

# MEMS-Based Inclinometer Solution

## Application Introduction

The tilt detection technique is used to measure the inclination of an object relative to its vertical/horizontal position. With the continuous development of production and science, inclination measurement is more and more widely used in industrial research, automotive, energy and utilization, medical care, consumer electronics, and other fields. The microelectromechanical system (MEMS) accelerometer is a common device for measuring the tilt angle of objects. In the face of increasing market demand, improving the precision of tilt angle measurement has become the focus of many sensor manufacturers.

Currently being trial installed in power and communications towers, tilt sensors can be used as an effective means of disaster and safety monitoring, and ADI's MEMS multiaxis accelerometer products can provide high precision solutions and algorithmic design improvements to meet customers' needs.

## System Design Considerations and Major Challenges

- ▶ Requirement
  - $\pm 0.05^\circ$  accuracy in  $30^\circ$  range
  - Temperature range:  $-45^\circ\text{C}$  to  $+70^\circ\text{C}$
  - Supply voltage: 3.5 V to 5.5 V
  - Protocol: customized though UART
- ▶ Purpose
  - Ensure the tower is perpendicular to the ground during construction
  - Monitor the tower inclination and provide alarm to central unit
- ▶ Various causes of misalignment
  - Silicon axis-to-axis misalignment
  - Chip-to-PCB mount misalignment
  - PCB-to-enclosure misalignment
  - Mounting misalignment
- ▶ System calibration can eliminate most alignment errors
- ▶ User alignment
  - Specify gravity direction
  - Eliminate installation error
  - Null output for relative measurement

## Solutions from ADI

### ADI Solution Value Proposition

- ▶ High precision
  - $0.001^\circ$  resolution: decided by system noise
  - $\pm 0.05^\circ$  accuracy in room temperature due to system calibration jig; current accuracy is  $0.05^\circ$  with margin for improvement
- ▶ Low noise accelerator
  - **ADXL355**:  $25 \mu\text{g}/\sqrt{\text{Hz}}$ , low noise application
  - **ADXL357**:  $80 \mu\text{g}/\sqrt{\text{Hz}}$ , design for vibration scenario, although the noise level of ADXL357 is not better than ADXL355, the ADXL357 has much better vibration rectification error (VRE) performance
- ▶ Ultra low power
  - Low power sensor: 200  $\mu\text{A}$  ADXL355/ADXL357 run mode
  - Low power microcontroller: 41  $\mu\text{A}/\text{MHz}$  **ADuCM4050**
- ▶ Integrated algorithm
  - Sensor calibration
  - Filtering
  - Gravity direction setting
  - User alignment
  - Relative inclination mode

## System Block Diagram

The hardware diagram shown in Figure 1 is composed of a super low power processor, a high accuracy accelerator, and a power supply.

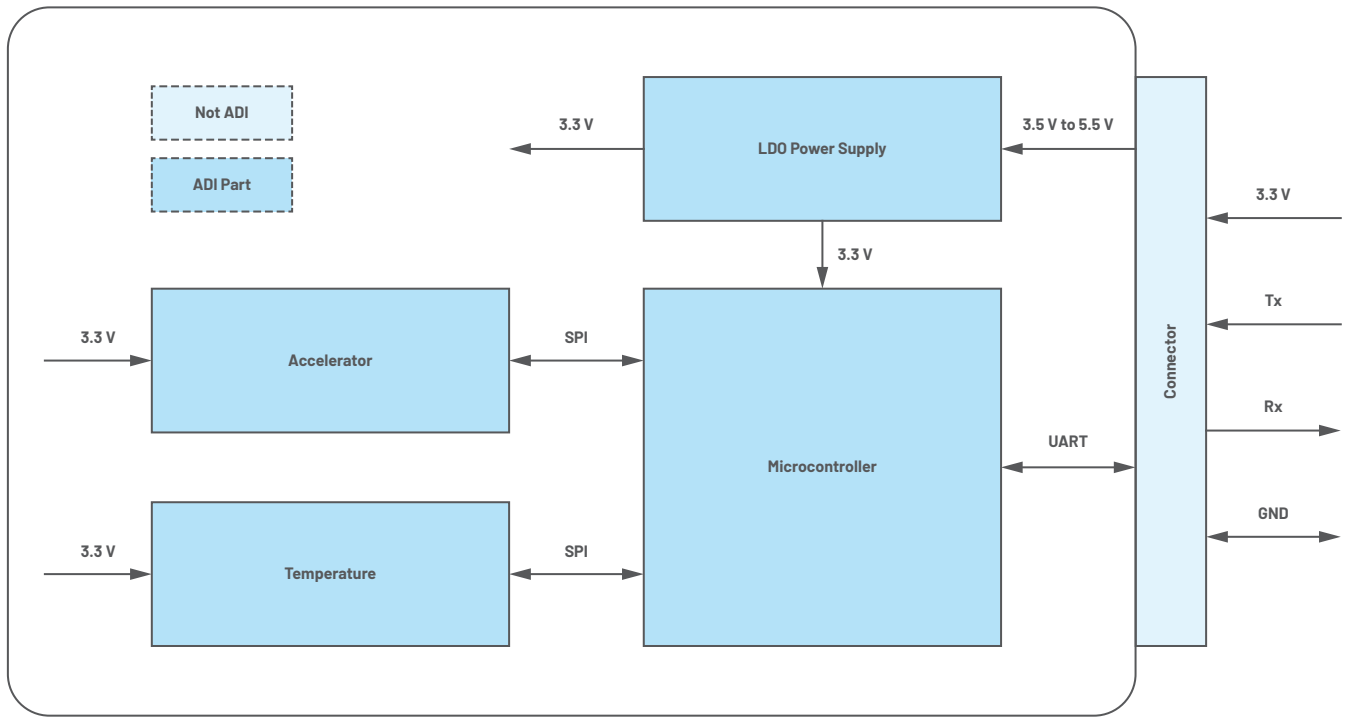


Figure 1. A hardware diagram composed of a super low power processor, a high accuracy accelerator, and a power supply.

## Software Diagram

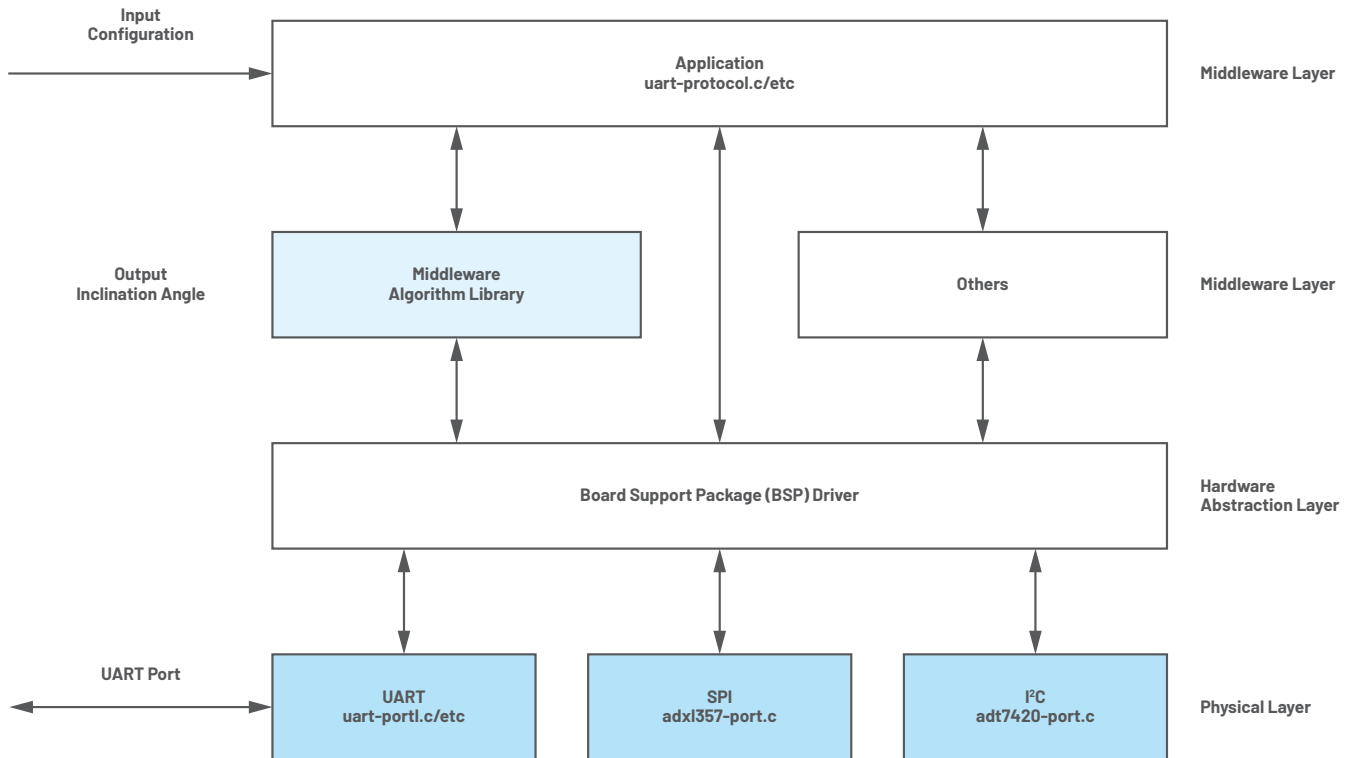


Figure 2. Software diagram.

## Prototype Picture

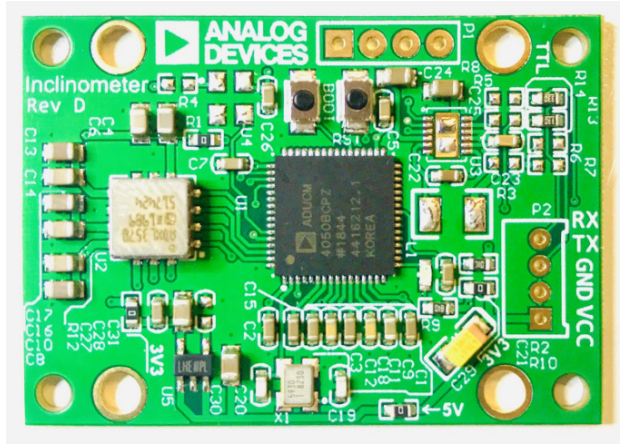


Figure 3. Picture of the ADuCM4050.

**Table 1. ADI Signal Chain**

Accelerometer	Microcontroller	Temperature Sensor	Power Supply
ADXL354/ADXL355/ADXL356/ADXL357	ADuCM3029/ADuCM4050	ADT7420/ADT7422	ADP150/ADP160

**Table 2. The Main Part**

Part	Description	Benefits
<b>Accelerometer</b>		
<a href="#">ADXL354/ADXL355</a>	The ADXL354/ADXL355 is part of a new family of low noise density, low 0 g offset drift, low power, 3-axis MEMS accelerometers with selectable measurement ranges; the ADXL355 supports the $\pm 2.048\text{ g}$ , $\pm 4.096\text{ g}$ , and $\pm 8.192\text{ g}$ ranges, and offers industry-leading noise, offset drift over temperature, and long-term stability, enabling precision applications with minimal calibration and with very low power consumption; the low noise performance of the ADXL354 and ADXL355 with low power consumption makes it now possible to cost-effectively enable low level vibration measurement applications such as structural health monitoring (SHM)	Low noise, low drift, low power, 3-axis accelerometer with digital output
<a href="#">ADXL356/ADXL357</a>	The analog output ADXL356 and the digital output ADXL357 are low noise density, low 0 g offset drift, low power, 3-axis accelerometers with selectable measurement ranges; the ADXL356B supports the $\pm 10\text{ g}$ and $\pm 20\text{ g}$ ranges, the ADXL356C supports the $\pm 10\text{ g}$ and $\pm 40\text{ g}$ ranges, and the ADXL357 supports the $\pm 10.24\text{ g}$ , $\pm 20.48\text{ g}$ , and $\pm 40.96\text{ g}$ ranges; the ADXL356/ADXL357 offer industry-leading noise, minimal offset drift over temperature, and long-term stability, enabling precision applications with minimal calibration	Low noise, low drift, low power, 3-axis MEMS accelerometers with digital output
<b>Microcontroller</b>		
<a href="#">ADuCM4050</a>	The ADuCM4050 microcontroller unit (MCU) is an ultra low power integrated microcontroller system with integrated power management for processing, control, and connectivity; the MCU system is based on the ARM® Cortex®-M4F processor; the MCU also has a collection of digital peripherals, embedded static random access memory (SRAM) and embedded flash memory, and an analog subsystem that provides clocking, reset, and power management capabilities in addition to an analog-to-digital converter (ADC) subsystem	Ultra low power ARM Cortex-M4F MCU with integrated power management
<b>Temperature Sensor</b>		
<a href="#">ADT7422</a>	The ADT7422 is a high accuracy, digital I <sup>2</sup> C temperature sensor designed to meet the clinical thermometry specification of the ASTM E1112 standards when soldered onto the final printed circuit board (PCB); the ADT7422 contains an internal band gap reference, a temperature sensor, and a precision analog-to-digital converter (ADC); the ADT7422 provides a 16-bit temperature result with a resolution of 0.0078°C and an accuracy of up to $\pm 0.1^\circ\text{C}$ across the temperature range of 25°C to 50°C without the need for calibration after the PCB soldering process	$\pm 0.1^\circ\text{C}$ accuracy, 16-bit, digital I <sup>2</sup> C temperature sensor for VSM applications
<b>Power Supply</b>		
<a href="#">ADP160</a>	The ADP160 is an ultralow quiescent current, low dropout, linear regulator that operates from 2.2 V to 5.5 V and provides up to 150 mA of output current; the low 195 mV dropout voltage at 150 mA load improves efficiency and allows operation over a wide input voltage range	Ultralow quiescent current 150 mA, CMOS linear regulator

## Design Resource

### Further Reading

- ▶ Choosing the Most Suitable MEMS Accelerometer for Your Application—Part 1  
[analog.com/en/analog-dialogue/articles/choosing-the-most-suitable-MEMS-accelerometer-for-your-application-part-1.html](http://analog.com/en/analog-dialogue/articles/choosing-the-most-suitable-MEMS-accelerometer-for-your-application-part-1.html)
- ▶ Choosing the Most Suitable Accelerometer for Your Application—Part 2  
[analog.com/en/analog-dialogue/articles/choosing-the-most-suitableaccelerometer-for-your-application-part-2.html](http://analog.com/en/analog-dialogue/articles/choosing-the-most-suitableaccelerometer-for-your-application-part-2.html)
- ▶ Choose the Right Accelerometer for Predictive Maintenance  
[analog.com/en/technical-articles/choose-the-right-accelerometer-forpredictive-maintenance.html](http://analog.com/en/technical-articles/choose-the-right-accelerometer-forpredictive-maintenance.html)
- ▶ MEMS Vibration Sensing: Velocity to Acceleration  
[analog.com/en/technical-articles/MEMS-vibration-sensing.html](http://analog.com/en/technical-articles/MEMS-vibration-sensing.html)
- ▶ MEMS Accelerometer Performance Comes of Age  
[analog.com/en/technical-articles/MEMS-accelerometer-performance-comes-of-age.html](http://analog.com/en/technical-articles/MEMS-accelerometer-performance-comes-of-age.html)
- ▶ Measuring AC Accelerations: To Calibrate or Not to Calibrate?  
[analog.com/en/technical-articles/measuring-ac-accelerations-to-calibrate-or-not-to-calibrate.html](http://analog.com/en/technical-articles/measuring-ac-accelerations-to-calibrate-or-not-to-calibrate.html)
- ▶ Accelerometer Tilt Measure over Temperature and in the Presence of Vibration  
[analog.com/en/analog-dialogue/raqs/raq-issue-144.html](http://analog.com/en/analog-dialogue/raqs/raq-issue-144.html)

### Design Tool

- ▶ EVAL-ADXL35X  
[analog.com/en/EVAL-ADXL35X.html](http://analog.com/en/EVAL-ADXL35X.html)
- ▶ EVAL-ADXL355-PMDZ  
[analog.com/en/EVAL-ADXL355-PMDZ.html](http://analog.com/en/EVAL-ADXL355-PMDZ.html)

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