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TUTORIAL 4690

Important Design Considerations for Digital Thermometers

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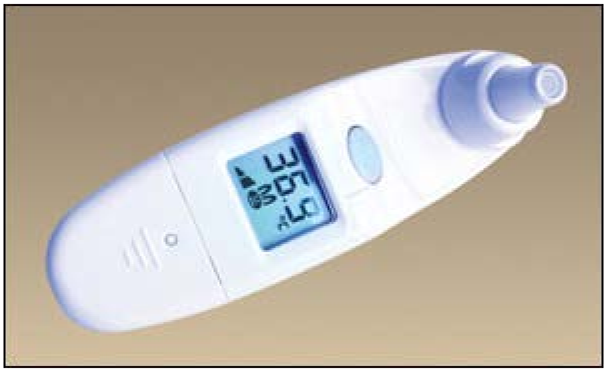
Abstract: This application note is an introduction to the types of digital thermometers and the basic concept of how thermistors and thermopiles calculate temperature. The use of natural logs versus lookup tables, the trade-offs designers make for faster calculation and accuracy, and the various components needed for a digital thermometer are also discussed.

Overview

A medical thermometer measures the temperature of the human body over a small temperature range centered around 37°C. Digital thermometers have been replacing mercury stick thermometers over the past 10 to 15 years due to new technologies that provide faster, more convenient measurements and also the environmental hazard of mercury in legacy thermometers. Probe and ear types are the two main digital thermometers on the market, with temple and forehead types emerging as other alternatives. The probe type is used in the same way as a traditional mercury stick thermometer and measures oral, rectal, or sometimes armpit temperatures. The ear type is a noncontact thermometer and measures the infrared energy radiated from the ear canal. The temple and forehead types are usually contact thermometers and measure the infrared energy radiated from the temple or forehead to determine body temperature.

Probe-type digital thermometer



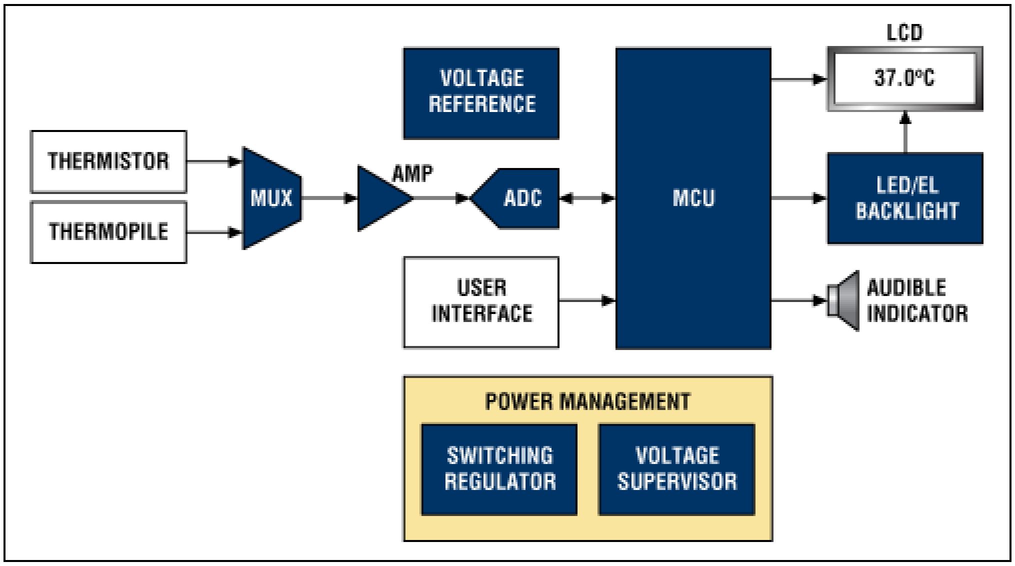
Ear-type digital thermometer

Forehead-type digital thermometer

Measurement

Probe-type thermometers usually use a thermistor in the probe tip to measure the temperature. A thermistor is a resistor whose resistance varies with temperature. A voltage-divider, composed of a thermistor in series with a precision resistor, is driven by a reference voltage and measured either single-ended at the midpoint or differentially across the thermistor. Additional precision resistors are sometimes used along with the same reference voltage in a separate circuit to eliminate errors caused by the reference voltage drifting over time. If the thermistor-divider circuit and the analog-to-digital converter (ADC) use the same reference voltage, then the precision calibration resistors are not needed. In such a case, the reference voltage is eliminated from the temperature calculation, thus easing the reference requirements.

A thermistor requires a calculation involving a natural log, which can consume a lot of computational cycles and code space in the microcontroller. Alternatively, a lookup table can be used to calculate the temperature, an approach that usually results in a faster calculation and more compact code. However, there is a trade-off between the size of the table and the interpolation error between table entries where increasing the number of points in the table will decrease the interpolation error. An ADC with 12 bits or more is sufficient for this measurement, and a gain stage is optional depending on the measurement range and desired accuracy.



Functional block diagram of a digital thermometer. For a list of Maxim's recommended solutions for digital thermometer designs, please go to: www.maximintegrated.com/thermometer.

Ear-type thermometers use thermopiles and thermistors to measure the temperature. A thermopile is composed of a number of thermocouples connected in series to increase the output voltage. Thermopiles generate an output voltage proportional to the energy absorbed. They use the principle of black body radiation, whereby any object above absolute zero will radiate energy; in this case, the infrared spectrum is being measured. The infrared radiation from the ear canal is focused and directed onto a thermopile, the low-level voltage output of which is amplified and converted by an ADC with 12-bit resolution or more. The thermistor measures the cold-junction temperature of the thermopile, and both the thermopile and thermistor measurements are used to calculate the body temperature.

Temple- and forehead-type thermometers use the same technology to measure infrared radiation as ear-type thermometers—they just measure it from a different location on the body. A specialized forehead thermometer, called a temporal thermometer, measures the temperature of the temporal artery in the forehead and the ambient temperature, and then uses these temperatures to calculate the body temperature.

Digital thermometers are much faster than mercury thermometers. Sometimes, the thermistor is preheated so that it gets to the final temperature faster. Often, predictive algorithms are used to determine the temperature. Instead of waiting for the temperature sensor to settle completely, the algorithm predicts what the final temperature will be based on the response during the beginning of the measurement cycle and the characteristics of the thermistor.

Power Management

Probe-type thermometers typically use a coin-cell battery or two button-cell batteries, and ear-type thermometers usually use a coin-cell battery or two AAA alkaline batteries. Both thermometer types can run either directly from the battery or from a step-up switching regulator, depending on the circuitry chosen.

Some forehead-type thermometers use 9V transistor batteries, thus requiring a step-down switching regulator or linear regulator. Low shutdown current and the ability to turn the switching regulator off when not in use are critical to long battery life in this application. A voltage supervisor can monitor the battery and provide a reset to the microcontroller if the battery falls below the microcontroller's safe operating voltage. Additionally, an extra input to the ADC can measure the battery so that the user is given a warning that the battery will soon need to be replaced.

Audible Indicators

Audible indicators are used to indicate when the thermometer is ready to be used and/or when the measurement is complete. This is usually a beeper or buzzer driven either single-ended or differentially from a microcontroller's timer outputs.

Display and Backlighting

All digital thermometers use a simple LCD display that can be driven by a microcontroller with an integrated driver. Backlighting can be implemented by using either a single white LED (WLED) driven by a discrete LED driver or an electroluminescent (EL) sheet and driver.

Related Parts		
MAX11600	2.7V to 3.6V and 4.5V to 5.5V, Low-Power, 4-/8-/12-Channel, 2-Wire Serial 8-Bit ADCs	Free Samples
MAX11605	2.7V to 3.6V and 4.5V to 5.5V, Low-Power, 4-/8-/12-Channel, 2-Wire Serial 8-Bit ADCs	Free Samples
MAX1162	16-Bit, +5V, 200ksps ADC with 10µA Shutdown	Free Samples
MAX1227	12-Bit 300ksps ADCs with FIFO, Temp Sensor, Internal Reference	Free Samples
MAX1229	12-Bit 300ksps ADCs with FIFO, Temp Sensor, Internal Reference	Free Samples
MAX1231	12-Bit 300ksps ADCs with FIFO, Temp Sensor, Internal Reference	Free Samples
MAX1393	1.5V to 3.6V, 312.5ksps, 1-Channel True-Differential/2-Channel Single-Ended, 12-Bit, SAR ADCs	Free Samples
MAX1396	1.5V to 3.6V, 312.5ksps, 1-Channel True-Differential/2-Channel Single-Ended, 12-Bit, SAR ADCs	Free Samples
MAX1415	16-Bit, Low-Power, 2-Channel, Sigma-Delta ADCs	Free Samples
MAX1416	16-Bit, Low-Power, 2-Channel, Sigma-Delta ADCs	Free Samples
MAX1574	180mA, 1x/2x, White LED Charge Pump in 3mm x 3mm TDFN	
MAX1722	1.5µA I_Q, Step-Up DC-DC Converters in Thin SOT23-5	
MAX1724	1.5µA I_Q, Step-Up DC-DC Converters in Thin SOT23-5	Free Samples
MAX1832	High-Efficiency Step-Up Converters with Reverse Battery Protection	
MAX1835	High-Efficiency Step-Up Converters with Reverse Battery	

	Protection	
MAX1848	White LED Step-Up Converter in SOT23	Free Samples
MAX1916	Low-Dropout, Constant-Current Triple White LED Bias Supply	Free Samples
MAX1947	Low Input/Output Voltage Step-Up DC-DC Converter with Active-Low RESET	Free Samples
MAX1984	Ultra-Efficiency White LED Drivers	Free Samples
MAX1986	Ultra-Efficiency White LED Drivers	Free Samples
MAX8569	200mA Step-Up Converters in 6-Pin SOT23 and TDFN	Free Samples
MAX8625	High-Efficiency, Seamless Transition, Step-Up/Down DC-DC Converter	Free Samples
MAXQ2000	Low-Power LCD Microcontroller	Free Samples
MAXQ2010	16-Bit Mixed-Signal Microcontroller with LCD Interface	Free Samples

More Information
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