# *TI 设计：TIDA-01239*
# *采用 CapTIvate 教学按钮的接近开关参考设计*

## 说明

该参考设计展示了如何基于 TI 的 CapTIvate™技术在 3.5mm 宽的超小 PCB 中实现电容式触控按钮。该按钮通常用作接近开关中的设置按钮。当与高度集成的 IO-Link PHY 相结合时，可实现灵活的 PNP 或 NPN 输出。该 SIO 级提供反极性、ESD、EFT 和浪涌保护，从而使设计符合 IEC 61000-4 标准。具有模拟输出信号的霍尔传感器能够通过电容式教学按钮就磁性物体的距离进行教学，从而实现灵活的使用。该模拟信号由 MCU 的集成 ADC 进行捕获。

## 资源

| | |
|---|---|
| TIDA-01239 | 设计文件夹 |
| TIOL111 | 产品文件夹 |
| DRV5053 | 产品文件夹 |
| MSP430FR2633 | 产品文件夹 |

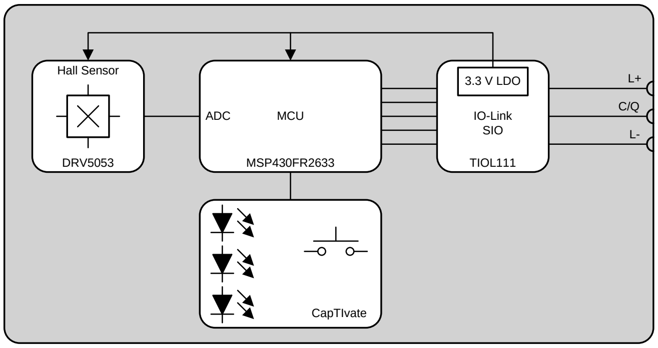
TI E2E™ Community　咨询我们的 E2E 专家

## 特性

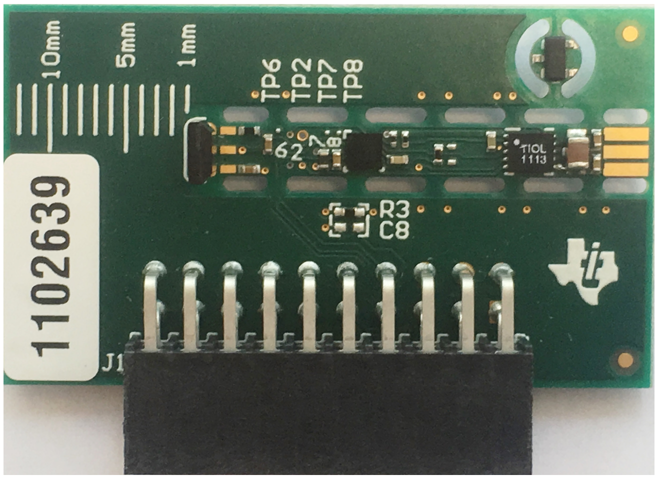
- 采用 CapTIvate 技术的电容式教学按钮：
  - 支持金属触控和防水设计
  - 自电容和互电容电极
  - 可提高针对电力线、射频及其他环境噪声的抗扰度
- 高度集成的输出驱动器：
  - NPN、PNP、IO-Link（可选）
  - 3.3V 或 5.0V LDO；20mA
  - 反极性保护
  - 符合 IEC 61000-4 标准的 ESD、EFT 和浪涌保护
  - 50 至 350mA 可配置输出电流限制
- 3.5mm 宽 PCB

## 应用

- 工厂自动化与控制：
  - 位移传感器
  - 接近开关




Copyright © 2017, Texas Instruments Incorporated



该 TI 参考设计末尾的重要声明表述了授权使用、知识产权问题和其他重要的免责声明和信息。




TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

# 1 System Description

In Factory Automation and Control systems, proximity switches or displacement sensors are widely used. The output changes once a certain threshold is achieved. This threshold can be set with a teach button. This reference design realizes the teach button with a capacitive touch based on TI's CapTIvate technology as part of the MSP430™ MCU. With only a tiny electrode of 2 mm × 5 mm on the PCB, solutions for very small space constraints can be realized. In this TI Design, the set button and the entire electronics fit onto a 3.5-mm wide PCB. This is achieved by using the 2.3-mm×2.3-mm small MCU including CapTIvate technology, as well as the 2.5-mm×3-mm highly integrated digital sensor output driver. The output can be configured either as NPN, PNP, or even IO-Link output. In addition, the output driver integrates reverse polarity protection and helps designers to meet system compliance with the International Electrotechnical Commission (IEC) 61000-4 standard. The built-in EMC protection allows for the following:

- ±16-kV IEC 61000-4-2 ESD Contact Discharge
- ±4-kV IEC 61000-4-4 Electrical Fast Transient (EFT)
- ±1.2-kV/500-Ω IEC 61000-4-5 Surge

With the capability of using the onboard LDO with either a 3.3-V or 5-V output, the remaining system can be supplied with up to 20 mA. This reference design uses the integrated 3.3-V LDO, which supplies the MCU and the Hall sensor with power from the voltage input that covers a range from 7 to 36 V with a ±65-V tolerant transient.

For object detection, many different methods are available depending on the material and distance of the object. In this reference design, a Hall sensor with an analog output is detecting the magnetic object, and the built-in ADC inside the MCU measures the magnetic field.

## 1.1 Key System Specifications

**表 1. Key System Specifications**

| PARAMETER | SPECIFICATIONS |
|---|---|
| **POWER SUPPLY** | |
| Operating voltage | 7- to 36-V DC |
| | ±65-V transients < 100 µs |
| LDO | 3.3-V output voltage |
| | 20-mA output current |
| **INTERFACE** | |
| SIO | NPN, PNP |
| | 50- to 350-mA configurable current limit |
| Communication | IO-Link (optional); requires IO-Link stack |
| **DIAGNOSTICS** | |
| Fault indicator (open drain output) | Overcurrent |
| | Overtemperature |
| | Power supply |
| **HMI** | |
| Indicator | RGB LED |
| Teach button | PCB electrode (2 mm × 5 mm) |
| | Connection for external or remote electrode |
| **FRONT-END** | |
| Sensor | Hall-effect sensor with analog output |



TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

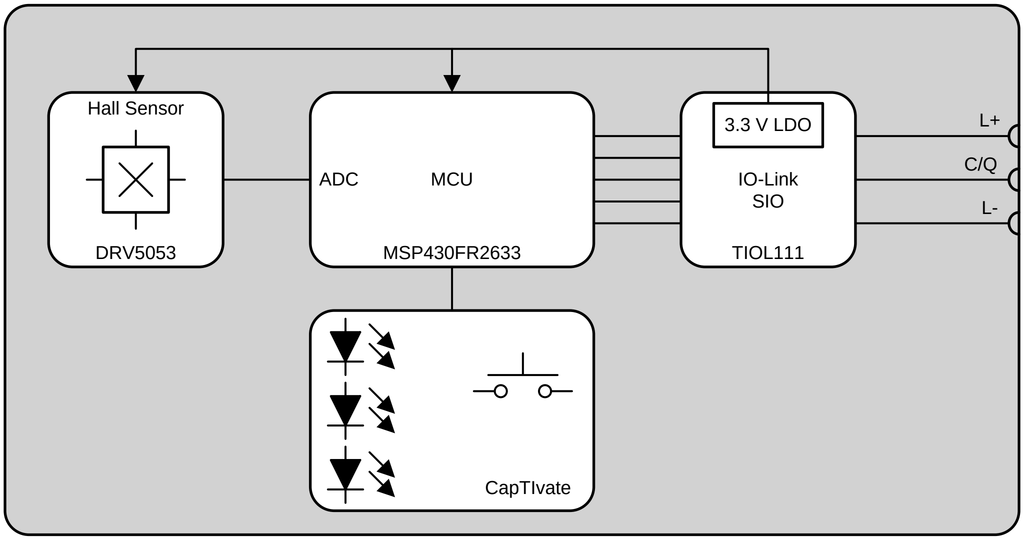
表 **1. Key System Specifications (continued)**

| PARAMETER | SPECIFICATIONS |
|---|---|
| ADC | integrated ADC inside MCU |
| **MECHANICS** | |
| Form factor | PCB width: 3.5 mm |


TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

# 2 System Overview

## 2.1 Block Diagram




Copyright © 2017, Texas Instruments Incorporated

图 **1. Block Diagram of TIDA-01239**

## 2.2 Design Considerations

The top layer of this reference design includes the following (see 图 2):

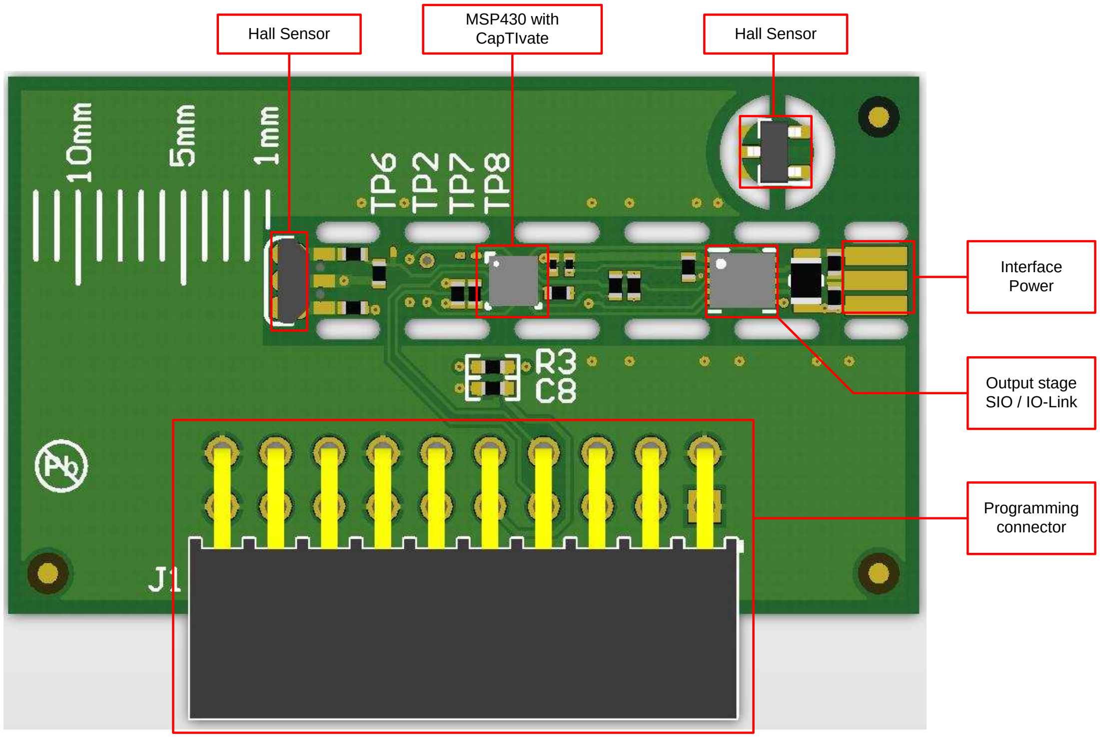
- Hall sensor
- MSP430 with CapTIvate: The MSP430FR2633 uses the integrated ADC to convert the voltage signal of the Hall sensor. in addition, the capacitive touch button, based on CapTIvate technology, is realized as well as the communication to the TIOL111, which is used in SIO mode. With an IO-Link stack, the system can also be used with IO-Link communication.
- Interface and power: The TIOL111 can be powered from 7 to 36 V and converts with the integrated LDO down to 3.3 V, providing up to 20 mA. With the built-in protection scheme, designers can easily design to meet the IEC 61000-4 standard.
- Output stage: The TIOL111 is used in SIO mode. The user can select if he or she wants to use an NPN or PNP output. The devices is also capable to communicate through IO-Link.
- Programming connector: J1 is the programming connector. This connector works in combination with the MSP CapTIvate MCU development kit.

The bottom layer of this reference design includes the following (see 图 3):

- CapTIvate electrode: This electrode builds the capacitive touch button in combination with the CapTIvate solution.
- RGB LED: This indicator LED shows the status of the system.
- Cut out area: The actual system can be removed once the programming and debugging is finalized. The Hall sensor in the TO-92 package remains on the PCB. Instead, the user can now use the Hall sensor in the SOP package.

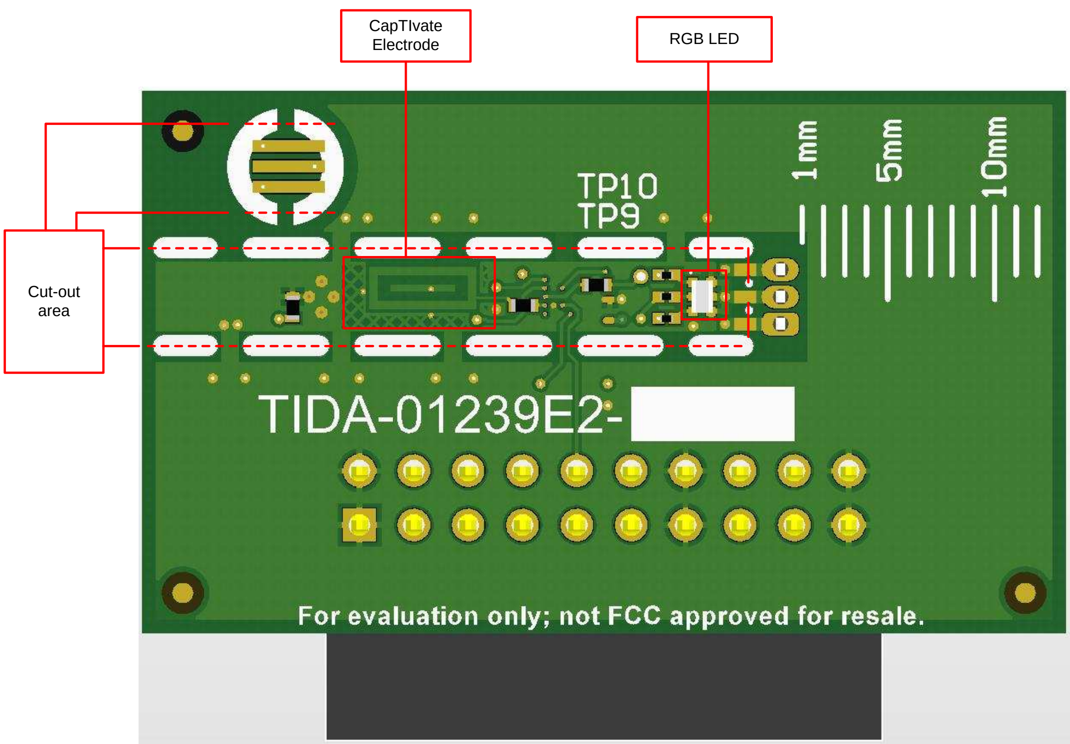


TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated




Copyright © 2017, Texas Instruments Incorporated

图 **2. Description of Subsystem Blocks in Top Layer**




Copyright © 2017, Texas Instruments Incorporated

图 **3. Description of Subsystem Blocks in Bottom Layer**



TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

## 2.3 Highlighted Products

### 2.3.1 TIOL111

The TIOL111 family of transceivers implements the IO-Link interface for industrial bidirectional, point-to-point communication. When the device is connected to an IO-Link master through a three-wire interface, the master can initiate communication and exchange data with the remote node while the TIOL111 acts as a complete physical layer for the communication.

These devices are capable of withstanding up to 1.2 kV (500 Ω) of IEC 61000-4-5 surge and have integrated protection against reverse polarity. A simple pin-programmable interface allows easy interfacing to the controller circuits. The output current limit can be configured using an external resistor. Fault reporting and internal protection functions are provided for undervoltage, overcurrent, and overtemperature conditions.

Key features of this device include:

- 7- to 36-V supply voltage
- PNP, NPN, or IO-Link configurable output:
  - IEC 61131-9 COM1, COM2, and COM3 data rate support
- Low residual voltage of 1.75 V at 250 mA
- 50- to 350-mA configurable current limit
- Tolerant to ±65-V transients < 100 µs
- Reverse polarity protection of up to 55 V on L+, CQ, and L–
- Integrated EMC protection on L+ and CQ:
  - ±16-kV IEC 61000-4-2 ESD Contact Discharge
  - ±4-kV IEC 61000-4-4 EFT
  - ±1.2-kV/500-Ω IEC 61000-4-5 Surge
- Fast demagnetization of inductive loads up to 1.5 H
- Large capacitive load driving capability
- < 2-µA CQ leakage current
- < 1.5-mA quiescent supply current
- Integrated LDO options for up to 20-mA current:
  - TIOL111: No LDO
  - TIOL111-3: 3.3-V LDO
  - TIOL111-5: 5-V LDO
- Overtemperature warning and thermal protection
- Remote wake-up indicator
- Fault indicator
- Extended ambient temperature: –40°C to 125°C
- 2.5-mm×3-mm 10-pin VSON package



TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

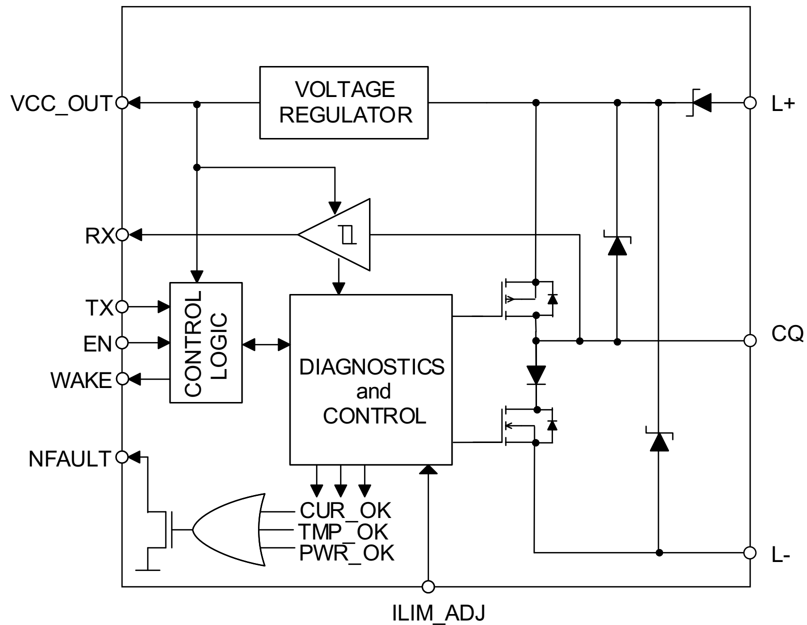



图 4. Block Diagram of TIOL111 With Integrated Volatge Regulator

### 2.3.2 DRV5053

The DRV5053 device is a chopper-stabilized Hall device that offers a magnetic sensing solution with superior sensitivity stability over temperature and integrated protection features.

The 0- to 2-V analog output responds linearly to the applied magnetic flux density and distinguishes the polarity of magnetic field direction. A wide operating voltage range from 2.5 to 38 V with reverse polarity protection up to –22 V makes the device suitable for a wide range of industrial and consumer applications.

Internal protection functions are provided for reverse supply conditions, load dump, and output short circuit or overcurrent.

Key features of this device include:

- Linear output Hall sensor
- Superior temperature stability:
  - Sensitivity ±10% overtemperature
- High sensitivity options:
  - –11 mV/mT (OA)
  - –23 mV/mT (PA)
  - –45 mV/mT (RA)
  - –90 mV/mT (VA)
  - 23 mV/mT (CA)
  - 45 mV/mT (EA)
- Supports a wide voltage range:
  - 2.5 to 38 V
  - No external regulator required
- Wide operating temperature range:
  - $T_A$ = –40 to 125°C (Q)
- Amplified output stage:
  - 2.3-mA sink, 300-µA source
- Output voltage: 0.2 to 1.8 V
  - B = 0 mT, OUT = 1 V
- Fast power-on: 35 µs
- Small package and footprint:
  - Surface mount three-pin SOT-23 (DBZ):
    - 2.92 mm × 2.37 mm
  - Through-hole three-pin TO-92 (LPG):
    - 4.00 mm × 3.15 mm
- Protection features:
  - Reverse supply protection (up to –22 V)



TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

– Supports up to 40-V load dump
– Output short-circuit protection
– Output current limitation

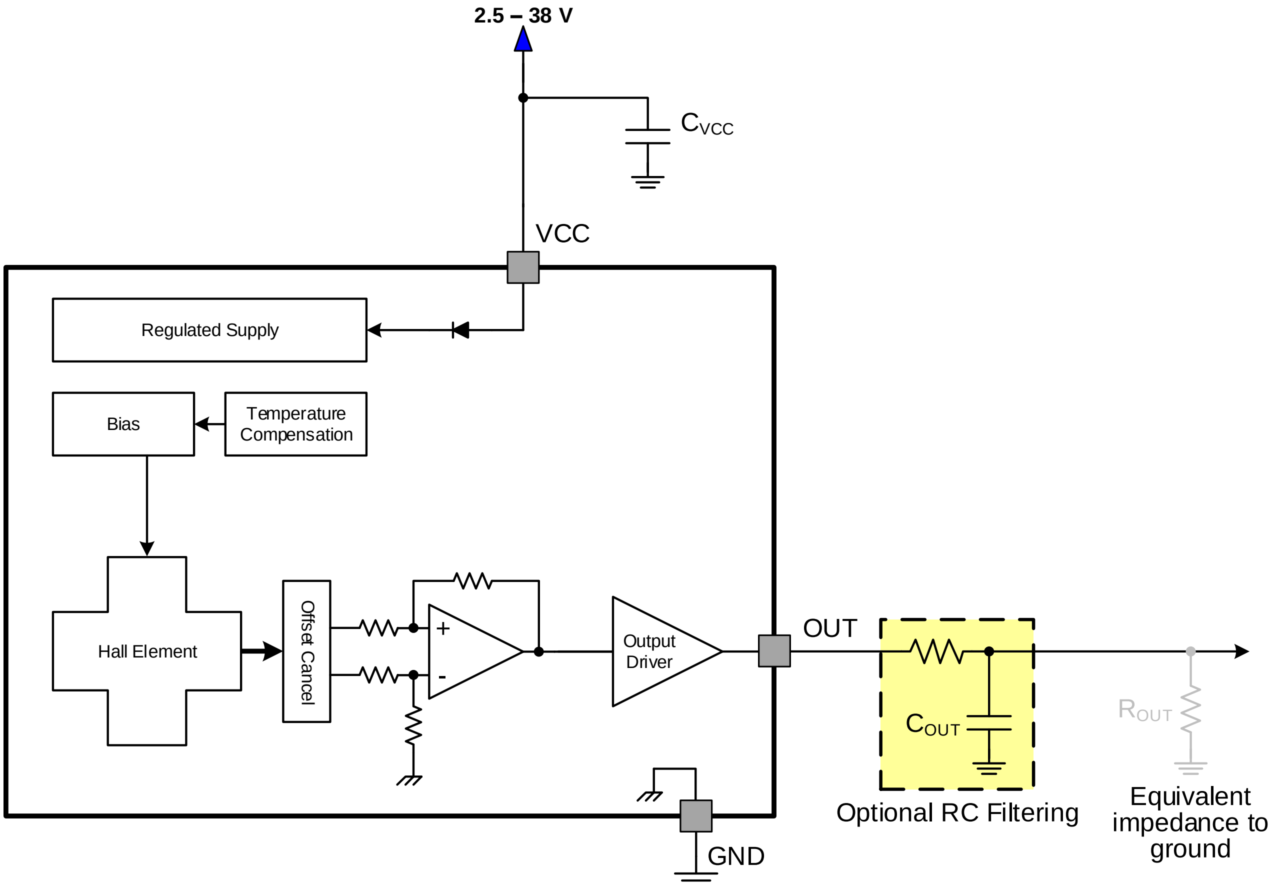



图 5. Block Diagram of DRV5053

### 2.3.3 MSP430FR2633

The MSP430FR263x and MSP430FR253x are ultra-low-power MSP430 microcontrollers for capacitive touch sensing that feature CapTIvate touch technology for buttons, sliders, wheels, and proximity applications. MSP430 MCUs with CapTIvate technology provide the most integrated and autonomous capacitive-touch solution in the market with high reliability and noise immunity at the lowest power. TI's capacitive touch technology supports concurrent self-capacitance and mutual-capacitance electrodes on the same design for maximum flexibility. MSP430 MCUs with CapTIvate technology operate through thick glass, plastic enclosures, metal and wood with operation in harsh environments including wet, greasy, and dirty environments.

MSP430 MCUs with capacitive touch sensing are supported by an extensive hardware and software ecosystem with reference designs and code examples to get a design started quickly. Development kits include the MSP-CAPT-FR2633 CapTIvate technology development kit. TI also provides free software including the CapTIvate Design Center, where engineers can quickly develop applications with an easy-to-use graphical user interface (GUI) and MSP430Ware™ software and comprehensive documentation with the CapTIvate technology guide.



TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

TI's MSP430 ultra-low-power FRAM microcontroller platform combines uniquely embedded FRAM and a holistic ultra-low-power system architecture, allowing system designers to increase performance while lowering energy consumption. FRAM technology combines the low-energy fast writes, flexibility, and endurance of RAM with the non-volatility of flash.

Key features of this device include:

- CapTIvate technology (capacitive touch):
  - Performance:
    - Fast electrode scanning with four simultaneous scans
    - Support for high-resolution sliders with > 1024 points
    - 30-cm proximity sensing
  - Reliability:
    - Increased immunity to power line, RF, and other environmental noise
    - Built-in spread spectrum, automatic tuning, noise filtering, and debouncing algorithms
    - Enables reliable touch solutions with 10-$V_{RMS}$ common-mode noise, 4-kV EFT, and 15-kV ESD, allowing for IEC-61000-4-6, IEC- 61000-4-4, and IEC-61000-4-2 compliance
    - Reduced RF emissions to simplify electrical designs
    - Support for metal touch and water rejection designs
  - Flexibility:
    - Up to 16 self-capacitance and 64 mutual-capacitance electrodes
    - Mix and match self- and mutual-capacitive electrodes in the same design
    - Supports multitouch functionality
    - Wide range of capacitance detection, wide electrode range of 0 to 300 pF
  - Low power:
    - <0.9 μA/button in wake-on-touch mode, where capacitive measurement and touch detection is done by hardware state machine while CPU is asleep
    - Wake-on-touch state machine allows electrode scanning while CPU is asleep
    - Hardware acceleration for environmental compensation, filtering, and threshold detection
  - Ease of use:
    - CapTIvate design center, PC GUI lets engineers design and tune capacitive buttons in real time without having to write code
    - CapTIvate software library in ROM provides ample FRAM for customer application




版权 © 2017, Texas Instruments Incorporated

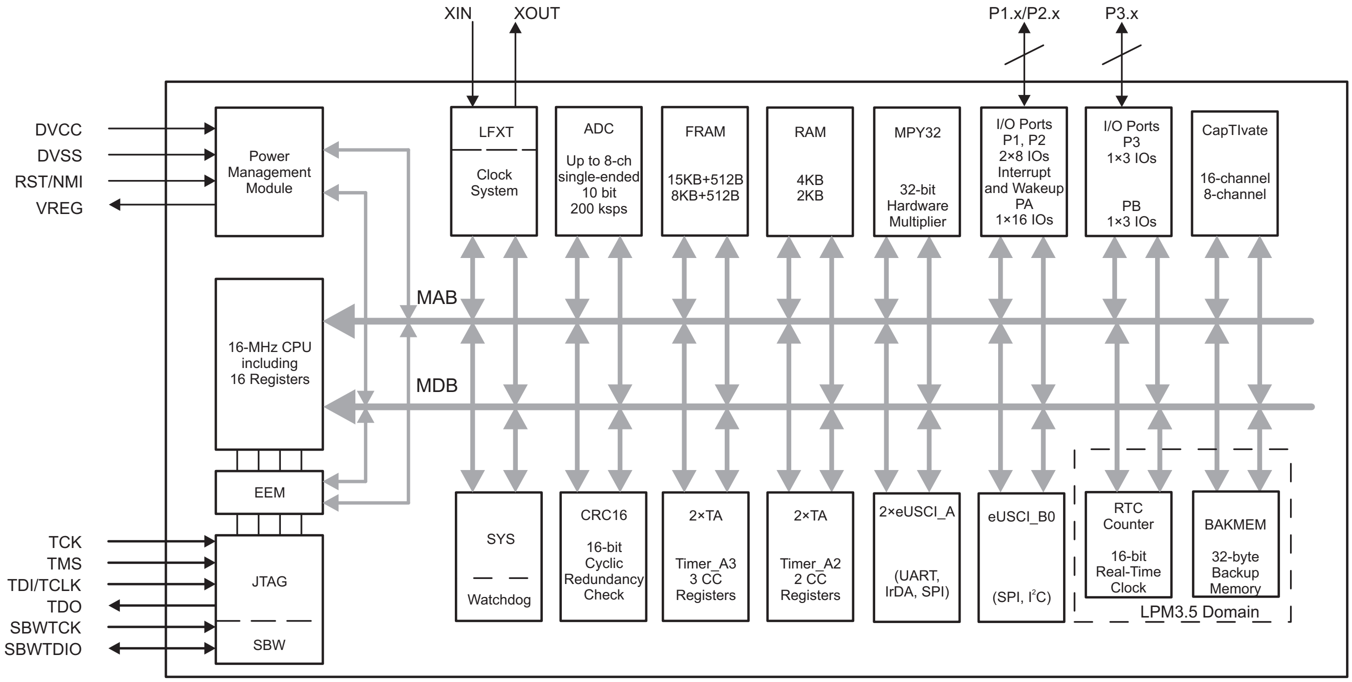



**图 6. Block Diagram of MSP430FR2633**



TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

# 3 Hardware, Software, Testing Requirements, and Test Results

## 3.1 *Required Hardware and Software*

- TIDA-01239 reference design
- MSP CapTIvate MCU Development Kit
- MSP CapTIvate Design Center GUI
- Code Composer Studio™
- A magnet

## 3.2 *Testing and Results*

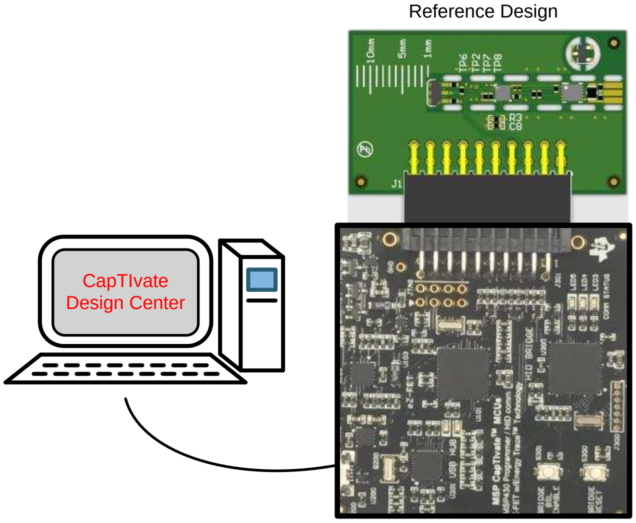
The reference design can be used in two different ways:

1. Investigate and evaluate the tiny CapTIvate touch button.
2. Use as a Hall sensor with a digital NPN or PNP output.

The first use case only requires the MSP CapTIvate Design Center and the MSP430 CapTIvate programmer (part of the MSP CapTIvate MCU Development Kit) is required with the GUI.

### 3.2.1 Test Setup

图 7 shows the simple test setup. This is the first step for programming the capacitive touch button.




Copyright © 2017, Texas Instruments Incorporated

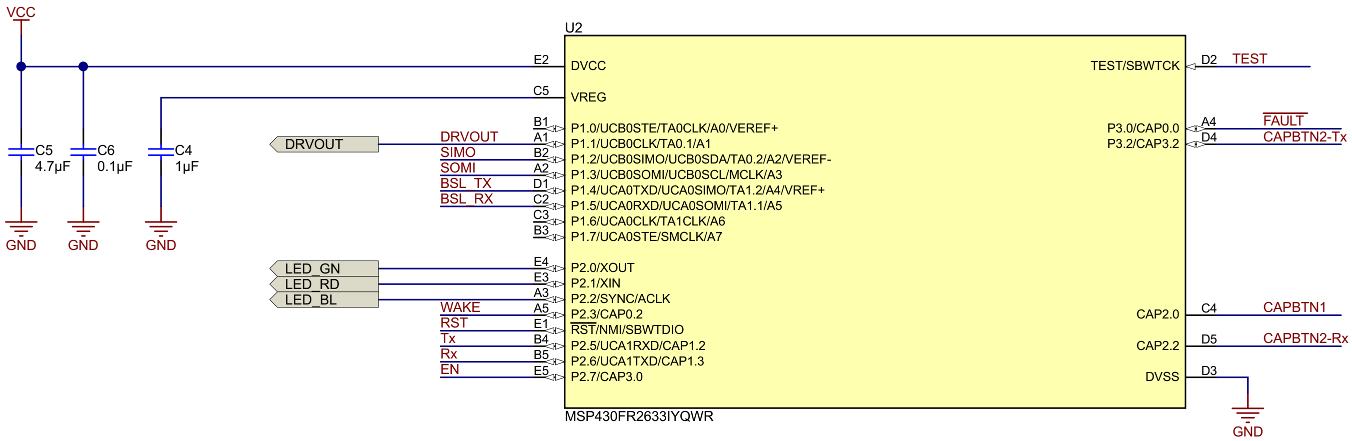
**图 7. Test Setup for Capacitive Touch Optimization**




版权 © 2017, Texas Instruments Incorporated

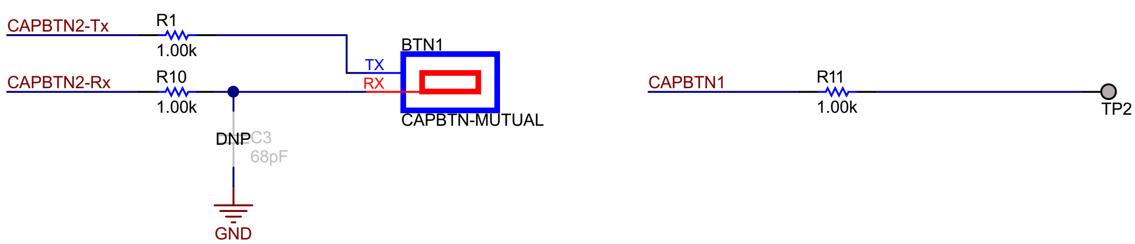
### 3.2.2 Capacitive Touch Button

With the CapTIvate Design Center, it is very easy to set the touch button (find a detailed description here: ). The reference design has two buttons assigned. 图 8 and 图 9 show the two electrodes. BTN1 is a mutual coupling button. The Tx signal is connected to pin CAP3.2 (D4) of the MSP430, and the Rx signal is connected to pin CAP2.2 (D5). The self-coupling electrode on pin CAP2.0 (C4) is on the PCB as a via. The user can solder a remote electrode to it.




Copyright © 2017, Texas Instruments Incorporated

**图 8. TIDA-01239 MCU Circuitry**




Copyright © 2017, Texas Instruments Incorporated

**图 9. TIDA-01239 Mutual and Self-Coupling Electrodes**


版权 © 2017, Texas Instruments Incorporated

According to 图 10, a project can be set up in the CapTivate Design Center. A mutual button is connected to the MSP430FR2633 with Tx to CAP3.2 and Rx to CAP2.2.

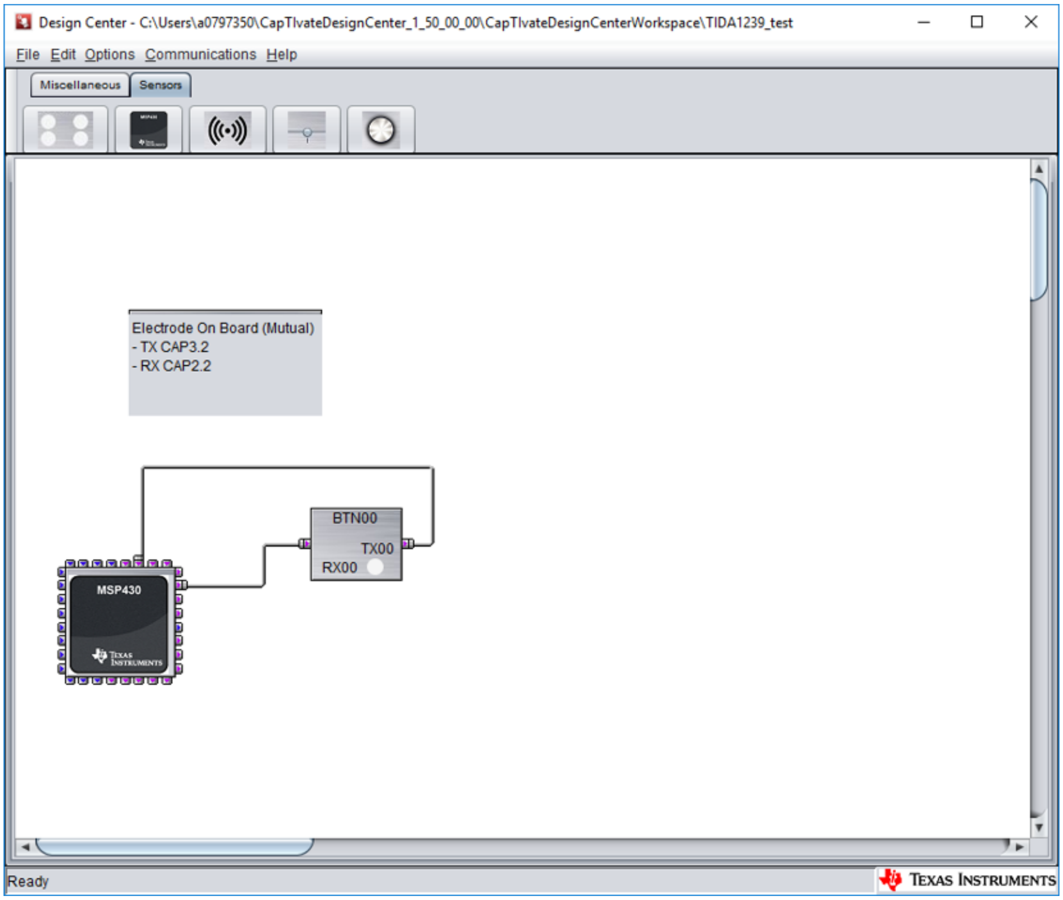



**图 10. CapTIvate Design Center: Setup of One Mutual Button**




版权 © 2017, Texas Instruments Incorporated

Once the project is setup, the connection between the Design Center and the reference design can be established by clicking "Connect" in the *Communications* menu. By double-clicking the BTN00 icon, the window shown in 图 11 appears. Once the button specific parameters are set in the tabs *Conversion Control* and *Tuning* (see ), the sensitivity of the touch button can be observed, for example, in the tab *Channel Bar Count* (see 图 11 and 图 12) or *Channel Oscilloscope Plot* (see 图 13).

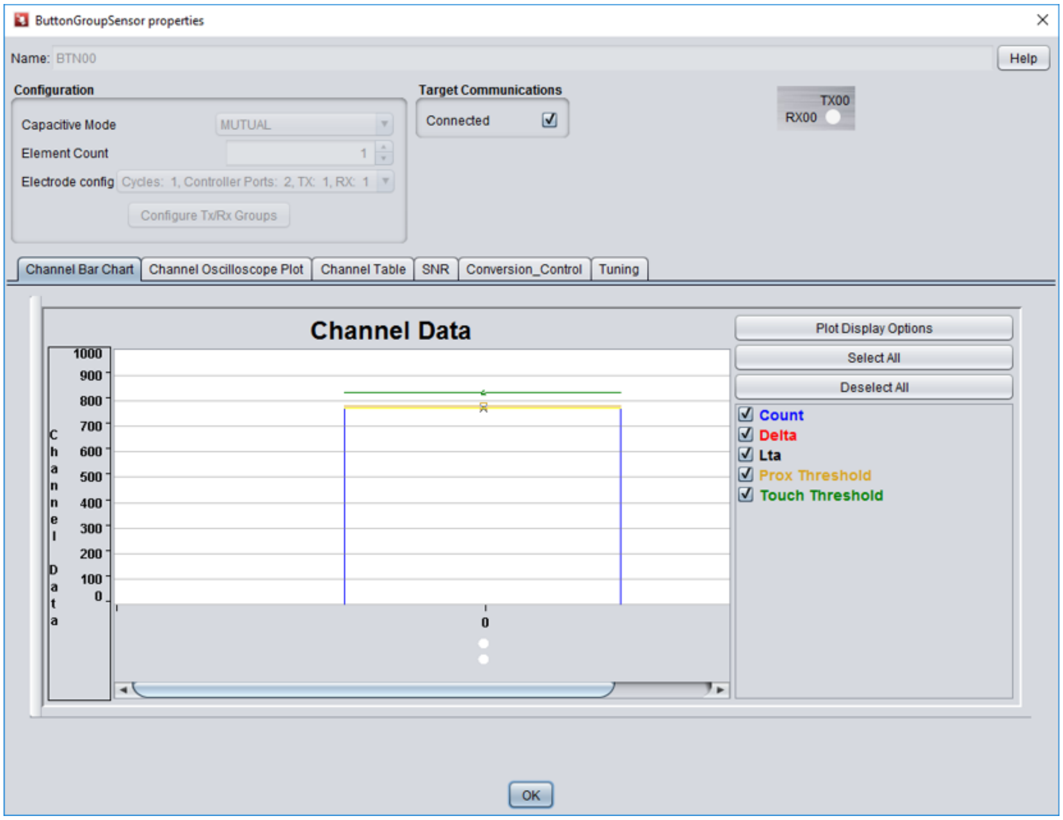



**图 11. CapTIvate Design Center: No Touch**




版权 © 2017, Texas Instruments Incorporated

图 12 shows an example of a touch event. In the Tuning tab and Conversion Control tab, the proximity threshold, touch threshold, and other parameters for increasing robustness can be set.

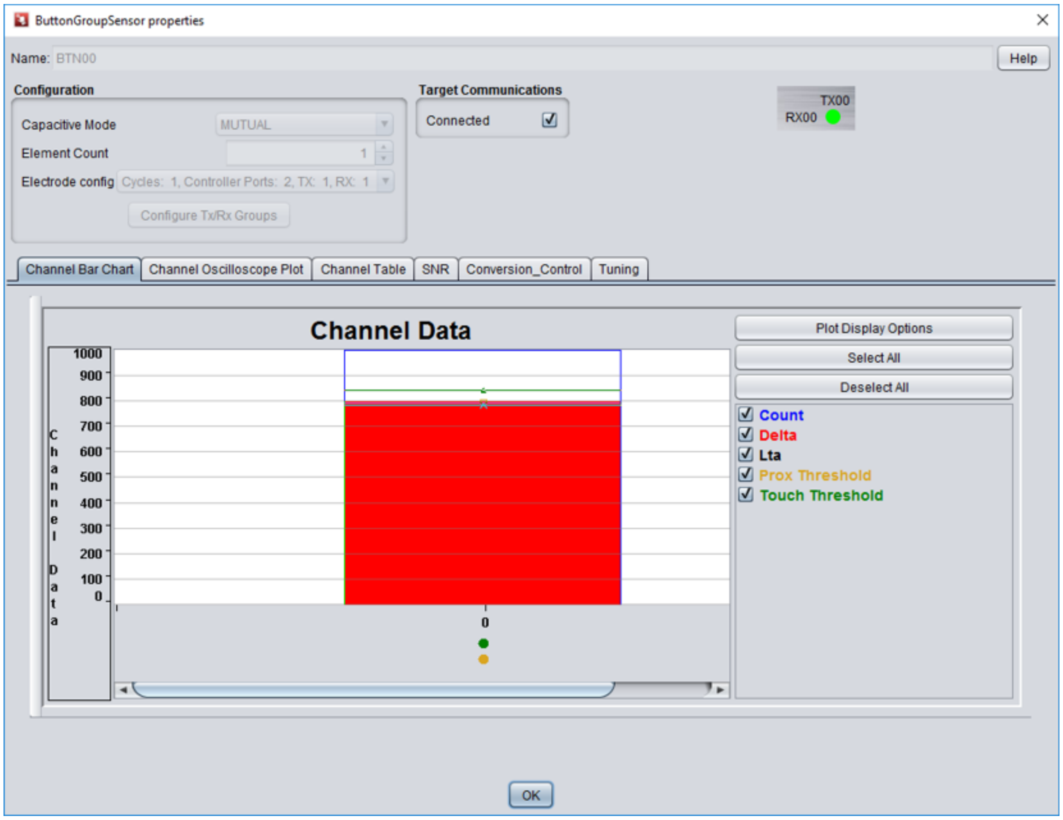



图 12. CapTIvate Design Center: Touch on Button Recognized


版权 © 2017, Texas Instruments Incorporated

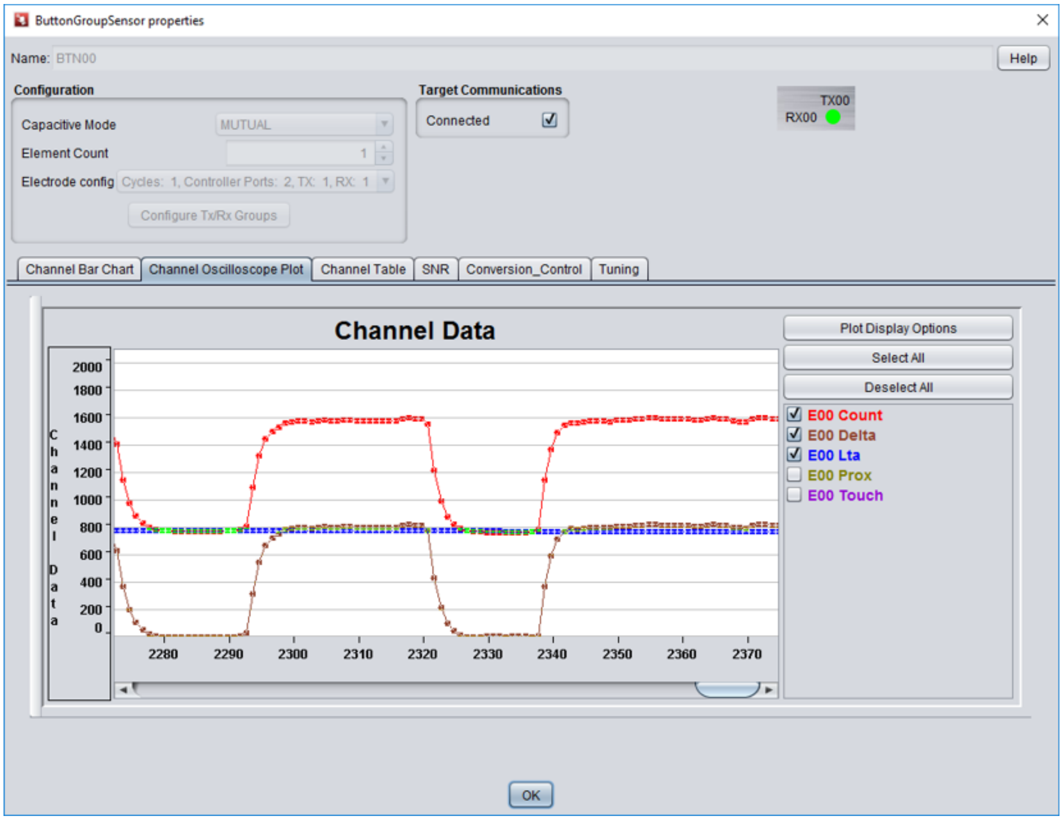



图 **13. CapTIvate Design Center: Time Plot With Several Touch Events**

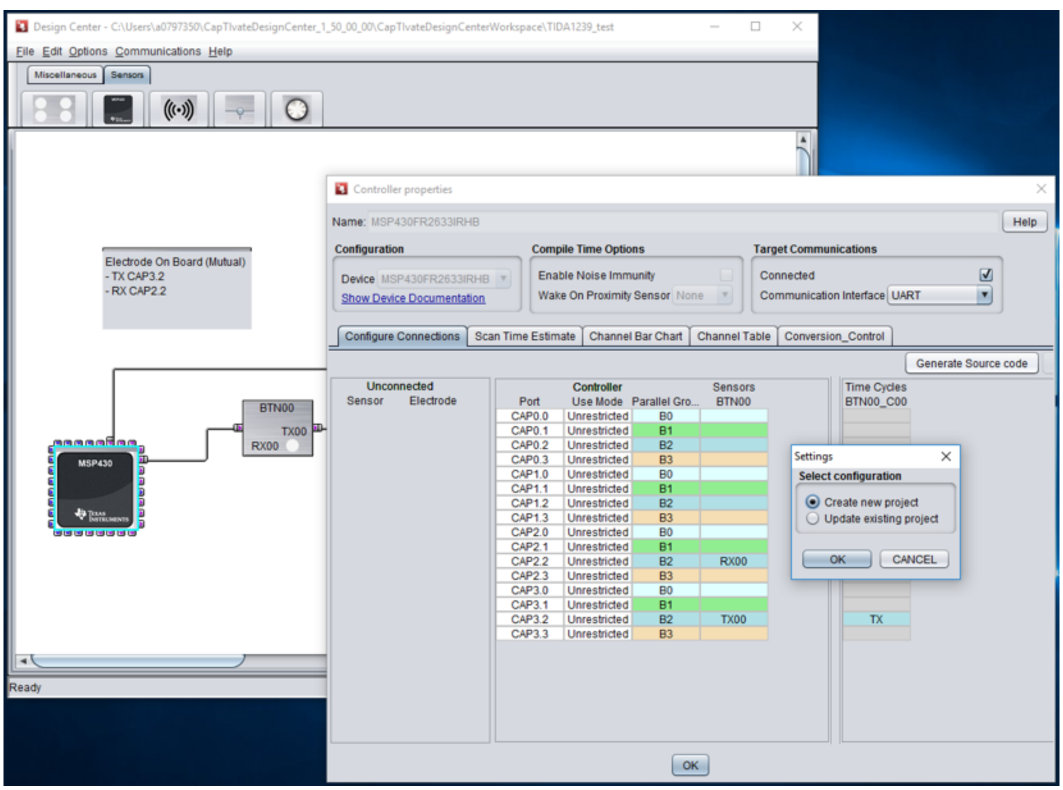



图 **14. CapTIvate Design Center: Code Generation**




版权 © 2017, Texas Instruments Incorporated

Once all settings are realized, the GUI can generate C-code to implement in the application code. By double-clicking on the MSP430, the Controller property window opens. The *Generate Source Code* button creates the code either for a new project or for an existing project (see 图 14).

### 3.2.3 Test Application

To showcase the functionality of the set button in combination with the SIO mode, the reference design has a Hall sensor with an analog output voltage depending on the magnetic field strength.

The ADC is implemented as a window comparator. It uses two threshold values: the high and low threshold. The ADC continuously receives values from the Hall sensor, which are sampled and sent to the MCU. If the magnetic field sensed by the Hall sensor is smaller than the lower threshold, the LED blinks green. If the value sensed is greater than the higher threshold, the LED blinks red. These threshold values are flexible and can be set during the runtime.

The values received by the Hall sensor in between the higher and lower threshold are ignored and no post processing is done by the MCU. When the Hall sensor measures values greater than the higher threshold, it provides a signal to the IO-Link to open the high-side switch, thus preventing any current to pass through. When the magnet is in the zone of the lower threshold, the MCU signals the IO-Link to close the high-side switch to allow current to pass through.

The MSP430FR2633 has CapTIvate technology integrated in it. Using this technology, there is a capacitive sense button implemented in this reference design. The button triggers the MCU to glow a blue LED once it senses a touch. The thresholds of the ADC are modified when the capacitive button is touched.

The difference between the higher and the lower threshold can be set using software. As shown in 图 15, once the capacitive button is pressed, depending on the position of the magnet, the new values of the lower and higher thresholds are set. This is done in runtime.

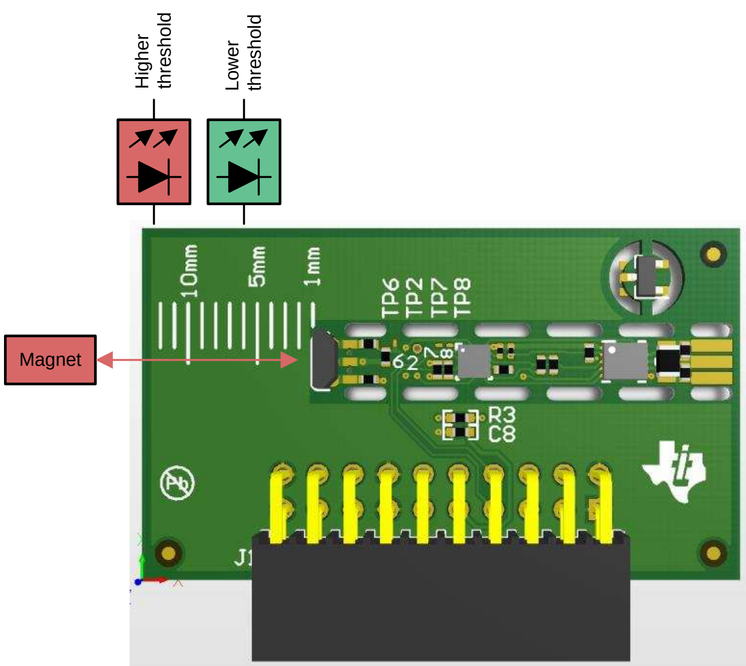



**图 15. Application Example**



TIDUCO7 — http://www-s.ti.com/sc/techlit/TIDUCO7
版权 © 2017, Texas Instruments Incorporated

# 4 Design Files

## 4.1 Schematics

To download the schematics, see the design files at TIDA-01239.

## 4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01239.

## 4.3 PCB Layout Recommendations

### 4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01239.

## 4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01239.

## 4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01239.

## 4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01239.

# 5 Related Documentation

1. Texas Instruments, *Getting Started With MSP MCUs With CapTIvate™ Technology*, Getting Started Guide (SLAU653)
2. Texas Instruments, *MSP430™ FRAM microcontrollers with CapTIvate™ technology*, Marketing White Paper (SLAY044)
3. Texas Instruments, *CapTIvate™ Technology Guide* (http://software-dl.ti.com/msp430/msp430_public_sw/mcu/msp430/CapTIvate_Design_Center/latest/exports/docs/users_guide/html/CapTIvate_Technology_Guide_html/markdown/index.html)

## 5.1 商标

CapTIvate, MSP430, MSP430Ware, Code Composer Studio are trademarks of Texas Instruments.
All other trademarks are the property of their respective owners.

# 6 About the Author

**ALEXANDER WEILER** is a systems engineer at Texas Instruments, where he is responsible for developing reference design solutions for the industrial segment. Alexander brings to this role his extensive experience in high-speed digital, low-noise analog, and RF system-level design expertise. Alexander earned his diploma in electrical engineering (Dipl.-Ing.(FH)) from the University of Applied Science in Karlsruhe, Germany.




版权 © 2017, Texas Instruments Incorporated

## 有关 TI 设计信息和资源的重要通知

德州仪器 (TI) 公司提供的技术、应用或其他设计建议、服务或信息，包括但不限于与评估模块有关的参考设计和材料（总称"TI 资源"），旨在帮助设计人员开发整合了 TI 产品的 应用； 如果您（个人，或如果是代表贵公司，则为贵公司）以任何方式下载、访问或使用了任何特定的 TI 资源，即表示贵方同意仅为该等目标，按照本通知的条款进行使用。

TI 所提供的 TI 资源，并未扩大或以其他方式修改 TI 对 TI 产品的公开适用的质保及质保免责声明；也未导致 TI 承担任何额外的义务或责任。TI 有权对其 TI 资源进行纠正、增强、改进和其他修改。

您理解并同意，在设计应用时应自行实施独立的分析、评价和 判断， 且应全权负责并确保 应用的安全性， 以及您的 应用 （包括应用中使用的所有 TI 产品））应符合所有适用的法律法规及其他相关要求。你就您的 应用声明，您具备制订和实施下列保障措施所需的一切必要专业知识，能够 (1) 预见故障的危险后果，(2) 监视故障及其后果，以及 (3) 降低可能导致危险的故障几率并采取适当措施。您同意，在使用或分发包含 TI 产品的任何 应用前， 您将彻底测试该等 应用 和该等应用所用 TI 产品的 功能。除特定 TI 资源的公开文档中明确列出的测试外，TI 未进行任何其他测试。

您只有在为开发包含该等 TI 资源所列 TI 产品的 应用时， 才被授权使用、复制和修改任何相关单项 TI 资源。但并未依据禁止反言原则或其他法理授予您任何TI知识产权的任何其他明示或默示的许可，也未授予您 TI 或第三方的任何技术或知识产权的许可，该等产权包括但不限于任何专利权、版权、屏蔽作品权或与使用TI产品或服务的任何整合、机器制作、流程相关的其他知识产权。涉及或参考了第三方产品或服务的信息不构成使用此类产品或服务的许可或与其相关的保证或认可。使用 TI 资源可能需要您向第三方获得对该等第三方专利或其他知识产权的许可。

TI 资源系"按原样"提供。TI 兹免除对 TI 资源及其使用作出所有其他明确或默认的保证或陈述，包括但不限于对准确性或完整性、产权保证、无屡发故障保证，以及适销性、适合特定用途和不侵犯任何第三方知识产权的任何默认保证。

TI 不负责任何申索，包括但不限于因组合产品所致或与之有关的申索，也不为您辩护或赔偿，即使该等产品组合已列于 TI 资源或其他地方。对因 TI 资源或其使用引起或与之有关的任何实际的、直接的、特殊的、附带的、间接的、惩罚性的、偶发的、从属或惩戒性损害赔偿，不管 TI 是否获悉可能会产生上述损害赔偿，TI 概不负责。

您同意向 TI 及其代表全额赔偿因您不遵守本通知条款和条件而引起的任何损害、费用、损失和/或责任。

本通知适用于 TI 资源。另有其他条款适用于某些类型的材料、TI 产品和服务的使用和采购。这些条款包括但不限于适用于 TI 的半导体产品 (http://www.ti.com/sc/docs/stdterms.htm)、评估模块和样品 (http://www.ti.com/sc/docs/sampterms.htm) 的标准条款。

邮寄地址：上海市浦东新区世纪大道 1568 号中建大厦 32 楼，邮政编码：200122
Copyright © 2017 德州仪器半导体技术（上海）有限公司