TI’s sensing technology for smart home appliance
Sensing in smart home

Smart connection

Smart HMI
Making an easy way to communication

Smart sensing
Monitoring the environment at home
TI is sensing the world

**Temperature**
- Temperature Sensors
- Passive Infrared
- Temperature & Humidity

**Current / Power**
- Current Shunt
- Magnetic

**Humidity**
- HDC Humidity Sensor Family

**Proximity**
- Hall
- Inductive
- Ultrasonic
- Capacitive

**Pressure**
- Precision Signal Conditioning

**Chemical**
- Optical
- Analog Front Ends

**Material**
- Inductive
- Optical
- Ultrasonic
- Capacitive

**Position**
- Ultrasonic
- Hall Effect
- Inductive
- Optical
- Current Shunt
- Capacitive

**Light**
- 3D Time of Flight
- DLP
- Ambient Light (ALS)

**Occupancy**
- Ultrasonic
- Passive Infrared
- 3D Time of Flight

**Gas / Fluid**
- Electrochemical & NDIR
- Analog Front Ends
- Ultrasonic
- Capacitive

**Bio-sensing**
- Pulse Rate
- Pulse Oximetry
- Body Composition
- Bio Potential
- Optical Scanning (DLP)
Agenda

- Inductive sensing
- Humidity sensing
- 3D-ToF
- Capacitive sensing
- Temperature sensing
Inductance-to-digital converters (LDCs) for inductive sensing
Key inductive sensing applications

Inductive sensing solutions
- Target
- Conductor
- PCB coil
- Inductance-to-digital
- LDC chip

Target applications
- Switches
- Knobs
- Buttons
- Keypads
- Encoders
- Rotation sensing
- Metal detection

Key system feature
- Full metal
- Full glass
- Contactless sensing
- Low-cost sensor

TI’s LDC Converters
- New LDCs: Multi-channel, easy-to-use
  - LDC1312/4: 2-/4-ch, 3.3-V, 12-bit
  - LDC1612/4: 2-/4-ch, 3.3-V, 28-bit
  - LDC 8051: 2-ch, On/Off switcher
Two parameters change as conductive plate enters the inductor’s magnetic field:

1) Resonance impedance (Rp)
2) Inductance (L)
System example --- ToM buttons for kitchen ventilator
Touch-on-Metal, Touch-on-Plastic, Touch-on-Glass

No touch:
Flat metal surface: no deflection

Finger light touch/press:
Metal surface deflects by ~5μm  ✓ Can be detected with LDC

Button deflection depends on:
• Type of metal
• Thickness of metal
• Diameter of button
• Etched pattern beneath

Uses
• Buttons, pressure/weight/force sensing

Target end equipment
• Industrial/white goods: refrigerator, range hoods, dishwashers, washing machines, thermostat, weigh scales, EPOS/POS
• Automotive: buttons on infotainment systems or steering wheels
• Consumer: cameras, mobile devices, weigh scales

System benefits
• Programmable threshold for different sensitivities and multi-function buttons
• One continuous grounded sheet of metal – sealed to water/oil/dirt, immune to EMI
• Works with gloves
• No moving parts – Haptics may be integrated
LDC1312/4
2-/4-ch, 3.3-V, 12-bit LDCs for inductive sensing

Features
- Multiple channels:
  - 2-ch: LDC1312, 4-ch: LDC1314
- Well matched channels w/ 13.3 ksps max. sampling rate
- Sensor frequency range: 1kHz to 10 MHz
- Power consumption:
  - Active: 540uA/ch (LDC1314)
  - Sleep: 35uA, Shutdown: 200nA
- Package
  - LDC1312: 12-pin WSON
  - LDC1314: 16-pin WQFN

Applications
- Knobs in consumer, appliance, & automotive
- Incremental linear and rotational encoders
- Buttons in home electronics, wearable, & factories
- Keypads, HMI, and POS in factories & appliances
- Slider buttons in consumer
- Metal detection in industrial & consumer
- Flow meters in consumer and appliances

Benefits
- Up to four channels enables multiple sensors in minimum system size, cost, and power
- Well-matched channels allow for easy compensation of environmental changes and aging
- Easy-to-use: sensor just needs to be within 1kHz and 10 MHz, simplifying and accelerating prototyping
- Large sensor frequency range supports very small PCB coils, supporting space-constrained applications
How to start inductive sensing --- TI design

Use cases

Dials
- Removable knob (TIDA-00508)
- 1° dial (TIDA-00508)
- Incremental encoder (TIDA-00615)

Wheels
- Event counter (TIDA-00851-LDC0851)
- Flow meter

Knobs
- Touch-on-aluminum (TIDA-00314)
- Touch-on-stainless steel (TIDA-01102)
- Snapdome buttons (TIDA-00509)
- Smartphone/wearable buttons

Buttons
How to start inductive sensing — WEBENCH®

Full WEBENCH® support!!

http://www.ti.com/lsds/ti/analog/webench/inductive-sensing.page
Stainless steel inductive touch
TIDA-01102

Features

- 0.6mm, 304 annealed stainless steel, #4 Finish
- Printed or etched patterns on the surface are possible
  - Outer frame makes improves button appearance
  - Inner frame is the psychological button area, encouraging user to push in the center
- GUI to provide button push and force sensing information
- Adjustable sensitivity
- Includes Audio and Haptics feedback
- Product: LDC1614

Benefits

- Replaces mechanical buttons with high-resolution inductive-sensing based touch-on-metal detection
- One continuous sheet of metal sealed and grounded against Electromagnetic Interference (EMI), water, oil, dirt, and other contaminants
- Works with gloves, underwater (if sealed), and in harsh environments
- Can be used for pressure and multi-step button press sequences

Markets & Applications

- Industrial/white goods: refrigerator, range hoods, dishwashers, washing machines, thermostat, weigh scales, EPOS/POS
- Automotive: buttons on infotainment systems or steering wheels
- Consumer: cameras, mobile devices, wearables

http://www.ti.com/tool/TIDA-01102
Knob-on-glass demo
Rotational sensing on glass surface using LDC1314

Features

- Instant absolute position detection on start-up
- Using LDC1314 and MSP430
- Easy-to-use and scalable rotational sensing design
- Standard FR4 PCB design allows for low cost system design
- Uses one-turn simple calibration
- Achieves 5° accuracy - 10° steps displayed in GUI
- Micro USB connection and clean GUI on the PC to display the angle and select settings
- Product: LDC1314

Benefits

- Standard FR4 PCB process
- Off-the-shelf parts
- No look-up table is required
- Great stability and consistency
- Easily attach the knob on glass surface with a magnet
- Easy one-turn calibration methods suits multiple applications

Markets & Applications

- Rotational sensing in Automotive: Knobs for HVAC & Infotainment
- Rotational sensing in White Goods: Knobs on washing machines, dryers, coffee machines, cooktops etc.
- Rotational sensing in Industrial: HMI knobs
LDC0851 flowmeter reference design
TIDA-00851

Features
- Contactless, non-magnetic approach to impeller-based flowmeter design using LDC technology
- Easy-to-use and scalable event counting design
- High speed sensing up to 4000 events per second
- Temperature stable switching operation
- Simple high/low output easily converted to rotational speed with MSP430
- LCD readout to easily display real time flow rate

Benefits
- No magnets needed
- Sensor can be placed on the outside of the container remotely with respect to LDC0851 device
- Safe for food-grade applications
- No calibration required
- Insensitive to environmental hazards such as dirt, oil, dust, moisture

Markets & Applications
- Event counting in Automotive: Wheel speed sensing
- Event counting in White Goods: Flowmeters in coffee machines, fan speed sensing, impeller-based flowmeter
- Event counting in Industrial: Water metering

Tools and Resources
- Design Files & User guide
- Device Datasheets:
  - LDC0851
  - MSP430F5500
  - TPD2E001
  - LP5951

Humidity sensing
Humidity sensors are EVERYWHERE

- **HDC** humidity sensor is used in dryer to monitor the exhaust air to optimized power consumption and dry level.
- **HDC** humidity sensor is used in microwave oven to optimize the output power.
- **HDC** humidity sensor is used in refrigerator to monitor the chilling point.
- **HDC** humidity sensor is used in dryer to monitor the exhaust air to optimized power consumption and dry level.

Humidity sensors are EVERYWHERE.
Dust falls on top of the sensing element reducing the performances until the complete blockage of the sensor.

Some competitors suggest to cover the sensor with a filter/grid (very expensive more than the device itself).

**HDC100x intrinsic dust resistant structure**

- HDC100x has the sensing element on the bottom part of the sensor.
- Sensing element is intrinsically protect from the dust that falls on the top part.
HDC1080
Humidity & temperature sensor

Features
- Relative Humidity Range: 0% to 100%
- Humidity Accuracy: ±2%
- Supply Current (Measuring): 180uA
- Avg Supply Current (@1sps): 1.2uA
- Temperature Accuracy: ±0.2°C
- Temperature Range (Operating): -20°C to +85°C
- Temperature Range (Functional): -40°C to +125°C
- Operating Voltage: 3V to 5V
- Package: 6 pin DFN HDC1080 (3mm x 3mm)

Benefits
- Completely integrated humidity and temperature IC provides guaranteed performance
- Fully calibrated sensor enables quick time-to-market
- Very low power consumption
- Small package size supports compact designs

Applications
- HVAC
- White goods (dryer, fridge, microwave, dishwasher)
- Printers
- Handheld Meters
- Camera Defog
- Smart Thermostats and Room Monitors
- Medical Devices
Roadmap

Supply voltage = 2.7V - 5.5V

HDC1080
2.7-5.5V
DFN-6
3x3mm

HDC1010
2.7-5.5V
WCSP
1.6x2.04mm

HDC2080
1.7-3.6V
DFN-6
3x3mm

HDC2080
1.7-3.6V
WCSP
1.5x1.5mm

Legend
Production
Develop

Supply voltage = 1.6V - 3.6V

Texas Instruments
How to start humidity sensing --- TI design

**TI Designs**

**TIDA-00374** Humidity & Temp Sensor Node for Star Networks Enabling 10+ Year Coin Cell battery life

- Use of Nano-Power System Timer to Duty-Cycle the System Results in 10+ Year Battery Life from CR2032 Coin Cell
- Configurable System Wakeup Interval
- Extremely Low Off-State Current (183 nA for 59.97 seconds)
- Ultra Low On-State Current Due to Low Active Processor and Radio Transmit Currents (4.04 mA for 30 ms)
- ±2% Relative Humidity Accuracy
- ±0.2°C Temperature Accuracy

**TIDA-00484** Humidity & Temp Sensor Node for Sub-1GHz Star Networks Enabling 10+ Year Coin Cell battery life

- Use of Nano-Power System Timer to Duty-Cycle the System Results in 10+ Year Battery Life from CR2032 Coin Cell
- Configurable System Wakeup Interval
- Extremely Low Off-State Current (270 nA for 59.97 seconds)
- Ultra-Low On-State Current Due to Low Active Processor and Radio Transmit Currents (3.376 mA for 30 ms)
- ±2% Relative Humidity Accuracy
- ±0.2°C Temperature Accuracy

**TIDC-CC2650STK-SENSORTAG**

- Support for 10 low-power sensors, including ambient light, digital microphone, magnetic sensor, humidity, pressure, accelerometer, gyroscope, magnetometer, object temperature and ambient temperature
- Ultra-low power, with years of battery life from a single coin cell battery and enabling battery-less applications through the high-performance ARM® Cortex®-M3 CC2650 wireless MCU.
- Multi-standard support enables ZigBee or 6LoWPAN through a simple firmware upgrade

**TIDA-00524** Ultralow Power Multi-sensor Data Logger with NFC Interface Reference Design

- 5 Year Battery Life on a CR-2032 coin cell
- RF430 NFC Dynamic Tag Type 4B Compliant Communication
- NFC configuration and data read back
- Multiple Sensor Options
  - Temperature (TMP112)
  - Ambient Light (OPT3001)
  - Humidity + Temperature (HDC1000)
- Up to 64KB of non-volatile FRAM memory
- Data is Date/Time stamped using RTC

---

**Texas Instruments**
Humidity & temperature sensing node for star networks enabling 10+ year coin cell battery life

TI Designs Number: TIDA-00374

Solution Features

- HDC1000 humidity and temp digital sensing
- Detect relative humidity from 0 – 100% ±3% accuracy
- Detect temp. at ±0.2°C (nominal) over 5°C to 60°C
- Configurable sleep time
- Power management partitioning for extremely low power consumption

Solution Benefits

- Small, integrated solution size due to the integrated sensor and radio SoC
- Long Battery Lifetime: Designing for 10+ years off a single CR2032 coin cell battery

Tools & Resources

- <TIDA-00374 Tools Folder>
- <User Guide>
- Design Files: Schematics, BOM, Gerbers, Software, and more
- Device Datasheets:
  - HDC1080
  - TPL5110
  - TS5A3160
  - CC2x

![Diagram](image-url)
3D Optical Time of Flight (ToF) Solutions
Typical applications
3D technologies - overview

**Stereoscopic**
- Two or more cameras at different angle retrieve RGB images
- Image processing SW identifies common feature, triangulates and finds depth

**Structured**
- IR source projects patterns on object. IR sensor records the deformation of pattern
- Image is processed in software to calculate depth

**Time Of Flight**
- Modulated light is sent out and the phase difference between Transmit & Received signal is measured
- Phase delay is used to calculate the depth

<table>
<thead>
<tr>
<th></th>
<th>Stereoscopic vision</th>
<th>Structured light</th>
<th>Time of Flight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed pattern</td>
<td>Programmable Pattern (DLP)</td>
<td></td>
</tr>
<tr>
<td><strong>Depth accuracy</strong></td>
<td>low</td>
<td>medium (mm to cm)</td>
<td>high (um to mm)</td>
</tr>
<tr>
<td><strong>Scanning Speed</strong></td>
<td>medium</td>
<td>Slow</td>
<td>Slow/medium</td>
</tr>
<tr>
<td><strong>Distance Range</strong></td>
<td>Mid range</td>
<td>Very short to mid range</td>
<td>Very short to mid range</td>
</tr>
<tr>
<td><strong>HW cost</strong></td>
<td>low</td>
<td>middle</td>
<td>middle/high</td>
</tr>
<tr>
<td><strong>SW complexity</strong></td>
<td>High (correspondence prob)</td>
<td>low/middle</td>
<td>middle/high</td>
</tr>
<tr>
<td><strong>Low Light Performance</strong></td>
<td>weak</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td><strong>Outdoor Performance</strong></td>
<td>good</td>
<td>weak/fair</td>
<td>weak/fair</td>
</tr>
</tbody>
</table>
3D technologies solutions

Programmable Structured Light
- Camera
- Illuminator
  - LEDs
  - LED Driver
- User defined Patterns
- Captured Image
- Digital Micromirror (DMD)
- DLP Controller

Time of Flight (ToF)
- Illuminator
  - LEDs
  - LED Driver
- ToF Sensor
- ToF AFE
- ToF Controller

Application Processor or PC
- Point Cloud Generation SW
- Video Analytics / Middleware SW
- Application SW

Offset Images
- Stereoscopic
- Identificatio & Tracking

Captured Image
- Point Cloud
Distance measured by emitting a modulated light and measuring phase delay of returned light
## System example --- cleaning robot

### Key Care-About

<table>
<thead>
<tr>
<th>Cleaning Around Pets, Cable Cords and Furniture</th>
<th>320 x 240 pixels @ 60fps sufficient to see chair legs and small wires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum More Efficiently</td>
<td>320x240 pixels @60fps with good depth resolution sufficient for room mapping and to execute planned path. Lower cost 80x60 model also available</td>
</tr>
<tr>
<td>Self Docking and Recharging</td>
<td>High pixel count and depth enable automatic alignment for docking and self-recharge</td>
</tr>
<tr>
<td>Easy to Program and Interact</td>
<td>3D-TOF enable segmenting of human (foreground) from background using depth, and then recognize hand and body gesture from the foreground image</td>
</tr>
<tr>
<td>Operate in Dark</td>
<td>Active IR illumination allows operation in both daylight and in dark</td>
</tr>
</tbody>
</table>

### Why 3D-TOF

<table>
<thead>
<tr>
<th>Potential Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereo Vision</td>
</tr>
<tr>
<td>Structured Light</td>
</tr>
<tr>
<td>3D Time-of-Flight (3D-TOF)</td>
</tr>
<tr>
<td>LiDAR</td>
</tr>
<tr>
<td>Ultrasound</td>
</tr>
</tbody>
</table>
OPT8241/OPT9221 system diagram

Driver

OPT8241
Sensor
QVGA

Timing and Control

OPT9221
TFC
Controller

DDR2
&
optional flash

Power
Management

Depth Map
Output
CMOS

I2C control

IR Illumination

Lens

Digital raw phase out
## OPT8241/OPT9221 DepthSense™ chipset

<table>
<thead>
<tr>
<th>Sensor: OPT8241</th>
<th>TOF Controller: OPT9221</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Measures Phase with QVGA (320x240) resolution</td>
<td>• QVGA TOF Controller + Phase processing engine</td>
</tr>
<tr>
<td>• 1/3” Optical Format</td>
<td>• Output Interface: DVP (CMOS Parallel) or SSI</td>
</tr>
<tr>
<td>• Up to 120fps frame rate</td>
<td>• I2C Slave control interface</td>
</tr>
<tr>
<td>• Integrated Functions</td>
<td>• Depth Output Data:</td>
</tr>
<tr>
<td>– Global Reset</td>
<td>– 12-bit Phase</td>
</tr>
<tr>
<td>– Global Shutter</td>
<td>– 12-bit Confidence (Signal Strength)</td>
</tr>
<tr>
<td>– Dynamic Region of Interest</td>
<td>– 4-bit Ambient</td>
</tr>
<tr>
<td>– Dynamic Illumination control</td>
<td>• Integrated Functions</td>
</tr>
<tr>
<td>• 8.75 mm x 7.85mm Optical BGA-78 package</td>
<td>– Pixel Saturation Detection</td>
</tr>
<tr>
<td>– IR pass filter (820nm to 865nm)</td>
<td>– Phase De-aliasing</td>
</tr>
<tr>
<td>• Operating Temperature: 0°C to +70°C</td>
<td>– Depth Calibration</td>
</tr>
</tbody>
</table>

**Sensor:**
- **Sensor:** OPT8241
- QVGA TOF Controller + Phase processing engine
- Output Interface: DVP (CMOS Parallel) or SSI
- I2C Slave control interface
- Depth Output Data:
  - 12-bit Phase
  - 12-bit Confidence (Signal Strength)
  - 4-bit Ambient
- Integrated Functions:
  - Pixel Saturation Detection
  - Phase De-aliasing
  - Depth Calibration
- 9-mm × 9-mm BGA-256
- Operating Temperature: 0°C to +85°C
Deliverables

- Complete evaluation kit including LED illumination, Lens, Sensor and TFC. USB Interface. Comes with driver, documentation, schematics, layout and BOM list

- 3D-Explorer® Software allows register control and depth map visualization. Win7 & Linux compatible

- TOF Design whitepapers and app notes available from TI
People counting using 3D Time-of-Flight for demand controlled ventilation ref. design

**TI Designs Number: TIDA-00750**

### Solution Features
- **Accuracy:** > 90%
- **Sensor Resolution:** 320 x 240 (QVGA) Array of ToF Pixels
- **Wide Field of View:** H74° x V59.3°
- **Fast Response Time:** Occupancy data available in real-time
- **Being Independent of ambient light, 3D ToF camera can see in the dark with Auto-Illumination:**
  - Four NIR Lasers provide large illumination area
  - Short diffused laser pulses inherently eye-safe

### Solution Benefits
- **No Moving Parts or Periodic Calibration required**
- **Save energy and energy cost and offers better indoor air quality by controlling the HVAC system based on occupancy**
- **Monitor people for safety, security, or control without infringing on their privacy**
- **Distance thresholds can ignore pet’s motion in residential applications**

### Tools & Resources
- **TIDA-00750 Tools Folder**
- **User Guide**
- **Device Datasheets:**
  - OPT8241
  - OPT9221
  - AM4379
  - OPT8241-CDK-EVM
  - MYIR AM437x Rico Board
Capacitive-to-digital converters (FDCs) for capacitive sensing
Key capacitive sensing applications

Liquid level sensing

Markets
- White goods
- Automotive
- Medical

Detect liquid level in container

Proximity & simple gesture sensing

Markets
- White goods
- Industrial
- Automotive
- Personal electronics

Detect presence, simple gestures

Collision avoidance

Markets
- Industrial
- Automotive

Detect object in path of motion
Capacitive sensing ---- basic physics

\[ C = \frac{\varepsilon_o \varepsilon_r A}{d} \]

- \( \varepsilon_o \): Permittivity of free space (8.854 x 10^{-12} \text{ F/m})
- \( \varepsilon_r \): Dielectric constant of material
- \( A \): Area of plate
- \( d \): Distance between plates

Change in capacitance is dictated by \( \varepsilon_r \), dielectric constant of the material if plate area and distance between plates are kept constant → Parallel plate capacitor

- Equation above can also be used to estimate capacitance for fringing field applications.

Electric flux density plot

- Shows the density of the electric field lines
- Field lines within the inner edges of the plates dominate the capacitance measurements (purple region)
### TI cap-to-digital vs traditional cap-to-digital

#### FDCXXXX

**Oscillation-Based Measurement**
- High-Q narrowband bandpass filter
- Strong noise rejection → Immune to noise

**Charge-Based Measurement**
- Wideband input/antenna
- Noise aliased in-band after sampling → Highly susceptible to noise

#### Feature | Benefits
--- | ---
1 | EMI Resistant
   - Narrow band architecture eliminates unwanted noise and interferences: ≤0.41fF noise with fluorescent lamp
2 | Fast sample rate
   - Up to 13.3Ksps sample rate enables duty cycling for low-power applications
3 | Highest capacitive sensing range
   - 250nF range easily allows compensation of changing conditions
4 | Low-cost, flexible sensor
   - Sensors are metal strips, wires, or PCB traces, enabling flexible designs

---

**Example: Time-based/Discharge**
System example --- level detection for coffee machine

**Uses**
- Measure liquid level in a container, measure flow rate

**Target end equipment**
- White goods: coffee maker, refrigerator
- Automotive: fuel level, washer fluid level, coolant level
- Industrial: process control, drug pens, insulin pumps

**System benefits**
- Low-cost level sensor
- Can achieve 0.5% level accuracy, robust to interference

**water level coffee machine auto-injectors**
- Sensor to obstacle (human) distance: 2mm
- System solution: 3 electrode (1 level + 2 reference)
- Full-scale: 50mL, resolution: 0.2mL
# FDC2212/4

## 2-/4-ch, 3.3-V, 28-bit FDCs for Capacitive Sensing

### Features

- **Number of channels / Packages:**
  - 2 (FDC2x12) / 12-pin QFN
  - 4 (FDC2x14) / 16-pin QFN
- **Maximum Input Capacitance:** 250nF (@10kHz with 1mH inductor)
- **Maximum output rate (one channel):** 13.3ksps (FDC211x)
- **Resolution:** 28-bit
- **Sensor excitation frequency:** 10kHz to 10MHz
- **Supply voltage:** 2.7V to 3.6V
- **Power consumption:**
  - Active: 2.1mA
  - Low-Power Sleep Mode: 35μA
  - Shutdown: 200nA
- **Interface:** I2C

### Benefits

- **Two and four channels enables multiple sensors in minimum system size and cost**
- **EMI-resistant architecture**
- **High excitation rate**
- **High output data rate**
- **Large maximum input cap value**

### Applications

- **Human proximity detection up to 50cm**
- **Object proximity/obstacle detection up to 50cm**
How to start Capacitive sensing --- WEBENCH®

http://www.ti.com/lsds/ti/analog/webench/capacitive-sensing.page

Full WEBENCH® support !!
How to start capacitive sensing --- TI design

Proximity sensing
TIDA-00466 / TIDA-00474 / TIDA-00373

Touch on glass
TIDA-00464
TIDA-00474

Proximity sensing of up to 30CM range with > 15dB SNR and robust capacitive touch reference design

Features

- Capacitive sensing based buttons and Proximity sensing implementation using FDC2114/FDC2214 having 28 bits of resolution
- MSP430G2xx MCU for ultra low power operation
- Very low standby current consumption
  - Average <1mA
- TPS92513 based LED lights (2) with dimming function
- LMT01 based hood temperature sensing and humidity sensing with HDC1050 to enable automatic speed variation based on conditions under the hood
- Isolated UART interface for communication with motor drive

Applications

- Kitchen hoods
- Kitchen Appliances With Touch and Proximity Sensing Interfaces

Benefits

- 6 capacitive touch keys implementation for robust touch detection against moisture and other disturbances
- Proximity sensing implementation and test results with copper on PCB and ITO (indium tin oxide) based implementations.
- 2 channels of high resolution proximity sensing, providing tested hardware platform for the implementation of gesture recognition
- Proximity sensing up to 30cm enabling automatic wakeup and PWM dimmable automatic lighting control.
- Low power consumption during standby. Less than 1mA current consumption on DC power supply during standby
- Highly integrated LED driver circuit on board with digital dimming, over current protection, over temperature protection and adjustable under voltage-lock-out functions
- Provision for temperature sensing and humidity sensing
## High temperature glass touch reference design

### Highly robust touch buttons – TIDA-00464

<table>
<thead>
<tr>
<th>Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Single and multi-step button press</td>
<td>• Finger detection through tick glass (8 – 12 mm)</td>
</tr>
<tr>
<td>• Four robust buttons option implemented</td>
<td>• Work with gloves and in harsh environment (water, oil, dust)</td>
</tr>
<tr>
<td>• Variable air gap between buttons and glass (1-2mm)</td>
<td>• Easy to use</td>
</tr>
<tr>
<td>• Power consumption (~8Hz scan): 75µA</td>
<td></td>
</tr>
<tr>
<td>• Temperature range: -40°C to 125°C</td>
<td></td>
</tr>
</tbody>
</table>

### Markets & Applications

- HMI in Industrial: Touch buttons in Harsh Environments

---

Temperature sensing
Temp sensors are EVERYWHERE

System Challenges
- Multi channels
- Long distance
- High accuracy
- Non-linear
- Low power
## Commonly Used Temperature Sensors

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Temp Sense IC</th>
<th>Thermistor</th>
<th>RTD</th>
<th>Thermocouple</th>
<th>IR Temp Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp Range</td>
<td>-55°C to +150°C</td>
<td>-100°C to +500°C</td>
<td>-240°C to 700°C</td>
<td>-267°C to +2316°C</td>
<td>-100°C to +500°C</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Good</td>
<td>Depends on Calibration</td>
<td>Best</td>
<td>Good</td>
<td>Depends on Calibration</td>
</tr>
<tr>
<td>Linearity</td>
<td>Best</td>
<td>Low</td>
<td>Better</td>
<td>Better</td>
<td>Better</td>
</tr>
<tr>
<td>Requires support circuitry</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Price</td>
<td>Low-Moderate</td>
<td>Low-Moderate</td>
<td>Expensive</td>
<td>Expensive</td>
<td>Moderate-Expensive</td>
</tr>
</tbody>
</table>
Silicon (IC) Temperature Sensors

**Principle**

IC sensors leverage the highly predictable thermal characteristics of a silicon PN junction.

\[ \Delta V_{BE} = \frac{KT}{q} \cdot \ln \left( \frac{I_{C1}}{I_{C2}} \right) \]

**Advantages**

- Accuracy is guaranteed across a broad temperature range (-55°C to 200°C)
  - Zero Calibration
  - Highly Linear
  - Low noise sensitivity
- Low power (<2.5uW possible with integrated ADC)
- Compact Packaging options (down to 0.64mm² footprint)
- Fast Response
- Standard CMOS process
  - Economies of scale
  - Reliability
  - Integration
System example --- Off board temperature solutions

Integrated ADC with industry standard interfaces (I2C, SPI, UART)
- Guaranteed Accuracy
- Programmable sampling rate & alerts
- Noise Immunity

Saving the system cost by saving cables !!

New Topologies

**Pulse Counter (LMT01)**
- Only 2 pins
- Simple Pulse Counter (1 pulse = 1 LSB)

**Daisy Chain (TMP107)**
- UART interface
- Auto Addressing
Current is modulated between 34\,\mu A and 125\,\mu A to create a series of pulses

\[ 1 \text{ Pulse} = 1 \text{ LSB} \]

\[ \text{Temp} = \left( \frac{\text{# of pulses}}{4096} \times 256^\circ C \right) - 50^\circ C \]
TMP107: SMAART wire™ interface

- ½ Duplex UART interface
- Auto addressing based upon location in the chain
- Non-volatile memory is available to store address & programming

Bus Times out and chain is back to forward buffer
All the devices know their position in the bus for any further reads and writes
LMT01 / LMT01-Q1

**Features**
- Pulse Counter Interface
  - Current modulation can operate up to 2 meters
- High accuracy:
  - ±0.5°C at -20°C to +90°C (max error)
  - ±0.62°C at 90°C to +150°C (max error)
  - ±0.7°C at -50°C to -20°C (max error)
- Voltage supply: 2.0V to 5.5V
- 2-pin package options:
  - 1.7mm x 2.5mm SMD (in development)
  - 4mm x 3.15mm TO-92s
- **Automotive AEC-Q100 Available (TO-92s)**

**Applications**
- Whitegoods
- Servers
- Medical Devices
- Automotive
- Building Automation
- Wired Probes

**Tools & Resources**
- **TI Designs**
  - TIDA-00752 (Isolation)
  - TIDA-00765 (Strain Gauge)
  - TIDA-00779 (Power Factor)
  - TIDA-00474 (Cap. Touch)
- **Device Datasheets:**
  - LMT01
- **EVM:**
  - LMT01EVM

**Benefits**
- Easy-to-use digital output interface with no need for an ADC
- Noise-free operation, even on cables up to 2 meters long
- 2-pin thermistor replacement with digital output
- Packages allow for on-board, off-board, and remote mounting

Voltage supply: 2.0V to 5.5V
2-pin package options:
- 1.7mm x 2.5mm SMD (in development)
- 4mm x 3.15mm TO-92s

---

![Feature Diagram](image-url)
### TMP107
2-Pin digital pulse-train output temperature sensor with 0.5°C accuracy

#### Features
- TI's SMAARTWire™ Interface
  - Robust single-wire daisy chain interface with Alert
  - Up to 32 devices on the chain
  - Self-addressing
  - Long distance between nodes (> 300m)
- High accuracy
  - ±0.4°C max @ -20°C - 70°C
  - ±0.55°C max @ -40°C - 100°C
  - ±0.7°C max @ -55°C - 125°C
- Supply Range: 1.7V – 5.5V
- Nonvolatile Scratchpad Memory
- TMP107–Q1 AEC-Q100 Grade 1

#### Benefits
- Connects to any standard half-duplex UART
- Low wire count
- Daisy Chain greatly simplifies installation of multiple sensors
- Single Orderable
- Built in Non-volatile memory
- Simplify thermal profiling

#### Applications
- Refrigeration
- Grain Silo
- Enterprise
- Asset Tracking / Cold Chain
- Building Automation
- Wired Probes

#### Tools & Resources
- Device Datasheets:
  - TMP107
- EVM:
  - TMP107EVM
### Digital Local Temp Sensors

**Accuracy & Features**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Local Range</th>
<th>Max Temp</th>
<th>Current (Max)</th>
<th>Alert</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TMP112</strong></td>
<td>0.5°C</td>
<td>10uA</td>
<td>Alert</td>
<td>SOT-563</td>
<td></td>
</tr>
<tr>
<td><strong>TMP175</strong></td>
<td>1.5°C</td>
<td>10uA (Max)</td>
<td>Alert</td>
<td>SOT-563</td>
<td></td>
</tr>
<tr>
<td><strong>TMP275</strong></td>
<td>0.5°C</td>
<td>85uA (Max)</td>
<td>Alert</td>
<td>SOT-563</td>
<td></td>
</tr>
<tr>
<td><strong>TMP75A/B/C</strong></td>
<td>2°C</td>
<td>20uA (Max on TMP75B)</td>
<td>Alert</td>
<td>SOT-563</td>
<td></td>
</tr>
<tr>
<td><strong>LM75A</strong></td>
<td>3°C</td>
<td>75uA (Max)</td>
<td>Alert</td>
<td>SOT-23</td>
<td></td>
</tr>
<tr>
<td><strong>LP102</strong></td>
<td>3°C</td>
<td>10uA (Max)</td>
<td>Alert</td>
<td>SOT-563</td>
<td></td>
</tr>
<tr>
<td><strong>TMP103</strong></td>
<td>3°C</td>
<td>3uA (Max)</td>
<td>Multiple Address options</td>
<td>WCSP: 0.76 x 0.76mm</td>
<td></td>
</tr>
<tr>
<td><strong>TMP108</strong></td>
<td>0.75°C</td>
<td>10uA (Max)</td>
<td>Alert</td>
<td>WCSP: 1.2 x 0.8mm</td>
<td></td>
</tr>
<tr>
<td><strong>TMP100/101</strong></td>
<td>3°C</td>
<td>75uA (Max)</td>
<td>Alert</td>
<td>SOT-23</td>
<td></td>
</tr>
<tr>
<td><strong>LMT01</strong></td>
<td>1°C</td>
<td>520uA (Max), 280 (typ)</td>
<td>Alert</td>
<td>SOT-23, SO-8</td>
<td></td>
</tr>
<tr>
<td><strong>LM71/71-DIE</strong></td>
<td>3°C, 175°C</td>
<td>553uA (Max)</td>
<td>Bare Die Option</td>
<td>SOT-23, SO-8</td>
<td></td>
</tr>
</tbody>
</table>

**New**

- **LM95071**
  - Local = 1°C Max
  - 13-b +sign
  - $I_q$: 520 uA (Max), 280 (typ)
  - SOT-23

- **TMP122 / 124**
  - Local = 1.5°C Max
  - Alert
  - $I_q$: 75uA (Max)
  - SOT-23, SO-8

- **LM71/71-DIE**
  - Local = 3°C Max
  - 175°C range
  - Alert
  - $I_q$: 553uA (Max)
  - Bare Die Option

**Existing**

- **TMP107**
  - Local = 0.4°C Max
  - UART Daisy Chain Topology
  - Up to 300 meters
  - Alerts
  - EEPROM

- **LM75071**
  - Local = 1°C Max
  - 13-b +sign
  - $I_q$: 520 uA (Max), 280 (typ)
  - SOT-23

**Roadmap**

- **Q100 Option**
- **Q100 in Development**

**Q100 Option Available**

**Q100 in Development**

**New**

- **TMP112**
  - Local = 0.5°C Max
  - Alert

- **TMP116**
  - Local = 0.2°C Max
  - Alert
  - SOT-563

- **TMP108**
  - Local = 0.75°C Max
  - Alert
  - $I_q$: 10uA (Max)

**Existing**

- **TMP100/101**
  - Local = 3°C Max
  - Alert
  - $I_q$: 75uA (Max)
  - SOT-23

**Roadmap**

- **Q100 Option**
- **Q100 in Development**

**New**

- **TMP102**
  - Local = 3°C Max
  - Alert
  - $I_q$: 10uA (Max)

**Existing**

- **TMP103**
  - Local = 3°C Max
  - Alert
  - $I_q$: 3uA (Max)

**Roadmap**

- **Q100 Option**
- **Q100 in Development**

**New**

- **TMP104**
  - Local = 3°C Max
  - Multiple Device Access
  - 1-Wire Daisy Chain
  - Alert
  - WCSP: 0.76 x 0.76mm

**Existing**

- **TMP107**
  - Local = 0.4°C Max
  - UART Daisy Chain Topology
  - Up to 300 meters
  - Alerts
  - EEPROM

**Roadmap**

- **Q100 Option**
- **Q100 in Development**
Analog local temperature sensors

**LM20**
- Local: 1.5°C Max
- Class A Output
- Gain: -11.77mV/°C
- 2.4V-5.5V I_q: 9uA
- microSMD (1mmx1mm), SC70

**LM94022**
- Local: 1.5°C Max
- -50°C to +150°C
- 1.5V-5.5V, I_q: 5.4uA
- Quad Gain, Class AB Output, SC70

**LM35°C/LM34°F**
- Local: 0.5°C Max
- -55°C to +150°C
- Gain: 10mV/°C, Class A Output
- 4V-30V I_q: 90uA
- TO46, TO220, TO92, SO8

**LMT89**
- Local: 2°C Max
- Class A Output, Gain: 9.7mV/°C
- 4.5V to 10V, I_q: 130uA
- SOT23-3

**LM94023**
- Local: 1.5°C Max
- -50°C to +150°C
- Dual Gain, Class AB Output
- 1.5V-5.5V, I_q: 5.4uA
- microSMD

**LM94021**
- Local: 2°C Max
- -50°C to +150°C
- Quad Gain, Class A Output
- 1.5V-5.5V I_q: 9uA
- UL Rated, AEQ100 Grade 0
- SC70

**LMT85**
- 1.8V-5.5V
- -8.2mV/°C

**LM50**
- Local: 2.5°C Max
- Class A Output, Gain: -11.77mV/°C
- 2.4V-5.5V I_q: 9uA
- SC70

**LMT84**
- 1.5V-5.5V
- -5.5mV/°C

**TMP20**
- Local: 2.5°C Max
- Class A Output, Gain: -11.77mV/°C
- 2.4V-5.5V I_q: 9uA
- microSMD

**LMT86**
- 2.2V-5.5V
- -10.9mV/°C

**LMT88**
- Local: 5°C Max
- Class A Output, Gain: -11.77mV/°C
- 2.4V-5.5V I_q: 9uA
- SC70

**LMT90**
- Local: 4°C Max
- Gain: 9.7mV/°C
- 4.5V to 10V, I_q: 130uA
- SOT23-3

**LMT87**
- 2.7V-5.5V
- -13.6mV/°C

**LMT90**
- Local: 3°C Max
- Gain: -11.77mV/°C
- 2.4V-5.5V I_q: 9uA
- microSMD

**LM335/LM335A**
- Local: 6°C/3°C Max
- -55°C to +150°C
- Shunt Output
- TO46

**LM235/LM235A**
- Local: 3°C/1°C Max
- Shunt Output
- TO46

**LM135/LM135A**
- Local: 3°C/1°C Max
- -55°C to +150°C
- Shunt Output
- TO46

**LM94022**
- Local: 1.5°C Max
- -50°C to +150°C
- 1.5V-5.5V, I_q: 5.4uA
- Quad Gain, Class AB Output, SC70

**LM50**
- Local: 2°C Max
- Gain: 9.7mV/°C
- 4.5V to 10V, I_q: 130uA
- SOT23-3

**LM60**
- Local: 3°C Max
- Gain: 6.25mV/°C
- 2.7V to 10V, I_q: 82uA
- SOT-563, SC70

**LMT82**
- Local: 2°C Max
- Gain: 9.7mV/°C
- 4.5V to 10V, I_q: 130uA
- SOT23-3, TO92-3

**LM94021**
- Local: 2°C Max
- -50°C to +150°C
- Dual Gain, Class AB Output
- 1.5V-5.5V I_q: 9uA
- SC70

**LMT85**
- 1.8V-5.5V
- -8.2mV/°C

**LMT86**
- 2.2V-5.5V
- -10.9mV/°C

**LMT87**
- 2.7V-5.5V
- -13.6mV/°C

**LMT90**
- Local: 5°C Max
- Gain: 9.7mV/°C
- 4.5V to 10V, I_q: 130uA
- SOT23-3

**LM335/LM335A**
- Local: 6°C/3°C Max
- -55°C to +150°C
- Shunt Output
- TO46, TO92, SO8

**LM235/LM235A**
- Local: 3°C/1°C Max
- Shunt Output
- TO46

**LM135/LM135A**
- Local: 3°C/1°C Max
- -55°C to +150°C
- Shunt Output
- TO46

**LM94022**
- Local: 1.5°C Max
- -50°C to +150°C
- 1.5V-5.5V, I_q: 5.4uA
- Quad Gain, Class AB Output, SC70

**LM35°C/LM34°F**
- Local: 0.5°C Max
- -55°C to +150°C
- Gain: 10mV/°C, Class A Output
- 4V-30V I_q: 90uA
- TO46, TO220, TO92, SO8

**LMT84**
- 1.5V-5.5V
- -5.5mV/°C

**LMT85**
- 1.8V-5.5V
- -8.2mV/°C

**LMT86**
- 2.2V-5.5V
- -10.9mV/°C

**LMT87**
- 2.7V-5.5V
- -13.6mV/°C

**LM94021**
- Local: 2°C Max
- -50°C to +150°C
- Dual Gain, Class AB Output
- 1.5V-5.5V I_q: 9uA
- UL Rated, AEQ100 Grade 0
- SC70

**LMT85**
- 1.8V-5.5V
- -8.2mV/°C

**LMT86**
- 2.2V-5.5V
- -10.9mV/°C

**LMT87**
- 2.7V-5.5V
- -13.6mV/°C

**LM94023**
- Local: 1.5°C Max
- -50°C to +150°C
- Dual Gain, Class AB Output
- 1.5V-5.5V, I_q: 5.4uA
- microSMD

**LM94021**
- Local: 2°C Max
- -50°C to +150°C
- Quad Gain, Class A Output
- 1.5V-5.5V I_q: 9uA
- UL Rated, AEQ100 Grade 0
- SC70
How to start temperature sensing --- TI design
The TIDA-00800 reference design entails 4 temperature sensors along a daisy chain in a cabling environment. The sensors connect to the SensorTag development platform via the UART interface where the information can be transmitted wirelessly. The Bluetooth low energy wireless technology makes testing and demonstration easier due to its integration in most modern equipment. The form factor and electrical connections are compatible with TI SensorTag 2.0 ecosystem, allowing easy prototyping with other wireless technology (Zigbee, Wifi, sub 1GHz...), while the selected sensor allows industrial grade accuracy and resolution.
# TIDA-00824

Human skin temperature sensing for wearable applications reference design

## Features

- How to use the LMT70 temperature sensor to measure human skin temperature
- Ideal signal path components to achieve high thermal accuracy
- Layout considerations for routing thermal paths
- Mechanical case example for ideal mounting considerations

## Description

TIDA-00824 features the LMT70 analog temperature sensor for measuring human skin temperature. This TI design features how to mechanically mount the temperature sensor for best thermal conductivity. Signal path considerations on how to achieve greater than 0.1°C accuracy is also discussed in this TI design.

## Temp Sensing

- Device
  - LMT70
- Functionality
  - Measurement
# 2-wire galvanic ally isolated IC temperature sensor with pulse count interface

**TI Designs Number: TIDA-00752**

## Solution Features

- **Accuracy Over Temperature:**
  - Measured Error using LUT: < 0.25°C (-35°C to 150°C)
  - Measured Error using Transfer Function: <0.25°C (15°C to 100°C)
- Functional Isolation of 400 V<sub>RMS</sub> and Dielectric up to 2500-V AC for 60 seconds
- Pre-Compliance Testing: Meets IEC61000-4-4 EFT (Level 4) ±2 kV – Class-A

## Solution Benefits

- Power and Data Coexist on 2-Wire Interface for Remote Temperature Sensing Across Isolation
- Replacement for RTDs and NTC or PTC Thermistors
- No Need of System Level Calibration Unlike Thermistors
- Eliminates High-Precision Active or Passive Components
- Single Low-Profile Transformer for Power and Data Isolation

## Applications

- **TIDA-00752 Tools Folder**
- **Design Guide**
- **Device Datasheets:**
  - LMT01
  - SN6505B
  - MSP430F5528

---

**TI Designs Number: TIDA-00752**

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**Texas Instruments**
On-line resource

On-line forum: http://www.deyisupport.com/
TI-Designs: http://www.ti.com.cn/general/cn/docs/refdesignsearchresults.tsp
Thanks
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