple schematic of the host control board. The most popular are the following two hardware options:

- **PC USB port –** This option is very popular due to circuit simplicity and possibility of writing system software with high-level programming languages like C, Visual Basic, or LabView. There are many USB-to-UART devices available today. One such device is the FT232R from FTDI. The board implementation is shown Figure 5 and board schematic in Figure 6. When connected to a Microsoft® Windows® PC, the FT232R enumerates as a serial comm port; therefore, all communication happens using the standard serial port commands. The FT232R IC has an onboard 50-mA, 3.3-V voltage regulator which can be used for the chain supply. It also has a separate pin to set the UART port IO voltage level. This provides an easy method to ensure proper level matching between controller and chain interface. If the Alert signals are used, the FT232R inputs CTS and DSR can be accessed via auxiliary UART commands. (Note the CTS and DSR signals will be inverted when reading from the serial port into PC software.)
  An open drain buffer (U3, Figure 6) is needed to protect the TXD pin in miscommunication case when the host is trying to send data into the chain and the first part of the chain is still sending data to the host. The TMP107 output driver is capable to drive up to 45 mA current and can damage the TXD output if the buffer is not used. A resistor (R3, Figure 6) is needed to limit ESD currents and to attenuate glitches that may occur.
  It is highly recommended to locate the first device of the chain on the control board. This allows easy debugging of hardware and software without worrying about the cable connection to the chain and verifying that communication is working with the first device placed in best condition. It also makes the first TMP107 responsible for the long wire communication to the second device making board design much simpler. Jumper J1 (Figure 6) selects either the 3.3-V output from the FT232R device, 5 V from the USB port directly, or an external supply. It is not recommended to use 5-V supply coming from the USB header as a main chain supply. This voltage is often noisy and since the noise spectrum significantly varies based on the activity of the PC and from one PC to another, it can affect the system precision and stability.

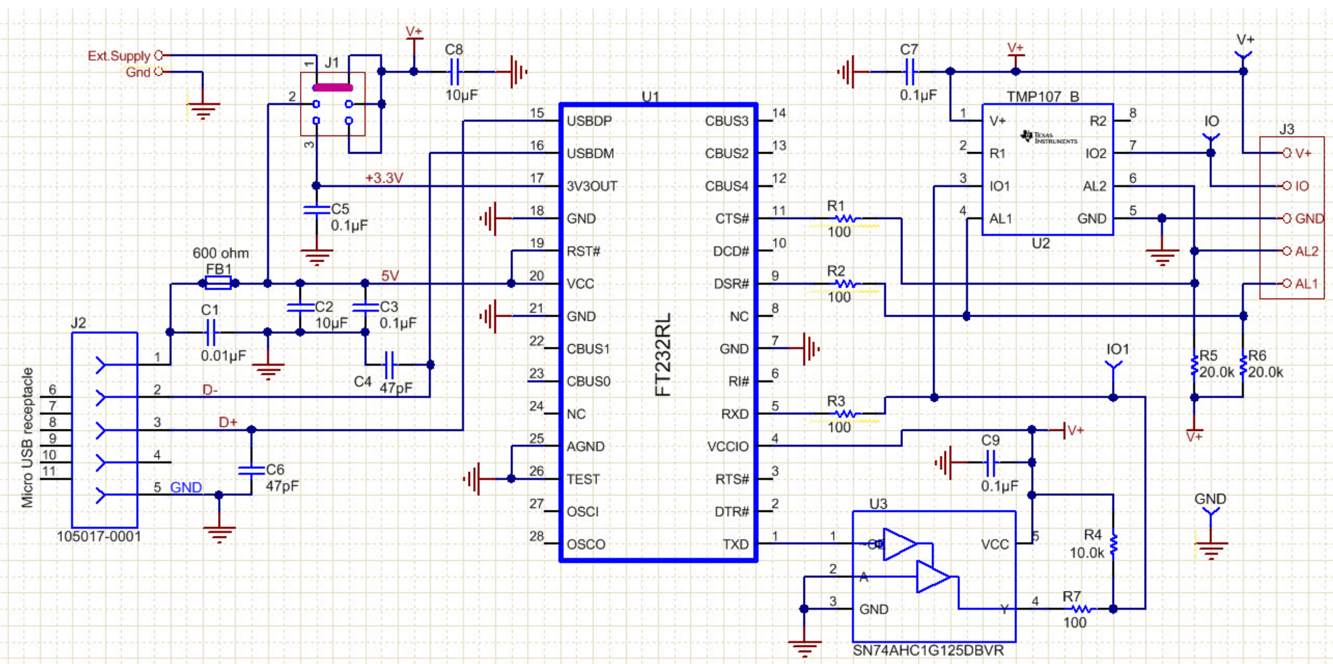


Figure 6. Example USB Port-Based Control Board

- **Microcontroller UART port –** Figure 7 shows TI's MSP432 UART microcontroller port configured to work with the SMAART bus interface. This example uses an even simpler schematic to unite the signals on the SMAART bus and to provide RXD and TXD pin protection. A Schottky diode (D1, Figure 7) is needed to lower the low signal level on the I/O1 pin when the MSP432 is transmitting a logic-level zero. All considerations mentioned in the previous case are true for this schematic too.

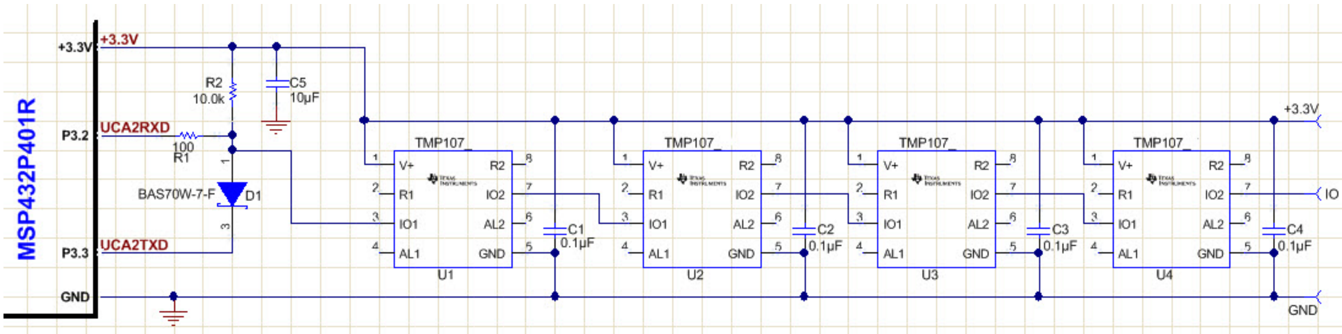


Figure 7. Example Microcontroller-Based Control Board

3 Working With Alert Pins

The main purpose of TMP107 Alert pins is to inform the user that the local temperature is outside of customer's preset range or to control environment heating/cooling system. Alert pins can also manipulate many external devices by using only three SMAART bus wires and by switching ON/OFF the polarity bits in the TMP107 control register.

An Alert pin is an open drain output used with a pullup resistor and can be connected with other Alert pins on other devices to behave as a common Alert. For this purpose, an internal 100-kΩ resistor is already connected to each Alert pin. To activate it, connect R1 to the supply voltage to pull up AL1, and R2 to the supply voltage to pull up AL2. If there is a common Alert line serving a number of parts, it is recommended to use an external pullup resistor located on a control board. In this case the combined pullup resistor value will not change when the number of parts changes. The common Alert signaling line allows the host to be alerted only when the temperatures fall outside of the preset range without having to constantly poll each of the devices on the chain.

The Alert pin's open drain driver behaves like a powerful field transistor for which the saturation current is dependent on the power supply voltage and temperature (see Figure 8). The sink current entering into the Alert pin should not exceed the transistor saturation current value; otherwise the Alert pin output voltage will be unpredictable. Another effect of the Alert pin's large sink current can be the part self-heating, which is described in Section 4.

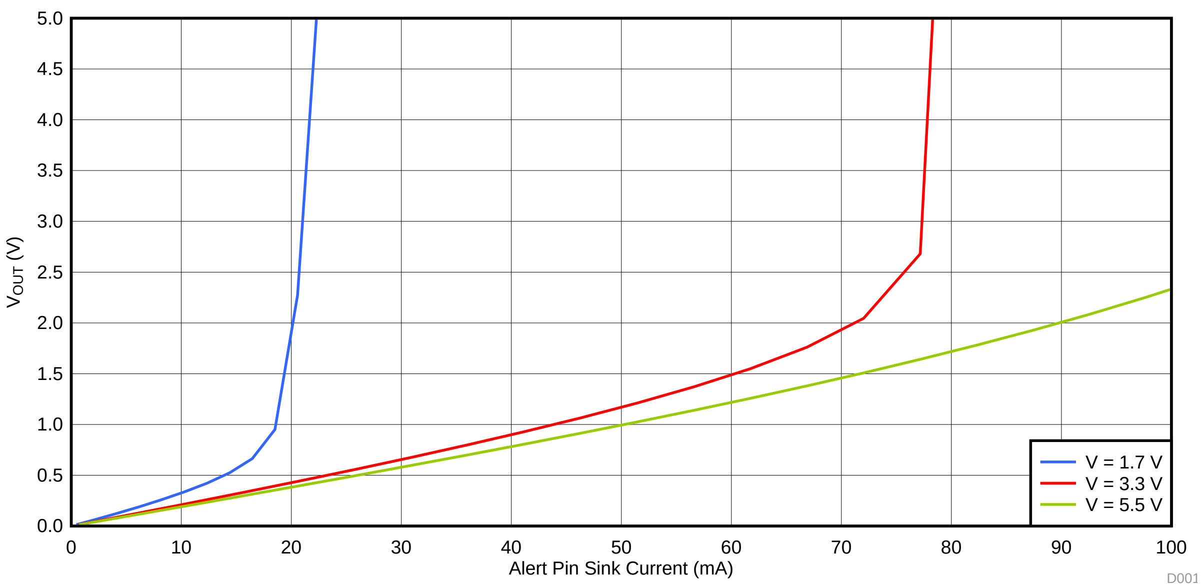
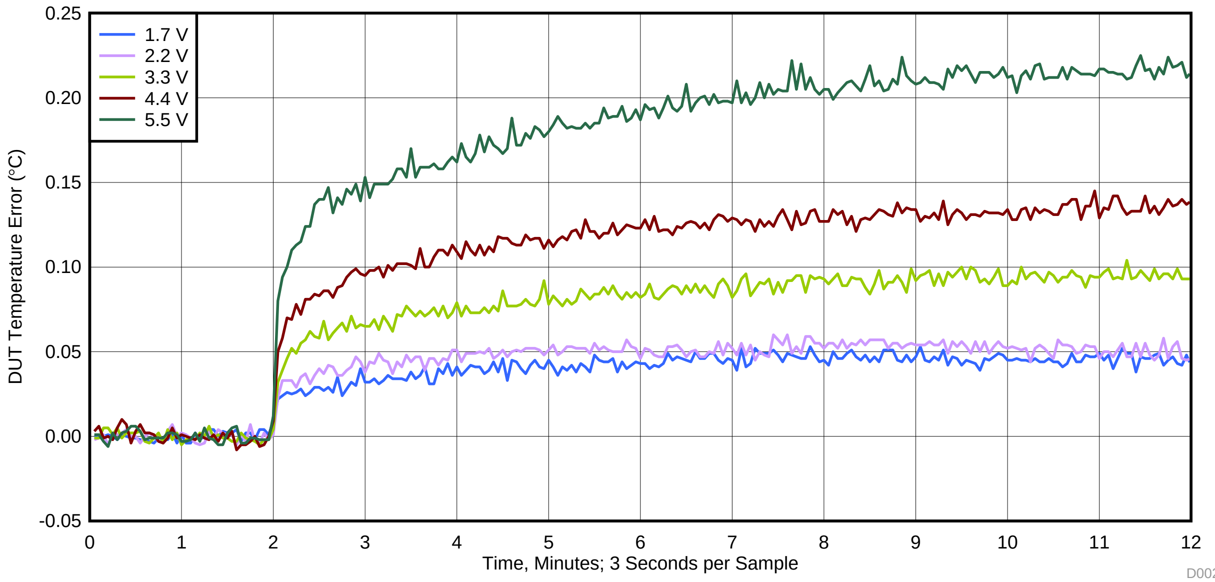


Figure 8. Alert Pin Output Voltage vs Sink Current: Temperature = 25°C

4 Self-Heating Effect

The TMP107 can measure local temperatures up to 62 samples/second while simultaneously transferring data from another device on the chain to the host. All this activity leads to increased power dissipation. Because there exists some thermal resistance between the die and environment, the TMP107 local temperature increases. The TMP107 data sheet temperature precision parameters are specified for situations with minimal power dissipation (one-shot mode with no communication during temperature conversion) and very low thermal resistance to environment. Figure 9 shows the self-heating effect when the part is suddenly switched from a one-shot conversion mode to the 15-ms continuous-conversion mode. In both modes the data reading rate by the host is 1 sample per 3 seconds. For this figure, the part is soldered onto a two-layer PCB with an area 2 cm x 3 cm, mounted horizontally in a “no airflow” environment with an air temperature of 25°C.



On second minute, TMP107 is switched from one shot mode to continuous 15-ms conversion mode. Data is read back every 3 s.

Figure 9. TMP107 Self-Heating Effect vs Supply Voltages: Temperature = 25°C

The self-heating effect is very sensitive to environmental factors. The air temperature, air flow, device orientation (horizontal or vertical), board thickness, stains on the parts, and so forth, impact the self-heating. Therefore, if high measurement precision is required for your system – which precludes you from using a high-voltage power supply – then additional system-level calibration is recommended.

As current flows into the Alert pin, the internal temperature of the device also increases. Figure 10 shows the self-heating effect from one Alert Pin current. The device is located on the same PCB as in the previous case, in the same environment and is in 15-ms continuous conversion mode.

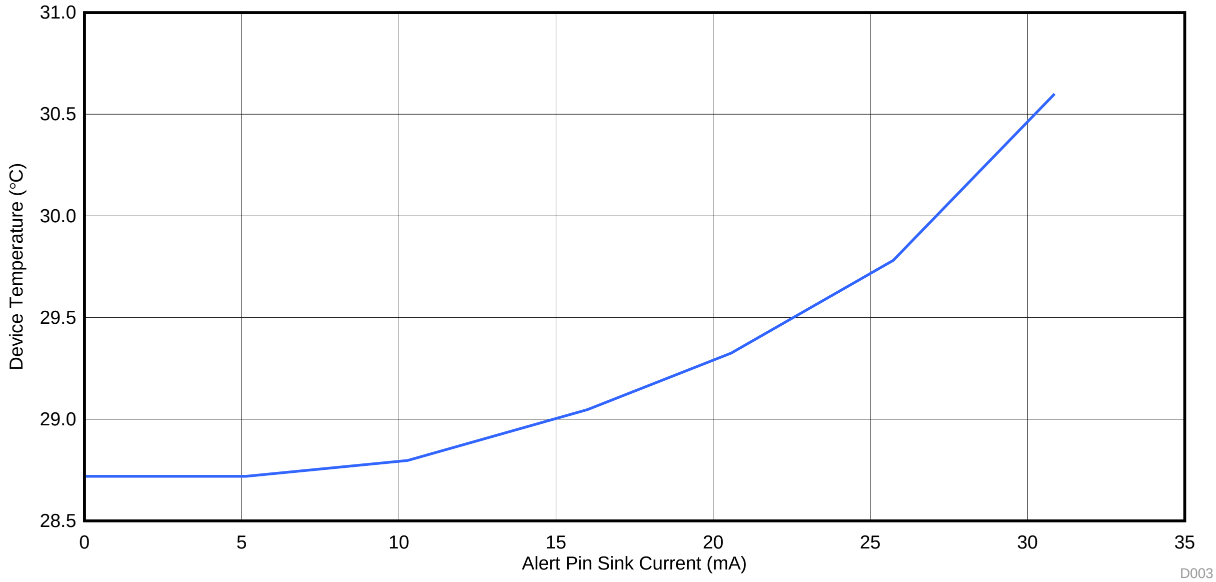


Figure 10. TMP107 Self Heating Effect vs Alert Pin Sink Current. V+ = 3.3 V

5 Chain Initialization

In an ideal case, the chain initialization happens one time when the chain is first used and takes less than one second. After initialization, the addresses are programmed in each device's internal memory and this process does not need to be performed again. On subsequent power-ups, the devices will retain the pre-programmed addresses. In real life, when many TMP107 devices are connected with long cables, complications may occur. Here are some recommendations on how to make chain initializations run smoothly. The chain initialization procedure can be repeated as many times as needed.

1. After the TMP107 chain is assembled but before the power supply is switched on, it is important to verify that all TMP107s are soldered properly; all connectors have a solid connection, and the ground and the power supply lines have the expected resistances. Note there must be no more than 32 TMP107 devices in the chain or the initialization will not occur properly. Also, the initialization procedure cannot finish properly if the I/O2 pin of the last device on the chain is not left floating.
2. Apply the supply voltage to the beginning of the chain. Verify that the voltage at the last device of the chain matches the expected value. If the measuring chain is long and the supply-line resistances are more than a couple Ohms, be aware that the voltage drop over ground and supply line depend on the device’s current consumption in its default condition. This current can be in the range from < 10 µA to 300 µA per part. Verifying the last part supply voltage is an important step because in some cases even if the supply line is broken, the TMP107 chain still can appear to work.
3. Upon initialization, the host issues the *Address Initialize* command with a starting address of one. (Note if there are 32 devices on the chain, the start address should be zero). In response to the command, the first device on the chain programs the address of one into its built-in EEPROM. After 7 ms the EEPROM programming is completed and device one forwards the *Address Initialize* command with address two to the second device on the chain. Immediately afterwards, device one sends an address response byte with a value of one to the host and sets itself into transparent mode to the host. In this transparent mode, device one is ready to forward to the host the address response byte from devices two, three, and so on. The procedure repeats itself sequentially for each device on the chain allowing the host to serially receive the address response byte from each initialized device. In case of an initialization problem, the host analyzes the received addresses and notes the last received address. This address points to the device where the initialization process stopped. During the initialization procedure, all devices along the chain remain in transparent mode (transmitting data to the host) until the address byte from the last device is sent or until a 1.25-s timeout has expired. To avoid bus contention issues, the host should not issue any commands 1.25 seconds after the *Address Initialize* command has been sent. The only way to interrupt the initialization process is to shut down the power supply.

Figure 11 shows an oscilloscope capture of a successful initialization process for a chain with 4 TMP107 devices. The probe is located on the I/O1 pin of the first device on the chain. The first 3 bytes are issued by the host. The four following bytes are response address bytes coming from the TMP107 devices. Intervals of 7 ms appear due to address programming time into the part's EEPROM.

4. The host sends out the *Software Reset* command and the *Last Device Poll* commands after that. The received address of the last device in the chain should match the total number of parts in the chain and then initialization is completed. The next action can be reading the parts temperature or programming the default values into the configuration registers.

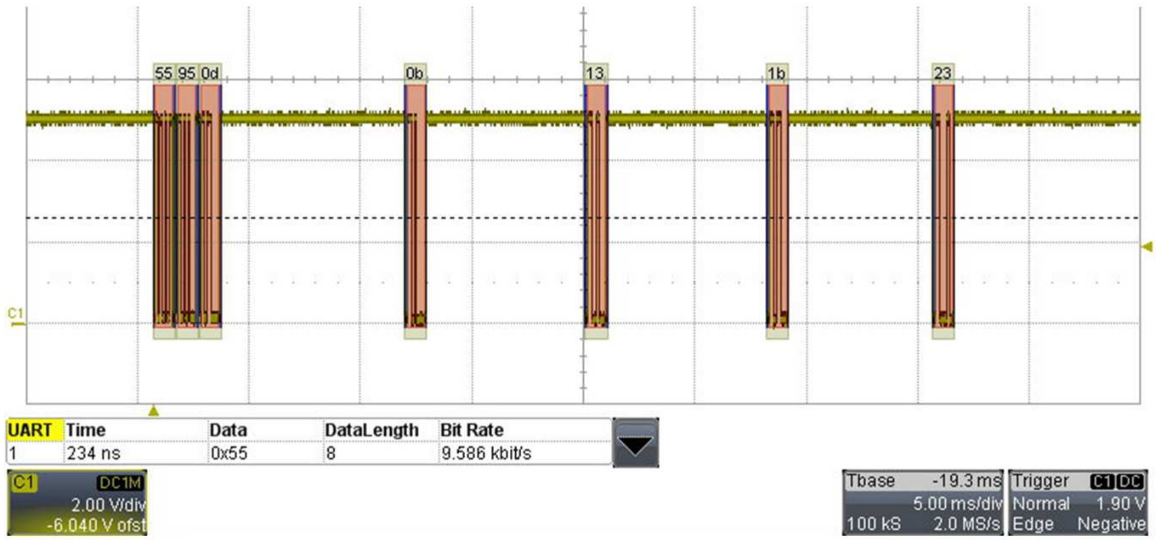


Figure 11. Oscilloscope of 4 Parts Chain Initialization Signal

6 Fixing Chain Problems

To assist in troubleshooting, the following is a list of most common problems that may be experienced during the initialization process or daisy-chain operation:

1. Somewhere the wire connecting the I/O pins of two neighboring devices is broken or gets shorted to the supply line. In the case of initialization, it means that the reported last part number doesn't match the total parts number in the chain. The last reported device address tells where the chain is broken and where the search should start.
2. The wire connecting the I/O pins is grounded. Because the I/O2 pin has a powerful driver and, by default, is in logic level high state, the consumption currents increase by 20 mA to 40 mA. The initialization procedures cannot be finished and the chain will timeout in 1.25 s. There will be no response to the *Last Device Poll* command. Try reading individually from all devices in an incrementing order. The last address to respond to this is the point where the chain is broken.

A convenient way to verify that the TMP107 chain is in good standing is to disconnect I/O1 from the host and apply a clock signal of 10 kHz to 100 kHz to the I/O1 pin of the first device. In a good chain, the clock should go through the all TMP107 devices and appear on the I/O2 pin of the last device in the chain. The clock signal should have the supply voltage amplitude at all devices of the chain, and if any device has an I/O2 output of about 0.7 V below supply, there is a good chance that the power supply connection at that device is broken or unsoldered. The importance of checking this output at each device in the chain is that sequential, fully-connected devices will often accept the attenuated clock signal and boost it back up to full supply strength as a buffer would, so just measuring the final device in the chain may not be enough to detect a faulty connection. The convenience of this debug method is that host commands are not required.

7 Conclusion

The TMP107 allows precise temperature measurement over cables with lengths over 100 m and up to 32 devices. For most cases, a very simple control board and a cable with only three conductors is needed. Alert pins can be used to inform the host that the temperature is out of the preset range, eliminating the need for constant data reads. Additionally, Alert pins can be used to control external devices located along the chain. To achieve the device's best performance, follow the recommendations in the data sheet (SBOS716A) and this application note.

Revision History

Changes from Original (September 2015) to A Revision **Page**

- Beginning in the *Introduction*, the wording of the entire document has been improved. 2
- Changed board photo. 7

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265