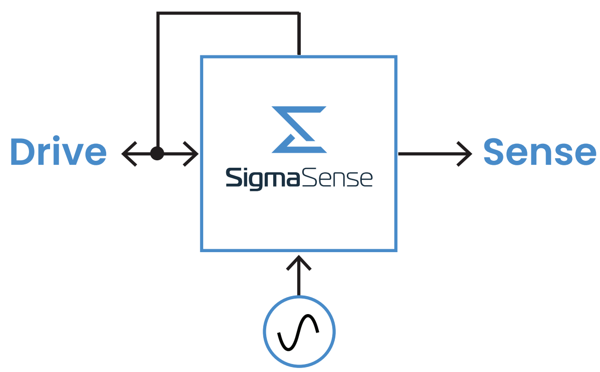
SigmaSense®

Capacitive Imaging Using Impedance Spectroscopy

SigmaDrive® — Realtime HMI Utilizing Capacitive Imaging

SigmaSense Redefines the Sigma-Delta

SigmaSense AFE's shift impedance sensing into the digital domain by uniquely converting minute changes in current to digital data. This direct-to-digital capability delivers unprecedented improvements in sensitivity and Signal to Noise Ratio (SNR). SigmaSense's proprietary sigma-delta drive-sense circuits offer continuous operation, ultra-low drive voltages, and self-excitation / self-biasing that moves digital sensing much closer to the analog event horizon.



This direct-to-digital approach allows for better brick wall noise filtering and more functions that are software definable. This novel drive-sense capability is called **SigmaDrive**®. For more details on the fundamentals of SigmaDrive, please see **"The Reimagined Sigma-Delta"** whitepaper.

This paper will briefly cover some of the functionality and theory behind SigmaDrive's core architectures for Capacitive Imaging and PCAP systems. This capability can yield signal to noise ratios greater than 100x better performance than conventional PCAP systems when voltage and time are considered. The result is ultra-low power (nano watts per channel) and enables real-world high sampling and imaging rates. Applications can also natively leverage low voltage digital communications expanding the future benefits of sharing high-fidelity data from active devices interfacing with the system.

BASIC CAPACITIVE TOUCH FUNCTION

A capacitive touch screen is a type of control display that accepts input from human fingers or other conductive objects. Capacitive touch screen panels can only be touched with a finger or a specific capacitive pen or glove, as opposed to resistive and surface wave panels that can detect input from either fingers or basic non-conductive styluses. The panel is coated with a substance that can conduct electrical charges, and the change in capacitance in that area indicates where the touch was made on the screen. A functioning capacitor is created when a capacitive panel is touched because a small charge is attracted to the point of contact. To determine the location, the electrostatic field's variation is measured.

In common projected capacitive touch sensors, the electrodes are arranged in rows and columns that are electrically isolated from one another via an insulating layer. A touch location is determined by driving column electrodes with a square wave signal (i.e., drive pulse). Sense circuitry coupled to the row electrodes measures the current flow between the row and column electrodes due to mutual capacitive coupling between the electrodes. When a user touches the substrate near the intersection of the row and column electrodes, the sense circuitry detects a change in mutual capacitance and registers a touch at that location.

Typically, sense circuits for measuring the mutual capacitance operate by repetitively switching the sense electrodes to an input of an analog to digital circuit where the digitized value is used to determine whether and where a touch has occurred. However, the relative magnitudes of parasitic capacitances of the switched circuit are large in comparison with the mutual capacitances between electrodes, which is typically measured in fractions of a pico-farad.

To overcome the effects caused by the parasitic capacitances, designers need several measurement cycles (i.e., integration) before a touch location can accurately be determined. The length of time to measure a touch location increases with the number of electrodes, which can adversely affect users of large displays that require an increasingly large number of electrodes. For example, the number of electrodes increases as the square of the diagonal for rectangular displays.

A touch location can also be determined by driving electrodes and sensing the current change only to the driven electrode. The sense circuitry measures current flow changes to the electrodes due to electrodes self-capacitive and mutual-capacitive coupling that exists between the driven electrode and impedance paths to ground which can include paths from the electrode to other electrodes. The self-capacitance will change when a user touches the substrate near the electrode altering the impedance paths to other electrodes but also adding new paths through the user to any ground potential.

Today's touch controller solutions based on analog and mixed signal components can be expensive and difficult to manage during design, integration, tuning, and manufacturing phases of product development. Adding pen support into devices from phones to large interactive flat panels is also challenging.

Design constraints of Projected Capacitive (PCAP) based touch systems require system engineers to essentially design around the sensitivities of the analog or mixed signal-based touch panel. From component positioning, to ground planes, from optical stack-ups to placement of individual traces the impact to the touch panel performance must be considered in nearly every design decision.

The difficulty in working with sensitive analog components in PCAP based systems is their propensity for false signals generated by noise emanating from the LCD, the ground plane, the environment, and even from parasitic capacitance between electrodes.

The latter problem regarding system parasitic capacitance is especially limiting in large screen PCAP based systems. Current analog components are not discerning but are sensitive to noise throughout the system. The benefit of analog and mixed signal PCAP systems is that they are very sensitive to touch and active pen(s). That is also their weakness — they are very sensitive to their surrounding environment.

TRADITIONAL MULTI-TOUCH SYSTEM FUNCTION

In typical multi-touch systems, the self-capacitive signal-to-noise ratio is much larger than the mutual capacitances. It is important to recognize that the self-capacitive signal contains the drive signal, the sensor parasitic capacitances, as well as the touch signal energy change, whereas the mutual capacitance signal is much smaller as it contains only the cross parasitic capacitance and change in touch signal energy. Also, the self-parasitic capacitances are large, because the surrounding channels are effectively grounded as only one signal is driven at a time.

In traditional PCAP systems, these parasitic capacitances interact with the pulse or square wave driving and sampling, which contain high frequency harmonics. These harmonics contain a significant portion of the touch energy change and attenuate faster than the fundamental frequency when passing down a RC impedance chain. Additionally, the self-capacitive signal-to-noise ratio is much larger than the mutual capacitances. It is important to recognize that the self-capacitive signal contains the drive signal, the sensor parasitic capacitances, as well as the touch signal energy change, whereas the mutual capacitance signal is much smaller as it contains only the cross parasitic capacitance and change in touch signal energy. Also, the self-parasitic capacitances are large, because the surrounding channels are effectively grounded as only one signal is driven at a time.

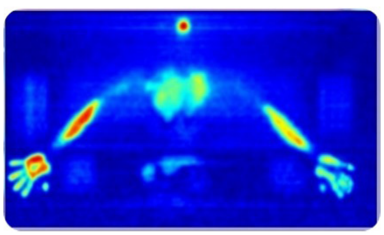
SELF CAPACITANCE CHALLENGES

Another problem typical of a self-capacitance measurement is an error due to contaminants on the substrate such as salt water, which adds to the user's touch and will bridge energy to surrounding impedance paths. The ability to measure a touch in the presence of saltwater contamination in some cases such as industrial, marine, or military applications, is highly desirable but does not work well with the current solutions available.

Capacitive touch control circuits widely in use today are capable of measurement in different modes, self-capacitance, mutual capacitance, and active pen input, but generally the modes of sampling can occur only one mode at a time. This limitation impacts the accuracy and speed at which a touch location can be determined. The length of time to sample each mode can adversely affect usability and degrades further as the number of electrodes being measured increases. Furthermore, various methods for scanning the rows and columns, switching the drive and sense circuits through analog muxes, and driving adjacent electrodes (guard bands) to reduce parasitic capacitances, all add to circuit complexity and cost.

With SigmaDrive architectures, sigma-delta converters are used for high resolution ADC, DAC, and sensing functions. They also perform noise shaping, filtering, decimation, and are inexpensive to produce. One of the unique characteristics of SigmaDrive is that the frequency transfer functions for the input signal and quantization noise thereby enabling very high-resolution signal creation with a significantly improved Signal to Noise Ratio (SNR).

CAPACITIVE IMAGING — SIGMASENSE REDEFINES HMI



How many fingers are supported? All of them, as well as other body parts that touch it, and active and passive devices. SigmaDrive enables high fidelity imaging by using concurrent drive operations, high SNR, and advanced signal processing to overcome the problems of traditional PCAP switched touch systems. The technology offers multi-mode, concurrent sampling on all channels simultaneously via DFTs at each cross point. This enables precise frequency analyzing of impedance changes and system noise measurements with high refresh rates.

This architecture allows for multiple frequencies and simultaneous drive/sampling independently on each row and column. Multiple frequencies on each channel provides concurrent modality which means both self and mutual capacitance detection are performed in the same sample cycle.

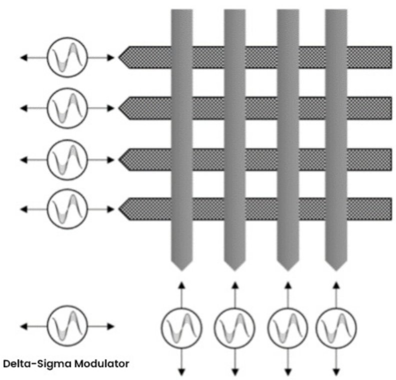
Further, different frequencies can be used for multiple pen recognition, which are also detected in the same sample cycle. Having a SigmaDrive modulator on each channel allows for the channel frequencies to be adapted in real-time to avoid environmental noise. In the case of a noise event saturating a channel, that channel is reset and moved to a different frequency band while the rest of the system remains operational. In contrast, saturation on a switched PCAP system will terminate touch operations until the noise source is removed.

SIGMADRIVE CAPACITIVE IMAGING AND DYNAMIC NOISE AVOIDANCE

To address the many problems inherent in today's PCAP touch systems, SigmaSense has developed the first all-digital processing solution for PCAP touch sensors using sigma-delta current drive architecture.

Using a digital controller over traditional analog systems has significant advantages including programmability, powerful DSP techniques, excellent noise characteristics, low cost due to a smaller die size, and many others. When SigmaDrive is implemented in large arrays, these fully integrated drive and sense functions yield "large array frequency analysis" in a small silicon package. This capability captures the data direct to digital and can be thought of as a network analyzer on each channel. SigmaSense SDC-200 ASIC supports 128 SigmaDrive channels, DSP, and micro-processing in a very small BGA package.

The image to the right represents a key part of the SigmaSense digital system which uses a low-cost 1-bit sigma-delta ADC/DAC connected to each row and column.



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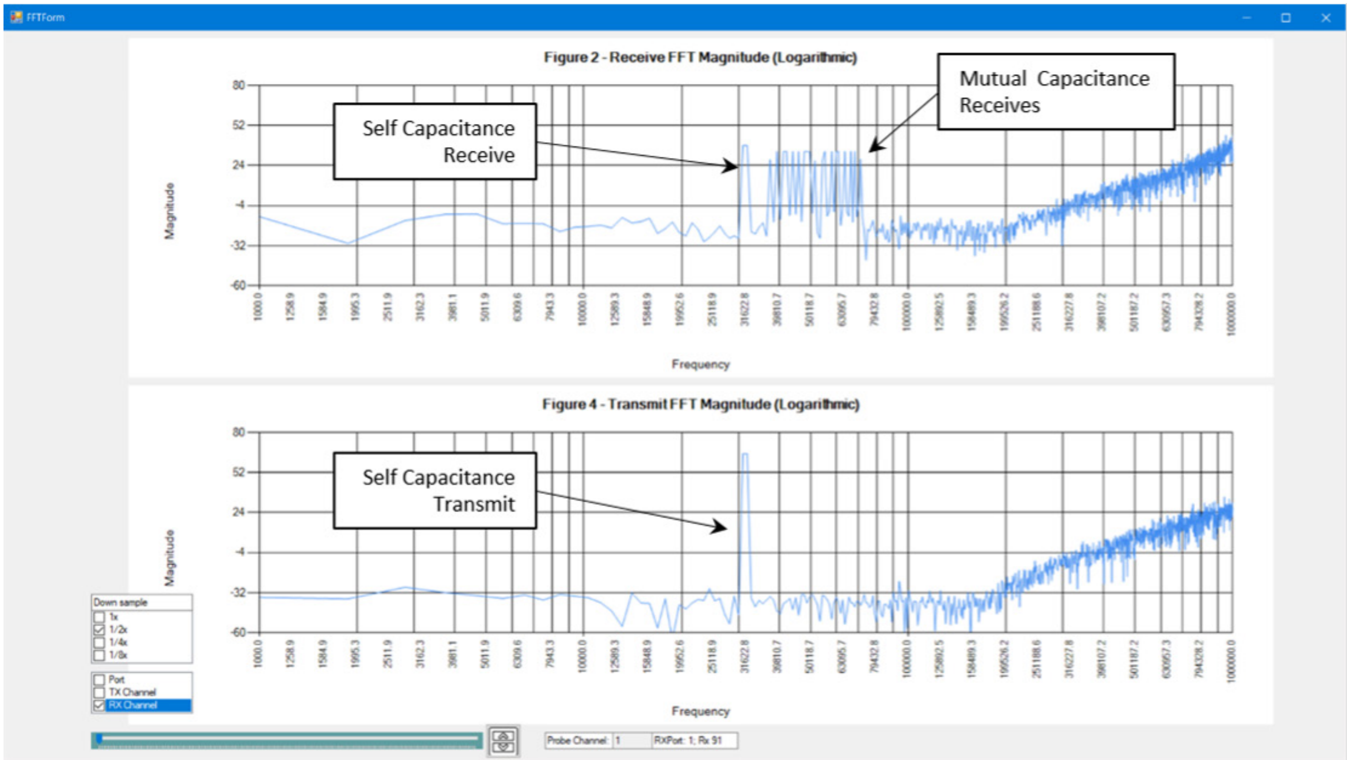
This is done, for example, by moving the drive frequency to a different band than that occupied by common mode interference (simultaneous sensing can see common mode noise on all channels, so we detect both the interference, and we also detect where there is no interference). This, along with powerful digital filtering that rejects out-of-band noise and the high SNR signal from the sigma-delta modulator, means that the SigmaSense approach has unparalleled noise immunity that meaningfully reduces the painful tuning process common in today's analog PCAP systems while at the same time improving touch sensitivity and system reliability.

SigmaSense touch technology further mitigates tuning difficulties by reducing parasitic capacitance. The sinusoidal drive signal does not have high frequency components that increase impedance (this is one reason long lines can be driven), and our simultaneous all-channel drive prevents impedance mismatch between channels.

The image below shows DFT transformations for both transmit and receive frequencies on one touchscreen column channel. In this configuration the lower plot shows the self-transmitted pure tone, and the upper plot shows the resultant self-receive plus all the mutual-row-receives. Note the noise shaping on the transmit and receive plots. No other switching PCAP system comes close to this transmit functionality and resulting low noise floor and stability. Dependent on configuration, continuous data rates of 600hz and higher are possible by the SigmaDrive architecture.



Continuous channel response of PCAP self-transmit (bottom) and self-receive plus row mutual-receives (top)

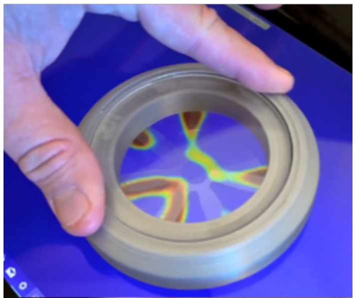
***Note the high SNR and noise shaping.**

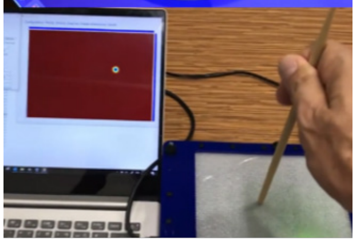
This is one of many advantages of simultaneous sensing. In this example, the common mode noise is detected on all channels in real time and drive frequencies are then re-assigned to a different band as needed to avoid interference.

In addition, powerful brick wall digital filtering rejects out-of-band noise and the high SNR from the SigmaDrive system yields impressive noise immunity. This can help reduce the painful tuning process common in today's analog PCAP systems while at the same time improving touch sensitivity and system reliability. As a note, in the above plot the mutual-row-receive frequencies are 300hz apart. In most cases, automated noise avoidance can move a channel 75hz in either direction of impactful noise to mitigate its effects.

SigmaDrive can also reduce tuning difficulties caused by large parasitic capacitances due to long lines or poor sensor design. This is because the pure low frequency sinusoidal drive signals do not have high frequency harmonic components because of the advanced noise filtering capabilities.

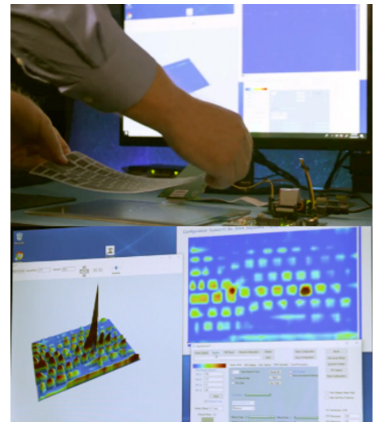
Furthermore, due to the self-referencing nature of each channel, impedance mismatch between channels is mitigated allowing for greater mechanical flexibility in sensor design. The image to the right shows a multi-zone sensor where all zones use unique transmit frequencies and common receive channels.





SigmaDrive and capacitive imaging can also precisely show the impact of dielectrics in the touch system (negative capacitance). This is extremely important to disambiguate what is not human like water or add additional functionality such as support for simple passive devices.

The image to the left shows a passive interactive button utilizing a patterned film element. The film element changes the impedance on the effected channels. In this case, rotation and push click features are supported with this film element alone.



The high inherent SNR and data fidelity allows for seeing minute changes in the system impedance state. Pressure and location are derived on a high resistance Pedot polymer touch sensor from a simple wood chop stick.

The image to the right shows a silicon keyboard applied to the top of a SigmaSense touch system. The dielectric silicone causes impedance changes which allow for the keys to be seen and interacted without additional circuitry.

CONCLUSION

SigmaSense's novel architecture using an all-digital solution that employs modulation provides the best performance for PCAP touch systems. Size constraints for PCAP are eliminated, as well as environmental constraints such as rain or saltwater. The challenges of building in-cell touch systems are overcome with a system that can perform with the sensor directly on or within a display. The ability to utilize ultra-low-cost sensors becomes a reality, and system designs are simplified, which also lowers costs. The chip itself is low cost, and the system supports a superior pen design to accompany touch systems.

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