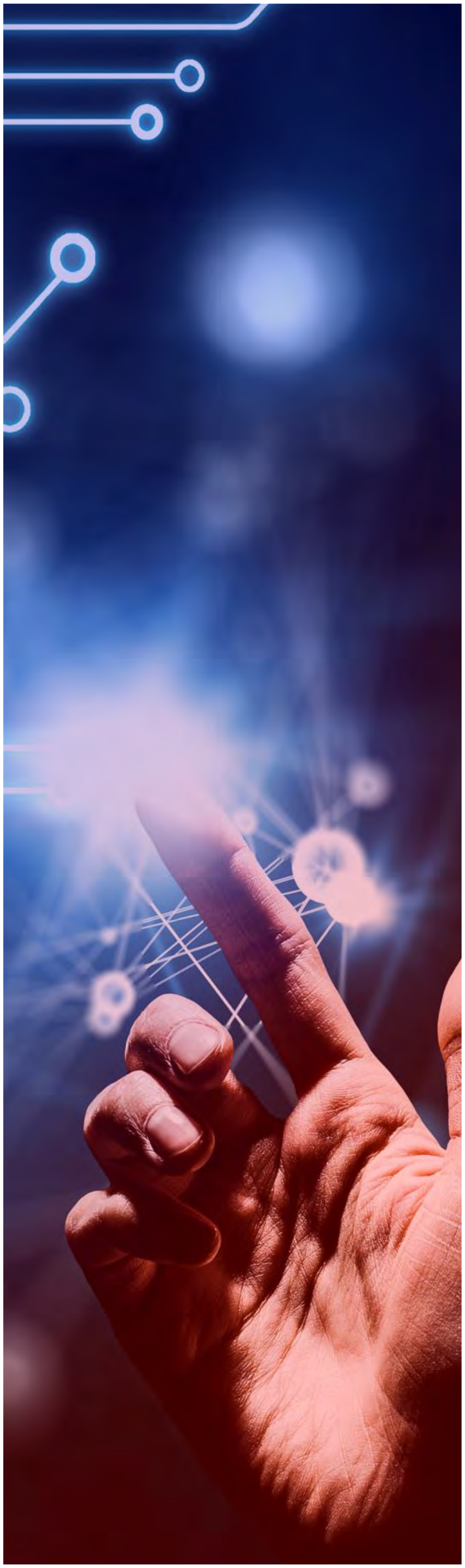
ENABLING LARGE PEDOT CONDUCTIVE POLYMER TOUCH SENSORS USING CURRENT MODE SIGMA DELTA SENSING TECHNOLOGY

WHITE PAPER

Sensing breakthrough enables large size, optically superior, lower cost PEDOT sensors

SigmaSense and Heraeus together provide a quantum leap forward in PEDOT sensor size, while providing more performance and functionality



The demand for interactive displays continues to experience large growth. Projected capacitance (PCap) touch sensors have the great user experience that customers now demand. Manufacturers seek solutions that are optically superior and, ideally, lower in cost. Conductive polymers possess superior optical properties when the conductive material is thinly applied and are cheaper to manufacture than the current mainstream alternatives, such as ITO and silver nanowire based solutions. However, conductive polymers have not gained acceptance due to their higher resistance and the inability of existing voltage mode ADC-based touch controllers to drive the resultant high resistance channels. This has precluded the use of conductive polymers in mainstream laptops, tablets and large interactive displays – until now.

SigmaSense's disruptive SigmaDrive™ technology enables significantly better touch performance while concurrently providing high fidelity imaging information of the entire sensor surface, including objects in proximity to the sensor surface. SigmaDrive technology overcomes the barrier of very high resistance. It is now feasible to use conductive polymer films for the full range of touch sensors, from watch sizes up through very large touch sensors (86″+). SigmaSense touch controllers make conductive polymer sensors viable for the full range of touch sensor sizes in addition to providing higher performance and improved functionality. SigmaSense controllers provide high fidelity sensor imaging information and new touchless hover interactions to unlock an entirely new generation of user experiences demanded by the market.

SigmaSense controllers enable the use of Heraeus' Clevios™ conductive polymer technology across the full range of sensor sizes while improving almost all performance metrics. The flexibility, optical clarity and cost-effectiveness of polymer conductor materials are now a viable and attractive option for PCap touch sensors of all sizes.

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ABOUT

SigmaSense has pioneered a new approach using current mode Sigma-delta modulation ADCs enabling PEDOT conductive polymer films to be used in large size interactive displays

SigmaSense, the global leader in touch sensing performance, has pioneered PCAP touch sensing using polymer conductive films that previously could not be used in large sizes due to the high resistance these sensors possess. SigmaDrive™ technology is a current mode ADC that is tolerant of high resistance sensor channels and non-uniformity of sensor resistance. PEDOT conductive polymer sensor films at 65 inches have been proven today with larger sizes forthcoming.

High fidelity information of the entire display surface is provided enabling machine learning to categorize objects on or in proximity to the display surface. Touchless interaction is also provided with a sophisticated hover capability and presence detection from a meter away using standard sensor designs.

Heraeus' Clevios™ sensors exhibit improved optical clarity while reducing sensor costs making the combination a compelling solution for large display PCap sensors.

C-Touch 2020 Technology Demonstration

Heraeus and SigmaSense have showcased their technologies and worked with TWS and EOC to demonstrate fully functional 65 inch touch sensors based on Clevios™ PEDOT:PSS and SigmaDrive™ current mode ADC touch controllers at C-Touch 2020.

The demonstration was the first to break the PCap sensor size barrier using conductive polymer materials delivering SigmaDrive industry leading performance and functionality.

SOLVING THE SENSOR PROBLEM

Overcoming limitations of existing voltage threshold Projected Capacitative (PCap) touch controllers that cannot drive high resistive or non-uniform resistance touch sensors

Today's common voltage sensing threshold-based touch controllers demand low channel resistance and uniform resistance from all channels. This limits not only yields and creates cumbersome design constraints but also eliminates high resistive sensor materials from being used at larger display sizes.

SigmaSense's SigmaDrive™ sensing technology overcomes these barriers. The technology is tolerant of both high resistance sensor channels and solves the problem with sensors possessing non-uniform resistance and high resistance channels. This enables new sensor materials to be used for large display sizes.

Conductive Polymers, PEDOT:PSS Background

Conductive polymers are deposited with high yield and throughput by the most cost-effective roll-to-roll wet-coating processes. This has already been done successfully for more than two decades in the production of antistatic films, e.g. disposable protective films used in LCD production and assembly. By the same means, transparent conductive electrode films can be produced. Their use has so far been limited to specific applications where requirements for sheet resistances were moderate, e.g. small-sized capacitive touch sensors, LC-writing boards and smart windows among others. Lower sheet resistances of 150 Ohm/sq or less are possible, but then a thick layer of conductive polymer has to be deposited that results in an undesired bluish tint and significantly reduced optical light transmission.

Therefore, for capacitive touch sensors in smartphones and tablets, typically indium tin oxide (ITO) films are used instead of conductive polymers. Larger PCap touch sensors used for interactive displays, monitors and televisions require even more conductive materials such as silver nanowires (AgNW) or metal mesh that can meet the low resistance drive requirements of existing voltage-mode ADC touch controllers.

SigmaSense's disruptive SigmaDrive™ technology can uniquely support touch sensors with high resistive materials and deliver higher performance that fundamentally changes the capabilities and requirements of capacitive touch technology.

CONDUCTIVE POLYMERS: A BOOST FOR TOUCH SENSORS

PEDOT:PSS (**p**oly-(3,4-**e**thylen**d**i**o**xy**t**hiophene) **p**oly **s**tyrene **s**ulfonate) has become the most successful conductive polymer. It was invented in the late 1980s by Bayer in Leverkusen, Germany, and these activities have been seamlessly continued by Heraeus being today's market and technology leader with its Clevios™ PEDOT:PSS products.

PEDOT:PSS is produced as a water based polymer dispersion that consists of tiny swollen gel particles, and it is used as a raw material to prepare ink formulations that can then be coated or printed on substrates. After drying, a transparent conductive layer is formed with a typical thickness of only a few hundred nanometers.

In industry and the scientific community there are sometimes still misperceptions about PEDOT:PSS. It is often referred to as being a single material with a specific set of properties.

However, Heraeus is offering already more than 100 different product grades and formulations based on PEDOT:PSS. Polymer dispersions of the polyelectrolyte complex PEDOT:PSS can greatly vary in their chemical and physical properties. These can be controlled and adjusted, e.g. by particle sizes and distributions, chemical compositions, conductivity, viscosity, solid content, etc. What is often forgotten when talking about PEDOT:PSS is that it is a raw material for coating and printing inks and is typically not ready-to-use. That means, it first must be formulated with suitable additives to provide good substrate wetting, film adhesion and cohesion, environmental as well as mechanical stability and durability. The formulations are tailored for different coating methods, e.g. to coat a PET film via a roll to roll process (Figure 1).

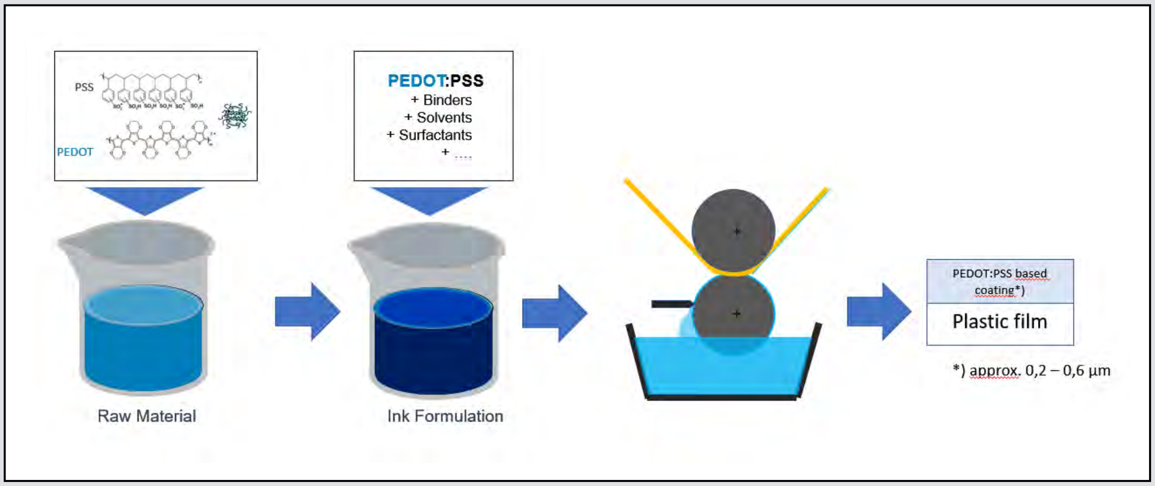


Figure 1: *PEDOT:PSS dispersions are conductive raw materials for ink formulations that can be coated by roll-to-roll process on plastic films.*

SUCCESSFUL COMMERCIALIZATION FOR MORE THAN 20 YEARS

One aspect that makes Clevios™ PEDOT:PSS formulations special, is that Heraeus has succeeded to stabilize PEDOT:PSS formulations. Being an organic polymeric material, PEDOT:PSS, as well as most other organic materials, can undergo oxidation and degradation processes that are accelerated for example by higher temperatures, oxygen, and UV light. This is sometimes mentioned to be a fundamental drawback of PEDOT:PSS and other organic conductors in literature. However, Clevios™ formulations have been successfully adopted even in very demanding automotive applications, e.g. in electrolytic capacitors and printed capacitive touch sensors. Superior reliability is actually one of the main drivers to adopt Clevios™ in capacitors.

Clevios™ PEDOT:PSS is already widely used in consumer electronics, e.g. smartphone and tablet displays with in-cell touch technology, tantalum polymer capacitors for notebooks, touch controls of home appliances, and many more. The largest application in terms of coated area are antistatic plastic films. Thanks to the use of efficient roll to roll wet-coating processes, both offline and inline, Clevios™ coated films can be produced cost effectively and thus are widely applied in LCD manufacturing and assembly processes today (Figure 1).

PEDOT:PSS AS AN IDEAL MATERIAL FOR TOUCH SENSORS

Transparent conductive PET films for capacitive touch sensors

Clevios™ PH 1000 is today's most conductive commercially available PEDOT:PSS with a conductivity of up to 1000 S/cm. High conductivity is important as it provides flexibility in the formulation process to optimize the properties required by the application, as well as to minimize the PEDOT:PSS dosage and thus be cost effective, as well as to maximize optical light transmission. That is why Heraeus' highly conductive coating formulations, e.g. Clevios™ FET and F DX 2, are the benchmark for transparent conductive film coatings.

Today, most touch sensors are made from ITO film. There have been many attempts to compare transparent conductors in literature or at conferences, and PEDOT vs. ITO is of particular interest. PEDOT:PSS is often referred to as excelling ITO in terms of mechanical flexibility and lower cost, while ITO is more conductive, stable, and mature. The higher cost of ITO film is attributed to the inefficient and expensive vacuum sputtering process of ITO versus an efficient and lower cost roll to roll (R2R) wet coating of PEDOT:PSS formulations.

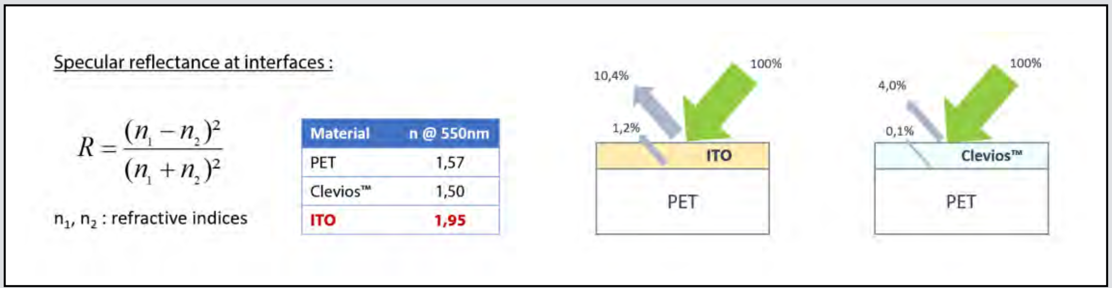
PEDOT:PSS vs. INDIUM TIN OXIDE (ITO)

Index matching

Display fidelity and users' overall impression of the display is important. Touch sensors that are not made from the best materials or not assembled correctly have adversely affected color, contrast, viewing angle. Index matching can greatly improve the user experience by mitigating the problems of internal and external light reflections caused by the touch sensor. For example, the optical differences of ITO and PEDOT:PSS do have some major implications for their respective conductive films used for display touch sensors. ITO is a metal-oxide with a very high refractive index ($n \sim 1.95$). If sputtered on plastic film, e.g. PET, there will be a large difference of refractive indices between ITO ($n \sim 1.95$) and PET ($n \sim 1.57$), termed "refractive index mismatch".

A refractive index mismatch leads to higher light reflections (Figure 2). Note that while the discussion so far has focused on film based touch sensors, Corning Gorilla Glass (also widely used in displays and touch sensors) has a refractive index of 1.50. This is even lower than PET film. So, if the ITO is coated on a glass based touch sensor, the refractive index mismatch will be even greater (and the amount of light reflected will be greater).

On the other hand, PEDOT:PSS coatings have almost the same refractive index as the PET substrate, i.e. there is no refractive index mismatch and thus a significant advantage vs. ITO in terms of lower light reflection (Figure 2).



Specular reflectance at interfaces :

$$R = \frac{(n_1 - n_2)^2}{(n_1 + n_2)^2}$$

n_1, n_2 : refractive indices

Material	n @ 550nm
PET	1,57
Clevios™	1,50
ITO	1,95

Figure 2: *PEDOT:PSS coated PET films exhibit lower light reflection and thus superior optical properties than ITO PET films.*

For a capacitive touch sensor, the ITO film needs to be patterned and some parts of the ITO coating are removed e.g. by laser or etching while others remain. Due to the mismatch of refractive indices between PET and ITO, the pattern would be easily visible by eye which is not acceptable for touch displays (Figure 3a). In order to overcome this issue additional index matching layers have to be deposited by sputtering on the PET film before ITO can be deposited (Figure 3b). This adds cost to the ITO film. This is not needed for PEDOT:PSS because there is a good refractive index match with the PET substrate and thus no expensive additional process steps are required in the film coating process (Figure 3c). Additionally, Heraeus has developed a special wet patterning technology for Clevios™ coatings that allows to create non-conductive patterns that are invisible to the eye. In the patterning step, the Clevios™ coating is not removed from the substrate but it just loses conductivity while the optical properties (transmission, haze, reflection) remain almost unchanged (Figure 3). This is a clever technology to produce a simple touch sensor with exceptionally high optical properties.

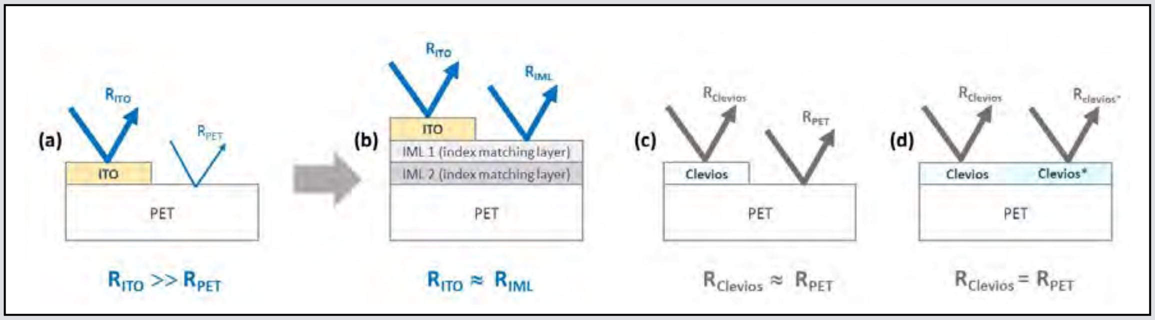


Figure 3: *the refractive index mismatch between ITO (n~1.95) and PET (n~1.57) leads to pattern visibility in touch sensors (a). This issue can be overcome by additional sputtering of index matching layers (b). Thanks to a good index matching between Clevios (n~1.50) and PET the film structure visibility is low (c). invisible patterns become possible with CleviosTM Etch, because the Clevios layer with its original optical properties remains but only the conductivity is removed in the process (d).*

Manufacturability

High temperature in the ITO sputtering process is required to achieve high conductivities, but using PET film substrates greatly limit processing temperatures. Therefore, ITO PET films often require additional thermal annealing processes, e.g. 150°C for 1 hour in an oven, in order to crystallize ITO and thereby lower the sheet resistance and improve the optical properties. Coated films based on PEDOT:PSS are ready to use and do not require such additional annealing steps. This helps to lower costs.

The ITO sputtering process is energy intensive and expensive. In case of PEDOT:PSS, the highly efficient wet-coating process is less expensive and the overall costs can be further reduced if a thinner PEDOT:PSS formulation layer is deposited. Because the sheet resistance (SR) is about proportional to the inverse of layer thickness, SR will double if the wetfilm thickness in the coating process will be reduced to half. The use of films with higher sheet resistances in touch sensors has so far been limited due to the existing controller technologies that rely on low sheet resistances especially when sensor sizes increase. However, limitations from high sheet resistance in capacitive touch sensors are easily solved with the SigmaSense touch controller.

Color shift

The intrinsic color of the materials is also of interest - ITO being yellowish and PEDOT having a bluish color. The color intensity and perception depends on the sheet resistance or thickness of the coatings and can be expressed by the color coordinate b*. Clevios™ coatings range from b* = 0 for sheet resistances of >= 300 Ohm/sq to about b* = -1 for 150 Ohm/sq, while ITO is typically between b*= +1 to +2 (Figure 4). A slightly negative b* can yield a brightness and contrast enhancement for LCD with LED backlight units which is of particular interest to display companies.

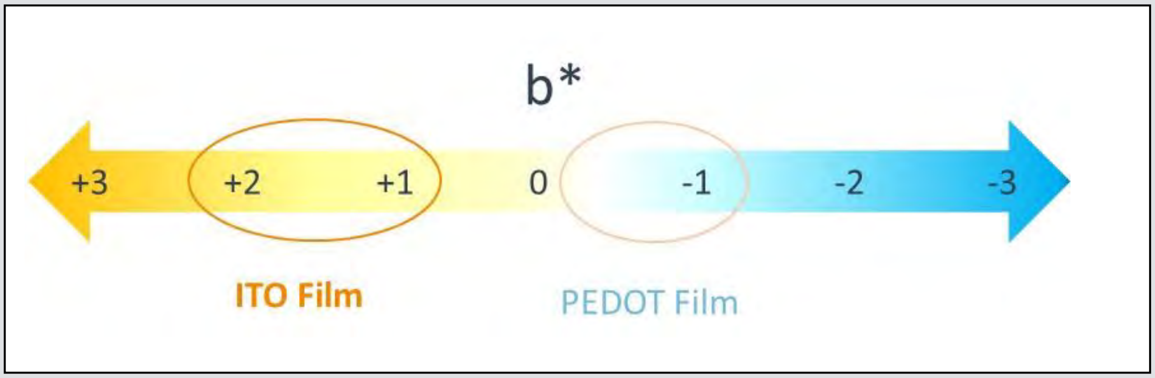


Figure 4: *Typical color coordinates b* for ITO and PEDOT coated films.*

Flexibility

An important characteristic for adding touch to folding displays is flexibility of the touch sensor substrate as well as the stability of the conductive material on the substrate. This is where PEDOT:PSS excel when compared to the most used ITO material. ITO is often deposited on glass substrates for stability reasons. When ITO is deposited on film, that sensor is then bonded to a glass substrate for the same reason. Figure 5 shows the change in sheet resistance of PEDOT:PSS and ITO when used with a flexible PET substrate. With a bend radius of 1.5 mm and a bend frequency of 3 Hz, the changes in ITO sheet resistance are dramatic. Indeed, the ITO sheet resistance climbs with bending to the point where it would quickly become unusable. PEDOT:PSS on the other hand, is reliable and unaffected making it ideal for all flexible touch sensors including touch “skins” on non-display objects.

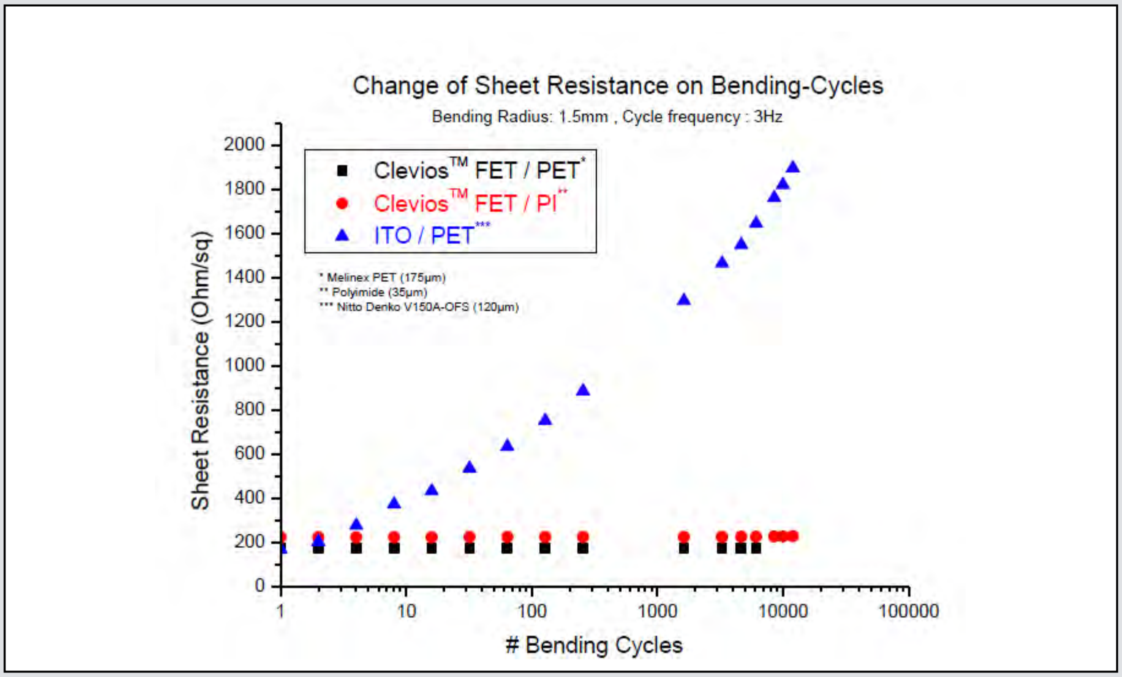


Figure 5: *Sheet Resistance stability of PEDOT:PSS over bending cycles*

Cost – PEDOT:PSS

Transparent electrodes based on films coated for example with Clevios™ FET can have significant cost advantages over ITO-coated films when fully leveraged by SigmaSense's new controller technology. The vacuum sputtering process of ITO is a major cost block while the ITO material cost itself is relatively small. Therefore, the cost difference of ITO films having lower or higher sheet resistances is rather small.

The roll-to-roll (R2R) wet coating process, e.g. by slot-die, that is used to coat Clevios™ is a much smaller cost block of the coated film. Wet-coating equipment is significantly cheaper and the coating process is more efficient with a higher throughput compared to ITO sputtering. The cost block of Clevios™ material, on the other hand is significantly larger than ITO but it directly scales with the sheet resistance of the coated films. This offers a significant cost saving potential. For example, Clevios™ FET requires a dosage of about 12 g/m2 for a 175 Ohm/sq film, but only about 6 g/m2 for a 350 Ohm/sq. That means, if the touch sensor is made from a film of 350 Ohm/sq instead of 175 Ohm/sq, the coating material cost block is immediately reduced by 50% (see figure 6), significantly reducing the overall film cost. The existing touch controllers in the market cannot drive larger touch sensors from films with higher sheet resistances, but Sigmasense is now changing the game.

Another cost advantage of Clevios™ vs. ITO coated film comes with the flexibility of Clevios™ that can positively impact touch sensor production yield. As described above, ITO's intrinsic brittleness prevents its use in foldable touch sensors. But even for standard touch sensors, especially when sensor size increases, e.g. touch sensors used in interactive flat panels, handling in production processes can lead to ITO cracks and defects that will lower production yields.

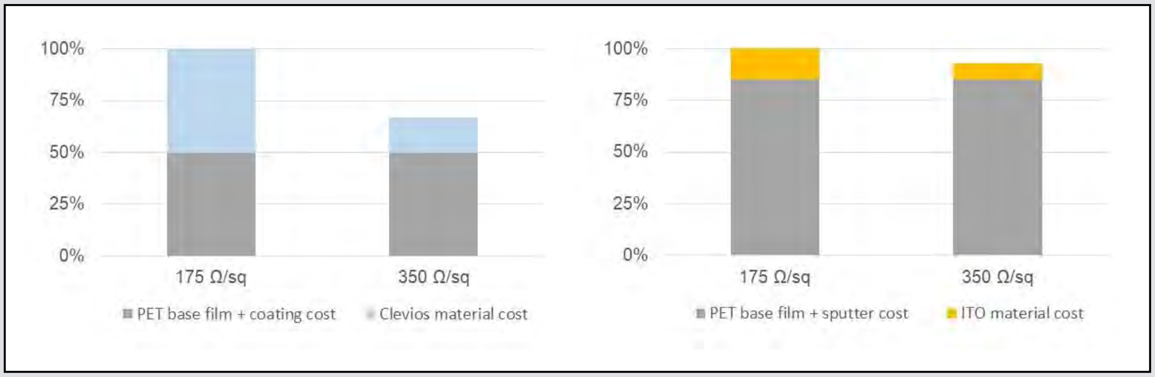


Figure 6: *Estimation of relative process and material costs of coated ITO and Clevios films with different sheet resistances indicating the cost saving potential of Clevios films that have higher sheet.*

Traditional Pcap touch sensing

Projected capacitive (PCap) touch sensors typically include a clear glass or film substrate with electrodes for sensing a touch location. When a user touches the substrate with a finger or a stylus, the location is determined by sensing changes in capacitances on or between the electrodes.

In typical switched 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 row electrodes with a square wave signal (i.e., drive pulse) and measuring the voltage coupled from the row to the 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 on each column 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, magnitudes of parasitic capacitances of the switched circuit can be 10x-20x larger than the mutual capacitances between electrodes, which can be less than a pico-farad. To overcome the effects caused by the parasitic capacitances, several measurement cycles are needed (i.e., integration) before a touch location can accurately be determined. Notably, the sense electrodes are scanned and so the length of time to measure a touch location increases with the number of electrodes, since 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 due to the electrodes self-capacitive coupling that exists between the driven electrode and impedance paths to ground. This self-capacitance will change when a user touches the substrate near the electrode by altering the impedance paths to ground.

In both mutual and self-capacitance, the alteration in impedance from a touch is measured by a change in voltage that is registered above some predetermined threshold above the noise in the system.

There are more parasitic capacitances when the touch sensor is integrated into a display system. These come from the display itself, the chassis, electronics and even the environment. Parasitic capacitances pose serious problems for typical capacitive controllers due to the switching of the drive and sense signals as it takes away touch energy from the main drive therefore requiring more total drive current. In addition, significant additional noise can be induced into the system through this extra capacitance. In typical touch controllers, the limits of the system are defined by the RC time constant – this is calculated for each channel by multiplying the channel resistance by the channel capacitance. So, as capacitance increases, resistance must decrease. As resistance increases, capacitance must decrease in order to keep the total RC time constant within an acceptable range. The worst case channel RC time constant determines the limit for the entire system. Large parasitic capacitance contributes to limiting the maximum electrode resistance to approximately 50-70 K-ohms. For this reason, many touch sensors are made from low resistance and often more expensive materials like silver nanowire and metal mesh which have poor optical properties that adversely affect the underlying display.

Another problem in typical systems is low touch SNR. This is caused by a variety of reasons from poor analog front end (AFE) performance, poor noise filtering and loss of signal energy to harmonics, etc. Many touch systems today have an SNR between the touch and no-touch states of 5-to-1 with more advanced systems achieving 15-to-1.

While widely used capacitive touch control circuits in use today can measure the different modes of self-capacitance, mutual capacitance or pen input, they generally sample only one mode at a time which impacts the 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 increases.

THE CONTROLLER SOLUTION

A novel PCap controller based on current mode sigma-delta architecture - Background

SigmaSense uses Sigma-Delta techniques with advanced digital filtering to overcome the problems of traditional PCap touch sensors. The novel design offers multi-mode concurrent touch sensor sampling that acquires the mutual touch, self-touch and pen signals simultaneously (i.e., no scanning). True continuous and simultaneous sampling of all electrodes using a lower-cost digital architecture provides excellent noise rejection, significantly improves speed, signal-to-noise ratio, and touch sensitivity. Sigma-Delta converters are used for high resolution current mode ADC and DAC applications. They also perform noise shaping, filtering, decimation, and are inexpensive to produce. One of the unique characteristics of Sigma-Delta converters is that the frequency transfer functions for the input signal and quantization noise are different thereby enabling very high-resolution signal creation with a significantly improved Signal to Noise Ratio (SNR). The result is signals with very high accuracy.

SigmaDrive Technology

Figure 7 depicts the core idea behind the electrode (channel) driver circuit which also senses simultaneously (drive-sense). In a real-world system that digitizes an analog effect (i.e., temperature, pressure, capacitance, etc.), there is some form of transducer that changes impedance with a change in the analog effect. In the case of capacitive touch, the touch sensor is that transducer and a single electrode is depicted as the Z block in figure 7. A proprietary sigma-delta ADC (A2D) block is shown with a Vref input. Vref is a configurable signal of any frequency and voltage that is driven on to the touch sensor electrode. This signal is purely sinusoidal and consists of one or more frequencies. A unique aspect of this design is that the Vref signal is held constant and is always present on the touch sensor electrode. It is not switched on and off the electrode like typical touch controller. When the electrode is touched, the impedance on the touch sensor changes; this would normally change the signal on the touch sensor. However, the SigmaSense circuit holds Vref constant on the sensor through a feedback mechanism that is equivalent to imposing a counter impedance, -ΔZ, back on the sensor to cancel out the change. In other words, the signal on the sensor is always forced to be the Vref signal and all the information about the changes in the sensor impedance is contained in the counter signal. That signal is sent to a DSP where advanced signal processing performs analysis and filtering for strong noise rejection and exceptional SNR resulting in high sensitivity able to detect extremely small impedance changes. This is completely different from a system that is looking for a voltage to cross some threshold above the noise. In fact, it is an entirely new way to sense changes in a transducer. Another unique aspect of this architecture is that both the drive signal and the sense mechanism are electrically on the same pin which means that both driving and sensing occur simultaneously on the same pin connected to the electrode. SigmaSense technology is a radical departure from traditional switched capacitive measurement systems that solves problems of parasitic capacitance, loss of signal due to harmonics, and RC settling time thereby allowing for driving of ultra-high impedance sensors. Indeed, real-world touch sensors with 350 K-ohm electrodes pose no difficulty for this novel design. This is important since the use of desirable materials like optically optimal, flexible, and robust PEDOT:PSS for touch sensors ranging from wrist to wall size is now possible.

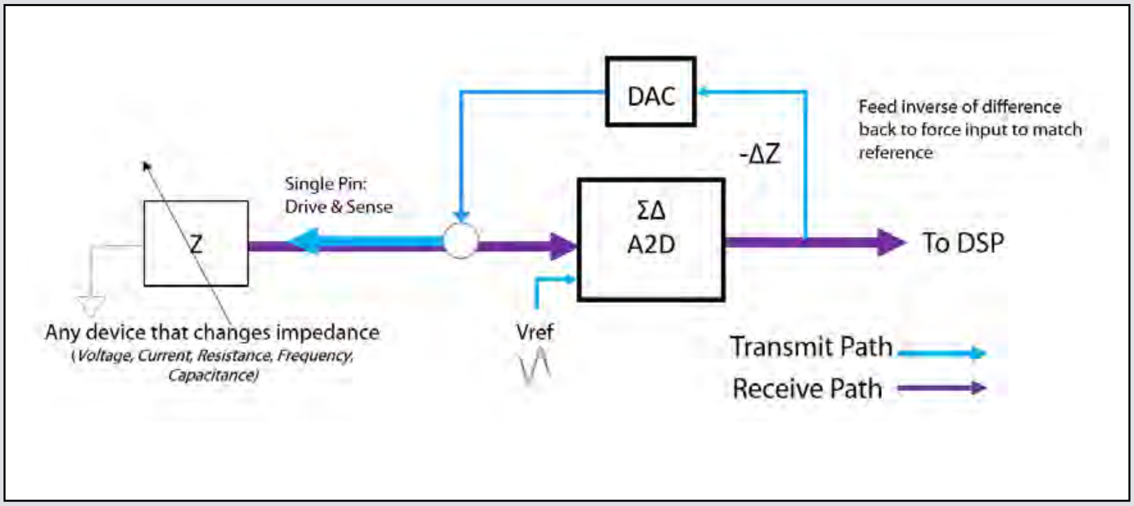


Figure 7: *The SigmaSense SigmaDrive driver architecture. Sigma-delta results in a SNR improvement of more than 6dB for each factor of 4x oversampling*

A defining feature of the SigmaSense touch controller architecture is that unlike systems that switch and scan, the SigmaSense architecture has a SigmaSense drive-sense driver (aka Sigma-Delta Modulator or SDM) on every row and column of the touch sensor. This architecture allows for multiple frequencies and simultaneous drive-sensing independently on each row and column. Since there is no time wasted on scanning, the SigmaSense controller is extremely fast, generating touch reports at a 300 Hz rate. Stated differently, the touch/non-touch state of every row and column is continuously sampled with the results reported 300 times per second. Multiple frequencies on each channel provides concurrent modality which means both self and mutual capacitance detection is performed in the same sample cycle. Further, different frequencies can be used for multiple pen recognition which are also detected in the sample cycle. Having a Sigma-delta modulator on each channel allows for the individual channel frequencies to be adapted in real-time to avoid environmental noise. This is done, for example, by moving the drive frequency to a different band than that occupied by common mode interference (simultaneous sensing sees common mode noise on all channels). This, along with powerful digital filtering that rejects out-of-band noise. The high SNR signal from the Sigma-delta modulator, means that the SigmaSense approach has unparalleled noise immunity that rejects out-of-band noise that is just 100 Hz away from the fundamental drive frequency thereby improving touch sensitivity and system reliability. To genuinely appreciate the breakthrough represented by the SigmaSense controller, it is instructive to contrast it against traditional PCap controllers.

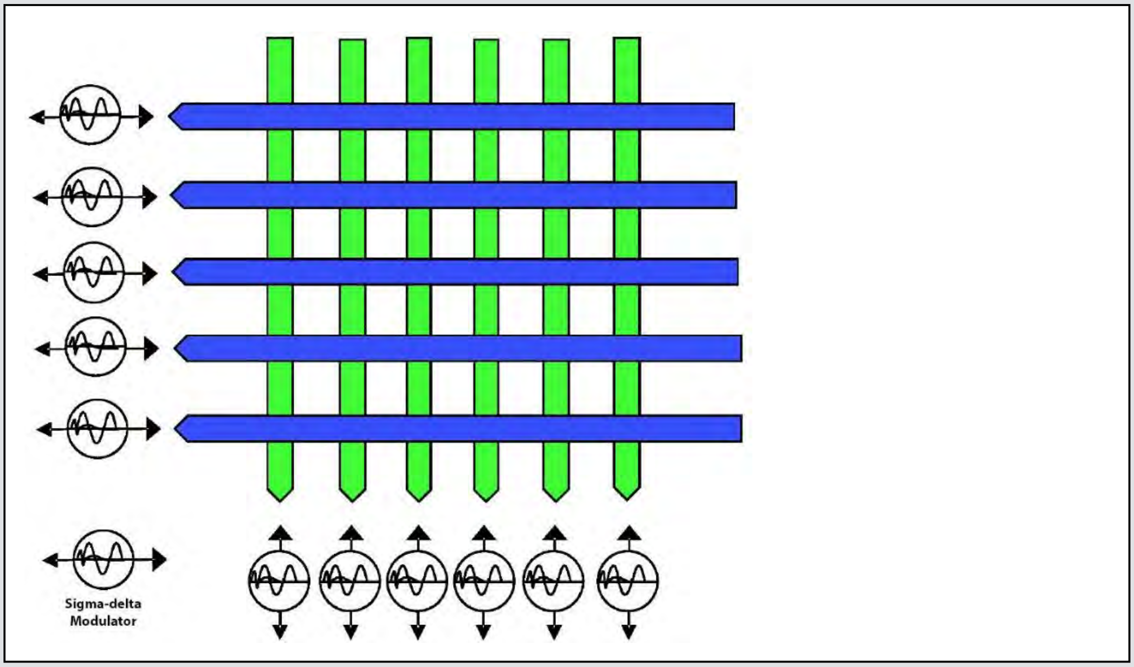


Figure 8: *A touch sensor with multi-frequency simultaneous drive for concurrent mode operation (self, mutual and pen). Each row and column interfaces to a SigmaSense drive-sense driver shown in Figure 7*

Traditional PCap controller Operation vs SigmaSense SigmaDrive Technology

The high-level operation of a traditional PCAP touch controller is shown in Figure 9. As previously described, this method works by switching a signal onto an electrode. This is traditionally done a single drive lead at a time. When the sensor is touched, the impedance changes which changes the voltage received by the sense circuit. The sense circuit is separate from the drive circuit and therefore needs another lead to acquire the signal from the electrode. The voltage change cause by touch is registered as a voltage difference from the no-touch state that appears above a predefined threshold above the noise. The signal is often very close to the system noise and so averaging of multiple samples is used to improve the SNR.

This slows down touch signal acquisition and averages-in interfering aliased noise far from the drive frequency – often as high as 5 kHz to 10 kHz. Typical systems provide combined pen and touch reports between 100 Hz to 150 Hz. Note that, for typical touch controllers, when pens are detected, the number of touch reports are reduced so that pen information can be detected and reported. Therefore the total report rate doesn't change. The SigmaSense touch controller reports pen, touch (self and mutual) each at 300Hz with no reduction in rate of touch reporting when pen is being reported. All functions are each reported at 300Hz.

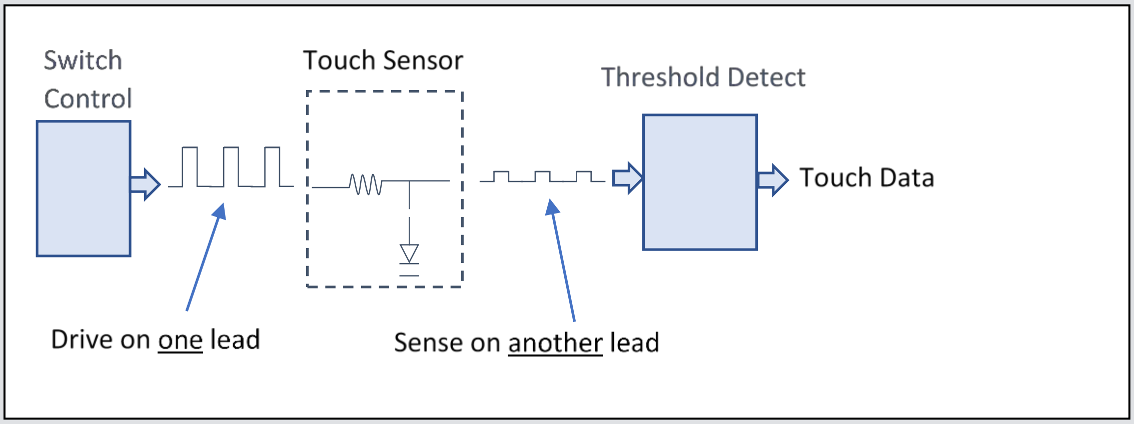


Figure 9: *Typical switched capacitive touch controller*

The SigmaSense controller shown in Figure 10 operates in a significantly different way. There is no time-consuming switching of the drive signal on the electrodes. The signal on the electrode is a continuous low-voltage pure-tone sinusoid.

The information from impedance changes caused by touch is oversampled at 20 MHz resulting in extremely fast detection. Because of the novel SigmaSense analog front end and special DSP filtering, the SNR is extraordinarily high (> 100 dB in the spectral domain) and the noise filtering is exceptional. This means there is no need to average samples and so the report rate of all information, pen, self-touch and mutual touch, is 300 Hz or greater. Also, due to the previously described feedback architecture, driving and sensing of the electrode is done on a single circuit connected by a single lead. Since all the information about the state of touch and no touch is acquired continuously, the voltage level on the sensor is held constant, enabling SNR in the spectral domain where analysis is done. The SigmaSense system is not voltage threshold based and does not have the many limitations found in voltage threshold based systems.

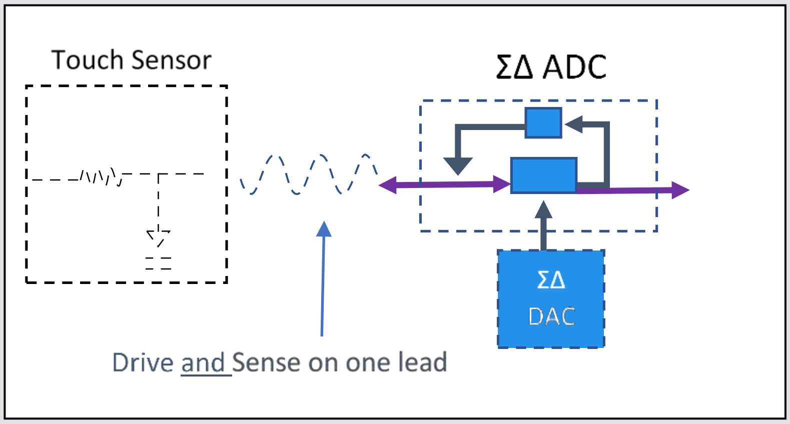


Figure 10: *The SigmaSense touch controller showing single lead Drive and Sense.*

Continuous and concurrent pure-tone sinusoidal drive and sense on all channels

In typical multi-touch systems, the self-capacitive signal-to-noise ratio is much larger than the mutual capacitances because 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 only contains the cross parasitic capacitance and touch signal energy change. Also, the self-parasitic capacitances are large because the surrounding channels are effectively grounded as only one signal is driven at a time. 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. This creates considerable signal loss thereby necessitating lower touch screen impedances which are costly to produce. Switching a signal on and off on an electrode is like driving it with a square wave as depicted by the wave form to the right in figure 11. Fourier theory shows that a square wave is made up of a composite of many sinusoidal frequencies. The frequencies show up in the spectral domain as depicted on the left of figure 11. It is not uncommon to see 17 different frequency harmonics. These harmonics generate EMI but a further problem is that they activate the parasitic capacitance by increasing impedance and drawing more current. These harmonics contain a considerable portion of the touch energy but are not part of the touch measurement thereby reducing touch sensitivity (lower SNR) and increasing the power required to drive the primary signal.

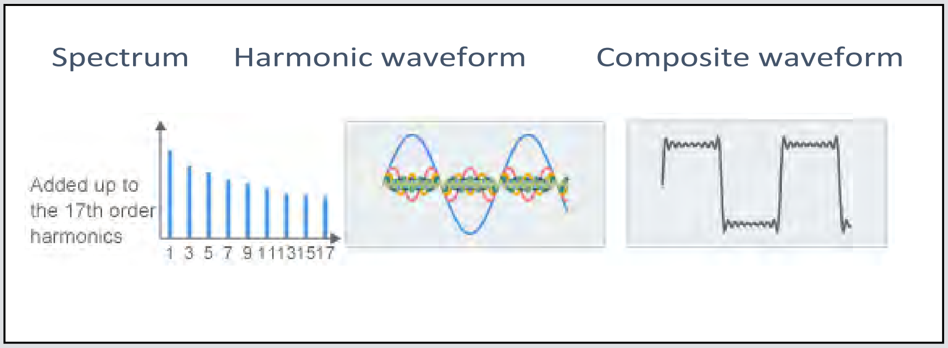


Figure 11: *Frequency spectrum of the typical switched capacitive controller showing many harmonic components.*

The SigmaSense system drives the electrodes continuously with a pure sinusoidal signal including multi-sinusoidal frequencies. Figure 12 shows this for a single frequency. The drive signal is on the right and the spectral response, showing only the fundamental tone, is on the left. The spectral response does not have high frequency harmonic components that increase impedance so longer high-impedance electrodes can be driven. The use of sinusoidal signals which mitigate the effects of parasitic capacitance result in our system being able to drive long electrodes found in large touch sensors, non-uniform sensors, high impedance electrodes found in in-cell sensors or a mixture of high/low impedance channels.

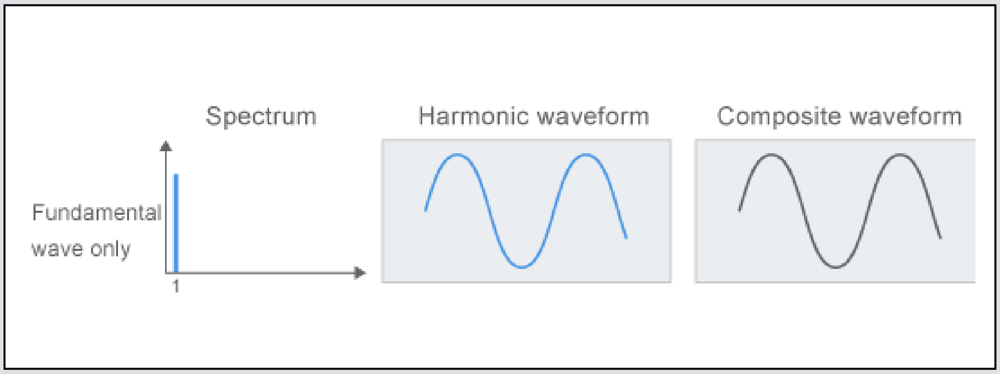


***Figure 12:** Frequency spectrum of the SigmaSense controller showing only the fundamental frequency component.*

High Impedance, long lines and touch sensitivity

The SigmaSense controller is fully configurable so that its drive-sense circuit can be dynamically configured to whatever frequency and voltage is needed for the sensor at hand. This is critical for being able to drive long line electrodes like those found in wall-size displays or high impedance sensors like those found in PEDOT:PSS sensors or in-cell sensors. Long resistive electrodes found in large touch sensors, high impedance due to capacitive loading, or poor material conductivity are all part of the same problem. They are only an issue when coupled with high current, which leads to a large voltage drop along the line. However, the SigmaSense circuit can tightly control both the frequency and voltage of our transmissions thereby choosing the current through the capacitive load to balance out the higher resistance lines. For example, due to the very high SNR afforded by the extremely sensitive analog front end, voltages imposed on an ITO electrode for a 32 inch sensor can be on the order of millivolts; the resulting very small current still provides the viable touch performance.

To achieve this level of performance, it is necessary to be able to measure very small currents. The SigmaSense drive-sense circuit is able to accurately measure current changes in the small nano-amp range. This is done by controlling the signal transmission and then with DSP algorithms, the receive signal is filtered to pick out ONLY the transmitted signal. The SigmaSense system is continuously transmitting & receiving (by oversampling), so that there is no aliased noise from scanning. And the SNR is high to begin with. Removing any noise allows for added gain to be able to see very small currents.

The ability to accurately measure small currents allows for low current transmission and sensitivity to changes in current caused by very small changes in capacitance. The SigmaSense circuit sees femto-farad changes which is why touch sensitivity is exceptional. These attributes, not possible with traditional switched PCap controllers, are why long electrodes and high impedance sensors do not pose difficulties for SigmaSense controllers.

Real world measurements with PEDOT:PSS

Using Heraeus PEDOT:PSS material, working with Xymox Technologies Inc (sensor design) and Eastman Kodak (poly film carrier), multiple custom touch sensors in several sizes were created. Up until now, due to the high impedance of PEDOT:PSS, a 9.3 inch PEDOT:PSS touch sensor would have caused design issues for any traditional PCap touch controller. Table 1 shows touch sensitivity results for 9.3 inch and 43 inch PEDOT:PSS sensors. Working with Heraeus, EOC (poly film) and TWS (sensor design) a 65 inch sensor was also demonstrated. Table 1 shows touch sensitivity results for 9.3 inch, 43 inch and 65 inch PEDOT:PSS sensors.

Touch sensitivity (SNR) results are presented for three locations: closest to the drive-sense circuit, middle of the sensor, and farthest from the drive-sense circuit In all three locations, touch sensitivity (SNR) was approximately 40 dB – an astonishing 100:1 SNR. These results clearly demonstrate the viability of PEDOT:PSS for touch sensors and 65 inch sensors, have now also been manufactured. Larger PEDOT:PSS sensors are anticipated soon.

Sensor Size (in)	Sensor Pitch (mm)	Voltage (V)	SNR Xmin, Ymin (dB)	SNR Middle (dB)	SNR Xmax, Ymax (dB)
9.3 inch	3	2.19	40.0	39.65	42.91
43 inch	5	4.02	40.62	44.16	N/A
65 inch	6.3	2.92	35.55	33.16	40.2

Table 1: *Real-world SNR measurements using PEDOT:PSS sensors.*

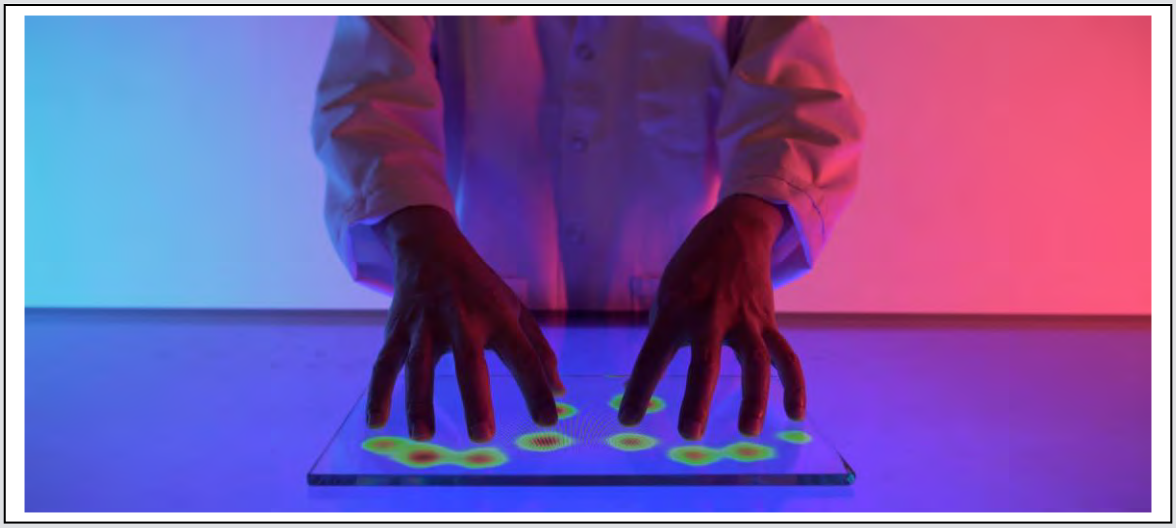


Figure 13: *Fully functional 65 inch PEDOT:PSS touch sensor shown in 2020 C-Touch exhibition.*

CONCLUSION

Large size PEDOT:PSS sensors are now a reality when driven by SigmaSense's SigmaDrive touch controllers

First time that PEDOT can be used in large sizes

PEDOT cost is coming down and can be lower cost than current solutions

PEDOT sensors provide flexible solutions

Heraeus and SigmaSense provide new capabilities/solutions for the industry

SigmaSense controllers are tolerant of high resistance sensors and parametric channel differences

Industry performance leading features with 300Hz reporting, high hover support and presence detection

At sheet resistances of 250 – 500 Ohm/sq, which is a perfectly suitable range for SigmaDrive™ technology controllers for small and even large size touch sensors, Clevios™ conductive polymers offer, compared to alternative sensor materials:

- Lower total cost of ownership
- Enhanced mechanical flexibility
- Superior optical properties

Lower total cost of ownership. With roll-to-roll wet coating, conductive polymer formulations can be deposited at the lowest processing cost in large scale. At 250 – 500 Ohm/sq, a low dosage of conductive polymer formulation is sufficient; typically 70 – 130 square meters can be coated per 1 kg, thus minimizing material cost. Conductive polymers are immediately functional after drying; they do not need an additional heat treatment step as ITO does to crystallize and become more conductive.

Enhanced mechanical flexibility. Foldable smartphones are already in the market and tablets and notebooks will soon follow, while televisions will also become interactive. New display form factors will be crucial to differentiate and further grow the consumer market of the future. Conductive polymers already offer ultimate flexibility. They can be folded hundreds of thousand times at 1 mm radius without degradation of conductivity, and they have been successfully demonstrated to undergo thermoforming and all steps of in-mold electronics to render curved and 3D surfaces touch sensitive. Conductive polymers are ideal materials for zero-bezel displays where the touch sensor is stretched and folded around the display to be (IC) bonded to the backs of displays. Adopting conductive polymers will prepare manufacturers for these key future display trends.

Superior optical properties. As described, conductive polymers have a low refractive index that matches well with plastics and glass. Therefore, light reflection is at its lowest, an optical property desired for all interactive displays, especially automotive displays. Good conductive polymer coatings have perfect optical clarity and do not add haze. Even from off-angle viewing the visual impression is superb. Transmission losses of 250 – 500 Ohm/sq coated films are negligible, and the color is neutral.

Disruptive SigmaDrive Technology

The disruptive SigmaDrive™ technology unleashes Clevios™ conductive polymers' strengths and this great combination provides industry leading performance. The biggest and instantaneous benefits are expected in large-sized touch sensors for interactive flat panel displays and whiteboards where costs can now be significantly reduced. Addressing the needs of future flexible display trends, e.g., zero bezel displays, 3D-molded, stretchable and wearable displays, is the other key value proposition of SigmaSense and Heraeus' technology package.

> *SigmaSense delivers a true breakthrough at the source of information capture…*
>
> \- **Rick Seger** / President