Enabling noise tolerant capacitive touch HMIs with MSP CapTIvate™ technology

Texas Instruments

Walter Schnoor
Applications Engineer

Ling Zhu
Applications Engineer

Texas Instruments

Capacitive touch as a human-machine interface (HMI) technology is finding its way into more and more applications each year.

It is rapidly becoming a popular technology for mechanical button replacement in end equipment such as small and large home appliances, industrial control panels, and automotive center stacks. While the technology offers designers new freedoms in how they can differentiate their products via the user interface, it also presents new challenges.

The challenges arise from the fact that these markets often share two important characteristics: they are high in electrical noise, and they have safety critical functions controlled by the user interface. Capacitive touch interfaces are inherently susceptible to many different types noise, posing serious challenges to designers looking to integrate capacitive touch into products that require a high level of reliability. Complicating things further, there are a wide variety of capacitive touch solutions available on the market from various semiconductor manufacturers. Each manufacturer has a unique approach to measuring changes in capacitance. Evaluating the performance of different capacitive touch solutions in the presence of noise is difficult because noise immunity is a system level design challenge. Factors that contribute to the noise performance of a solution include the capacitive measurement technology itself, the hardware design of the system, and the software that is used to interpret the raw data and process it into a touch status. The new CapTIvate™ technology from Texas Instruments, integrated in select MSP microcontrollers (MCUs), provides designers with a feature-rich capacitive sensing peripheral that can be configured for ultra-low-energy battery-powered applications as well as applications that require a high level of noise tolerance. In order to demonstrate system-level design principles for creating a noise-tolerant solution, TI has certified the CAPTIVATE-EMC EVM for immunity to conducted noise, electrical fast transients, radiated noise and electrostatic discharge per the IEC 61000-4-6, IEC 61000-4-4, IEC 61000-4-3 and IEC 61000-4-2 system level standards, respectively. This design provides a reference for schematic, layout, and software best practices when designing for noise tolerance with CapTIvate™ technology.

MSP CapTIvate™ technology

The CapTIvate™ technology from Texas Instruments is a capacitance measurement peripheral that is targeted specifically at human-machine interface applications such as buttons, sliders, scroll wheels, proximity detection, and more. It supports self and mutual capacitance measurement topologies to allow designers to create unique interfaces that leverage the benefits of each topology in the same design using the same MCU.

In a given MCU, the peripheral may contain multiple CapTIvate™ technology measurement blocks. The MSP430FR2676 MCU has 4 measurement blocks. Measuring electrodes in parallel optimizes the overall conversion time for a system and provides common-mode rejection of noise in slider and scroll wheel implementations, since noise will effect each element of the sensor proportionally.

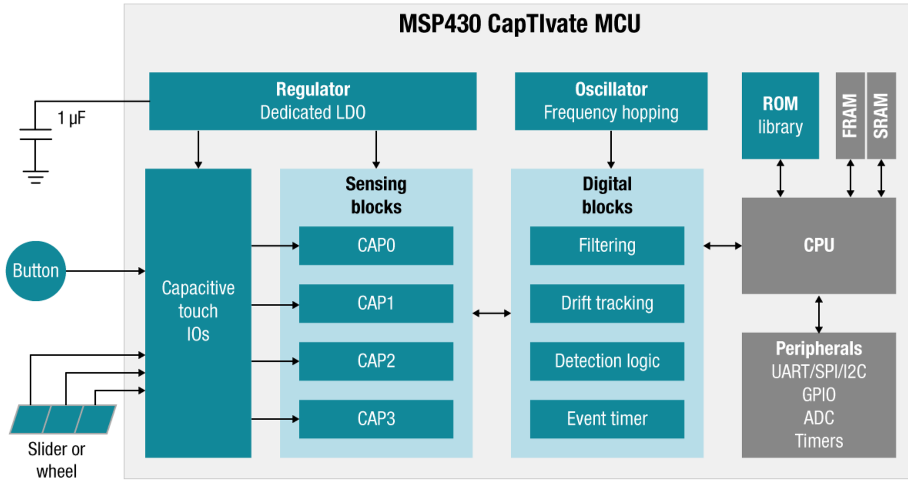

Figure 1: Peripheral diagram.

The CapTIvate™ technology measurement block is an integrator-based charge transfer engine that has the capability of applying gain and offset to a charge transfer, allowing for compensation of large parasitic capacitances. This offset capability allows designers to use dense ground shielding structures in the PCB to limit fringing E-field lines, improving immunity to noise.

To enable designs with noise tolerance, the capacitance-to-digital conversion is clocked by a dedicated oscillator with frequency hopping capability and spread-spectrum modulation. The ability to move the conversion around in the frequency domain allows for the CapTIvate™ technology software library to gather more information about a product's current operating environment, allowing for accurate touch detection in the presence of conducted and radiated noise.

Three-sided approach to immunity

Ultimately, creating a capacitive touch interface that is robust in the presence of many different possible noise sources requires careful application of a three-sided approach that consists of CapTIvate™ technology features, hardware design techniques, and signal processing algorithms. All three elements must work together to provide immunity. Only applying signal processing algorithms while neglecting good hardware design techniques will not lead to a successful design.

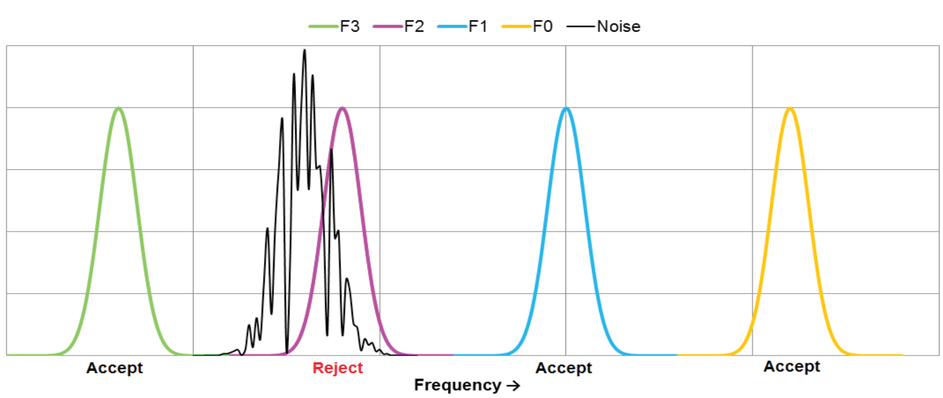

Figure 2: Frequency hopping to avoid noisy bands.

1. CapTIvate™ technology features

- Integrator-based charge transfer engine
- Parasitic capacitance offset subtraction
- Frequency hopping oscillator
- Spread-spectrum clock modulation in self mode
- Input bias current (CapTIvate 2nd Generation)
- DVCC charge voltage mode (CapTIvate 2nd Generation)
- Hardware state machine for signal processing algorithms (CapTIvate 2nd Generation)

2. Hardware design techniques

- Ground shielding of electrodes in layout
- 68 pF filter capacitors on receive sensing lines in mutual mode

3. Signal processing algorithms

- Multi-frequency processing (MFP) algorithm
- IIR filtering + de-bounce
- Dynamic threshold adjustment (DTA) algorithm in self mode

CAPTIVATE-EMC EVM

The CAPTIVATE-EMC is an evaluation board that enables users to easily evaluate CapTIvate's electromagnetic compatibility performance relative to their design requirements. The EVM features the MSP430FR2676 CapTIvate MCU with hardware accelerated frequency hopping and oversampling. This reference design demonstrates how to design hardware and software that can pass challenging system level tests for conducted RF immunity, electrical fast transient/burst immunity, electrostatic discharge immunity and radiated immunity.

The CAPTIVATE-EMC consists of a 2-layer, 1.6 mm thick FR4 printed circuit board featuring 16 capacitive touch buttons. A 3 mm acrylic overlay material is bonded to the PCB using 3M 467MP adhesive. The 3 mm overlay represents a typical product overlay thickness. LED illumination is provided from the bottom side of the board through holes in the PCB. A speaker is also provided on the bottom side of the board. There are 8 self-mode buttons and 8 mutual-mode buttons on the CAPTIVATE-EMC panel, requiring a total of 14 touch sensing pins. The CAPTIVATE-EMC is powered by a DC input (5 VDC - 20 VDC).

Noise testing methodology

The International Electrotechnical Commission (IEC) 61000-4 international standard for electromagnetic compatibility was utilized as the foundation for certification. This is a system-level test standard that defines test procedures and pass/fail criteria for EMC as it relates to immunity. The following tests were applied to the CAPTIVATE-EMC EVM:

- Conducted RF Noise Immunity (IEC 61000-4-6)
- Electrical Fast Transient/Burst Immunity (IEC 61000-4-4)
- Radiated Immunity (IEC 61000-4-3)
- Electrostatic Discharge (ESD) Immunity (IEC61000-4-2)

During testing a simulated finger that consisted of a copper square sized to represent a human finger was used. The simulated finger was terminated to reference ground during the test through a 220 pF ±20% capacitor in series with a 510Ω ±10%resistor, per the International Special Committee on Radio Interference (CISPR) standard.

The CAPTIVATE –EMC EVM was powered by 12 VDC from a PSM-UACTO3.3 VDC module.

Figure 3: *CAPTIVATE-EMC EVM.*

TI pass/fail criteria for capacitive touch interfaces

The following capacitive touch specific pass/fail criteria were used for testing:

- **Class A:** The equipment under test (EUT) operates as intended with no degradation of performance during the test or after the test. In the context of a capacitive sensing interface, **Class A** requires the following:

• The EUT shall not exhibit any false touch detections during or after the test.

• The EUT shall always detect valid touches during and after the test.

• If the EUT contains slider or wheel sensors, their position shall be reported accurately to within an acceptable limit during and after the test.

• The EUT shall not exhibit any integrated circuit (IC) device resets or faults during the test. No non-recoverable IC errors such as FRAM memory corruption, I^2C bus errors, or I^2C bus glitches are allowed.

- **Class B:** The EUT experiences a temporary loss of function or degradation of performance during the test. This degradation of performance ceases after the test, after which the EUT recovers on its own without operator intervention. In the context of a capacitive sensing interface, **Class B** requires the following:

• The EUT shall not exhibit any false touch detections during or after the test.

• The EUT is allowed to miss (not detect and report) a valid touch during the test, so long as it recovers on its own to full functionality after the test is complete.

• The EUT is allowed integrated circuit (IC) device resets during the test. No non-recoverable IC errors such as FRAM memory corruption, I^2C bus errors, or I^2C bus glitches are allowed.

- **Class C:** The equipment under test (EUT) experiences a loss of function or degradation of performance during the test which it does not recover from after the test stimulus is removed. The full functionality can be recovered by disconnecting and reconnecting power to the EUT.

Conducted noise immunity

Generally speaking, conducted RF noise is the most difficult test for capacitive touch interfaces to pass. This is a result of the fact that most capacitance measurement solutions operate by charging and discharging sensing electrodes at a frequency that usually falls within the conducted RF range of 100's of kilohertz to 10's of megahertz. The conducted noise immunity test simulates the effect of radio frequency noise coupling into power cables leading to a product. The cables are used as the coupling medium because the wavelengths of the frequencies being tested are very large. A radiated immunity test would not be feasible because the antennas involved would be prohibitively large. Conducted noise creates problems for capacitive touch because it leads to injected currents during sampling, corrupting conversion results.

The conducted noise immunity test is also valuable for systems that may be powered from a variety of switching power supplies. Low cost switching power supplies tend to be great sources of common-mode emissions around their switching frequency. This common-mode interference is very similar to the stress applied during a conducted noise test.

Class A immunity to conducted RF noise was tested for by applying the IEC 61000-4-6 standard in three different ways:

1. The standard noise frequency sweep (150 kHz to 80 MHz, amplitude modulated on a 1 kHz carrier at 80% depth) was applied with no simulated finger present, to ensure that no false detections occur during the duration of the test.

2. The standard noise frequency sweep (150 kHz to 80 MHz, amplitude modulated on a 1 kHz carrier at 80% depth) was applied with a simulated finger affixed to a touch button to ensure that the button remains correctly in touch detect throughout the duration of the test.

Electrical fast transient/burst immunity

It is very likely that a line powered product with a capacitive touch interface will see electrical fast transients at some point in its life. These transients, typically in the 100's of volts to a few kilovolts, are typically created by the switching of high-current inductive loads. This type of stress is seen more frequently in harsh industrial environments, but it is also present in residential environments.

Fast transients tend to create a disturbance similar to that of conducted noise, but the effect is more broadband in frequency. In addition, transients are short events that do not last for extended periods of time. For this reason, the best defense against fast transients is a well-designed power supply to protect the sensitive ICs in the product, and the application of de-bounce logic to prevent false detections from a sample that was effected by a transient.

Class A immunity to electrical fast transients was tested for by applying the IEC 61000-4-4 standard. Transients were coupled onto the AC mains supply feeding the EVM. Line (L), neutral (N), and line + neutral (L+N) coupling modes were tested. Burst rates of 5 kHz and 100 kHz were applied.

Radiated immunity

The test was performed in a fully anechoic chamber. The transmit antenna was located at a distance of a 3 meters from the EVM. The frequency range is swept from 80 MHz to 1000 MHz, with the signal 80% amplitude modulated with a 1 kHz sine-wave. The rate of sweep did not exceed 1.5×10-3 decade/s, where the frequency range is swept incrementally, the step size was 1% of preceding frequency value.

A proper ground plane on the PCB reduces both RF emissions and interference. And series resistors on touch trace help in eliminating higher order harmonics and attenuating the RF interference and emission.

Class A immunity to radiated noise was tested for by applying the IEC 61000-4-3 standard. The test was performed with the EVM exposed to both vertically and horizontally polarized fields on each of the four sides.

Electrostatic discharge immunity

When it comes to ESD, first line of defense for any capacitive touch interface is the overlay material and mechanical design. Plastic overlays such as acrylic, polycarbonate and ABS have high breakdown voltages that often provide all of the necessary protection. Care should be taken in enclosure design to ensure that off-board connectors are protected and that there are no unshielded gaps where a discharge might spread into a product.

Designs that have exposed electrodes or extremely thin overlays should utilize low-capacitance transient voltage suppression (TVS) diodes to provide a low-impedance path for discharge current, which can be on the order of several amps in a system level ESD test.

IC protection aside, the strong electric fields that result from electrostatic discharges can disrupt capacitive touch measurements. The same de-bounce methods that are applied for fast transient protection work well for preventing false touch detections due to an electrostatic discharge near the product, since discharges are momentary and not continuous.

Class B immunity to ESD events was tested for by applying the IEC 61000-4-2 standard. Contact discharge was applied to horizontal and vertical coupling planes, and air discharge was applied to the sensor area, power connector and side of the EVM.

Test reports

TA Technology (Shanghai) Co., Ltd provided external testing services on the CAPTIVATE-EMC. The test report is appended to this document.

CAPTIVATE-EMC (REV A, PSM-UACT03.3VDC)	Conducted Immunity (IEC 61000-4-6)	10 Vrms	Class A	SLAK027, Page 14
	Electrical Fast Transient/Burst Immunity (IEC 61000-4-4)	±4 kV	Class A	SLAK027, Page 12
	Radiated Immunity (IEC61000-4-3)	10 V/m	Class A	SLAK027, Page 10
	Electrostatic Discharge Immunity (IEC 61000-4-2)	±8 kV/15 kV contact /air	Class B	SLAK027, Page 8

IMPORTANT NOTICE AND DISCLAIMER