参考資料

TI Designs: TIDA-01239
CapTIvate学習ボタンを持つ近接スイッチのリファレンス・デザイン

概要

このリファレンス・デザインでは、TIの CapTIvate™テクノロジをベースとし、超小型の3.5mm幅のPCBに搭載された、静電容量式タッチ・ボタンの実装を紹介します。このボタンは一般に、近接スイッチの設定ボタンとして使用されます。高度に統合されたIO-Link PHYと組み合わせることで、PNPとNPNのどちらでも柔軟な出力を実現できます。このSIO段は、逆極性、ESD、EFT、およびサージから保護されており、設計でIEC 61000-4標準を満たすことができます。アナログ出力信号を持つホール・センサにより、静電容量式学習ボタンを使用して磁気性の物体の距離を教え、柔軟な使用が可能になります。アナログ信号は、MCUの内蔵ADCによりキャプチャされます。

リソース

TIDA-01239	デザイン・フォルダ
TIOL111	プロダクト・フォルダ
DRV5053	プロダクト・フォルダ
MSP430FR2633	プロダクト・フォルダ

TI E2E™ Community

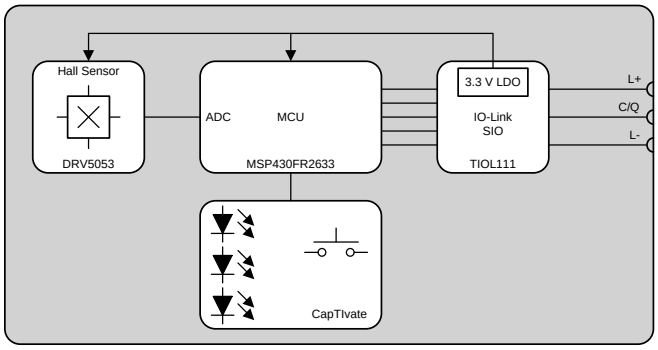
E2Eエキスパートに質問

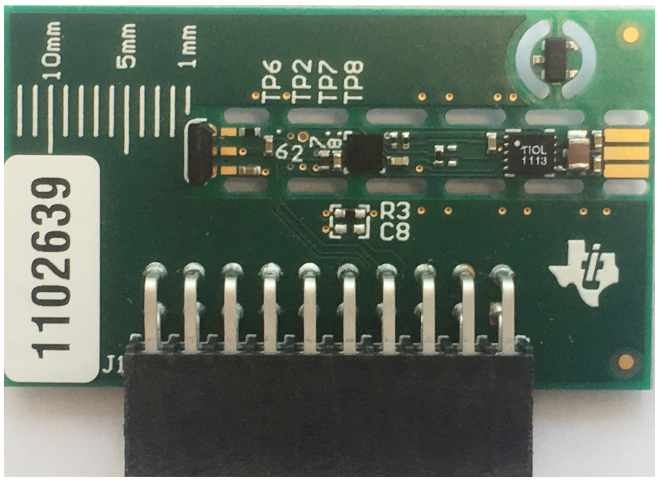
特長

- CapTIvateテクノロジを採用した静電容量式学習ボタン
  - 金属タッチと水分除去のデザインをサポート
  - 自己および相互容量電極
  - 電源ライン、RF、その他環境ノイズへの耐性の強化が可能
- 高度に統合された出力ドライバ
  - NPN、PNP、IO-Link (オプション)
  - 3.3V～5.0V LDO、20mA
  - 逆極性保護
  - IEC 61000-4に従うESD、EFT、サージ保護
  - 出力電流制限は50～350mAの範囲で設定可能
- 3.5mm幅のPCB

アプリケーション

- ファクトリ・オートメーション/制御
  - 変位センサ
  - 近接スイッチ





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

表 1. Key System Specifications (continued)

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

2 System Overview

2.1 Block Diagram

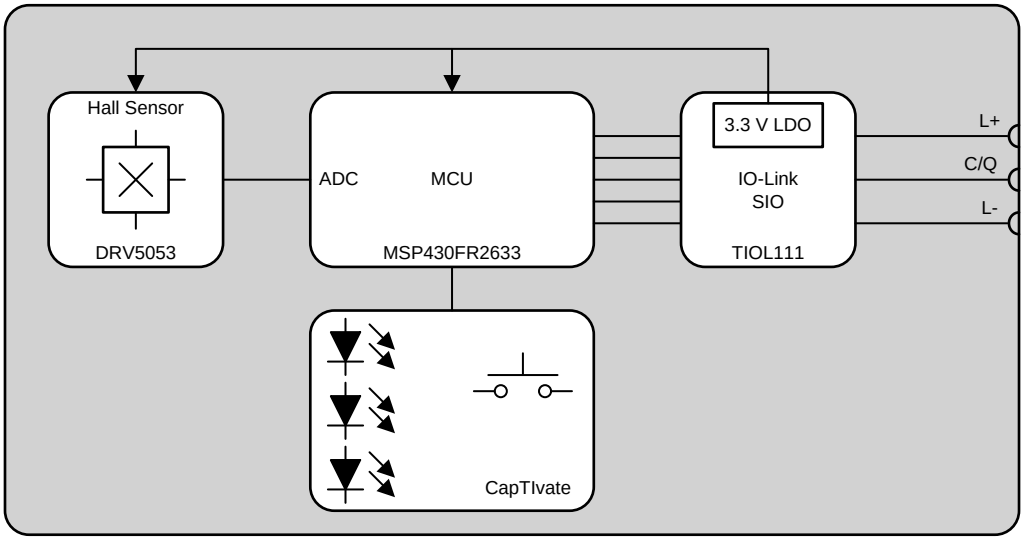


図 1. Block Diagram of TIDA-01239

2.2 Design Considerations

The top layer of this reference design includes the following (see 図 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 図 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.

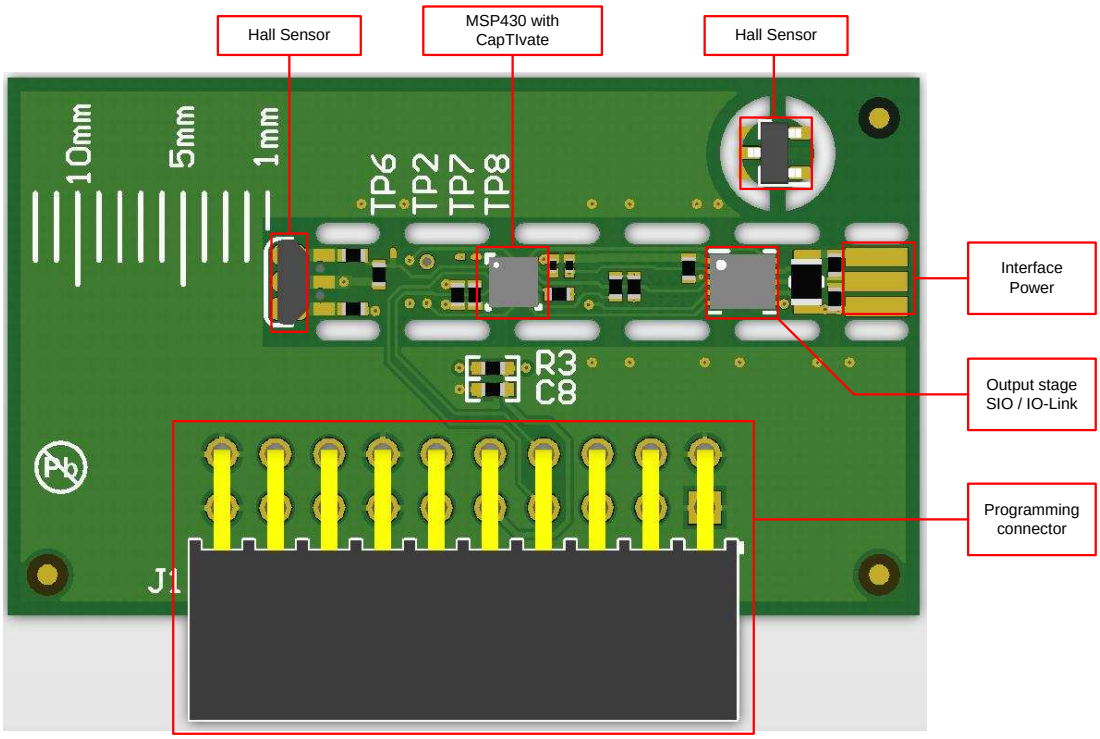


図 2. Description of Subsystem Blocks in Top Layer

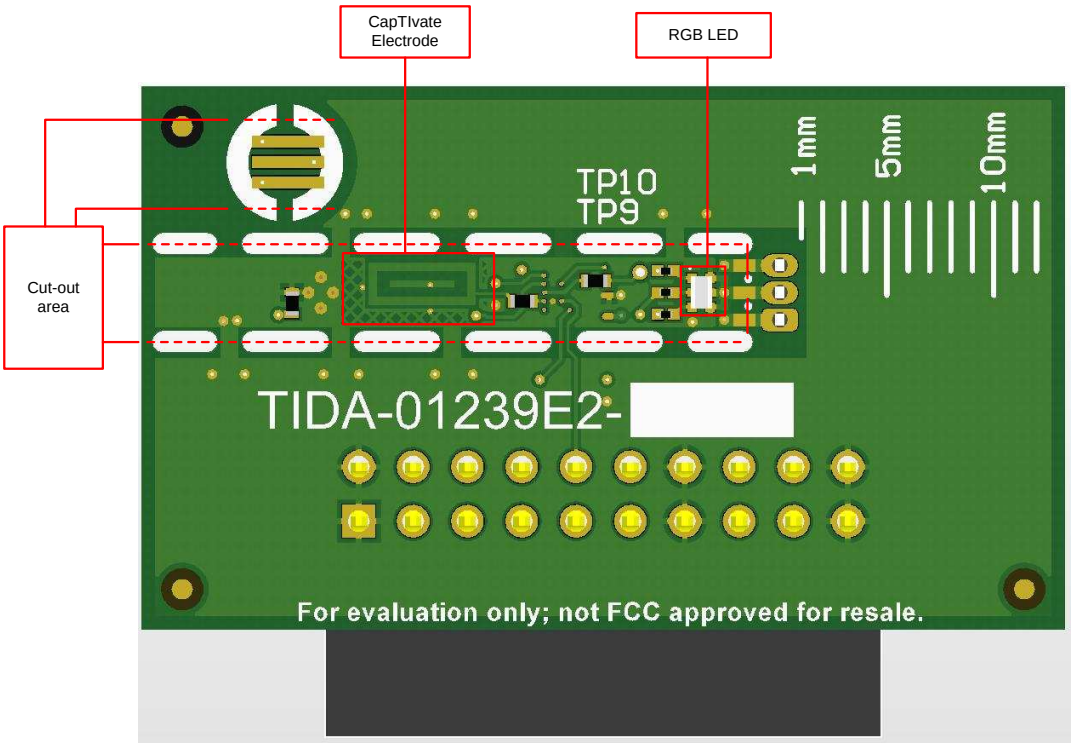


図 3. Description of Subsystem Blocks in Bottom Layer

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

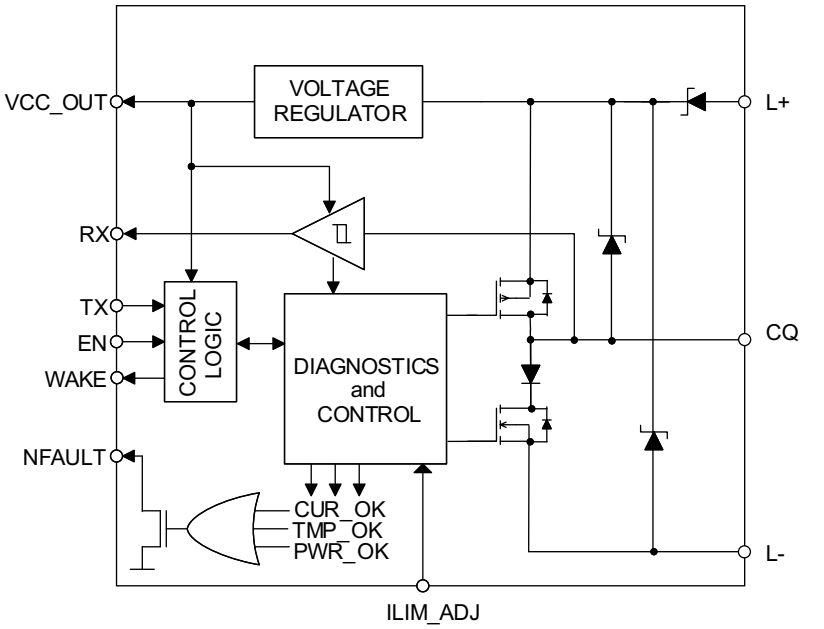


図 4. Block Diagram of TIOL111 With Integrated Volatge Regulator

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)

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

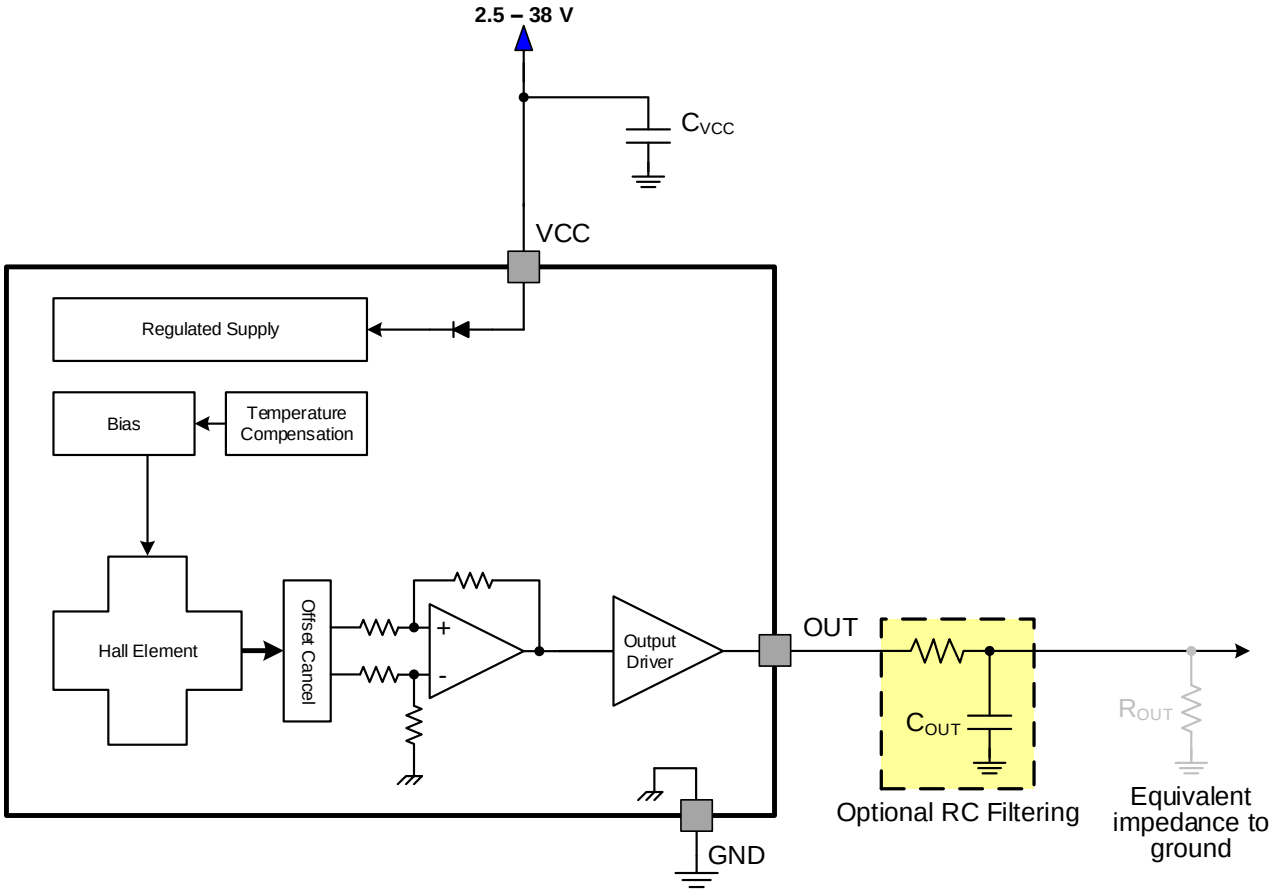


図 5. Block Diagram of DRV5053

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.

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

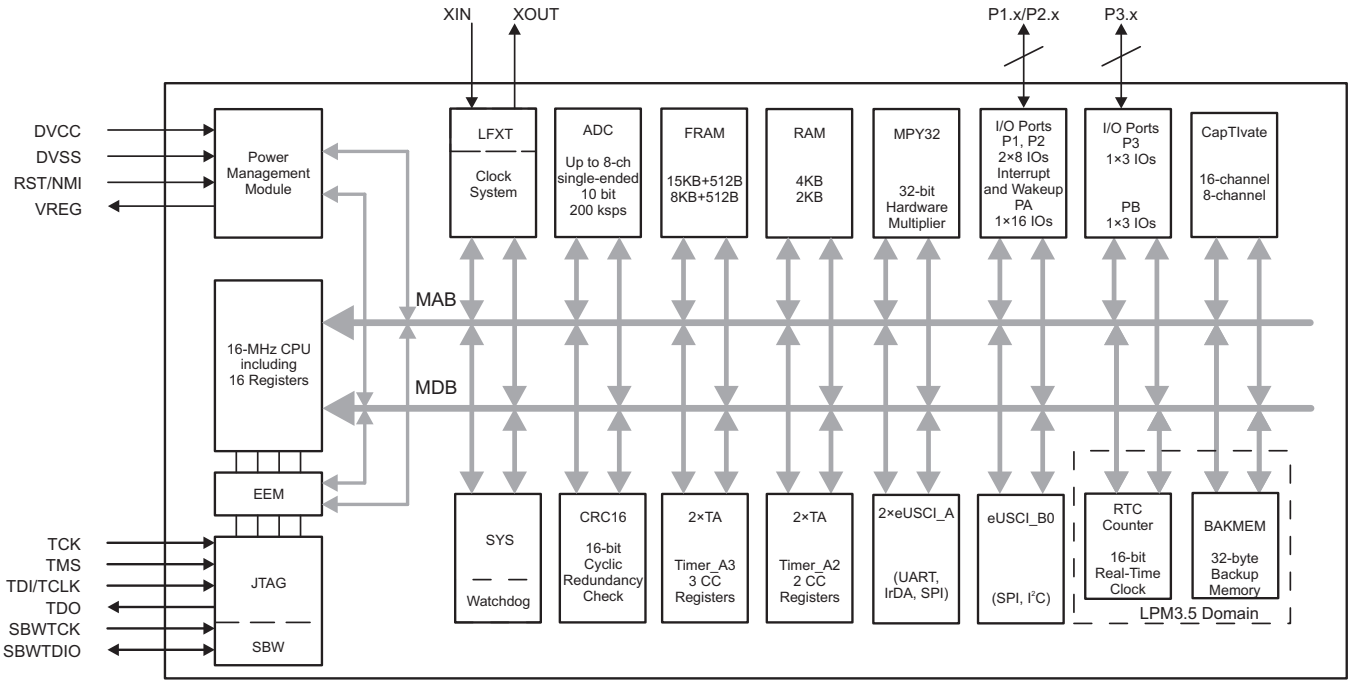


図 6. Block Diagram of MSP430FR2633

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

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

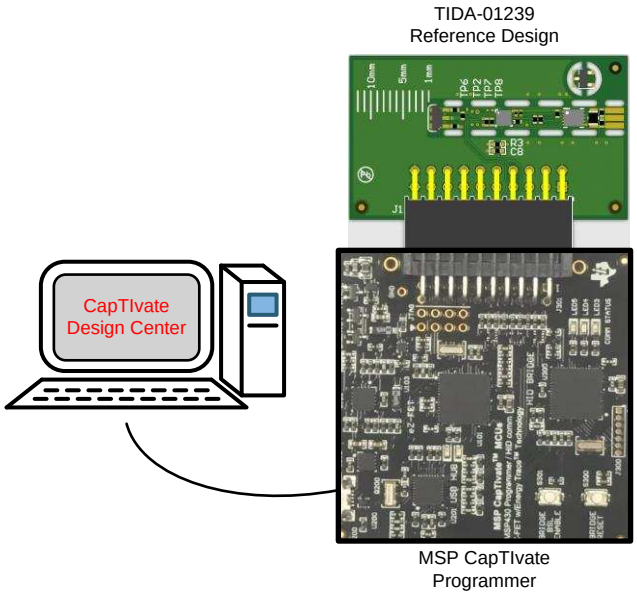


図 7. Test Setup for Capacitive Touch Optimization

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. 図 8 and 図 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.

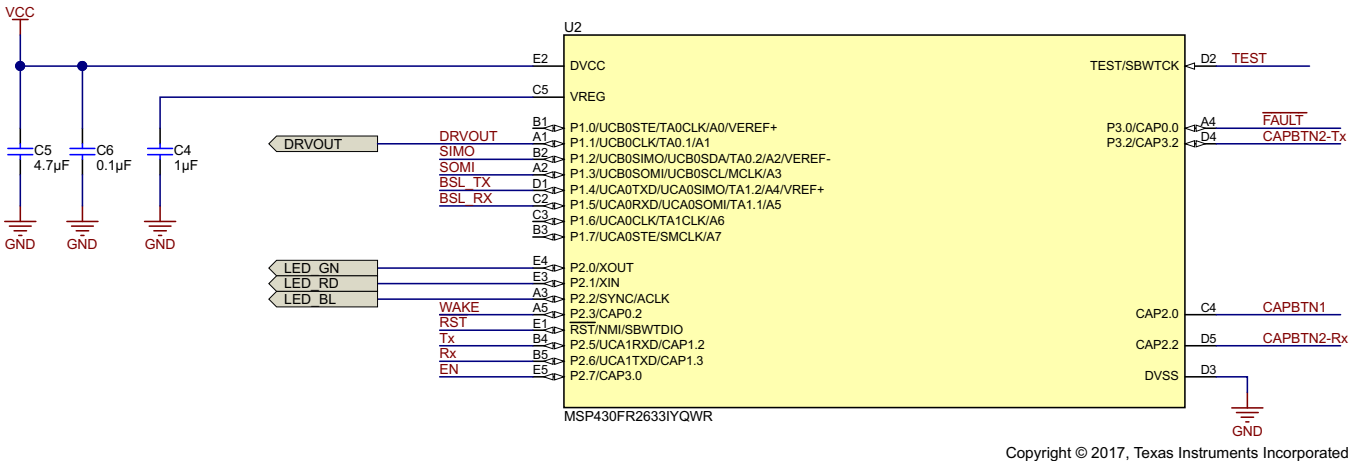


図 8. TIDA-01239 MCU Circuitry

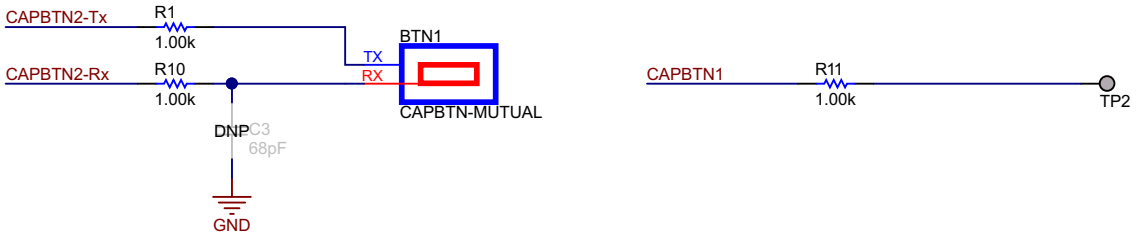


図 9. TIDA-01239 Mutual and Self-Coupling Electrodes

According to 図 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.

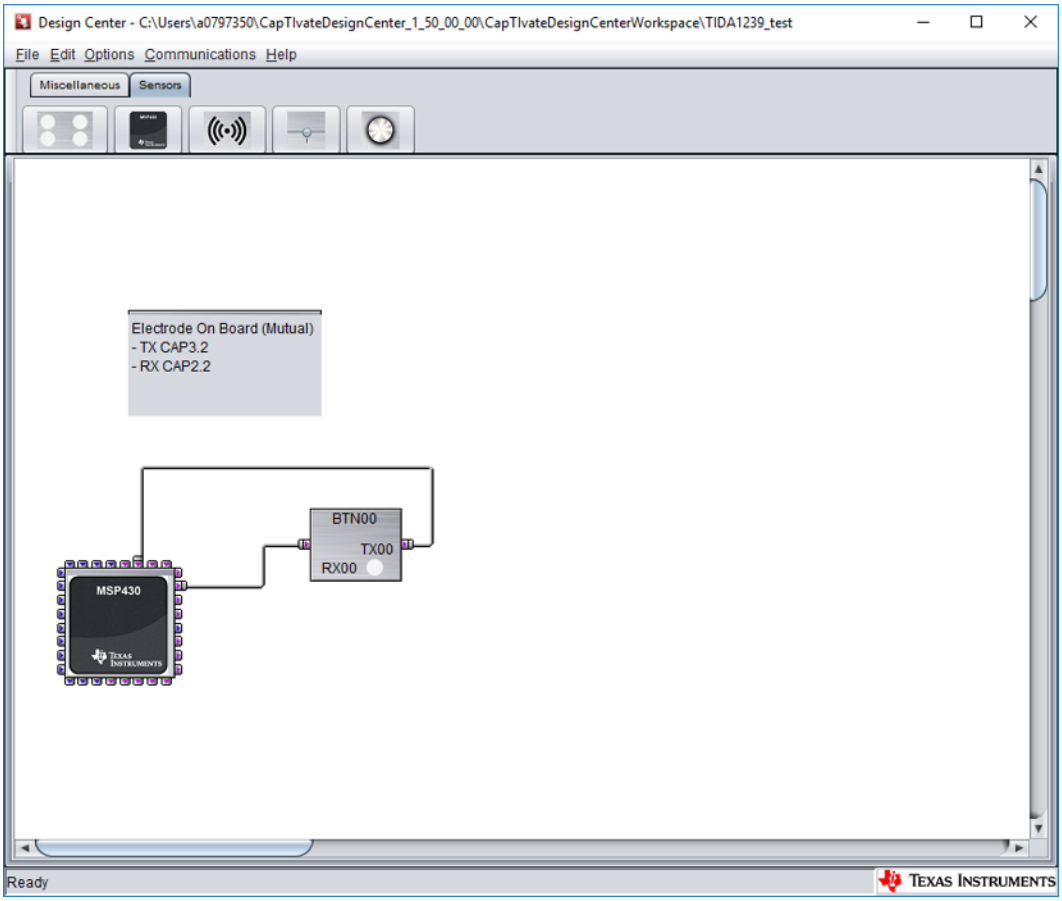


図 10. CapTIvate Design Center: Setup of One Mutual Button

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 図 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 図 11 and 図 12) or *Channel Oscilloscope Plot* (see 図 13).

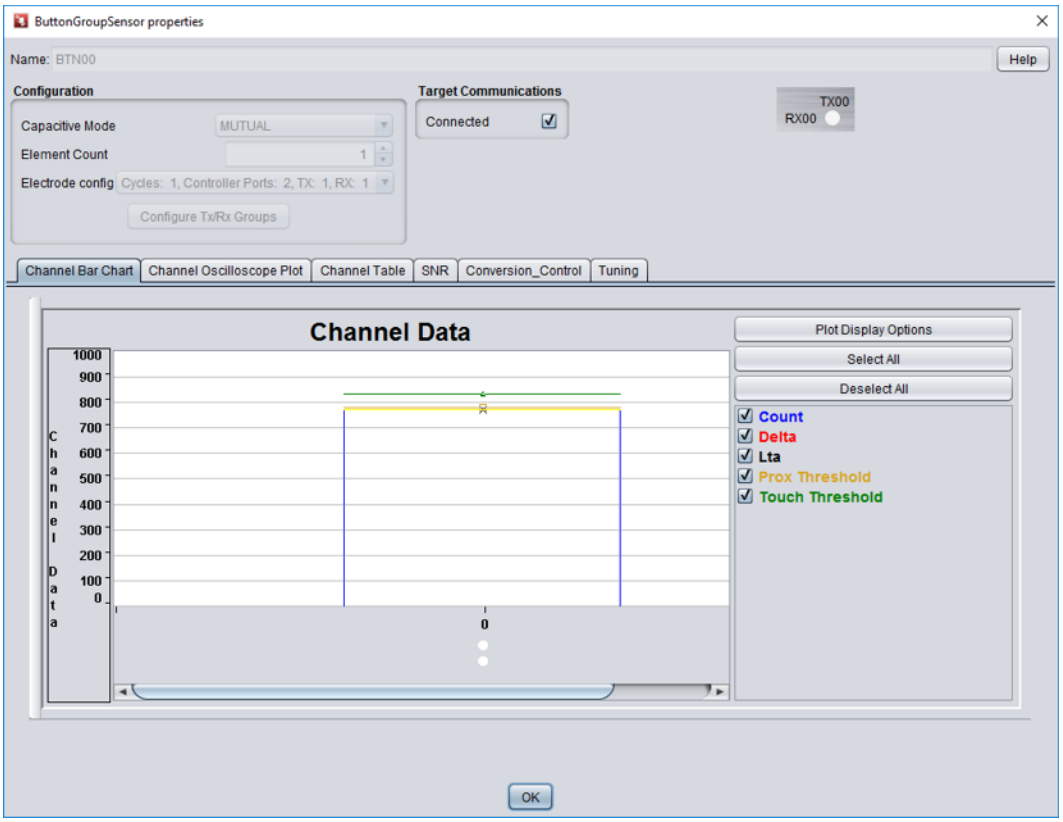


図 11. CapTIvate Design Center: No Touch

図 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.

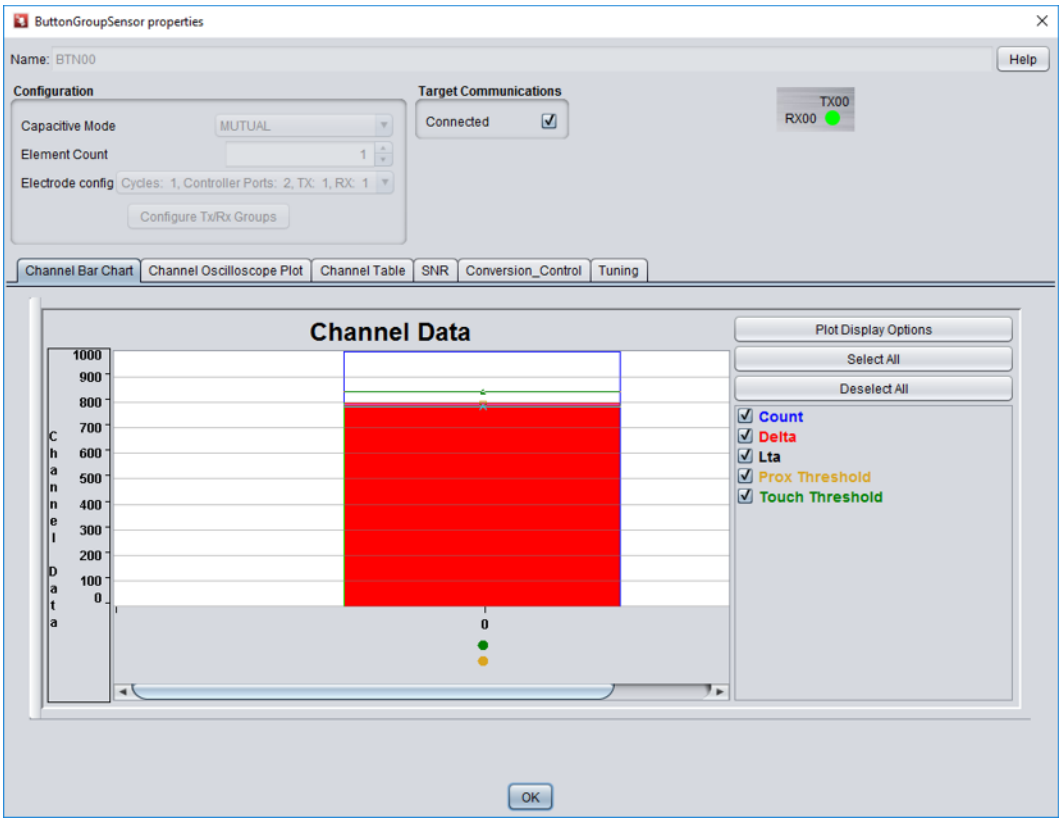


図 12. CapTIvate Design Center: Touch on Button Recognized

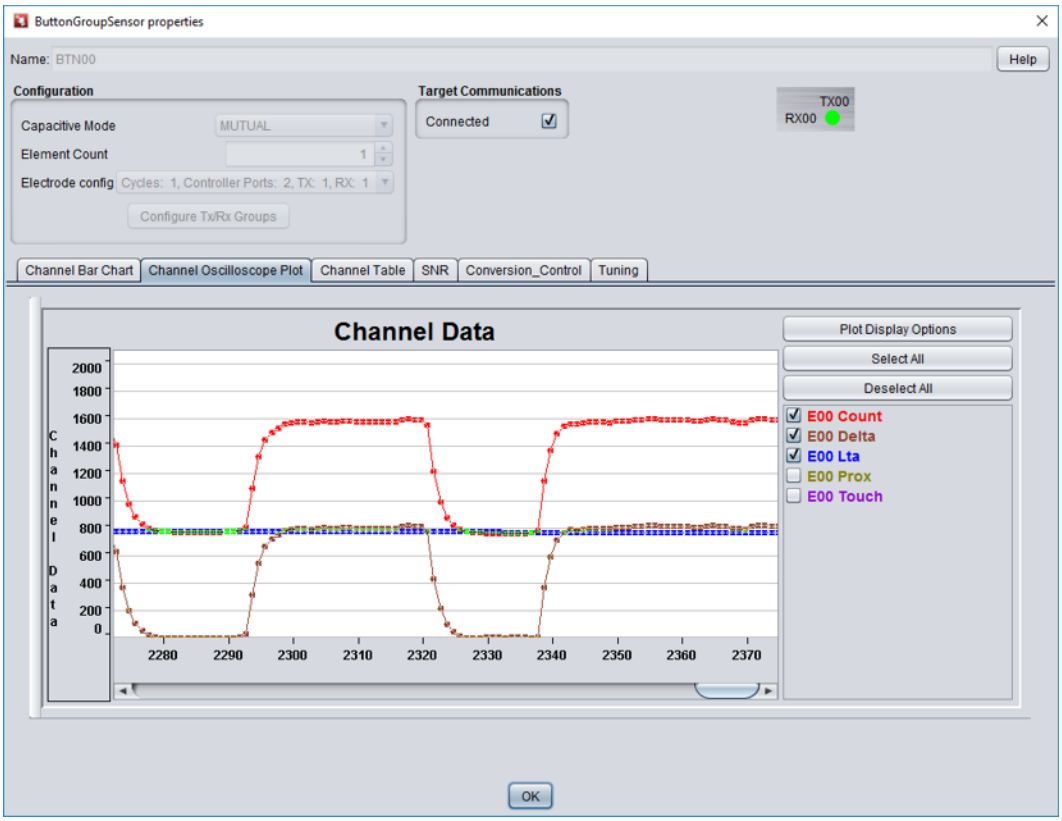


図 13. CapTIvate Design Center: Time Plot With Several Touch Events

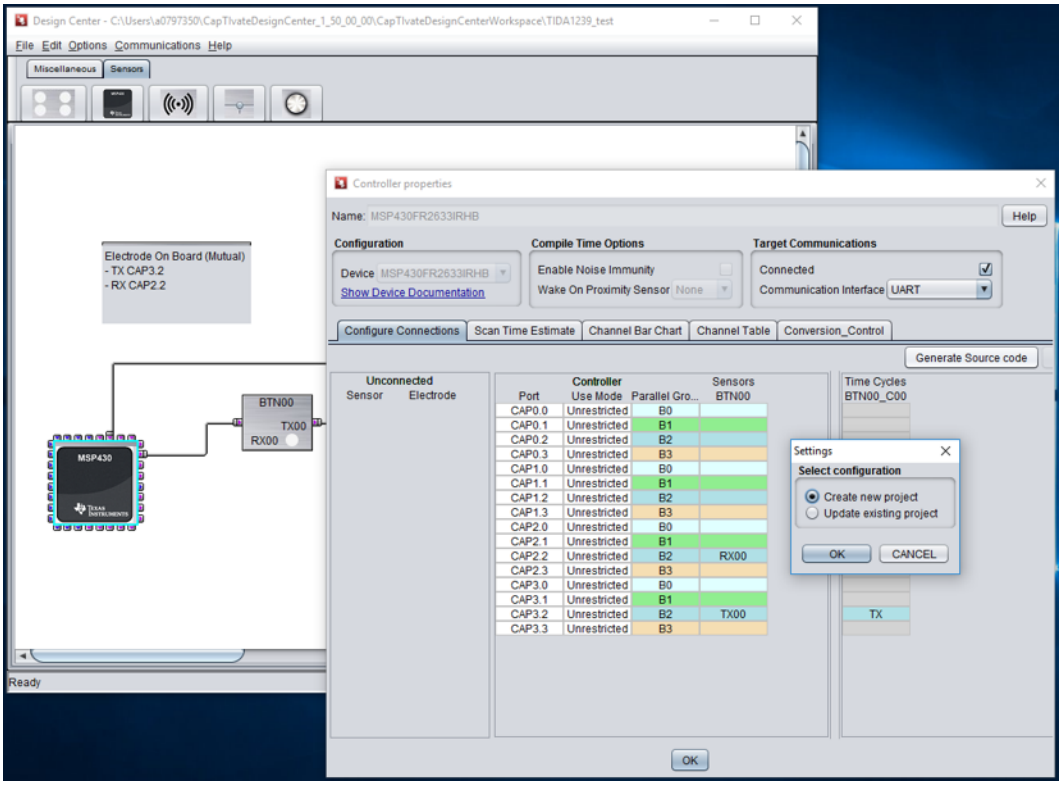


図 14. CapTIvate Design Center: Code Generation

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 図 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 図 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.

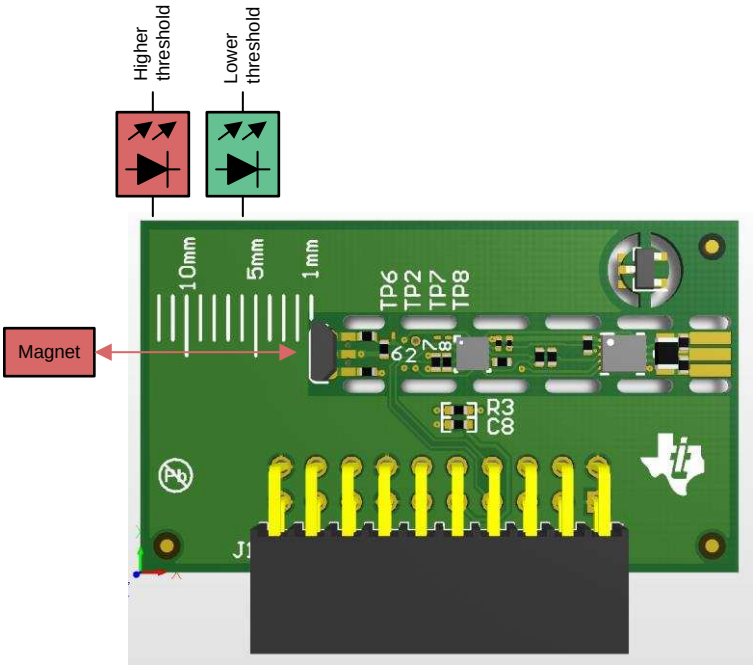


図 15. Application Example

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 商標

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.

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お客様は、自らのアプリケーションの設計において、ご自身が独自に分析、評価、判断を行う責任がお客様にあり、お客様のアプリケーション(および、お客様のアプリケーションに使用されるすべてのTI製品)の安全性、および該当するすべての規制、法、その他適用される要件への遵守を保証するすべての責任をお客様のみが負うことを理解し、合意するものとします。お客様は、自身のアプリケーションに関して、(1) 故障による危険な結果を予測し、(2) 障害とその結果を監視し、および、(3) 損害を引き起こす障害の可能性を減らし、適切な対策を行う目的での、安全策を開発し実装するために必要な、すべての技術を保持していることを表明するものとします。お客様は、TI製品を含むアプリケーションを使用または配布する前に、それらのアプリケーション、およびアプリケーションに使用されているTI製品の機能性を完全にテストすることに合意するものとします。TIは、特定のTIリソース用に発行されたドキュメントで明示的に記載されているもの以外のテストを実行していません。

お客様は、個別のTIリソースにつき、当該TIリソースに記載されているTI製品を含むアプリケーションの開発に関連する目的でのみ、使用、コピー、変更することが許可されています。明示的または黙示的を問わず、禁反言の法理その他どのような理由でも、他のTIの知的所有権に対するその他のライセンスは付与されません。また、TIまたは他のいかなる第三者のテクノロジまたは知的所有権についても、いかなるライセンスも付与されるものではありません。付与されないものには、TI製品またはサービスが使用される組み合わせ、機械、プロセスに関連する特許権、著作権、回路配置利用権、その他の知的所有権が含まれますが、これらに限られません。第三者の製品やサービスに関する、またはそれらを参照する情報は、そのような製品またはサービスを利用するライセンスを構成するものではなく、それらに対する保証または推奨を意味するものでもありません。TIリソースを使用するため、第三者の特許または他の知的所有権に基づく第三者からのライセンス、あるいはTIの特許または他の知的所有権に基づくTIからのライセンスが必要な場合があります。

TIのリソースは、それに含まれるあらゆる欠陥も含めて、「現状のまま」提供されます。TIは、TIリソースまたはその仕様に関して、明示的か暗黙的かにかかわらず、他のいかなる保証または表明も行いません。これには、正確性または完全性、権原、続発性の障害に関する保証、および商品性、特定目的への適合性、第三者の知的所有権の非侵害に対する黙示の保証が含まれますが、これらに限られません。

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お客様は、この注意事項の条件および条項に従わなかったために発生した、いかなる損害、コスト、損失、責任からも、TIおよびその代表者を完全に免責するものとします。

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