5th generation CAPSENSE™ technology

Improved capacitive touch-sensing performance and higher integration enable single-chip implementations of more advanced HMI designs

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Contents

1. The market context

Capacitive touch sensing is a familiar and popular way to implement sleek, attractive and intuitive human-machine interfaces (HMIs) in devices such as smartphones, tablets and automotive displays.

Now many manufacturers operating elsewhere, including in the industrial automation and home appliance markets, are exploring ways to increase the appeal, usability and value of their products by replacing older HMI technologies – electro-mechanical buttons and switches, or resistive touch-sensing buttons – with modern capacitive sensing interfaces.

But in these new applications, capacitive touch-sensing interfaces are exposed to a different and often more challenging set of operating conditions. In products such as cooker stovetops, they may be required to operate in HMI systems that have a high number of buttons and control switches, and that extend over a much larger area than earlier implementations of capacitive sensing have supported.

This has created demand for new touch-sensing control capabilities. Simply repurposing existing capacitive sensing technology built for personal consumer devices and applying it to industrial and home appliance applications risks producing an inadequate and disappointing user experience. Infineon has instead chosen to introduce a new fifth generation of its market-leading CAPSENSE™ technology, to provide dramatically improved performance, and capabilities that match the requirements of the new use cases.

This paper describes the nature of the new industrial and home appliance use cases, the challenges they present in implementing a high-performance touch-based HMI, the most important advances made by Infineon in its 5th generation of CAPSENSE™ technology, and the ways that these advances enable product manufacturers to produce an outstanding user experience while streamlining both their bill-of-materials (BoM) and their development process.

2. The new use cases for capacitive sensing: bigger, more complex, noisier

The move to implement capacitive sensing is driven by a desire to provide an improved user experience, a sleeker product appearance and more reliable operation.

CAPSENSE™ capacitive sensing is superior to the alternative technologies, either electro-mechanical buttons or resistive touch sensing, on all three counts:

User experience: capacitive sensing touch panels can be combined with lighting, haptic and acoustic effects to make control options appear intuitive. Compared to resistive touch-sensing, capacitive sensing is faster, and responds to a light touch rather than requiring a forceful press.

Appearance: a capacitive touch sensing panel can be flat, sleek and smooth. If required, it can be made flush with the enclosure of the product it is embedded in. In applications such as cooktops and ovens, this flat surface is easier to keep clean and hygienic than an HMI made of electro-mechanical buttons and switches that stand proud of the surface. In touchscreens, capacitive sensing attenuates the optical output of the display less than resistive sensing, producing a brighter and more attractive display appearance.

Reliability: electro-mechanical buttons, dials and switches have moving parts and are assemblies of multiple small metal and/or plastic parts. These parts can fail when they are exposed to temperature stress or are over-exercised mechanically. Resistive touch sensors also have moving parts – the surface of a touch button is depressed to contact the sensor. This can result in mechanical failure over time. By contrast, a capacitive sensing system has no moving parts, and the sensor assembly may be hermetically sealed to eliminate the risk of exposure to liquid or other contaminants.

Manufacturers of industrial automation equipment and home appliances are increasingly adopting capacitive sensing to take advantage of all three benefits. But in these new use cases, manufacturers are requiring a touch-sensing panel to extend the scope of its operation, and to operate in more challenging conditions. At the same time, product development teams are under intense pressure to manage BoM cost pressures, to streamline the development process to reduce development cost and effort, and to accelerate a product's time-to-market.

Let's examine each of these factors in more detail.

3. Larger HMI panels that contain more touch sensors

In a personal consumer device such as a smartphone, the size of the touchscreen is determined by the form factor of the device itself. The smartphone is a handheld device, so the touch surface is limited to the size of screen that the user can hold.

- In industrial equipment and household appliances, this limitation does not apply. To take the example of a kitchen stovetop containing five or more heating elements, the application might require multiple controls to:
- Switch the unit on and off
- Adjust the heat of each element on a graduated scale
- Set timers for each element
- Control peripheral devices such as extractor fans

In the past, these controls have often been constricted to a small area of the touch panel, so that multiple controls were only available to the user via a nested series of menu options. The presentation of control options via menus can be confusing to many users, and it is less convenient for all users – it requires more touches to produce the desired action. The reason that product manufacturers have implemented capacitive sensing buttons in a small area, operated via a low number of touch sensors, is because of limitations in the capability and performance of previous generations of touch-sensing controller. But in this application, the user has a better experience when multiple controls are laid out over a large area, with a single function allocated to each touch-sensing button, switch or slider.

This approach to UI design, however, greatly intensifies the demands made of the touch-sensing controller:

- Longer traces connecting touch sensors to the touch controller are subject to much more noise, attenuating the signal received by the controller.
- A large touch-sensing interface in a home appliance can contain more than 100 sensing elements. The user expects an instant response to touch events, which means that the touch controller must scan this high number of nodes at very high speed.

These operating parameters make high demands of the touch controller, in particular requiring a superior signal-to-noise ratio (SNR), and the ability to support high-speed scanning of multiple sensor elements.

4. Increased exposure to noise and interference

More than personal consumer and computing devices, industrial equipment and appliances are exposed to multiple strong sources of noise and interference.
As stated above, noise is more readily coupled to the long traces in large touch panels than the short traces in a smartphone, for instance. But in industrial equipment and home appliances, the touch panel can also be subject to interference caused by:

- Condensation and water droplets
- Contamination by liquid spillage – on a cooktop, for instance, sauces and other cooking liquids can come to rest on touch-sensing surfaces
- Swings in ambient temperature
- Power-supply noise
- In industrial applications, the user might operate HMI controls while wearing gloves, attenuating the capacitance of the finger

Contaminants such as water droplets and other liquids have capacitance. If this capacitance effect is not rejected by the touch controller, the contamination might be registered as a false touch event, or a real touch might not be recognized above the noise caused by the contamination.

Temperature changes have a marked effect on the sensitivity of many touch controllers, leading to inconsistent behaviour and an unpredictable user experience.
Power-supply noise can disturb the signal received by the touch controller, leading it to register false touches or fail to detect genuine touches.
Finally, the wearing of gloves dramatically reduces the change in capacitance value sensed by the touch controller. If the capacitance of the touch is so low that it is indistinguishable from the controller's noise floor, touch events will fail to be registered.
These challenging operating conditions call for a touch-sensing system with a superior SNR and a very low noise floor.

5. Streamlined system architecture

The design engineering team's task is to achieve a design that balances competing requirements: to provide the user with high performance and desirable features, while controlling the costs of both the BoM and of the development process itself.
An effective way to control BoM costs is integration. In touch-sensing designs, this means that the designer will want to aggregate all HMI control functions into the same chip that controls the interface to the touch buttons, sliders and switches.
This integration becomes harder to achieve the more touch sensors the HMI contains. As described above, an application such as a stovetop could contain more than 100 touch sensing elements. In previous generations of touch controller, the burden of scanning so many sensors has often left insufficient processing resource available to implement the HMI application.
When scanning a high number of touch sensor nodes, system designers have also sought to accelerate operation – to make the latency between a touch event and the system's response imperceptible to the user – by performing simultaneous scanning of multiple nodes. This is an effective acceleration technique, but has entailed the development of extremely complex synchronization firmware.
To enable the use of a single-chip architecture for the HMI, then, designers need a touch controller that can maintain sufficient spare processing capacity after scanning multiple nodes.
Meanwhile, the development process will be streamlined if multi-sensor scanning can be implemented without the need for complex synchronization firmware.

6. 5th generation CAPSENSE™: a solution to the challenges of designing large, noisy touch-sensing HMIs

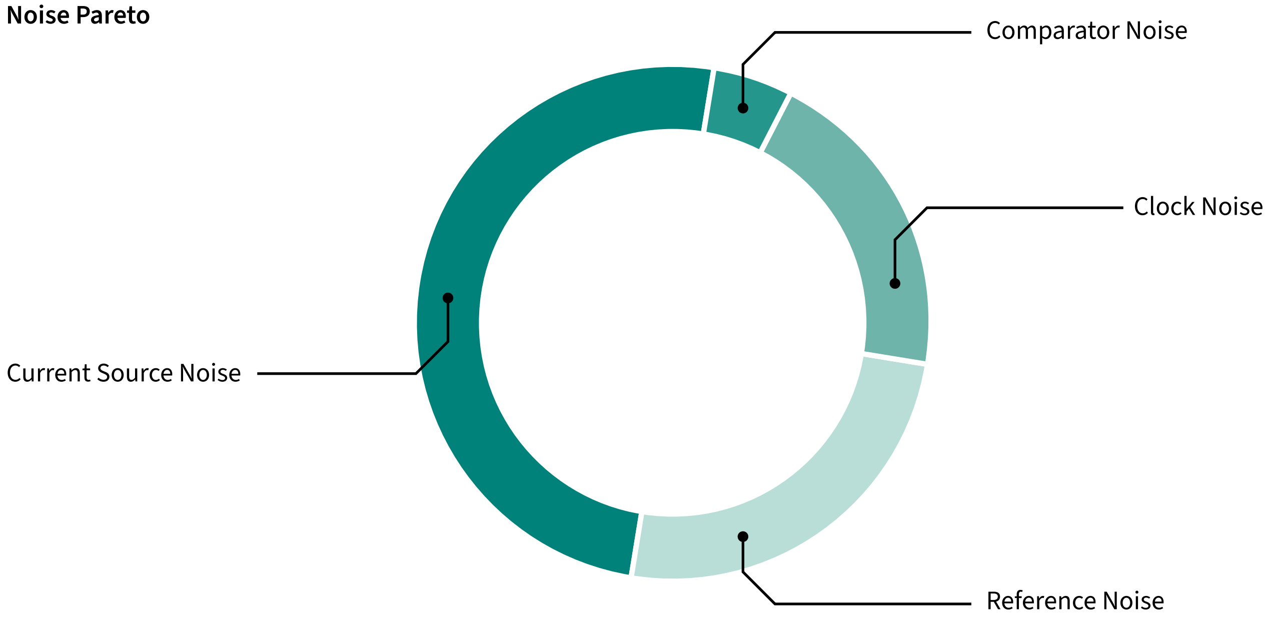
As manufacturers work to replace traditional electro-mechanical buttons and resistive sensing interfaces with modern capacitive touch sensing in large HMIs or applications exposed to multiple sources of noise, they will require touch-sensing controllers that offer new capabilities and performance enhancements compared to earlier devices:
- Superior SNR and a very low noise floor
- High-speed scanning of multiple sensor nodes while maintaining sufficient processing capacity to implement a complete HMI application.
- Streamlined scanning operation that does not require the implementation of complex synchronization firmware

The introduction of a new 5th generation of the popular CAPSENSE™ technology enables the latest PSoC™ controller products from Infineon to meet all three of these demanding requirements. The 5th generation CAPSENSE™ technology is implemented in products such as the PSoC 4100S Max, a highly integrated, low-cost Arm® Cortex®-M0+-based controller for industrial control, home appliance, and home automation applications. Designers can begin development of the kind of sophisticated HMI systems described in this white paper by using the PSoC 4100S Max Kit (CY8CKIT-041S-MAX). Its capacitive sensing expansion board provides multiple touch-sensing interfaces, including buttons, slider, touchpad and proximity sensor. The kit is supported by the ModusToolbox™ Software Suite and code examples.
Below, the key new features of 5th generation CAPSENSE™ technology sensing are described, to show how the PSoC 4100S Max can be used to produce a touch-sensing interface that offers an outstanding user experience in large touch panels exposed to multiple sources of noise.

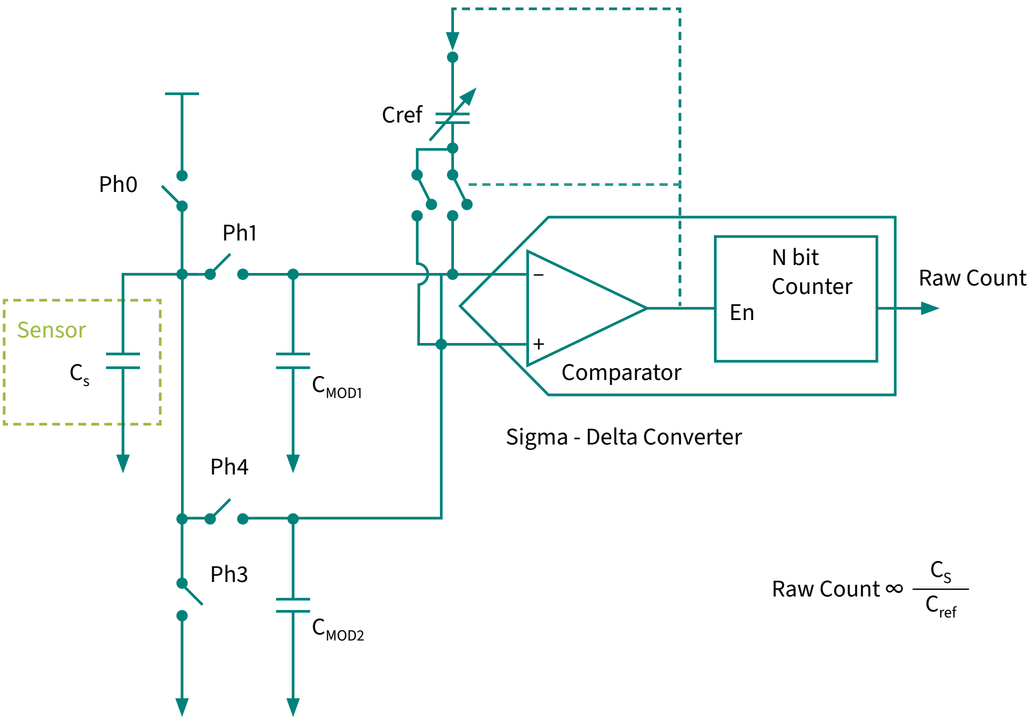
7. Ratiometric sensing dramatically increases SNR and lowers noise floor

The classic topology for the sense converter circuit in a touch-sensing controller is single-ended. The single-ended circuit configuration relies on an internal reference voltage. This means that the touch sensor output is prone to error generated by the internal reference when it is exposed to voltage or current noise, to clock jitter or drift, or to other low-frequency internal or external noise sources. The diagram illustrates the effect of the various types of noise encountered in typical single-ended capacitance-to-digital converters.

Noise Pareto



Infineon's 5th generation CAPSENSE™ technology uses a differential configuration for the sensing front-end coupled with a ratiometric sensing architecture, in which the sensor output is simply a ratio of the sensor capacitance to the reference capacitance. This ratiometric sensing architecture eliminates the need for internal references in the sensing circuits, and thus removes this source of error. At the same time, the differential sensing front-end removes low-frequency external noise from the sensor output.
Benefiting in addition from a valuable reduction in comparator noise in its delta-sigma modulator design, the 5th generation CAPSENSE™ technology provides a substantial increase in SNR and a much-reduced noise floor of less than 100aF – some 10 times better than 4th generation CAPSENSE™ devices can achieve.



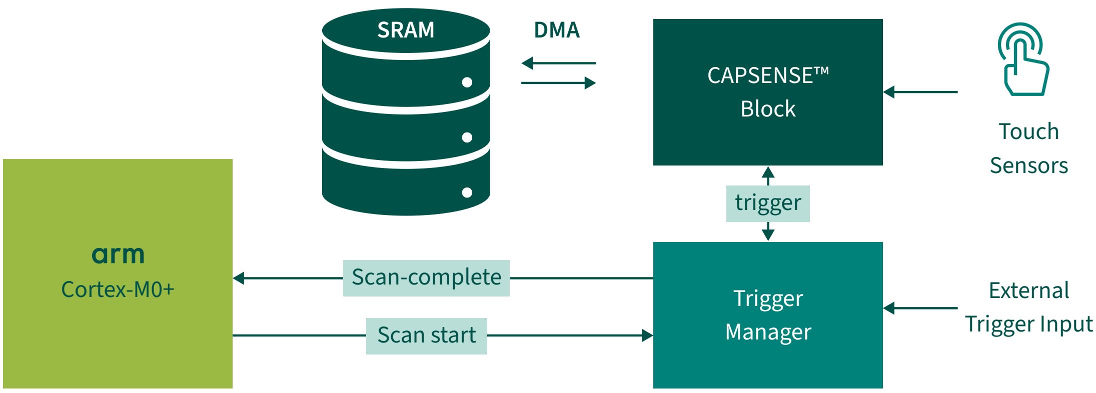
The high SNR and low noise floor are the attributes of 5th generation CAPSENSE™ technology that enable the PSoC 4 100S Max to reliably detect touches by a user wearing thick gloves, as well as light finger touches. It also provides reliable and predictable touch-sensing performance in large touch panels with long sensor traces that are highly susceptible to power supply and temperature noise.

8. High-speed scanning with minimal intervention of CPU core

In 5th generation CAPSENSE™ products, Infineon has introduced its chained-scan direct memory access (CS-DMA) technology for offloading touch sensor scanning from the PSoC device's CPU to its DMA controller.
The diagram below illustrates how state-of-the-art capacitive sensing-enabled MCUs use the CPU to trigger touch-sensor scanning, leading to continual CPU intervention in an application using as many as 100 touch sensors.

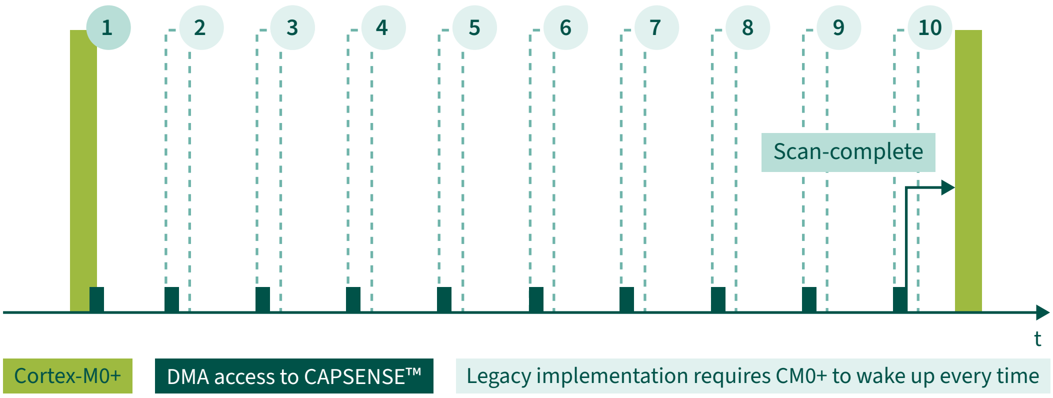
By offloading touch sensor scanning to the DMA controller, the 5th generation technology dramatically reduces CPU loading, from 40% of its processor capacity to just 5%. The diagram below shows the sharply reduced frequency of CPU events attributable to sensor scanning.
Applications with many touch sensors require high-speed scanning – the entire array should be scanned at intervals of no more than 16ms to ensure that latency is not perceptible to the user even in advanced functions such as gesture sensing. The CS-DMA technology results in higher-speed scanning: systems that depend on the CPU for sensor scanning are exposed to the risk that a scan will be delayed because the CPU is performing another time-critical task at the same time that a scan is due to be triggered.
With CS-DMA, this risk of CPU-induced latency is eliminated.

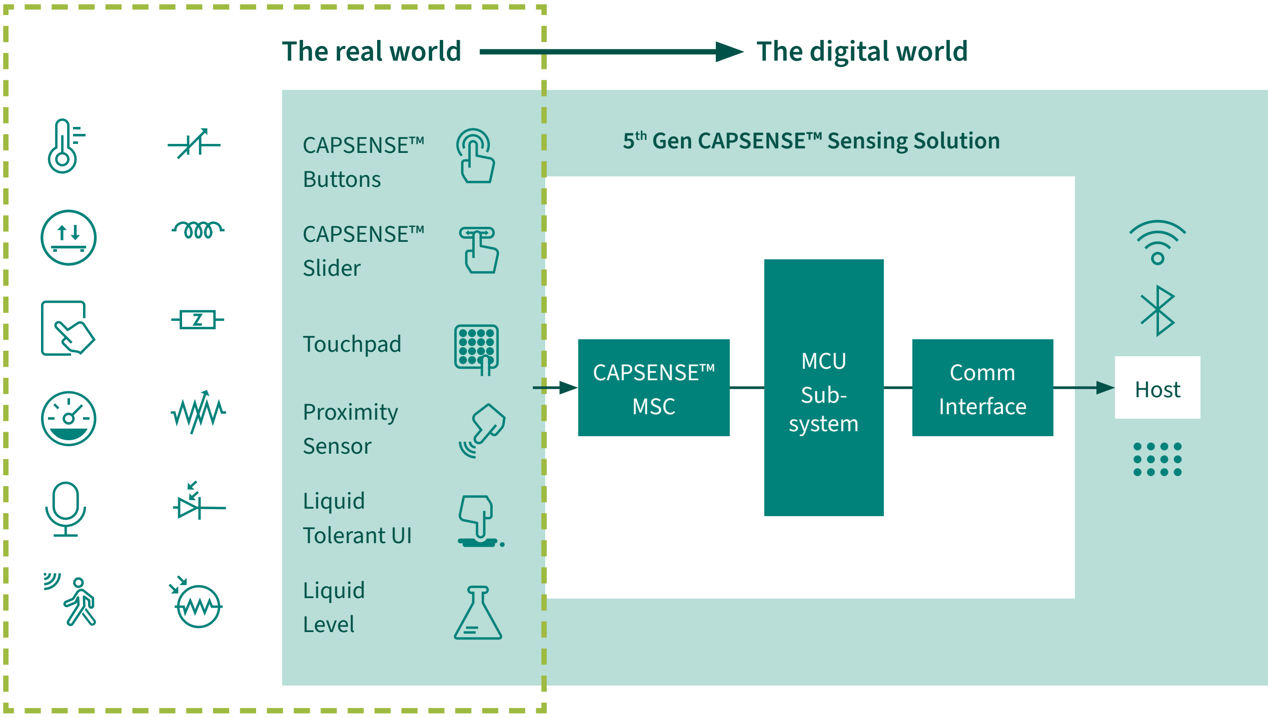
Autonomous sensing block diagram in PSoC 4100S Max with CAPSENSE™



5th Generation CAPSENSE™ operating autonomously while CPU in sleep using DMA. In this mode, two sensing channels can support up to 64 sensor inputs in autonomous mode and support a combination of self and mutual-cap sensing methods.

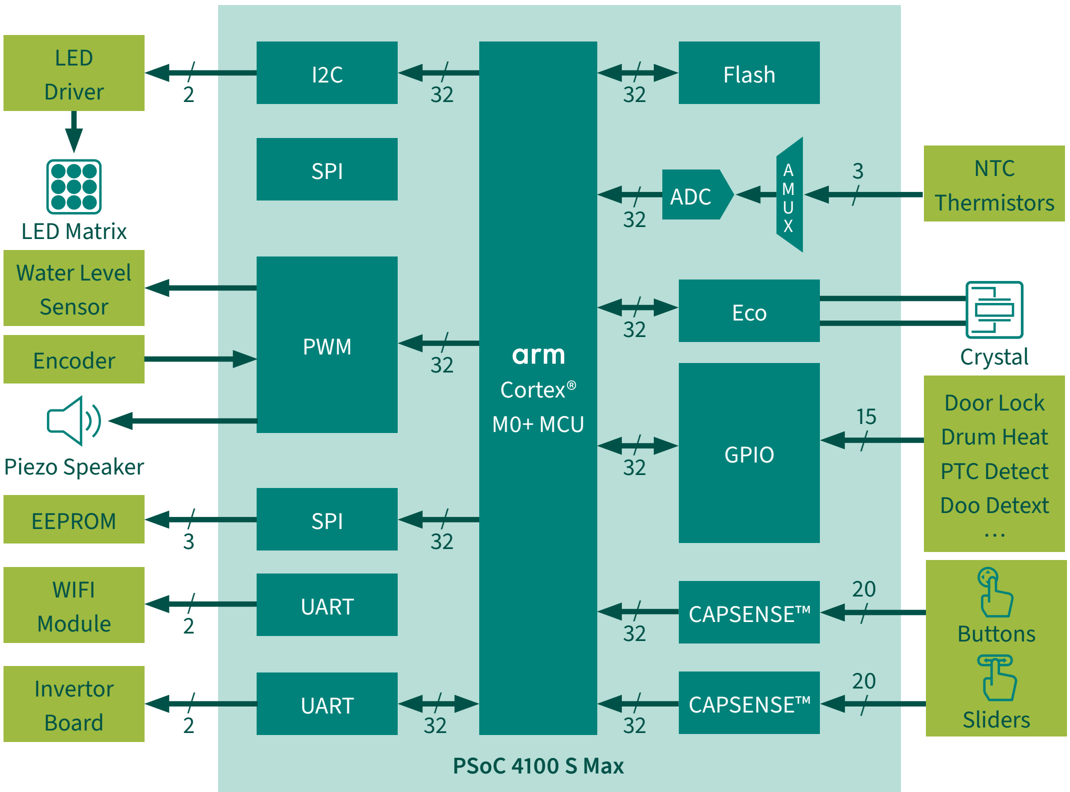
The Autonomous Sensing avoids waking up the Cortex M0+ core every time we collect data from the CAPSENSE™ Block resulting in energy savings





9. Higher integration streamlines bill-of-materials

The innovations implemented in the 5th generation of CAPSENSE™ technology enable HMI system designers to reduce the number of controllers in their design, and so to streamline the system's bill-of-materials and integrating more functionalities into the single chip. A 5th generation CAPSENSE™ controller such as the PSoC 4100S Max uses only a small fraction of its CPU bandwidth to scan multiple touch-sensing elements while maintaining very low latency and instant responsiveness to user touches hence the remaining CPU bandwidth can be utilized to implement other system functionalities in the same feature rich PSoC 4 MCUs.



This means that the same PSoC 4100S Max device used for touch-sensing control can also perform many other HMI functions that would previously have been implemented in an additional, discrete MCU. Such functions include display control, LED driving, and control of sound and haptics effects.
The 5th generation CAPSENSE™ technology thus enables HMI system designers to reduce component count, system size, and bill-of-materials cost while implementing a sophisticated, multi-function HMI – all with the PSoC 4100S Max.

10. Improved functionality in industrial touchscreens

The improved capabilities of the latest CAPSENSE™ technology are particularly applicable to touchscreen HMIs for use in demanding industrial environments.
The superior sensitivity and high SNR of 5th generation CAPSENSE™ systems enable reliable detection of touch events in circumstances that defeat other touch-sensing controllers. With CAPSENSE™, industrial touchscreens can have extra-thick cover glass, to survive high shock or impacts – CAPSENSE™-enabled touchscreens can even be made vandal-proof.
The high sensitivity of 5th generation CAPSENSE™ technology also allows an industrial touchscreen to detect touches made by an operator wearing gloves, even thick safety gloves. Gloves greatly attenuate the capacitance of the finger, but the CAPSENSE™ system's high SNR enables it to detect weak touch signals.
Operation remains unaffected by other hazards that disable other capacitive sensing systems. Infineon has demonstrated industrial touchscreens that operate normally even when soaked by water or other liquids.

11. A simpler implementation of multi-channel and multi-chip scanning

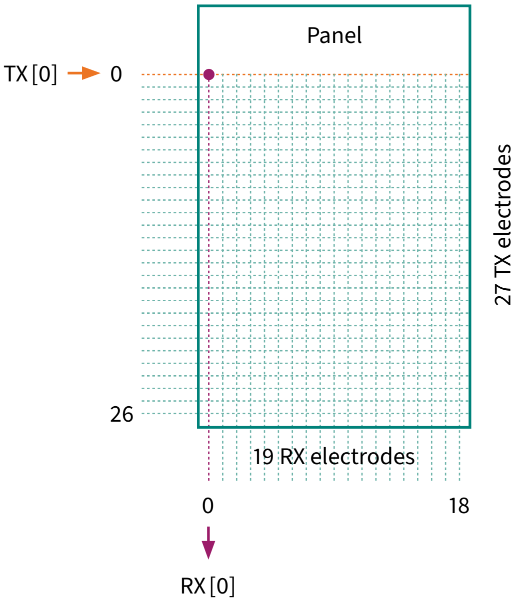
In very large touch panels, the time taken to scan a complete array of touch sensor nodes can be so extended in single-channel mode that latency becomes perceptible to the user. In this case, the panel manufacturer may implement multi-channel sensing: scanning two nodes in a row simultaneously, to cut scan time in half.
In most touch controllers today, dual-channel sensing is supported, but requires complex firmware running in the controller's CPU to synchronize the two simultaneous channels to nanosecond levels of precision.
An innovation in 5th generation CAPSENSE™ products is the multi-channel consensus mechanism. This implements synchronization of multiple Receive channels autonomously in hardware. This eliminates the need to develop synchronization firmware and run it on the controller's CPU.
The autonomous multi-channel consensus mechanism can be applied in multi-channel configurations on a single PSoC chip, and also in a multi-channel/multi-chip configuration, providing for the simultaneous scanning of four Receive channels across two PSoC chips.
These multi-channel/single-chip and multi-channel/multi-chip configurations are shown below.

Single-Channel operation

Touch Panel

Single Channel

Example: 19 x 27 panel

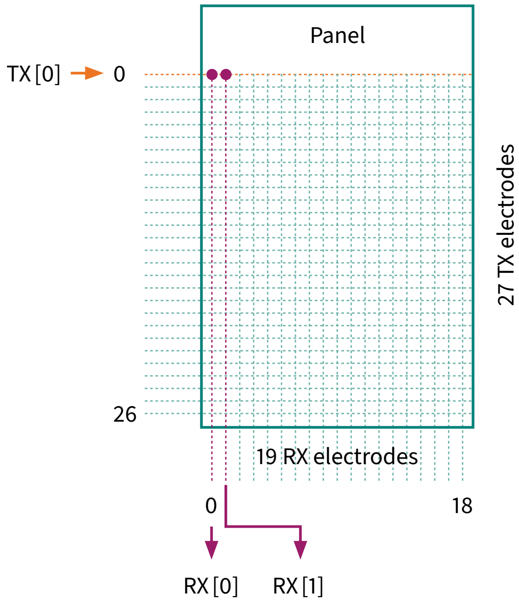


Single-Channel operation

Touch Panel

2 Channel

Example: 19 x 27 panel

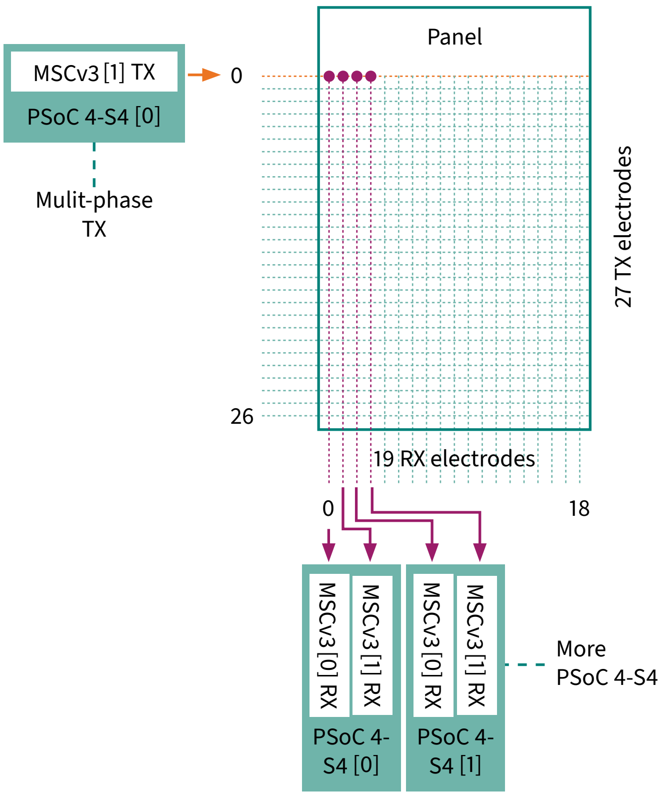


Multi-chip operation

Touch Panel Frame

2 Channel

Example: 19 x 27 panel



The provision of the new multi-channel consensus mechanism is a demonstration of the way in which the 5th generation CAPSENSE™ technology streamlines HMI designs. By eliminating complex firmware and precision timing analysis, the new CAPSENSE™ system implemented in a device such as the PSoC 4100S Max reduces development effort and saves development time.

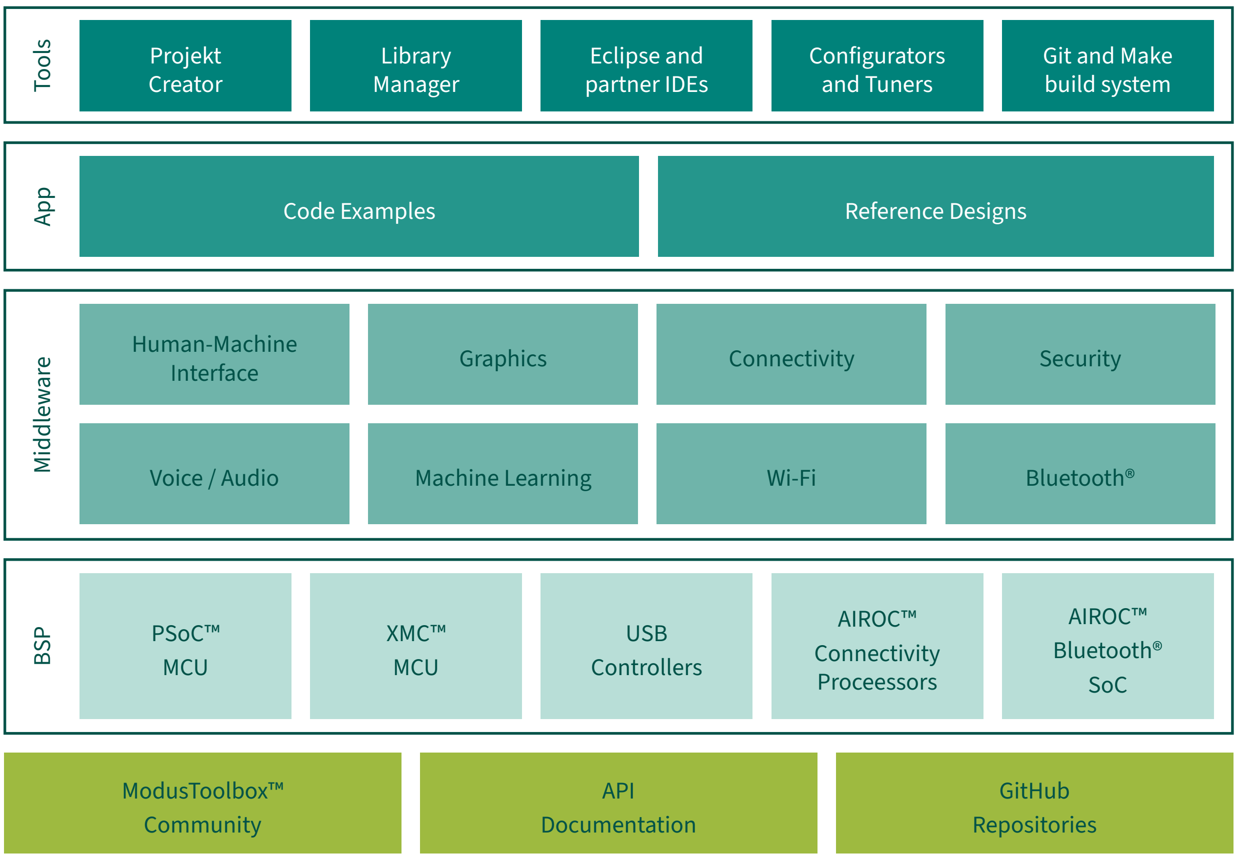
This advantage is reinforced by the effect of the CS-DMA technology, which enables the PSoC 4100S Max to operate as a complete HMI system-on-chip, integrating the entire HMI application into a single chip. This simplifies the HMI system's hardware architecture, reducing component count and BoM cost, and also accelerating the hardware development process.

12. 5th generation CAPSENSE™ capacitive sensing technology backed by comprehensive hardware and software resources

This white paper has described the ways in which the latest CAPSENSE™ capacitive sensing technology enables a new approach to the design of large HMI panels, and those exposed to multiple sources of noise.
Designers who as a result wish to explore the potential for implementing CAPSENSE™ technology in their designs will find that Infineon supplies a rich set of development resources to support them. Development of CAPSENSE™-based systems is backed by the ModusToolbox development platform (see below). ModusToolbox software is a modern, extensible development environment supporting a wide range of Infineon microcontroller devices, including the PSoC products. Provided as a collection of development tools, libraries, and embedded runtime assets, it provides a flexible and
comprehensive development experience.

The ModusToolbox package includes desktop programs that enable:
- The creation of new embedded applications
- The management of software components
- Configuration of device peripherals and middleware
- Compiling, programming, and debugging

ModusToolbox runtime software includes an extensive collection of GitHub-hosted repositories comprised of code examples, board support packages, middleware, and application support.



The ModusToolbox platform's support for HMI development includes software supporting the development of touch-sensing buttons and sliders, and of touchscreen interfaces. The ModusToolbox platform also enables development of other capacitive sensing functions such as gesture and proximity sensing, and enables the PSoC 4100S Max's sensor hub functionality for integration with other analog sensors such as a temperature sensor or microphone.

13. Scalable system design

Thanks to the ModusToolbox platform, CAPSENSE™ applications are easily portable from one PSoC controller to another, providing for scalability of HMI applications across broad families of product designs.
From a hardware point of view, the latest 5th generation CAPSENSE™ technology is implemented in the PSoC 4100S Max controller. This device provides various programmable analog and digital blocks, up to 84 GPIOs including 24 smart IOs, and a CAN controller.
Designers can evaluate the device with the PSoC™ 4100S Max pioneer kit (part number CY8CKIT-041S-MAX), a low-cost hardware platform for design and debugging which includes a capacitive sensing expansion board (see below).

14. Technical documentation supporting development from concept to production

Infineon supplies comprehensive and ideal documents for those who want to design touch HMIs. They guide the user from concept through to production, and help them to overcome various system-level challenges in creating a robust touch HMI for a product.

– CAPSENSE™ capacitive sensing overview web page
– Getting started with CAPSENSE™, application note AN6846
– CAPSENSE™ Configurator Guide as part of ModusToolbox
– PSoC 4 and PSoC 6 MCU CAPSENSE™ design guide

Code examples are also available via GitHub.
Developers can also find help via the Infineon Developer Community.

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